Nanoparticles in Fingerprinting

Advanced Methods for Development of Latent Fingerprints

Kumud Kant Awasthi | Mahipal Singh Sankhla
Chandra Shekhar Yadav | Anjali Awasthi
Editors

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About the Editors

Kumud Kant Awasthi, PhD
Professor and Head, Department of Life Sciences, Vivekananda Global University (VGU), Jaipur India

Kumud Kant Awasthi, PhD, is currently working as a Professor and Head at the Department of Life Sciences at Vivekananda Global University (VGU), Jaipur, India. Prior to this position, he worked at the National Institute of Animal Welfare (NIAW), Faridabad, India. Dr. Awasthi's research focuses on environmental toxicology in relation to nanoparticles. He has extensive experience in toxicity assessment for various nanomaterials in different in vivo and in vitro models, with a focus on their safe use for drug development. He also authored or edited books in his field and holds German and Indian patents for his innovative works. Dr. Awasthi is a lifetime member of several prestigious national and international scientific societies. He is also a nominated member of the committee for ethical use of laboratory animals in research by the Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA), Government of India. He serves as Environment Auditor for the Rajasthan State Pollution Control Board, Govt of Rajasthan. Dr. Awasthi remains actively engaged in research activities, serving as a member of editorial boards and a reviewer for various scientific journals, including Springer and Elsevier, and participating in the organizing committees for many national and international conferences.

Mahipal Singh Sankhla
Assistant Professor, Department of Forensic Science, University Center for Research and Development (UCRD), Chandigarh University, Punjab, India

Mahipal Singh Sankhla, PhD, is a distinguished Assistant Professor in the Department of Forensic Science, University Centre for Research and Development, Chandigarh University, Mohali, Punjab, India. Dr. Sankhla earned his Bachelor of Science (Hons.) degree in Forensic Science, his Master of Science degree in Forensic Science, and his PhD.in Forensic Science from Galgotias University, Greater Noida, Uttar Pradesh, India. His exceptional work has been recognized with numerous awards, including a Young Scientist Award, Young Researcher Award, and the Forensic Researcher Award. In addition to his teaching and research responsibilities, Dr. Sankhla has been honored by the Government of India with the nomination to mentor the 'Atal Innovation Mission' of NITI Aayog, aimed at setting up Atal Tinkering Labs (ATL) across Indian schools. His dedication to research is further reflected in his extensive publication record, with over 270 peer-reviewed articles in national and international journals, more than 30 book chapters, and nine edited books. His contributions have also been recognized through two Indian copyrights, four patents, and the publication of over 65 Indian patents.

Chandra Shekhar Yadav, PhD
Assistant Professor, School of Forensic Sciences, National Forensic Science University, Gandhinagar, Gujarat, India

Chandra Shekhar Yadav, PhD, is currently working as an Assistant Professor at the School of Forensic Sciences at National Forensic Science University, Gandhinagar, Gujarat, India. Previously, he worked at the Department of Life Sciences, Vivekananda Global University, Jaipur, India, as an Assistant Professor. His area of research interest is

environmental toxicology with reference to chemical exposure assessment and its impact on human health. He has more than 10 years of teaching and research experience and has published 22 research papers in peer-reviewed national and international journals. He has also presented papers at national and international conferences. He is a member of several international and national professional bodies and is an active editorial board member and reviewer for national and international journals. Dr. Yadav has worked on various collaborative projects with the Central Pollution Control Board, New Delhi, on environmental health and persistent organic pollutants estimation in the Delhi population. He was also a nominated member of the committee for the ethical use of laboratory animals in research by the Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA), Government Ministry of Environment Forest and Climate Change, Govt. of India. He has been invited as guest speaker at many national and international conferences. More than 14 students have completed their master's dissertations and doctoral work under his exemplary guidance in the area of environmental toxicity and remediation. He earned his PhD in Medical Biochemistry at the University of Delhi, India.

Anjali Awasthi, PhD
Assistant Professor, Department of Zoology, Centre for Advanced Studies, University of Rajasthan, Jaipur, India

Anjali Awasthi, PhD, is currently working as Assistant Professor in the Department of Zoology at the Centre for Advanced Studies of the University of Rajasthan, Jaipur, India. Her area of research is molecular biology and nanobiotechnology. She has a vast experience in the field of toxicity assessment for different nanomaterials in different in vivo and in vitro models as well as in biosensor development and biofouling studies of nanomaterials. She is guiding PhD and MTech scholars for their degrees. She is a life member of several esteemed scientific national and international societies. Dr. Awasthi is also a nominated member of the Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA), Ministry of Environment Forest &

Climate Change, Govt. of India. She is a reviewer for several journals and has organized many international and national conferences. She was awarded her MSc and MPhil (Zoology) degrees from Dr. B. R. Ambedkar University, Agra, and her PhD (Biotechnology) from the Indian Institute of Technology, Roorkee, India.

Contents

Contributors

Shreya Arora
College of Traffic Management, Institute of Road Traffic Education, Faridabad, Haryana, India

Anjali Awasthi
Department of Zoology, University of Rajasthan, Jaipur, Rajasthan, India

Garima Awasthi
Department of Life Sciences, Vivekananda Global University, Jaipur, Rajasthan, India

Kumud Kant Awasthi
Department of Life Sciences, Vivekananda Global University, Jaipur, India

Manik Chand
Department of Forensic Science, University Institute of Applied and Health Sciences, Chandigarh University Gharuan, Mohali, Punjab, India

Anoop M Divakaran
Toyota Technological Institute, Hisakata Tempaku, Nagoya, Japan

Eugenio D'Orio
Direttore Generale, Bioforensics Research Centre, Italy

Archana Gautam
Department of Forensic Science, UIAHS, Chandigarh University, Mohali, Punjab, India

Divyansh Jain
Department of Forensic Science, Vivekananda Global University, Jaipur, India

Rohith Krishna
Biomolecular Research Centre, Sheffield Hallam University, Sheffield, United Kingdom

Maheep Kumar
Shri Varshney College, RMPSS University, Aligarh, Uttar Pradesh, India

Rajeev Kumar
Department of Forensic Science (SBMS), Galgotias University, Greater Noida, Uttar Pradesh, India

Poonam Kumari
Department of Forensic Science (SBMS), Galgotias University, Greater Noida, Uttar Pradesh, India

Supriya Kumari
Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India

Ruby Kumari
Forensic Science Laboratory, Haryana, India

Sneha Lohar
Department of Forensic Science (SBMS), Galgotias University, Greater Noida, Uttar Pradesh, India

Dipak Kumar Mahida
Research Scholar, Department of Biochemistry and Forensic Science, Gujarat University, Ahmedabad, Gujarat, India

Badal Mavry
Department of Forensic Science (SBMS), Galgotias University, Greater Noida, Uttar Pradesh, India

Vaibhav Mishra
Department of Forensic Science, UIAHS, Chandigarh University, Mohali, Punjab, India

Mona
Department of Applied Science, Galgotias College of Engineering and Technology, Greater Noida, Uttar Pradesh India

Varad Nagar
Department of Forensic Science, Banaras Hindu University, Varanasi, Uttar Pradesh, India

Pratiksha Nimbkar
Research Scholar, Gujarat Technological University, Ahmedabad, Gujarat, India

Harsh Pandey
Department of Biotechnology and Chemical Engineering, Manipal University, Jaipur, Rajasthan, India

Kamakshi Pandey
Department of Physics and Material Research Centre, Malaviya National Institute of Technology, Jaipur, Rajasthan, India

Pritam P. Pandit
Department of Forensic Science, Sandip University, Nasik, Maharashtra, India

Kapil Parihar
Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India

Ankita Patel
Department of Biochemistry and Forensic Science, Gujarat University, Ahmedabad, Gujarat, India

Abhishek R. Rai
Department of Forensic Science, Vivekananda Global University, Jaipur, India

Mahipal Singh Sankhla
Department of Forensic Science, UIAHS, Chandigarh University, Mohali, Punjab, India
University Centre for Research and Development, Chandigarh University, Mohali, Punjab, India

Anuj Sharma
Department of Forensic Science, ITM University, Gwalior, Madhya Pradesh, India

Priya Sharma
Forensic Science Department, University Institute of Allied Health Sciences, Chandigarh University, Mohali, Punjab, India

Ruhani Sharma
Department of Life Sciences, Vivekananda Global University, Jaipur, India

Tina Sharma
Head, Department of Forensic Science, Bahra University, Shimla Hills

Vaibhav Sharma
Department of Forensic Science, Vivekananda Global University, Jaipur, India

Snehalata U. Shenoy
Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India

Anubhav Singh
School of Forensic Science, National Forensic Science University, Gandhinagar, Gujarat, India

Apoorva Singh
Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India

Gaurav Kumar Singh
Department of Forensic Science, Sharda School of Allied Health Sciences (SSAHS), Sharda University, Greater Noida, Uttar Pradesh, India

Pratik Singh
Amity Institute of Forensic Sciences, Amity University, Noida, Uttar Pradesh, India

Anjali Soy
Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India

Sudhanshu Shekhar Tiwari
Assistant Director, Narcotics, Directorate of Forensic Science and Laboratory, Ranchi, Jharkhand

Chandra Shekhar Yadav
School of Forensic Science, National Forensic Science University, Gandhinagar, Gujarat

Megha Yadav
Guru Ghasidas Vishwavidyalaya, Bilaspur, Chhattisgarh, India

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Abbreviations

AFIS	automated fingerprint identification system
ASTM	American Society for Testing and Materials
CDFD	centered dark field
Cds	carbon dots
Cnms	carbon-based nanomaterials
CPC	condensation particle counter
Cpds	carbonized polymer dots
Cps	conjugated polymers
Cu	copper
CVD	chemical vapor deposition
EELS	electron energy loss spectroscopy
eV	electron volt
EXAFS	extended X-ray absorption fine structure
FT-IR	Fourier transform infrared
I	iodine
ISO	International Organization for Standardization
LSPR	localized surface plasmon resonance
NaOH	sodium hydroxide
Nps	nanoparticles
Pdots	polymer dots
Pnps	polymer nanoparticles
PPDP	phenylenediamine, an organic compound commonly used in hair dyes
PPV	poly (p-phenylene vinylene)
PXRD	powder X-ray diffraction
SAED	selected area electron diffraction
SAXS	small angle X-ray scattering
SEM	scanning electron microscopy
SERS	surface-enhanced Raman scattering
SPR	surface plasmon resonance
SQUID	superconducting quantum interference device
TEM	transmission electron microscopy
TGA	thermogravimetric analysis
THF	tetrahydrofuran
UV	ultraviolet
UV-SERS	ultraviolet laser-simulated surface scattering

VMD	vacuum metal deposition
ZnO	zinc oxide

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We are eternally grateful to *Lord Krishna* for being our source of inspiration, knowledge, and direction. By dedicating this work to Lord Krishna, we acknowledge the spiritual power that penetrates our lives and provides the strength and clarity required for this endeavor. May His blessings keep shining on our paths and fill this book with the spirit of heavenly wisdom.

—Editors

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Foreword

The search for novel techniques to improve the precision and effectiveness of fingerprint analysis has been unrelenting in the dynamic field of forensic research. Nanotechnology integration has become a new frontier as we explore the complex realm of latent fingerprints. In the intersection of forensic investigation and nanoscience, this book, *Nanoparticles in Fingerprinting: Advanced Methods for Development of Latent Fingerprints*, is a noteworthy turning point.

Conventional fingerprinting methods have long served as the cornerstone of criminal investigations, offering vital proof for person identification. Still, a scientific revolution has been sparked by the difficulties presented by diverse surfaces, environmental factors, and the sensitive character of latent impressions. Inspired by a desire to solve the puzzles hiding in the details of fingerprints, the authors of this volume have used nanoparticle technology to overcome the constraints of traditional approaches.

Readers will go through the complex realm of nanotechnology used for creating fingerprints inside the pages of this book. The writers explore the manufacturing and use of nanoparticles, delving into the special qualities that allow them to precisely uncover latent fingerprints.

The toolkit of nanomaterials covered in this book, which ranges from magnetic nanoparticles to quantum dots, offers up new possibilities for the preservation and visualization of latent prints and turns forensic science into an area where the unseen is made strikingly visible. This encyclopedia acts as a thorough guide, leading readers through the experimental procedures, theoretical underpinnings, and practical uses of nanoparticle-based fingerprinting. This multidisciplinary approach fosters a comprehensive knowledge of this cutting-edge topic by reflecting the joint work of specialists from chemistry, forensic science, and nanoscience.

As we stand on the cusp of a new era in forensic investigation, this book not only chronicles the advancements achieved but also ignites the imagination of researchers, practitioners, and enthusiasts alike. This book is not merely a collection of insights; it is a catalyst for continued

exploration and innovation in the symbiotic realms of nanotechnology and fingerprint analysis. May it inspire and guide future endeavors in unraveling the secrets held within the delicate ridges and valleys of latent fingerprints.

—Dr. Kamlendra Awasthi
Secretary, Soft Materials Research Society (SMRS)
Associate Professor & Head
Department of Physics
Malaviya National Institute of Technology Jaipur, Rajasthan, India

Preface

*"*Advancements in forensic science have continually pushed the boundaries of investigative techniques, particularly in the field of fingerprint analysis. Among these innovations, the utilization of nanoparticles represents a cutting-edge approach that holds immense promise for enhancing the development and visualization of latent fingerprints. This book, *Advanced Methods for Development of Latent Fingerprints,* delves into the principles, methodologies, and applications of nanoparticle-based techniques in the realm of fingerprint forensics.

The identification and analysis of latent fingerprints are crucial components of criminal investigations and forensic examinations. Traditional methods for fingerprint development have relied on chemical reagents and physical enhancement techniques. However, these methods often present limitations in terms of sensitivity, specificity, and reproducibility. The integration of nanoparticles into fingerprinting methodologies offers a transformative solution by leveraging the unique properties of nanomaterials to enhance fingerprint visualization and detection.

This book is designed to provide a comprehensive overview of the role of nanoparticles in fingerprint development. It explores the underlying principles of nanoparticle interactions with latent fingerprint residues, the synthesis, and characterization of nanoparticle-based reagents, and the practical application of these techniques in real-world forensic scenarios. Additionally, the book examines the potential challenges, future directions, and ethical considerations associated with the adoption of nanoparticle-based fingerprinting methods.

Contributions from leading experts in the fields of nanotechnology and forensic science enrich this volume with diverse perspectives and practical insights. Whether you are a seasoned forensic professional, a researcher in materials science, or a student exploring the intersections of nanotechnology and criminalistics, this book aims to serve as a definitive resource on the transformative role of nanoparticles in advancing fingerprint analysis.

We hope that readers will find this book informative, engaging, and instrumental in expanding their understanding of nanoparticle-based approaches for developing latent fingerprints, ultimately contributing to the evolution of forensic science and its impact on criminal investigations.

CHAPTER 1

Advancements in Nanotechnology: Harnessing Nanoparticles for Enhanced Latent Fingerprint Development

ANUJ SHARMA[1], SUPRIYA KUMARI[2], ROHITH KRISHNA[3], VAIBHAV SHARMA[2], KUMUD KANT AWASTHI[4], CHANDRA SHEKHAR YADAV[5], MAHEEP KUMAR[6], MAHIPAL SINGH SANKLHLA[7,8], and HARSH PANDEY[9]

[1]*Department of Forensic Science (SOS), ITM University, Gwalior, Madhya Pradesh, India*

[2]*Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India*

[3]*Biomolecular Research Centre, Sheffield Hallam University, Sheffield, United Kingdom*

[4]*Department of Life Sciences, Vivekananda Global University, Jaipur, Rajasthan, India*

[5]*School of Forensic Science, National Forensic Science University, Gandhinagar, Gujarat, India*

[6]*Shri Varshney College, RMPSS University, Aligarh, Uttar Pradesh, India*

[7]*Departmemnt of Forensic Science, (UIAHS), Chandigarh University, Mohali, Punjab, India*

[8]*University Centre Research for Development, (UCRD), Chandigarh University, Mohali, Punjab, India*

[9]*Department of Biotechnology and Chemical Engineering, Manipal University, Jaipur, Rajasthan, India*

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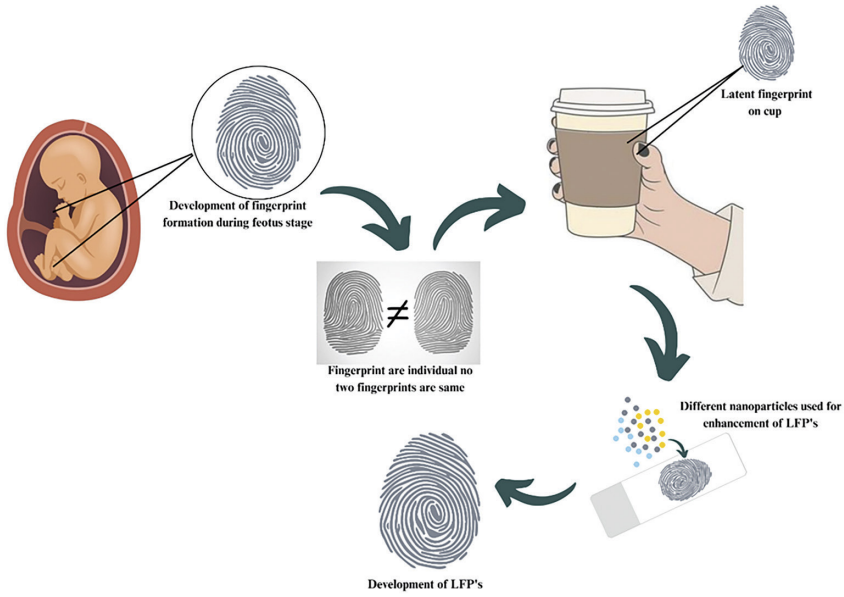
ABSTRACT

This comprehensive review delves into the progressive advancements made in the domain of fingerprint development techniques, with a specific focus on the utilization of nanoparticles. With an emphasis on the application of nanoparticles, this in-depth examination explores the steady developments achieved in the field of fingerprint formation procedures. In forensic investigations, fingerprint identification is essential, and recent research has demonstrated that nanoparticles have tremendous potential to improve the visualization and preservation of latent fingerprints. This study provides an in-depth overview of the advantages, restrictions, and potential applications of the most recent approaches, materials, and procedures used in nanoparticle-based fingerprint generation. This study intends to further knowledge of how nanoparticles can revolutionize the area of forensic science and enhance the effectiveness and accuracy of fingerprint recognition by analyzing cutting-edge methods.

Graphical abstract



1.1 INTRODUCTION

Friction ridge skin is a fascinating and unique characteristic found on the palms of hands, fingers, soles of feet, and toes of humans. These ridges consist of raised and curved lines that form distinct patterns, commonly referred to as fingerprints [1]. On the palms, fingers, soles, and toes of people, friction ridge skin may be seen, which is a unique and exceptional characteristic. These extraordinary ridges are made up of several elevated and curved lines that combine to form distinctive and complex patterns, more generally known as fingerprints. Forensic specialists, criminologists, and scientists have all been fascinated by the study and inspection of fingerprints for generations. Fingerprints are a significant tool in a variety of sectors, including forensic identification, criminal investigations, and biometric authentication, due to their uniqueness and permanence. The study of these patterns is known as dermatoglyphics. The development of friction ridge skin begins during the early stages of embryonic development, specifically between the ninth and twenty-fourth weeks in the womb. During this period, the skin on the fingers and toes undergoes a complex process of growth and differentiation, resulting in the formation of these intricate patterns [2]. The specific factors and mechanisms that contribute to the formation of friction ridge skin are not yet fully understood, but it is believed to be influenced by a combination of genetic and environmental factors. What makes friction ridge skin truly remarkable is its uniqueness [3]. Even identical twins, who share the same genetic makeup, possess distinct patterns on their fingertips. This is primarily because each embryo experiences different pressures and growth rates in the womb, leading to individual variations in the final design of its friction ridge skin. The patterns found on friction ridge skin can be broadly classified into three main types: arches, loops, and whorls. Arches are characterized by a smooth, continuous flow of ridges, resembling a wave-like pattern [4]. Loops have ridges that enter from one side of the finger or toe and exit from the other side, creating a loop-like shape. Whorls, on the other hand, exhibit circular or spiral formations of ridges. These patterns serve a crucial purpose beyond their uniqueness and aesthetic appeal [3]. The ridges and furrows found in friction ridge skin enhance grip and provide traction, allowing us to grasp objects firmly and perform delicate tasks with precision. A ridge pattern that enters from one side of the fingerprint and departs from the same side, mimicking a loop shape, is what distinguishes loops from other fingerprint types. They make up

between 60 and 70% of all fingerprints and are the most prevalent sort of fingerprint pattern. Whorls, on the other hand, have spiral or circular patterns that seem to radiate from a central point in concentric circles or spirals. Depending on their unique qualities, they can also be divided into four more categories: plain whorls, center pocket loops, double loops, and accidental whorls. With only about 5% of all fingerprints having an arch, arches are the least frequent type of fingerprint pattern. Without producing any loops, they display a smooth, flowing pattern that rises at one side of the fingerprint and descends on the other. Additionally, the distinctive patterns serve as a means of personal identification, forming the basis of forensic science techniques such as fingerprint analysis. The field of fingerprint analysis has long been utilized in various areas, including law enforcement, identification systems, and forensic investigations. Fingerprint analysis has long been a key component of criminal investigations in the world of law enforcement. For decades, law enforcement organisations all around the world have depended on fingerprints as a distinctive and trustworthy way to identify suspects and connect them to crime scenes. Investigators can make connections, rule out prospective suspects, and develop solid cases against offenders by matching fingerprints taken at the scene of a crime with those in a database. Numerous cases, involving both small offences and high-profile crimes, have been successfully solved thanks to this vital strategy. The uniqueness and persistence of friction ridge skin patterns make fingerprints a reliable method of individual identification. Automated fingerprint recognition systems, coupled with advances in technology, have significantly improved the speed and accuracy of fingerprint matching, enabling efficient and reliable identification processes [1, 2]. Since the late 19th century, forensic investigations have used this distinctive pattern to confirm a person's identification [4]. Friction skin has a number of lines that indicate the ridges and grooves.

A fingerprint's individuality comes from the configuration of these ridges and grooves, which remains constant during a person's lifetime [1]. Each skin ridge has a single row of pores through which sweat is released and left on the skin's surface. Three different types of natural secretory glands exist in the body. Each gland generates one of three forms of sweat: eccrine, sebaceous, and apocrine [5]. The composition of these three secretions is extremely intriguing to forensic investigators. Despite being found all throughout the body, eccrine sweat glands are more common in the palmar and plantar surfaces [6]. Between 98 and 99% of eccrine sweat is

water, and it also contains a number of inorganic ions, including chloride, bromide, iodide, fluoride, and phosphate, as well as organic substances like amino acids, fatty acids, and urea [7]. The only areas of the body without sebaceous glands are the friction ridge surfaces of the hands and feet. Sebaceous glands secrete sebum, which is mostly composed of saturated lipids, waxes, and squalene [8]. Human axillae and anogenital regions are the main locations for apocrine glands, which release a thick milky fluid.

Particularly in improving the visualization and detection of latent fingerprints, nanoparticles are important in the development of fingerprints. They improve sensitivity, selectivity, and resolution over conventional approaches, which gives them various benefits. Due to their distinctive physical and chemical characteristics, nanoparticles have attracted attention for application in the development of fingerprints. The capacity of nanoparticles to interact with the elements of latent fingerprints, or the invisible impressions left behind by the ridges of the skin, is one of their major advantages in the production of fingerprints. The many components of fingerprints, such as amino acids, fatty acids, proteins, and oils, can be engineered to selectively bind to nanoparticles, improving their visibility and making detection easier. By leveraging this specific interaction, it is possible to see fingerprints that would be difficult to see using more traditional methods because they are weak or damaged [9].

To interact with the elements of latent fingerprints, nanoparticles can be functionalized with various substances, such as metal ions, dyes, or fluorescent markers. These modified nanoparticles have the ability to attach to proteins, fatty acids, amino acids, and other elements found in sweat residues seen in fingerprints. The contrast and visibility of latent prints are improved by nanoparticles by specifically targeting components of the fingerprint residue. The unique biomolecules present are adhered to by the nanoparticles when they come into touch with the fingerprint residue, which highlights the differences between the background surface and the latent print. Because of the improved contrast, forensic investigators can more easily see and record the fingerprint's details, which helps with identification and analysis. In order to maintain the validity of the evidence, the nanoparticles can also assist shield the fingerprint against deterioration or contamination.

One typical method is using metal nanoparticles with a strong surface plasmon resonance, such as gold or silver nanoparticles. The greater light absorption and dispersion made possible by this characteristic makes it

easier to see latent fingerprints. One typical method for enhancing the visibility of latent fingerprints is by utilizing metal nanoparticles that exhibit a strong surface plasmon resonance, particularly gold or silver nanoparticles. The unique optical properties of these nanoparticles enable enhanced light absorption and dispersion, thereby facilitating the visualization of latent fingerprints with greater ease. Surface plasmon resonance refers to the collective oscillation of electrons on the surface of metal nanoparticles when they are exposed to light of a specific wavelength. This phenomenon arises due to the interaction between incident light and the free electrons within the metal nanoparticles. Gold and silver nanoparticles, in particular, are known to exhibit a pronounced surface plasmon resonance in the visible or near-infrared region of the electromagnetic spectrum. When metal nanoparticles with strong surface plasmon resonance properties are brought into contact with latent fingerprints, they interact with the incident light in a unique manner. The surface plasmons of the nanoparticles enhance light absorption and scattering in the vicinity of the fingerprint ridges, leading to an increased contrast between the ridges and the surrounding background. The improved light absorption and dispersion achieved through this characteristic of metal nanoparticles result in a more distinct visualization of latent fingerprints. By selectively enhancing the optical signals from the fingerprint ridges, the background noise is reduced, allowing for a clearer and more identifiable representation of the fingerprint pattern. Also, metal nanoparticles can react with fingerprint elements to produce visible precipitates or color changes [10].

Utilizing luminous or fluorescent nanoparticles is another way that nanoparticles are used in the formation of fingerprints. When stimulated by an external light source, these nanoparticles produce light with a certain wavelength. Researchers have developed very sensitive and specific probes for detecting latent fingerprints by conjugating fluorescent nanoparticles with certain ligands that interact with fingerprint residues [11, 12]. Magnetic nanoparticles have been utilized to enhance fingerprint recognition by taking advantage of their unique properties. These nanoparticles can be easily manipulated and controlled using magnetic fields, providing a method to improve the visibility and clarity of latent fingerprints. It is important to note that the specific techniques and methods used for applying magnetic fields and manipulating magnetic nanoparticles can vary depending on the particular fingerprint detection system or protocol being employed [13, 14].

1.2 FINGERPRINT AND THEIR COMPOSITION

The study of fingerprints extends beyond their visual patterns to the composition of sweat secretions that leave an imprint on surfaces. Sweat, the primary component of these secretions, contains a mixture of substances that contribute to the complexity of fingerprints. Extensive scientific research has been conducted to analyze the quantitative and qualitative makeup of sweat [16]. Studies have investigated various aspects, including the chemical composition, metabolites, drug traces, and contaminants present in fingerprints. This research has aimed to understand the potential applications of fingerprint analysis in forensic science, as well as the limitations and challenges associated with interpreting fingerprint evidence [17, 18].

The composition of fingerprints is influenced by both intrinsic and extrinsic factors. Intrinsic components refer to the natural substances produced by the body, such as metabolites and drug residues. These components can provide valuable information about an individual's health, lifestyle, and even their recent activities. Advancements in technology have led to the development of sophisticated fingerprint analysis techniques, such as mass spectrometry and chromatography, which allow for the identification and quantification of specific components present in fingerprints. These techniques enable researchers and experts to delve deeper into the intricate composition of fingerprints and extract valuable information that can have significant implications in various fields. The presence of certain metabolites or drug traces in fingerprints can be indicative of drug use or exposure to specific substances. Extrinsic contaminants, on the other hand, encompass a wide range of substances that can be transferred to the fingertips from the external environment. These contaminants can include blood, grease, dirt, makeup, food impurities, moisturizers, hair care products, and more [19–21]. The presence of extrinsic contaminants in fingerprints can be influenced by an individual's occupation, hobbies, or environmental exposure. It is important to note that the composition of fingerprints can vary significantly between individuals, leading to inter variability. Additionally, within a single individual, the composition of fingerprints can exhibit intravariability, meaning that it can change throughout the day or at different times of the day. Factors such as hydration levels, physical activity, and exposure to different environments can contribute to these

variations in the fingerprint's composition [22–25]. The original structure of a fingerprint can be altered as it ages or interacts with external factors. The triangle of interaction concept illustrates the relationship between the environment, the substrate (the surface on which the fingerprint is deposited), and the composition of the fingerprint. Changes in environmental conditions, the nature of the substrate, and the presence of contaminants can all affect the stability and preservation of the fingerprint [26–29]. Understanding the composition of perspiration on fingerprints is a complex task due to the wide range of potential components and the variability inherent to individuals and their environments. Analyzing and interpreting the information contained within fingerprints requires sophisticated techniques and methodologies, including advanced analytical instruments and expertise in forensic science [30].

TABLE 1.1 The Chemical Composition of Fingerprint Sweats [31].

S. No	Source of Sweat on Fingerprint	Constituents	
		Organic	**Inorganic**
1	Sebaceous	Glycerides, fatty acids, wax ester, squalene, sterol esters, sterols	
2	Eccrine	Amino acids, proteins, urea, uric acid, lactic acid, sugars, creatinine, choline	Chlorides, metal ions, sulfates, phosphates, ammonia, water
3	Apocrine	Carbohydrates, proteins, sterols	Iron, water

1.3 NANOMATERIAL AND LATENT FINGER-MARKS

Nanomaterials, characterized by their large surface area, small size, unique optical properties, and ease of surface modification, have gained significant attention in various fields. When it comes to fingerprint analysis, nanomaterials offer several appealing features that make them valuable tools for enhancing fingerprint detection and visualization. One of the key advantages of nanomaterials in fingerprint analysis is their ability to interact effectively with both nonporous and porous surfaces. Traditional fingerprint detection methods often face challenges when dealing with different types of surfaces, such as smooth glass or rough paper. Nanomaterials, however, can readily adhere to these surfaces and facilitate the interaction between the fingerprint residues and the substrate.

The use of nanomaterials in fingerprint analysis has been shown to improve the quality of fingerprint images. Due to their unique characteristics, such as high surface reactivity and hydrophilic properties, nanomaterials enable better adhesion of fingerprint components to the substrate. This leads to sharper ridge patterns and reduced background interference, resulting in clearer and more distinguishable fingerprint images [33].

Moreover, nanomaterials exhibit enhanced sensitivity, allowing for the detection of both recent and ancient fingerprints. Fingerprint residues can persist on surfaces for extended periods, and traditional detection methods may struggle to identify aged or partially degraded prints. However, nanomaterials have the ability to interact with trace amounts of fingerprint residues, even after significant time has passed. Their nanoscale surface interactions, combined with their unique chemical and physical properties, enable the detection and visualization of latent fingerprints that may have been challenging to observe using conventional methods [30, 31].

The versatility of nanomaterials extends beyond their interaction with fingerprint residues. These materials can be engineered and tailored to meet specific requirements, such as the modification of their surface properties or the incorporation of additional functionalities. This flexibility allows for the development of targeted and specialized nanomaterials for fingerprint analysis. For example, researchers have explored the use of functionalized nanoparticles that can selectively bind to specific components of fingerprints, enhancing the contrast and resolution of ridge patterns [32].

In addition to their visual enhancement capabilities, nanomaterials have also shown promise in the preservation and recovery of fingerprints. By forming a protective layer around the fingerprint residues, nanomaterials can help prevent contamination or degradation over time. Furthermore, they can facilitate the lifting and transfer of fingerprints from surfaces, enabling their preservation for further analysis and investigation [35–37].

The field of nanomaterials in fingerprint analysis is continuously evolving, with ongoing research focused on exploring new materials, improving detection methods, and enhancing the understanding of the underlying interactions between nanomaterials and fingerprints. Challenges remain, such as the standardization of protocols and the

integration of nanomaterial-based techniques into existing forensic workflows. However, the potential benefits and advancements offered by nanomaterials make them an exciting and promising avenue for the future of fingerprint analysis [38]. As shown in Table 1.2, several nanoparticles are described together with their sizes and how well they form on various surfaces.

TABLE 1.2 Different Types of Nanoparticle Used in the Development of Latent Finger Marks and the Sizes of the Various Nanoparticles are Discussed. ⏎

S. No	Nanoparticle	Size	Description	References
1.	AgNP	1–200 nm	The physical developer (Ag-PD) technology may create fingerprints on surfaces after hours of exposure to bright sunlight. Additionally, it may remove fingerprints from your object.	[32, 33]
2.	AuNP	2–3 nm	Gold nanoparticles significantly increase the intensity and clarity of the prints produced as compared to Ag-PD alone.	[34]
3.	AuNP	2.5 nm	The SND method yields positive results (clear ridge features) when using the gold nanoparticle solution on porous surfaces in a single step. However, the MMD method requires several bath stages in a small pH range.	[35]
4.	ZnO Nano Powder	1–3 nm	The method works effectively to remove both recent and old fingerprints from nonporous surfaces.	[36, 37]
5.	Siliconoxide nanoparticles	70 nm ± nm	The silicon nanoparticles (SiO_2-NPs) have an exceptional capacity to coat surfaces and help visualize fingerprint traces left on nonporous surfaces.	[37]
6.	AuNP	16 nm	The method has produced encouraging results for improving fingerprints that are older than a week.	[38]
7.	AuNP coupled to a bifunctional agent	-	The method enhances fingerprint analysis since it makes it possible to identify prints even when they are damp.	[39, 40]
8.	Eu^{3+}-doped Al_2O_3 nanocrystalline powder	36.38 nm	The technique encourages strong contrast of the latent fingerprints on nonporous surfaces when exposed to UV light.	[41]

TABLE 1.2 *(Continued)*

S. No	Nanoparticle	Size	Description	References
9.	Fluorescent starch-based carbon nanoparticles	10–40 nm	The method is easy and eco-friendly. The mixture has a unique UV fluorescence. The feature that is helpful in the creation of indelible fingerprints.	[42]
10	Electro-deposited metal nanoparticles	10–100 nm	The method can be used to improve sebaceous and eccrine fingerprints on conducting surfaces. This technique works on both smooth and textured metallic surfaces.	[43]
11	Amphiphilic silica nanoparticles	250, 550, and 700 nm	The method is effective for creating latent prints on smooth, nonporous materials.	[44]
12	CdSe nanoparticles	Nonregular size	When exposed to ultraviolet light, the fingerprints made on various nonporous surfaces—including the magnetic strip of a credit card, the screen of a mobile phone, and iron tweezers—treated with this powder glow a soft orange.	[45]
13	AuNP	10 nm, pseudo spherical shape	Different kinds of AuNPs with various SPR characteristics allow for the clear observation of LFPs with bare eyes.	[46]
14	AuNP	10.66 ± 1.22 nm	AgNPs were discovered to remain stable for more than a month and were able to generate unique ridge features. In contrast, only weak ridge patterns were seen when $AgNO_3$ was utilized as the developing agent for the latent fingerprints, further demonstrating the decrease of fingerprint stability over roughly 20 days.	[47]

1.3.1 GOLD NANOPARTICLES FOR DETECTION OF LATENT FINGERPRINTS

For the identification of fingerprints, gold nanoparticles have shown significant qualities including selectivity, sensitivity, inertness, and long-term stability. These nanoparticles are frequently used to detect LFP on substrates with nonporous surfaces. Due to lipophilic interaction with fatty acid molecules on fingerprint ridges, amine functional groups of gold nanoparticles are adsorbed on fingerprint residues [48]. A forensic science study is being done, according to Tang et al. [46], for the identification and

visualization of LFP detection. Nanomaterials are mostly kept in touch with the finger's ridges to enhance the visibility of latent fingerprints. Mass spectrometry has utilized gold nanoparticles to image and identify latent. Tang et al. [46] have combined a few unique qualities of gold nanoparticles (AuNPs) with imaging mass spectrometry to see and image LFPs at the molecular level. Different surface plasmon resonance (SPR) bands of the AuNPs provide two contrasting colors (blue and pink), which show the optical pictures of LFPs [49]. The ability to identify fingerprints is made feasible by the gold nanoparticle deposition on chitosan-treated latent fingerprints, which improves contrast. This approach can be a cheap and effective way to improve fingerprints and then identify them as chitosan is the second most common natural polymer. Chitosan is a natural polymer derived from chitin, which is found in the exoskeletons of crustaceans and insects. It is known for its biocompatibility, biodegradability, and adhesive properties. Chitosan can be used as a coating or substrate to enhance the adhesion and stability of nanoparticles, such as gold nanoparticles, on the surface of latent fingerprints.

1.3.2 SILVER NANOPARTICLE USED FOR DETECTION OF FINGERPRINT [47]

The quality and stability of fingerprints made on paper or a porous substrate using $AgNO_3$ and AgNPs, respectively, compared as well AgNPs were shown to remain stable for more than a month throughout the investigation and were able to generate unique ridge features. In contrast, only weak ridge patterns were seen when $AgNO_3$ was utilized as the developing agent for the latent fingerprints, further demonstrating the decrease in the fingerprint stability over roughly 20 days. Strategy for LFP detection has been devised to find fingerprints on porous, wet, and dry substrate materials. Image development on porous materials, such as paper products, clay substrates, and sticky tape substrates, is used to increase LFP detection. In order to create visuals during photos, photographers and FGPT image producers have corporate. Redox reagents like iron salt produce oxidation–discount reactions in the pictures, which serves as the foundation for this. The iron salt's reducing qualities enable the silver nitrate technique, which is used to create the film, to convert silver nitrate to metallic silver. The latent fingerprint picture, however, is recorded as a black image and is dark gray in color because metallic silver particles react with the lipids

and fatty acids in the finger's sweat residue [33]. Forensic science has also used silver nanoparticles for fingerprint recognition. Silver nanoparticles have led to definite increases in the quality of fingerprint pictures, although they are still better in terms of fingerprint detection. In order to identify fingerprints, metal ions supported on substrates are no longer widely used [50]. In forensic science today, metal nanoparticle powders are used increasingly often for LFP detection on porous and nonporous substrates at crime scenes. These powders can effectively identify latent fingerprints since they are inexpensive and have high adhesive qualities [51]. Finely powdered silver nanoparticles have been adsorbed on sweaty and greasy surfaces in fingerprint ridges. A silver ink solution might be used to detect LFP, according to Yang et al. [52]. In order to see the ridge regions, the silver ink solution is absorbed onto the finger residue substrate. Due to its high cost and complex equipment, the silver ink solution is performed poorly for LFP detection. LFP detection needs to be done quickly and easily in the current situation. As a result, this technique has advanced the visualization of LFP pictures and is widely used in forensic science. Due to their strong affinity for the chemical compounds included in fingerprint residue, silver nanoparticles have been discovered as powders that are particularly appealing for the generation of latent fingerprints. Latent fingerprints are impressions left behind by the ridges and valleys on the surface of the skin. They are often invisible to the naked eye and require enhancement techniques to make them visible for identification purposes. Traditional methods of fingerprint development involve the application of powders or chemical reagents that adhere to the sweat and oil residues present in the fingerprint, thereby revealing the hidden pattern. Silver nanoparticles have emerged as an innovative and advantageous alternative to conventional methods. One of the key reasons for the popularity of silver nanoparticles in latent fingerprint development is their strong affinity for the chemical compounds found in fingerprint residue. Fingerprint residue typically contains various organic and inorganic substances, such as amino acids, fatty acids, proteins, and metal ions. Silver nanoparticles have been found to exhibit a high affinity for these components, leading to enhanced adhesion and visualization of the latent fingerprint.

The unique properties of silver nanoparticles contribute to their effectiveness in latent fingerprint development. These nanoparticles possess a large surface area-to-volume ratio, which enables them to interact more extensively with the chemical compounds in fingerprint residue. Additionally, their small

size and excellent dispersibility allow for uniform coverage and distribution over the fingerprint, resulting in improved contrast and clarity. The interaction between silver nanoparticles and fingerprint residue can be attributed to several mechanisms. The silver nanoparticles may form coordination complexes with metal ions present in the residue, leading to the formation of visible complexes. They can also interact with the organic compounds through adsorption or electrostatic interactions, thereby facilitating the visualization of the fingerprint pattern. Furthermore, silver nanoparticles can be synthesized with tailored surface properties to optimize their interaction with fingerprint residues. Surface modifications, such as functionalization with specific chemical groups or coatings, can enhance the nanoparticles' selectivity toward certain compounds commonly found in fingerprints. This customization allows for the development of latent fingerprints with higher sensitivity and specificity. The application of silver nanoparticles in latent fingerprint development offers several advantages. First, they provide enhanced sensitivity, enabling the detection of faint or aged fingerprints that may be challenging to visualize using conventional methods. Second, they exhibit a reduced background interference, resulting in improved contrast and higher-quality fingerprint images. Lastly, silver nanoparticles are relatively simple to use, making them practical for forensic professionals and reducing the overall processing time required for fingerprint analysis. For instance, latent fingerprints from the year 1970 on porous surfaces were discovered using silver nanoparticle powder as a physical developer [32]. Using iron salt as an oxidant, the silver was reduced to silver nanoparticles throughout the fingerprint-detecting process. Because of the oxidation and reduction processes involved, the porous surface revealed crisp pictures as well as gray and dark-colored silver nanoparticles. The nanoparticles fill in the ridges and valleys of the fingerprint, highlighting the pattern and making it more discernible. It is important to note that the specific details of the fingerprint detection process, including the concentration of the iron salt, the method of application, and the subsequent imaging or analysis techniques, can vary depending on the specific method or protocol being used.

1.3.3 OXIDE NANOPARTICLES FOR LATENT FINGERPRINT DETECTION

EuO nanoparticles have therefore been utilized for the identification of latent fingerprints because of their distinct fluorescence characteristics.

Prabakaran and Pillay [53] reported the use of a composite material derived from a europium salt Na [Eu (5,5′-DMBP) (phen)3] Cl_3/D-Dextrose (Eu(III)-CPLx/D-Dex) by using 5,5′-Dimethyl-2,2′-bipyridyl (5,5′-DMBP), 1,10-phenanthroline (phen), europium chloride hexahydrate ($EuCl_3 \cdot 6H_2O$), and D-dextrose as precursors. On several surfaces, this composite made of europium was employed for latent fingerprint detection. This showed capability as a good labeling agent for LFP examination for forensic applications and produced superior LFP pictures, ridge details, and high contrast. By fuming cyanoacrylate with europium compounds, similar chemicals are employed to identify fingerprints [54–58]. In their study of latent fingerprint detection utilizing amine-coated EuO nanoparticles, Menzel et al. [59]. The discovery that the material can be readily functionalized with the carboxylic moieties of fingerprint residues is significant, as it allows for the creation of fluorescent fingerprint pictures when single-particle techniques are employed. This functionalization process involves the attachment of fluorescent molecules or probes to the carboxylic groups present in fingerprint residues. When these fluorescent materials are applied to the fingerprint surface, they selectively bind to the carboxylic moieties, resulting in the creation of fluorescent patterns that correspond to the fingerprint ridges and valleys. This fluorescence-based approach enhances the contrast and visibility of the fingerprint, making it easier to detect and analyze. Additionally, the use of time-resolved techniques can further improve the fingerprint detection process. Time-resolved techniques involve the measurement of fluorescence signals over a specific time period, allowing for better discrimination between the fingerprint fluorescence and background noise. By analyzing the temporal characteristics of the fluorescence emission, it becomes possible to differentiate the fingerprint signal from other interfering signals, resulting in improved fingerprint picture quality.

1.3.4 SILICA (SiO_2) NANOPARTICLES FOR LATENT FINGERPRINT DETECTION

According to Huang et al. [44], silica (SiO_2) nanoparticles can be modified using 4-(chloromethyl) phenyltrichlorosilane for the purpose of detecting old fingerprints and fingerprints on glass surfaces. Different mass ratios of silica and 4-(chloromethyl) Phenyl trichlorosilane with 700

nm of SiO_2 nanoparticles were used to create the silica nanoparticles. With a ratio of (50:1) SiO_2:4-(chloromethyl) phenyltrichlorosilane, the best latent fingerprint detection was accomplished. On nonporous surfaces, these nanoparticles have demonstrated the best LFP detection. The research on novel silica nanoparticles modified with 4-(chloromethyl) phenyltrichlorosilane for fingerprint detection showcases the exploration of new materials and surface modifications to enhance the sensitivity and selectivity of latent fingerprint detection. In this approach, silica nanoparticles are employed as the base material, which offers several advantages such as high surface area, stability, and ease of functionalization. The surface of the silica nanoparticles is modified by attaching 4-(chloromethyl) phenyltrichlorosilane, a compound that imparts sensitivity and selectivity to latent fingerprints. The modification of silica nanoparticles with 4-(chloromethyl) phenyltrichlorosilane provides a surface that can interact specifically with the components present in fingerprint residues. The compound contains functional groups that have an affinity for certain substances found in fingerprints, enabling the nanoparticles to selectively bind to these specific components.

By producing a powder from these modified silica nanoparticles, it becomes easier to apply them to surfaces containing latent fingerprints. The powder can be dusted onto the surface, and the modified silica nanoparticles will selectively adhere to the fingerprint residues due to their chemical interactions. This results in the enhancement and visualization of the latent fingerprints. By utilizing modified silica nanoparticles in powder form, the process of applying them to surfaces that may contain latent fingerprints becomes significantly more convenient and efficient. The powder, consisting of these specially engineered silica nanoparticles, can be easily dusted onto the surface of interest. As it settles, the modified silica nanoparticles exhibit selective adhesion to the fingerprint residues present on the surface due to specific chemical interactions.

The modified silica nanoparticles possess unique surface properties and chemical functionalities that enable them to selectively interact with the components of latent fingerprints. These nanoparticles are designed to recognize and adhere to the organic compounds, moisture, and other residue left behind by the ridges and valleys of a fingerprint. This targeted adhesion is made possible by the careful modification of the nanoparticles' surface chemistry, which ensures they have an affinity for the specific substances found in fingerprints. Once the powder is applied

and the modified silica nanoparticles adhere to the fingerprint residues, an enhancement and visualization process is initiated. This process takes advantage of the distinctive properties of the modified nanoparticles, which are designed to create contrast and highlight the ridge patterns of the latent fingerprints. The nanoparticles may possess fluorescent or colorimetric properties, allowing for easy detection and differentiation of the fingerprint residues from the background surface. The enhanced visualization of the latent fingerprints occurs as a result of the modified silica nanoparticles binding selectively to the organic and moisture components of the fingerprint residues. By forming a distinct and visible layer on top of the latent fingerprints, the modified silica nanoparticles enable forensic experts to capture clearer images or lift the fingerprints using various techniques. This enhanced visualization is crucial in forensic investigations, as it aids in identifying and comparing fingerprints, potentially leading to the identification of individuals involved in criminal activities or linking them to specific surfaces or objects.

1.3.5 CdSe QDs FOR LATENT FINGERPRINT DETECTION

Mercaptoacetic acid in an aqueous solution with CdSe nanoparticles on top was utilized by Wang et al. [60] to detect fingerprints, and its fluorescent components were employed as adhesives on the sweaty surfaces where fingerprints were found. As a result, the potential toxicity brought on by the inclusion of CdSe nanoparticles for surface modification is reduced. When compared to modified CdSe nanoparticles, CdSe fluorescent materials showed stronger brightness and improved picture quality in the identification of fingerprints. The CdSe QDs have also been compared to gentian violet and employed as sticky materials for fingerprint identification to improve fingerprint photos with low contrast backgrounds. For applications in latent fingerprint detection, Algarra et al. [45]. The proposed use of freshly modified CdSe quantum dots (QDs) with porous phosphate heterostructures (PPH-NH2) for latent fingerprint (LFP) detection demonstrates a promising approach to enhance fluorescent pictures and improve the overall performance of luminescent materials. The CdSe QDs are modified with porous phosphate heterostructures (PPH-NH2). The PPH-NH2 acts as a coating or shell around the CdSe QDs, controlling their unfolding and surface properties. This modification is aimed at optimizing the interaction

between the nanoparticles and fingerprint residues. By incorporating the PPH-NH2 structure, the luminescent materials derived from CdSe QDs exhibit enhanced fluorescence properties. The porous heterostructures play a crucial role in controlling the way the nanoparticles unfold, potentially improving their efficiency in capturing and emitting light. When used for LFP detection on nonporous surfaces, these luminescent materials show improved performance in generating fluorescent pictures. The enhanced fluorescence from the PPH-NH2@CdSe nanocomposite contributes to increased signal intensity and improved visualization of the fingerprint patterns. Furthermore, the luminescent materials produce a backdrop with reduced contrast, which can facilitate better contrast between the fingerprint ridges and the background surface. This reduction in contrast helps to isolate and highlight the fingerprint details, making them more discernible and easier to analyze.

1.4 CONCLUSION

In conclusion, the creation of latent fingerprints has been revolutionized by the use of nanoparticles such as silica, gold, silver, CdSe, and others. Amino acids, proteins, and other elements included in latent fingerprints have been successfully identified using gold and silver nanoparticles, which also show great sensitivity and selectivity. They have shown to be quite useful in improving the contrast and visibility of fingerprints, especially on difficult surfaces, due to their capacity to induce unique color changes or fluorescence upon contact with fingerprint residues. The extraordinary capacities of these nanomaterials to improve the visibility and preservation of latent fingerprints have made them priceless instruments for criminal investigations and judicial systems across the world. The accuracy and effectiveness of latent fingerprint analysis have the potential to be significantly improved with ongoing research and development in this field, which will eventually progress forensic science as a whole.

There are still issues and constraints that need to be resolved in this sector, despite the substantial progress that has been made. Future research must focus on standardizing nanoparticle-based fingerprint creation techniques, optimizing nanoparticle size and surface functionalization, and making these techniques compatible with actual forensic situations.

KEYWORDS

- **Advancements**
- **fingerprint development**
- **forensic science**
- **latent fingerprints**
- **nanoparticles**
- **visualization**

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CHAPTER 2

Enhancing Fingerprint Development: Utilizing Titanium Dioxide Nanoparticles for Improved Forensic Identification

VAIBHAV SHARMA[1], DIVYANSH JAIN[1], ABHISHEK R. RAI[1], ANOOP M DIVAKARAN[2], MAHIPAL SINGH SANKHLA[3,4], ANUBHAV SINGH[5], and KAMAKSHI PANDEY[6]

[1]*Department of Forensic Science, Vivekananda Global University, Jaipur, India*

[2]*Toyota Technological Institute, Hisakata Tempaku, Nagoya, Japan*

[3]*Department of Forensic Science, UIAHS, Chandigarh University, Mohali, Punjab, India*

[4]*University Centre for Research and Development, Chandigarh University, Mohali, Punjab, India*

[5]*School of Forensics, National Forensic Science University, Gandhinagar, Gujarat, India*

[6]*Department of Physics and Material Research Centre, Malaviya National Institute of Technology, Jaipur, Rajasthan, India*

ABSTRACT

Science and technology have made significant strides thanks to nanotechnology. Additionally, it is crucial to forensic science and its use. The

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Kumud Kant Awasthi, Mahipal Singh Sankhla, Chandra Shekhar Yadav, and Anjali Awasthi (Eds.)

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identification of fingerprints can benefit from nanoparticles. As one of the most valuable and reliable forms of forensic evidence, fingerprints are frequently used as the primary method of identifying humans during investigations. The need for the quick and easy finding and extraction of latent fingerprints at crime scenes is still critical since latent or invisible fingerprints are frequently found on crime scenes, and one of the tools used at crime scenes to find latent fingerprints is TiO_2 nanoparticles. The many techniques for creating and characterizing TiO_2 nanoparticles, as well as their use for fingerprint development, are summarized in this chapter.

2.1 INTRODUCTION

Fingerprints have long been valued as a distinctive human identifier, making them crucial for both civil and criminal investigations [1]. The unique patterns and ridges present in fingerprints have been utilized for decades to identify individuals and establish their presence at a particular location. At crime scenes, fingerprints play a pivotal role as a source of evidence due to their durability and uniqueness, often serving as a reliable means of linking suspects to the scene of a crime. However, the detection of fingerprints is not always straightforward. Latent prints, which are the most prevalent type of fingerprint, are left behind unintentionally and are typically invisible to the naked eye. These latent prints can be caused by sweat, oil, or other substances present on the fingertips, and they need to be visualized and collected for further analysis. Unfortunately, without the aid of specialized equipment and techniques, latent prints can be challenging to discover and process [2]. In recent years, nanotechnology has emerged as a prominent field, offering a wide range of applications across various research domains, including forensics [3]. Nanoparticles, such as titanium dioxide (TiO_2), have gained attention in the field of fingerprint analysis due to their unique properties and their potential to enhance the detection and visualization of latent prints. This chapter focuses on the utilization of nanoparticles, particularly TiO_2, in the creation and recognition of latent fingerprints. TiO_2 is known for its photocatalytic properties, which can be harnessed to visualize latent prints by inducing a chemical reaction when exposed to certain wavelengths of light. By utilizing TiO_2-based methods, latent prints can be made visible, allowing forensic investigators to capture and preserve the fingerprint details for further examination. The

chapter delves into the underlying mechanisms of how TiO_2 nanoparticles interact with latent prints, exploring the chemical reactions that occur and the subsequent visualization techniques employed. It discusses the various methods of applying TiO_2 nanoparticles to latent prints, such as spray deposition, electrostatic dusting, or immersion, highlighting their advantages and limitations. Furthermore, the chapter explores the advancements in fingerprint recognition techniques enabled by nanotechnology. The unique characteristics and enhanced visibility of latent prints using TiO_2 nanoparticles can aid in the development of automated fingerprint identification systems (AFIS) and enhance the accuracy of fingerprint matching algorithms.

Nanoparticles are subatomic particles with diameters between 1 and 100 nm (1–10 m) [4]. They have distinctive qualities that distinguish them from bulk materials because of their small size and high surface area-to-volume ratio. A typical nanoparticle has three layers: the surface layer, the shell layer, and the core [5]. The surface layer is functionalized with a range of chemicals, metal ions, surfactants, and polymers whereas the shell layer and the core are chemically distinct from one another [6, 7]. Due to the exponential properties of nanoparticles and their potential uses in a variety of scientific domains, researchers have expressed a great deal of interest in them [8].

Nanotechnology has revolutionized the field of forensic science, particularly in the realm of latent fingerprint detection. Researchers have explored the potential of using specially designed nanoparticles to create and enhance latent fingerprints discovered at crime scenes [9]. Among these nanoparticles, TiO_2 nanoparticles have emerged as a standout candidate due to their versatility and wide range of applications across various industries [10]. TiO_2 nanoparticles exhibit exceptional properties that make them suitable for diverse applications. One of their notable uses is in solar cells, where they can enhance the efficiency of energy conversion by capturing sunlight more effectively. Their high photocatalytic activity enables them to break down organic compounds, making them ideal for self-cleaning materials. By incorporating TiO_2 nanoparticles into coatings, surfaces can repel dirt and maintain their cleanliness. Additionally, TiO_2 nanoparticles are employed in antireflection coatings, which minimize light reflection and improve optical clarity in devices such as eyeglasses, camera lenses, and display screens. Their unique properties also make them valuable in the development of light-emitting diodes (LEDs), where

they help enhance brightness and color rendering. The application of TiO_2 nanoparticles extends beyond optics and electronics. They are utilized as pigments in paint formulations, providing enhanced durability and color stability. In sensor technologies, TiO_2 nanoparticles play a crucial role in improving the sensitivity and selectivity of various sensors, enabling more accurate detection and measurement of different substances. Furthermore, TiO_2 nanoparticles contribute to the advancement of battery technology. They can enhance the performance and lifespan of batteries by improving charge storage and transfer efficiency. These nanoparticles are also utilized in the production of sunscreen lotions, where they provide effective protection against harmful ultraviolet (UV) radiation. TiO_2 nanoparticles have found applications in the field of photonics as well. Their unique optical properties, such as high refractive index and light-scattering capabilities, enable the development of advanced optical devices and components. Additionally, these nanoparticles can facilitate the generation of hydrogen, a clean and sustainable fuel source, through water-splitting processes.

Another significant advantage of TiO_2 nanoparticles is their ability to reduce air pollution. Due to their photocatalytic properties, they can effectively degrade harmful pollutants present in the air, contributing to the mitigation of environmental pollution. Given the diverse features and applications of TiO_2 nanoparticles, they hold significant promise for latent fingerprint detection. These nanoparticles can be employed to enhance the visibility and clarity of latent fingerprints, making them more easily identifiable and traceable by forensic experts. Their unique properties, such as their photocatalytic activity and optical characteristics, can aid in revealing latent fingerprints that might otherwise be difficult to detect.

The focus of this chapter is on the numerous techniques used to create and characterize TiO_2 nanoparticles. The solution combustion method, the hydrothermal method, and the homogeneous approach are some of the synthesis procedures that are covered [14]. Each technique is explained in depth, highlighting the methods required and the features of the produced nanoparticles. Techniques including powder X-ray diffraction (PXRD) [15], scanning electron microscopy (SEM) [16], transmission electron microscopy (TEM) [17], Raman spectroscopy, and X-ray fluorescence (XRF) [18] studies are used to characterize TiO_2 nanoparticles. The size, shape, crystal structure, content, and elemental analysis of the synthesized TiO_2 nanoparticles are all revealed by these characterization approaches [19].

Clear fingerprint pictures and ridge patterns on diverse surfaces are produced by TiO_2 nanoparticles' good interactions with the sebaceous gland fingerprint residue. This chapter focuses on the visualization of TiO_2 nanoparticles on diverse substrates, including paper, glass, metal, and plastic [20]. It is explored how well TiO_2 nanoparticles work to create latent fingerprints as well as the effects of other elements such as nanoparticle concentration, deposition techniques, and substrate characteristics [21]. The long-term durability of TiO_2 nanoparticles for fingerprint detection is also discussed, highlighting its applicability for forensic science applications even after long periods [22].

TiO_2 nanoparticle use in forensic science is a ground-breaking method of latent fingerprint detection. TiO_2 nanoparticles are the best choice because of their special characteristics and wide range of known applications.

2.2 SYNTHESIS OF TIO_2 NANOPARTICLES USED FOR LATENT FINGERPRINT DEVELOPMENT

TiO_2 nanoparticle production is crucial in the field of creating latent fingerprints. TiO_2 nanoparticles have garnered a lot of interest due to their remarkable properties and many uses. This paper provides information on the synthesis techniques used to produce TiO_2 nanoparticles that are specifically made for the recognition and improvement of latent fingerprints. Understanding the synthesis procedures is necessary to optimize the characteristics of nanoparticles and ensure that they function properly in forensic science applications. The following are a few of the techniques utilized to create TiO_2 nanoparticles:

1. Solution Combustion Method: A common approach utilized in the creation of TiO_2 nanoparticles for latent fingerprint development is the solution combustion method. This process offers numerous advantages, including its user-friendly nature, affordability, and the ability to produce nanoparticles with specific properties. The synthesis process begins with a precursor solution consisting of titanium salts, such as titanium (IV) isopropoxide or titanium (IV) chloride, dissolved in a suitable solvent. This precursor solution serves as the initial stage in the synthesis process. To initiate the synthesis, the precursor solution is combined with a fuel agent, typically a reducing agent like urea or glycine. When the fuel

agent interacts with the precursor solution during combustion, it acts as a heat source and reduces the precursor, leading to the creation of TiO_2 nanoparticles. The combustion process is exothermic and self-sustaining, as the fuel agent rapidly decomposes when heated. During combustion, a high-temperature flame is generated, rapidly heating the precursor solution. This elevated temperature promotes nucleation, which is the formation of small clusters of atoms or molecules, and facilitates the growth of TiO_2 nanoparticles. The burning process enables the reduction of the titanium precursor and the swift production of TiO_2 nanoparticles. The properties of the TiO_2 nanoparticles produced using the solution combustion method are influenced by several key variables. The precursor concentration determines the availability of titanium ions for nanoparticle formation. A higher precursor concentration typically results in a higher concentration of titanium ions and, consequently, affects the size and number of nanoparticles produced. The fuel-to-oxidizer ratio is another important variable that impacts the intensity and heat production during combustion. Adjusting this ratio can control the combustion process and, consequently, the characteristics of the resulting nanoparticles [23–25].

2. Hydrothermal Method: The hydrothermal approach is a widely used method for creating TiO_2 nanoparticles, which are essential for latent fingerprint development. This technique offers precise control over the synthesis process, allowing for the production of nanoparticles with specific properties under high temperature and high-pressure conditions. The first step in the synthesis process involves preparing a precursor solution using titanium salts, such as titanium (IV) isopropoxide or titanium (IV) chloride, dissolved in a suitable solvent. This precursor solution is then transferred into a sealed container, often referred to as an autoclave or a stainless-steel reactor with Teflon lining. Subsequently, the sealed vessel is subjected to extreme pressure and heat within an oven or a hydrothermal reactor. The hydrothermal conditions, typically ranging from 100 to 300°C, and pressures of several hundred atmospheres, create an environment conducive to the nucleation and growth of TiO_2 nanoparticles. The high pressure maintains the solvent in a liquid state at temperatures exceeding its boiling

point, promoting the development of nanoparticles. The reaction time within the hydrothermal reactor varies depending on the desired size and properties of the nanoparticles, ranging from a few hours to several days. Throughout this period, TiO_2 nanoparticles are generated through the hydrolysis and condensation processes of the precursor. The resulting nanoparticles exhibit different characteristics influenced by factors such as temperature, reaction time, precursor concentration, and the presence of additives. By carefully manipulating these variables, researchers can precisely control the size, shape, and crystalline structure of the TiO_2 nanoparticles. These nanoparticles play a crucial role in latent fingerprint development, as their unique properties allow them to adhere to and enhance the visibility of latent prints on various surfaces [26–28].

3. Homogenous Precipitation Method: The creation of TiO_2 nanoparticles has given rise to numerous homogenous synthesis techniques. These techniques, which include sol-gel, precipitation, and sonochemical synthesis, are described in general in this section. The ideas, response steps, and control settings of each approach are explained. As their potential for customizing nanoparticle properties is highlighted, the benefits and drawbacks of homogeneous approaches for the manufacture of TiO_2 nanoparticles are explored [29, 30].

The production of TiO_2 nanoparticles is one of the key phases in the development of effective latent fingerprint detection methods. By carefully regulating the synthesis parameters and the selection of synthesis process, the characteristics of TiO_2 nanoparticles may be specially designed to meet the requirements of forensic science applications. By improving the characteristics of nanoparticles, such as size, shape, and surface chemistry, the detection and visibility of latent fingerprints may be considerably enhanced.

2.3 CHARACTERIZATION METHODS OF TIO_2 NANOPARTICLES

Understanding TiO_2 nanoparticle characteristics and behavior requires the use of characterization techniques. These methods enable the analysis of the nanoparticles' size, shape, structure, composition, surface properties, and optical properties, among other characteristics [31]. Researchers can

learn more about the synthesized TiO_2 nanoparticles and their applicability for latent fingerprint development by combining characterization methods. Here is a summary of a few typical characterization techniques for TiO_2 nanoparticles:

1. X-ray Diffraction (XRD): XRD is a widely used technique for the characterization of TiO_2 nanoparticles. By employing XRD, scientists can obtain valuable information about the crystal structure of the material in a nondestructive manner. This analytical method relies on the phenomenon of X-ray scattering, which occurs when X-rays interact with the atoms in a crystal lattice, causing them to diffract in specific directions. To perform an XRD analysis, a sample containing TiO_2 nanoparticles is subjected to an X-ray beam, and the resulting scattered X-rays are collected by a detector. By carefully analyzing the detected X-rays, a diffraction pattern is generated. This pattern holds crucial clues about the crystal structure of the material under investigation. One of the primary applications of XRD in the context of TiO_2 nanoparticles is the identification of their crystal structure and phase. TiO_2 nanoparticles can exist in three distinct crystal forms, namely anatase, rutile, and brookite. By examining the diffraction pattern produced by the TiO_2 nanoparticles, researchers can determine the presence and relative amounts of each phase in the sample. The XRD patterns of TiO_2 nanoparticles often exhibit several unique peaks that correspond to specific crystal lattice planes. The location and intensity of these peaks can be used to identify the crystal structure and phase of the TiO_2 nanoparticles. Each crystal lattice plane produces a characteristic diffraction peak, allowing scientists to differentiate between different crystal forms and gain insights into the arrangement of atoms within the material.
2. Screening Electron Microscopy (SEM): An effective method for characterizing TiO_2 nanoparticles is SEM [40]. SEM is a powerful imaging technique that allows for the high-resolution visualization of the nanoparticles' surface morphology [41]. By employing electron beams to scan the surface of the nanoparticles, SEM generates images with exceptional resolution and magnification [42]. These detailed photographs offer valuable insights into the distribution, size, and shape of TiO_2 nanoparticles. In addition to surface morphology analysis, SEM can be combined

with energy-dispersive X-ray spectroscopy (EDX) to perform elemental analysis [43]. EDX enables the determination of the chemical composition of the nanoparticles, providing further valuable information about their characteristics. By using SEM in conjunction with EDX, researchers can effectively analyze both the structural and chemical properties of TiO_2 nanoparticles. The high-resolution pictures obtained through SEM offer a wealth of information about TiO_2 nanoparticles. The images reveal intricate details of the surface, allowing researchers to observe the nanoscale features and topography of the particles. The distribution of nanoparticles within a sample can be assessed, providing insights into their aggregation behavior or dispersion patterns. Moreover, the size and shape of TiO_2 nanoparticles can be determined through SEM analysis. By measuring the dimensions of individual particles in the SEM images, researchers can obtain quantitative data on the particle size distribution. This information is crucial for understanding the physical properties and behavior of the nanoparticles. The combination of SEM and EDX offers a comprehensive characterization approach for TiO_2 nanoparticles. EDX analysis provides elemental mapping and quantitative information about the elemental composition of the nanoparticles. This analysis can identify impurities or surface contaminants, as well as determine the presence of other elements that may influence the nanoparticles' properties [44, 45].

3. Transmission Electron Microscopy (TEM): For characterizing the size, form, and morphology of TiO_2 nanoparticles, transmission electron microscopy (TEM) is an incredibly powerful tool [46]. TEM offers the ability to visualize individual particles and their internal structures with exceptionally high resolution. By passing a thin sample through with an electron beam, TEM enables the interaction between the beam and the material, resulting in the creation of an image [47]. TEM not only allows for the visualization of TiO_2 nanoparticles but also facilitates the study of their crystal structure [48]. This aspect of TEM provides valuable insights into the presence of flaws and other structural elements within the TiO_2 nanoparticles. By examining the crystal structure, researchers can gain a deeper understanding of the characteristics and behavior of TiO_2 nanoparticles at the nanoscal [49].

4. Fourier Transform Infrared Spectroscopy (FTIR): The characterization of TiO_2 nanoparticles involves the application of a powerful analytical technique known as Fourier Transform Infrared Spectroscopy (FTIR) [50]. FTIR is utilized to investigate the functional groups present on the surface of the nanoparticles. This technique involves passing an infrared beam through a sample and observing the resulting spectrum, which provides information about the vibrational modes of the molecular bonds in the sample. By employing FTIR, researchers can delve into the surface chemistry of TiO_2 nanoparticles in detail. It enables the identification and analysis of various surface functional groups that may significantly impact the physical and chemical properties of the nanoparticles, as well as their interactions with other molecules and substances. Through FTIR analysis, the unique fingerprint region of the infrared spectrum can be examined, allowing for the identification and characterization of specific functional groups present on the TiO_2 nanoparticle surface. These functional groups play a crucial role in determining the behavior and reactivity of the nanoparticles in different environments. FTIR also aids in understanding the bonding patterns and molecular structure of TiO_2 nanoparticles. By comparing the obtained spectrum with reference spectra or using computational methods, researchers can determine the nature of the bonds present on the surface, such as Ti-O and Ti-OH, among others. This information helps in elucidating the surface properties and potential applications of TiO_2 nanoparticles. Furthermore, FTIR analysis can provide insights into the surface modification and functionalization of TiO_2 nanoparticles. By studying changes in the infrared spectrum after surface treatments or coating with different materials, researchers can investigate the impact of these modifications on the surface functional groups and their subsequent influence on the nanoparticles' properties [51].
5. Raman Studies: Raman spectroscopy is an efficient and widely used method for characterizing TiO_2 nanoparticles [52]. By examining the material's vibrational modes, Raman spectroscopy provides valuable insights into its structural characteristics [53]. In particular, the anatase and rutile phases of TiO_2 nanoparticles exhibit distinct peaks in their Raman spectra [54]. These peaks can be used to determine important properties such as particle size,

crystallinity, and phase composition [55]. The location, intensity, and shape of the Raman peaks offer valuable information about the TiO_2 nanoparticles. For example, the position of the peaks can be correlated with specific crystalline phases, allowing researchers to identify whether the nanoparticles are predominantly anatase or rutile. The intensity of the peaks can provide insights into the concentration and abundance of different phases present in the sample. Additionally, the shape of the peaks can indicate the level of crystallinity, with sharper and narrower peaks typically associated with higher crystallinity. One of the advantages of Raman spectroscopy is its versatility in analyzing TiO_2 nanoparticles in various forms, including suspensions, films, and powders. This flexibility enables researchers to study TiO_2 nanoparticles in different experimental setups, allowing for a comprehensive characterization of their properties. Furthermore, Raman spectroscopy is nondestructive and noninvasive, meaning that it does not cause any damage to the sample being analyzed. This nondestructive nature is especially advantageous when studying valuable or delicate samples [56].

6. X-ray Fluorescence Spectroscopy (XRF): XRF is a powerful and nondestructive analytical technique employed to investigate and determine the elemental composition of various materials [57]. When it comes to characterizing TiO_2 nanoparticles, XRF proves to be an invaluable tool. This method involves subjecting the sample to X-rays, which leads to the emission of fluorescence radiation that is then detected. By analyzing the emitted radiation, one can identify and quantify the elements present in the sample [58]. The intensity of the fluorescence radiation is inversely proportional to the concentration of the elements, allowing for precise measurements and assessments of the chemical composition of TiO_2 nanoparticles. With XRF, scientists can gain valuable insights into the quality of TiO_2 nanoparticles. By quantifying the chemical makeup of these nanoparticles, researchers can assess their purity, determine the presence of impurities or contaminants, and evaluate the consistency of the production process. This information is crucial in various fields, including materials science, nanotechnology, environmental analysis, and quality control. XRF offers several advantages in the analysis of TiO_2 nanoparticles. First, it is a nondestructive technique, meaning that the sample

remains intact and can be further studied or used in other experiments. This aspect is particularly important when working with limited or precious samples. Additionally, XRF is a highly sensitive method, capable of detecting elements across a wide range of concentrations, from trace amounts to high levels. Its versatility allows for the analysis of TiO_2 nanoparticles in different forms, such as powders, thin films, coatings, or bulk materials. Moreover, XRF is a rapid and relatively simple technique compared to other analytical methods. It does not require extensive sample preparation, making it a cost-effective and time-efficient solution for analyzing TiO_2 nanoparticles. Furthermore, XRF can provide quantitative results, enabling researchers to determine the exact elemental composition and concentrations of the nanoparticles with a high degree of accuracy [59].

2.4 CLASSIFICATION OF TIO_2 NANOPARTICLES USED IN THE DEVELOPMENT OF LATENT FINGERPRINT

Here, TiO_2 is classified based on the method used to synthesize the particle and the method used to characterize the nanoparticle that confirms its synthesis and the surfaces used to develop a latent fingerprint over it. Here is the data:

2.4.1 SYNTHESIZATION AND CHARACTERIZATION OF TIO_2:CE^{3+} NANOPARTICLES

2.4.1.1 SYNTHESIZATION

Ce^{3+} doped TiO_2 nanoparticles were created by a multi-step process. First, 10 mL of titanium butoxide were carefully mixed with 10 mL of double-distilled water. The mixture was then added 10 mL of 0.5 $NHNO_3$, which was constantly swirled at room temperature. Titanyl nitrate (TN), a transparent solution, was created as a result of this method. A magnetic stirrer was used to mix stoichiometric proportions of TN, ammonium nitrate, glycine, and cerium nitrate in order to create a homogenous solution. The experiment began by taking the resultant mixture, which consisted of certain components, and transferring it into a muffle furnace. Prior to this step, the furnace had already been preheated and maintained at a temperature of

TABLE 2.1 Synthesization and Characterization of TiO_2 Nanoparticles.

S. No.	Synthesis	Method	Characterization	Surfaces Under Study	References
1)	TiO_2:Ce^{3+} Nanoparticles	Solution combustion	PXRD, FESEM, Raman studies, TEM, photoluminescence	Porous surfaces: bedsheets, barcode, aluminum foil Nonporous surfaces: wall, coin	[60]
2)	TiO_2:Eu^{3+} Nanoparticles	Hydrothermal method	XRD, SEM, TEM, Raman studies, photoluminescence	Porous surfaces: multicolored magazines, aluminum foil, plastic sheets Nonporous surfaces: mouse, metallic scale, scissor	[61]
3)	Cr and Sb codoped TiO_2 nanoparticles	Homogenous precipitation	XRD, TEM, SEM, Raman studies, XRF	Porous surface: printing paper, cardboard Semi-porous surfaces: leather, painted wood Nonporous surfaces: glass, plastic sheets, stainless steel, ceramic tiles	[62]
4)	TiO_2 nanoparticle with N, N′-Dioleyl-3,4,9,10-perylene dicarboximid dye	Hydrothermal method	SEM, reflectance spectrum	Nonporous surfaces: glass Semiporous surfaces: painted wood	[63]
5)	C-dot in TiO_2 nanoparticles	Hydrothermal method	XRD, TEM, Raman studies, energy-dispersive spectroscopy	Porous surfaces: aluminum foil, textured marbles. Nonporous surfaces: magzine surfaces	[64]

approximately 450°C. The purpose of using a muffle furnace was to provide controlled and uniform heating for the subsequent thermal processing. Once inside the furnace, the mixture underwent a thermal treatment process. The intense heat caused the fluid to evaporate rapidly, leaving behind a solid residue. As the temperature increased, the solid gradually transformed into a powder-like substance with a unique foam-like appearance. This

transformation was a result of the physical and chemical changes occurring within the mixture due to the applied heat. Following the initial thermal processing, the foam-like powder was subjected to a secondary heat treatment. This step aimed to further enhance the material properties and achieve the desired characteristics. The powder was kept inside the same muffle furnace for a duration of two hours, with the temperature raised to 700°C. The extended exposure to this elevated temperature allowed for the consolidation of the material and the completion of any necessary reactions or transformations. By employing this sequential approach, involving both the initial thermal processing at 450°C and the subsequent heat treatment at 700°C, the production of Ce^{3+} doped TiO_2 nanoparticles was facilitated. The controlled heating and specific temperature conditions enabled the successful synthesis of these nanoparticles with the desired doping of cerium (Ce^{3+}). These nanoparticles hold potential in various applications such as photocatalysis, solar cells, and sensor technologies due to their unique optical and electronic properties.

2.4.1.2 CHARACTERIZATION

1. PXRD: The powder X-ray diffraction (PXRD) technique was used to do a structural investigation on the doped TiO_2 nanoparticles. The obtained powder diffraction patterns were compared to standard reference cards created by the Joint Committee on Powder Diffraction Standards (JCPDS). The diffraction peaks of the doped TiO_2 nanoparticles and the pure rutile phase of TiO_2 (JCPDS card number 87–920) were well matched. The rutile phase peak at 2θ = 27°C, however, changed to 2θ = 25°C with the addition of Ce^{3+} ions, indicating a transition to the anatase phase. The JCPDS card number 84–1286 was matched by the anatase phase's diffraction peaks. Impurity peaks were not present, proving that the doping ions had successfully occupied lattice positions inside the TiO_2 structure.
2. FESEM: Images of TiO_2:Ce^{3+} nanoparticles obtained using FESEM (field-emission scanning electron microscopy) showed clusters of particles with flaky surface appearance. The release of gases throughout the reaction phase is to blame for this agglomeration. The doping had an impact on the particle morphology, as evidenced by the unique visibility of individual particles after the addition of Ce^{3+} ions.

3. Transmission electron microscopy (TEM) imaging was used to determine the TiO_2:Ce^{3+} nanoparticles' diameters, which ranged from 9 to 30 nm. Additionally, by examining the TEM images, it was determined that the interplanar distance for the (1 0 1) plane was roughly 0.33 nm.

2.4.2 SYNTHESIZATION AND CHARACTERIZATION OF TIO_2:EU^{3+} NANOPARTICLES

2.4.2.1 SYNTHESIZATION

TiO_2:Eu^{3+} nanoparticles using a one-pot hydrothermal method, incorporating epigallocatechin gallate (EGCG) as a biocompatible surfactant. The synthesis process involved a series of steps to obtain the desired nanoparticles. To begin the synthesis, europium(III) nitrate pentahydrate ($Eu(NO_3)3.5H_2O$), 20 mL of ethanol, and titanium(IV) isopropoxide (Ti[$OCH(CH_3)2$]4) were combined in a beaker. The mixture was then vigorously stirred for approximately 10 min using a magnetic stirrer. This step ensured proper mixing of the precursors. Following that, 5 mL of EGCG and 15 mL of ethanol were sequentially added to the precursor solution. The addition of EGCG, a biocompatible surfactant, served as a stabilizing agent during the nanoparticle formation process. The mixture was thoroughly mixed to ensure homogeneity. Next, the resulting solution was transferred into an autoclave containing an 80 mL Teflon liner. The autoclave was sealed, and the solution was subjected to a hydrothermal treatment. This treatment involved maintaining the autoclave at a temperature of approximately 100°C for a duration of six hours. The hydrothermal conditions promoted the controlled growth and formation of TiO_2:Eu^{3+} nanoparticles within the solution. After the completion of the hydrothermal treatment, the obtained samples were carefully washed with distilled water and ethanol. This washing process aimed to remove any residual pollutants or impurities that might have been generated during the synthesis or hydrothermal treatment. Thorough washing ensured the purity of the samples. Finally, the washed samples were subjected to a second annealing procedure. The samples were exposed to high temperatures of approximately 600°C for a duration of around three hours. Annealing refers to the process of heating a material to enhance its structural properties. In this case, the annealing step further improved the crystallinity and stability of the TiO_2:Eu^{3+} nanoparticles, leading to the desired final product.

2.4.2.2 CHARACTERIZATION

1. PXRD: PXRD technique used for structural characterization of pure and TiO_2:Eu^{3+}(1–11 mol%) NPs. The obtained profiles closely matched the typical JCPDS card no. 21–1272 for the pure anatase phase of TiO_2. The absence of additional impurity and Eu^{3+} ion peaks in the profiles shows that the dopant Eu^{3+} ions efficiently replaced the Ti^{4+} site in the TiO_2 host. Indicating that the dopant Eu^{3+} was effectively replaced for the Ti^{4+} site in the TiO_2 host, the value of the percentage difference was measured and found to be 30%. The average crystalline size of the synthesized NPs was determined using Scherrer's relation. It was clear that the crystal size reduced as the concentration of Eu^{3+} rose.
2. SEM: When EGCG concentration was added to the precursor solution, the EGCG reacts with the Ti^{4+} and Eu^{3+} via strong chelating interaction and forms strong hierarchical NPs, as shown by SEM images of hydrothermally synthesized TiO_2:Eu^{3+} hierarchical structure prepared by various concentrations of EGCG surfactant (5–30 mL). EGCG inhibits nucleate development in an orientated direction by adhering only to the facets of nucleates. Since these orientated subunits have a propensity to aggregate and a high surface energy, this energy is reduced, thermodynamic stability is achieved by self-assembly, and hierarchical NPs are produced.
3. TEM: A smooth, uniform nanoflower-like architecture was shown in TEM images, and the interplanar spacing between the lattice planes was calculated to be between 0.27 and 0.31 nm for the (1 0 1) plane. The samples were properly crystallized, according to the SAED pattern, which is compatible with the PXRD study.

2.4.3 SYNTHESIZATION AND CHARACTERIZATION OF CR AND SB CODOPED TIO_2 NANOPARTICLES

2.4.3.1 SYNTHESIZATION

A typical homogeneous precipitation technique was employed to synthesize codoped Cr and Sb TiO_2 nanoparticles. The synthesis process involved several sequential steps to obtain the desired nanoparticles. The initial step involved the creation of a solution by gently swirling 250 mL of deionized

water along with 8.79 mL of titanium tetrachloride, 2.66 g of cadmium acetate dihydrate, and 2.99 g of antimony acetate. These components were constantly mixed to ensure a homogeneous solution. In the subsequent step, a precipitator solution was prepared by combining a specific quantity of sodium dodecyl benzene sulfonate with a 250 mL solution of 5 M urea. The precipitator solution served as a medium for the reaction with the first prepared solution. The first solution was carefully added to the precipitator solution, allowing the metal ions and precipitators to react. This reaction took place at a temperature of 95°C for a duration of 4 h, during which the mixture was vigorously stirred. As a result of this reaction, a distinctive blue precipitate formed. To separate the blue precipitate from the solution, centrifugation was employed. The precipitate was repeatedly washed with deionized water to eliminate any impurities or unwanted residues. In order to remove any remaining adherent anions from the precipitate, the final product underwent an additional washing step. This involved washing the precipitate once more with a solution consisting of 0.1 M ammonium hydroxide and ethyl alcohol. After completing the washing steps, the resulting precursor was dried in an oven for a duration of two hours at a temperature of 180°C. Subsequently, the precursor was subjected to calcination at a temperature of 1000°C for one hour. This calcination process facilitated the transformation of the precursor into the desired yellow substance.

2.4.3.2 CHARACTERIZATION

1. XRD: XRD was used to determine the nature and phase composition of the as-prepared NPs. The wide diffraction peaks, which nearly closely matched the report data of rutile TiO_2 (JCPDS card no. 76–0649), validated the rutile crystal texture. Very few peaks from impurities, such as Sb_2O_3 and Cr_2O_3, were seen, suggesting that there was enough reactivity of metallic precursors. The outcome also showed a high degree of purity and complete crystalline degree.
2. TEM and SEM: By using TEM and SEM, the produced Cr and Sb codoped TiO_2 nanoparticles' shape and size were determined. The end result had a diameter of 34.8 nm and had a virtually spherical shape. Stronger interactions between the NPs and ridge deposits

arise from the smaller particle size's increased surface area and higher interface energy.

3. XRF: Quantitative analysis of the Cr and Sb TiO_2 NP contents was performed by XRF to confirm the relative amount of four elements. The theoretical percentages of the element were calculated to be 36.5% O, 43.68% Ti, 5.9% Cr, and 13.89% Sb in $Cr_{0.1}Sb_{0.1}Ti_{0.8}O_2$ NPs according to the initial dosage, which was similar to what was observed, that is, 37.84% O, 41.98% Ti, 5.20% Cr, and 14.98% Sb.

2.4.4 SYNTHESIZATION AND CHARACTERIZATION OF TIO_2 NANOPARTICLES WITH C-DOT

2.4.4.1 SYNTHESIZATION

The C-dots@TiO_2 composite was synthesized using the hydrothermal technique, which involved several steps. Initially, a mixture was prepared by combining 40 mL of ultrapure water, 25 mg of C-dots, and 20 mL of ethanol. To ensure a uniform solution, the mixture underwent ultrasonic dispersion for 30 min at room temperature. Next, 13.2 mL of tetra-n-butyl ortho-titanate (TBOT) was swiftly added to the previously prepared solution, followed by vigorous agitation for two hours. This step aimed to incorporate the TBOT into the mixture thoroughly. Subsequently, a 200 mL stainless steel autoclave with a Teflon liner was employed for the hydrothermal treatment. The autoclave, containing the mixture, was heated to 180°C and kept at that temperature for 36 h. This specific thermal condition facilitated the desired chemical reactions to occur, leading to the formation of the composite. After the completion of the hydrothermal treatment, the autoclave was allowed to cool down to room temperature. The resulting product was a white precipitate, which was separated from the liquid by filtration. To eliminate any residual impurities, the precipitate was washed multiple times with distilled water. Following the filtration process, the white precipitate underwent further processing. It was transformed into a black-brown powder, which was obtained by drying the precipitate at 100°C in a vacuum oven for 10 h. This drying step served two purposes: Enhancing the stability of the powder and eliminating any remaining moisture.

2.4.4.2 CHARACTERIZATION

PXRD: Carbon dots, pure TiO_2, and carbon-coated TiO_2 PXRD patterns were obtained. Following thermal annealing, all the PXRD peaks of TiO_2 were solely in the anatase phase (JCPSD 21-1272). With the aid of Debye-Scherrer's relation, the average crystalline size is calculated. Utilizing the FULLPROF suit software, Rietveld refinement is used to evaluate the lattice parameters.

1. TEM: The C-dot@TiO_2 coated TEM pictures demonstrate that the particles were virtually spherical in form and ranged in size from 2 to 5 nm. For C-dot@TiO_2 coated NPs, the greater interplane distance was calculated and determined to be between 0.28 and 0.33 nm.
2. Energy-Dispersive Spectroscopy: Energy-dispersive spectroscopy was utilized to demonstrate the presence of carbon in TiO_2. The spectra showed that the corresponding peak matched a pure O, Ti, and C composition.

2.4.5 SYNTHESIZATION OF TIO_2 NANOPARTICLE WITH N, N′-DIOLEYL-3,4,9,10-PERYLENEDICARBOXIMIDE DYE

2.4.5.1 SYNTHESIZATION

A 10 mL solution containing 10 mM of the fluorescent dye in dichloromethane, a volatile organic solvent, was carefully applied to 0.3 g of TiO_2 particles. This process aimed to produce TiO_2 particles coated with N, N′-Dioleyl-3,4,9,10-perylenedicarboximide dye. Upon the addition of the dye solution, an intriguing transformation took place as the TiO_2 particles swiftly underwent a color change, transitioning to a vivid pink hue. To separate the excess liquid from the coated particles, the mixture was allowed to settle, enabling gravity to aid in the separation process. Gradually, the liquid portion was poured off, leaving behind the desired TiO_2 particles coated with the N, N′-Dioleyl-3,4,9,10-perylenedicarboximide dye. In order to eliminate any remaining traces of color and to ensure the purity of the coated particles, a rinsing step was carried out. Ten mL of dichloromethane, the same solvent used for the initial solution, was employed to rinse the particles six times. These repeated rinses were performed meticulously to thoroughly cleanse the particles and completely

remove any residual dye molecules. Following the rinsing process, the coated TiO_2 particles were left to dry in the open air, allowing the solvent to evaporate naturally. This step was crucial to achieve dry, stable particles ready for further characterization or utilization in subsequent experiments. It is important to emphasize the significance of adhering to proper safety precautions when handling organic solvents like dichloromethane. Organic solvents are known to be volatile and can pose risks if not handled with care. Therefore, appropriate safety measures, such as working in a well-ventilated area, using protective equipment (e.g., gloves, goggles), and following established protocols, should be diligently observed to ensure the well-being of individuals involved in the experimental process.

2.5 VISUALIZATION OF FINGERPRINT DEVELOPED BY TIO_2 SYNTHESIZED BY DIFFERENT METHODS

The fingerprint grading scale system, which is used to evaluate the brightness of formed fingerprints on various surfaces, is introduced in Table 2.2. The clarity and quality of fingerprints are assessed using this scale, which takes into account elements including contrast, visibility, and ridge distinction. The grading system offers a quantifiable way to compare and evaluate how well-developed fingerprints are on various surfaces.

TABLE 2.2 Fingerprint Grading Scale System. ⏎

Clarity Score	Description
0	Fully smudged outline of the print or no evidence of the print.
1	The presence of several types cannot lead to identification.
2	A major part of the print is smudged, several ridge details are present and analysis cannot be performed.
3	A minor part of the print is smudged, most ridge details are visible and analysis can be performed.
4	Full mark and ridge details are visible, some ridgelines may be thinned or smudged but identifiable print.
5	Full mark and ridge details are visible, identifiable markings can be visualized.

2.5.1 BY TIO_2:CE^{3+} NANOPARTICLES

For the inspection of the use of these nanoparticles in forensics, fingerprints were developed on both porous and nonporous surfaces [59]. Porous

surfaces used are bedsheet, barcode and aluminum foil and nonporous surfaces used are wall, coin, and stainless steel. It was observed that on bed sheets and barcode, the clarity of fingerprint is between 2 and 3 as a minor part of the fingerprint developed are smudged and analysis can be performed [65]. On the other hand, the clarity of print developed on aluminum foil ranged between 4 and 5 as it provides good ridge details and can lead to the identification of the individual. Wall, coin, and stainless steel have good fingerprint recovery rates respectively, that is, 3 [66].

Thus, the recognition of foremost ridge details of FPs on different surfaces is well established by optimized TiO_2:Ce^{3+} nanoparticles. High-quality fingerprints are developed on both porous and nonporous surfaces and hence, it shows the possible usage of the nanoparticle fabricated via solution combustion route for forensic application [67].

2.5.2 BY TIO_2:EU^{3+} NANOPARTICLES

To inspect the possible use of optimized $TiO_{2:}$:Eu^{3+} nanoparticles in forensic, fingerprints are developed on various porous and nonporous surfaces [68]. For study purposes, porous surfaces used are multicolored magazines, aluminum foil, and plastic sheets and nonporous surfaces used are mice, metallic scale, and scissors [61, 69]. The clarity of emerged fingerprint on magazines, aluminum foil, and plastic sheets are between 4 and 5 as some ridgelines may smudge or thin but can be identifiable. On the other hand, fingerprint clarity on the mouse, metallic scale, and scissor emerged between 3 and 4 as a minor part of the print may smudge on some surfaces but is identifiable.

Thus, the optimized TiO_2:Eu^{3+} nanopowder can be used for forensic applications as high-quality fingerprints are developed on both porous and nonporous surfaces.

2.5.3 BY CR AND SB CODOPED TIO_2 NANOPARTICLES

Fingerprint by optimized powder is developed on porous, semi-porous, and nonporous surfaces and visualized under both white and UV-light of 365 nm [70]. Porous surfaces used are printing paper and cardboard, semi-porous surfaces used are manmade leather, and painted wood and nonporous surfaces used are glass, plastic sheets, stainless steel, and

ceramic tiles [71]. For printing paper and cardboard, the clarity score when visualized with white light was between 2 and 3 and when visualized with UV-light of 365 nm, the clarity score was between 3 and 4 because with white light print was smudged in minority and analysis can be performed but with UV-light ridge lines visualized yet some ridge line got smudged but analysis can be performed for identification.

On manmade leather, the clarity score of a fingerprint with both white and UV-light was between 3 and 4 as a minor part of the print may smudge but analysis can be performed. On painted wood, when visualized with white light, the fingerprint is completely smudged, some ridge lines can emerge but analysis cannot be performed so the clarity score for the surface is 1 while under UV light, ridge lines appear but the print is still smudged in minority, analysis cannot be performed so the clarity score is 2.

On the glass, plastic sheets and stainless steel clarity score of a fingerprint when viewed under white light was between 4 and 5 as the print developed was clear and better analysis can be performed. When the same surfaces were observed under UV light, the clarity score emerged between 3 and 4 because some ridge lines were smudged but analysis can be performed. On ceramic tiles, fingerprints when observed under white light clarity score was between 1 and 2 because the print is fully smudged, some ridge lines disappear but analysis cannot be performed.

Thus, the nanopowder can be useful for forensic applications because quality images are developed on porous, semi-porous and nonporous surfaces.

2.5.4 BY N, N′-DIOLEYL-3,4,9,10-PERYLENE DI CARBOXAMIDETIO$_2$ NANOPARTICLE

A newly developed fluorescent dye, which was adsorbed onto TiO_2 nanoparticles, was employed in combination with a novel powder to effectively visualize fingerprints on both nonporous and semi-porous surfaces, as documented in a study [72]. The nonporous surfaces that were utilized in the experiment included glass, while the semi-porous surfaces consisted of painted wood. When the newly developed technique was applied to glass surfaces, the clarity score of the fingerprints obtained ranged between 3 and 4. This score indicated that the quality of the prints was relatively high, allowing for analysis and identification. However, it should be noted that some ridge lines within the fingerprints exhibited slight smudging, which could potentially affect the accuracy of analysis but did not render the prints unusable. On the

other hand, the fingerprints developed on painted wood surfaces yielded poor results. The clarity score for these prints was between 0 and 1, indicating that the quality was significantly compromised. Due to the nature of the painted wood surface, the developed technique was not as effective in visualizing the fingerprints, potentially due to the presence of irregularities or the composition of the paint. As a result, the clarity and distinctness of the ridge lines were insufficient, making analysis difficult. In summary, the application of the newly fluorescent dye adsorbed onto TiO_2 nanoparticles, in conjunction with the developed powder, proved successful in visualizing fingerprints on nonporous surfaces such as glass. Although some smudging was observed in the ridge lines, the prints still possessed a satisfactory clarity score, allowing for analysis. However, the same technique did not yield favourable results on semi-porous painted wood surfaces, as the clarity of the fingerprints was greatly compromised, resulting in a lower clarity score.

Hence, the powder provides high-quality images so it can be useful for forensic applications.

2.5.5 BY C-DOT TIO_2 NANOPARTICLES

Fingerprint developed on both porous and nonporous surfaces with C-dotTiO_2 nanoparticles [73]. Porous surfaces used are aluminum foil and textured marbles and nonporous surfaces used are multicolored magazines. On aluminum foil and textured marble, the clarity score was between 3 and 4 as the print is smudged but analysis can be done for individual identification. On multicolored magazines, the clarity score was between 2 and 3 as the print is smudged, analysis can be done.

Hence, it provides good quality, it can be used for forensic applications.

2.6 FUTURE ASPECTS

The use of TiO_2 nanoparticles in creating fingerprints for forensic science is expected to have excellent future prospects. This emerging field presents numerous potential directions for further study and application. One area of emphasis is enhancing the sensitivity of these nanoparticles for latent fingerprint detection. This can be achieved through the development of novel production techniques and surface chemical adjustments, which would allow for improved visibility and identification of fingerprints that are not easily visible to the naked eye. Additionally, there is room for investigation

into the creation of multifunctional nanoparticles with additional qualities such as fluorescence or antibacterial properties. By incorporating these characteristics into the nanoparticles, forensic scientists can not only improve fingerprint visibility but also expand their utility in other areas, such as tracking and identifying specific bacteria or microbes present in a crime scene. To increase the practical usage of TiO_2 nanoparticles in real forensic scenarios, research can be focused on optimizing their effectiveness on different substrates commonly encountered in crime scenes. This would involve studying the nanoparticles' interactions with various surfaces and developing tailored techniques to ensure consistent and reliable results across different materials. In order to ensure repeatability and dependability among laboratories, it is essential to standardize and validate synthesis procedures, characterization techniques, and application protocols for TiO_2 nanoparticles. This will enable consistent and comparable results, allowing for seamless collaboration and exchange of data between different forensic facilities. Furthermore, the efficiency of TiO_2 nanoparticles can be further enhanced by combining them with other cutting-edge fingerprint development methods, such as advanced imaging technologies. By integrating these complementary techniques, forensic scientists can improve the accuracy and reliability of fingerprint analysis, leading to more effective and efficient criminal investigations. Moreover, the use of TiO_2 nanoparticles enables the development of quick and on-the-spot detection techniques, facilitating the processing and analysis of fingerprints directly at crime scenes. This reduces the need for time-consuming transportation and processing of fingerprint samples, allowing investigators to obtain crucial evidence in a timely manner. To facilitate the practical application of TiO_2 nanoparticles in forensic laboratories, it is important to investigate cost-effective synthesis methods and scalable production procedures. By identifying efficient and economical ways to produce these nanoparticles, their widespread adoption in forensic science can be promoted, leading to improved fingerprint analysis and ultimately more effective criminal investigations.

2.7 CONCLUSION

In conclusion, the application of TiO_2 nanoparticles in forensic science has demonstrated immense potential for enhancing latent fingerprint development. These nanoparticles have significantly improved the visibility and resolution of latent prints on various surfaces, including nonporous and

semi-porous materials. The utilization of TiO_2 nanoparticles as a latent print development approach offers numerous advantages, such as its nontoxic nature, user-friendliness, and affordability. One of the primary benefits of employing TiO_2 nanoparticles is their nontoxicity. Unlike some traditional fingerprint development techniques that involve the use of hazardous chemicals, the nanoparticles pose minimal risk to forensic investigators and individuals being examined. This aspect ensures the safety and well-being of those involved in the forensic process, making it a preferable method. Furthermore, the usability of TiO_2 nanoparticles contributes to their effectiveness in latent print development. These nanoparticles can be easily applied to various surfaces, and their interaction with the sweat and oils present in latent fingerprints enhances the visibility of ridge details. The simplicity of the application process allows forensic scientists to efficiently process a wide range of crime scene materials, leading to more accurate and reliable results. In addition to their usability, the affordability of TiO_2 nanoparticles is another advantage. Compared to some conventional fingerprint development techniques that may require expensive equipment or reagents, the nanoparticles offer a cost-effective alternative. This affordability aspect is particularly important in forensic science, where budget constraints may limit the availability of resources. The utilization of TiO_2 nanoparticles allows for wider access to latent print development techniques, benefiting forensic investigations on a larger scale. The use of TiO_2 nanoparticles in latent print development represents a significant advancement in the field of forensic science. However, it is crucial to address certain challenges associated with their application. One such challenge involves optimizing the concentration and size of the nanoparticles. Fine-tuning these parameters can further enhance the visibility and resolution of latent prints, ensuring more accurate identification and analysis. Moreover, it is important to investigate any potential interference with other forensic techniques. As TiO_2 nanoparticles become more widely adopted, it is essential to ensure that their application does not hinder or compromise the effectiveness of other commonly used forensic methods. Collaborative research and evaluation are necessary to assess any potential conflicts and develop strategies for harmonious integration into the existing forensic protocols. In summary, the utilization of TiO_2 nanoparticles for latent print development holds great promise in forensic science. With their ability to enhance the visibility of latent prints on various surfaces, their nontoxic nature, usability, and affordability, these nanoparticles offer valuable advantages to forensic investigators. While

challenges remain, such as optimizing nanoparticle concentration and size and addressing potential interference with other techniques, the continued exploration and refinement of this technology are likely to lead to further improvements in latent print analysis and contribute to the advancement of forensic science as a whole.

KEYWORDS

- **Forensic science**
- **latent fingerprint**
- **nanoparticles**
- **titanium dioxide**
- **fingerprints**

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CHAPTER 3

Fluorescent Nanoparticles: An Advanced Approach for Latent Fingerprint Development

SNEHA LOHAR[1], POONAM KUMARI[1], BADAL MAVRY[1], KAPIL PARIHAR[2], VARAD NAGAR[3], PRITAM P. PANDIT[4], MAHIPAL SINGH SANKHLA[5,6], and RAJEEV KUMAR[1]

[1]Department of Forensic Science (SBMS), Galgotias University, Greater Noida, Uttar Pradesh, India

[2]Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India

[3]Department of Forensic Science, Banaras Hindu University, Varanasi, Uttar Pradesh, India

[4]Department of Forensic Science, Sandip University, Nasik, Maharashtra, India

[5]Department of Forensic Science, UIAHS, Chandigarh University, Mohali, Punjab, India

[6]University Centre for Research and Development, Chandigarh University, Mohali, Punjab, India

ABSTRACT

One of the most reliable characteristics for identifying someone is their fingerprint. In criminal investigations, recovering or gathering latent fingerprints from the crime scene is crucial. The contrast between the

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Kumud Kant Awasthi, Mahipal Singh Sankhla, Chandra Shekhar Yadav, and Anjali Awasthi (Eds.)

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ridges and the substrate allows for the detection and description of fine features, which is essential for the successful use of created fingerprints for identification. A nanoparticle, often called an ultrafine particle, is a tiny material particle with a size range of 1–100 nm. Due to their small size, nanomaterials are exceptional in their ability to alter mechanical, electrical, and optical properties. At a crime scene, latent or invisible fingerprints are frequently left behind. Some of the nanoparticles used to obtain latent fingerprints include silica, carbon, aluminium, copper, barium, iron, and vanadium. Traditional methods have drawbacks such as low contrast, sensitivity, selectivity, and danger. These methods include powder dusting, chemical processes, and small particle reagent methods. The creation of latent fingerprints using fluorescent nanoparticles is the main subject of this review. Due to their distinctive optical and chemical properties, fluorescent nanoparticles were chosen because they offer greater contrast and sensitivity than conventional methods while also being less dangerous.

3.1 INTRODUCTION

Biometrics, particularly fingerprints, play a crucial role in identifying individuals. Fingerprint evidence is highly valuable due to its permanence, distinctiveness, and universal presence. In forensic investigations, it is essential to employ appropriate techniques to visualize potential fingerprints, even those that are not readily visible, in order to determine their source [1]. The elevated papillary ridges and deep ridges on the skin of a human finger form a complex pattern, unique to each individual [2]. When a person touches an object with their finger, water-based exocrine glands, such as sweat and oily sebum, can adhere to the surface, leaving behind fingerprints [3]. Ridge fingerprints have long been regarded as the optimal source for human identification in forensic science, primarily due to their intricate patterns, distinctiveness, and stability [4]. The powder dusting technique was initially used to reveal latent fingerprints, as it was cost-effective, easily accessible, and simple to apply, making it a preferred method at crime scenes. However, traditional powder dusting methods have several drawbacks, including lower sensitivity, poor contrast, toxicity, and increased autofluorescence transmission [5, 6]. To overcome these limitations and achieve more precise and accurate results, the use of nanoparticles has emerged as a superior alternative. Using fluorescent nanoparticles to develop latent fingerprints is a technique that offers high

sensitivity and spatial resolution [7]. Unlike typical powders, which lack contrast and pose challenges when reproducing fingerprints on multicolored, patterned, or bright surfaces [8], luminous dusting powder can be employed. Luminous dusting powder, unlike black, gray, or white powder, possesses luminescent properties [9]. The field of nanotechnology has made significant advancements and innovations in fingerprint development procedures, enhancing their selectivity and sensitivity. Various types of nanoparticles are utilized, including conjugated-polyelectrolyte dots, aggregation-induced emissive molecules, metal nanoparticles, metallic oxide nanoparticles, semiconductor quantum dots (QDs), carbon dots (CDs), polymer dots, fluorescent silica nanoparticles, fluorescent mesoporous silica nanoparticles, and chemical probes [10, 11]. Fluorescent nanoparticles are particularly valuable in forensic science, as they enhance the detection of latent fingerprints [10]. QDs, CDs, and polymer beads are luminous materials commonly employed in this context [12]. These fluorescence materials offer unique properties, such as increased contrast, sensitivity, and selectivity [13, 14]. CDs, in particular, are utilized as labeling agents to enhance visibility and contrast for detecting latent fingerprints when exposed to ultraviolet (UV) light [15]. CDs possess numerous advantages, including high fluorescence intensity, small size, chemical and photostability, ease of surface modification, and low toxicity [16]. This chapter discusses the current state of classical fingerprint development methods, as well as recent advancements in latent fingerprint development techniques utilizing various fluorescent nanomaterials [11].

3.2 NANOTECHNOLOGY IN FINGERPRINT DEVELOPMENT

Fingerprints are considered one of the most significant pieces of evidence found at the crime scene. It can be helpful in the individualization of any person. Fingerprints are generally of the following three types [18, 19]:

1. Patent fingerprints are images of a person's fingertip left on any surface. They are evident to the naked eye and when these fingertips came in contact with substances such as oil, grease, ink, paint, and so on, they can be developed on different surfaces.
2. Plastic fingerprints are three-dimensional impressions of friction ridges formed due to pressure applied on soft substances such as wax, soap, clay, putty, and so forth.

3. Latent fingerprints are the traces of oil and sweat found on any object that came in contact. They are not visible to the naked eye [18, 20].

Latent fingerprints play a crucial role as prominent evidence discovered at crime scenes. These fingerprints are formed through a combination of sweat and fatty acid secretions originating from various glands, including eccrine, apocrine, and sebaceous glands [18, 21]. When a fingertip comes into contact with a surface, this composition is transferred, leaving behind trace amounts and resulting in the development of latent fingerprints. Traditionally, several methods have been employed for fingerprint development, including powder dusting, iodine fuming, ninhydrin, and cyanoacrylate [18]. However, when dealing with aged fingerprints, traditional methods may encounter difficulties due to environmental contamination, making it challenging to identify the prints [22]. In recent times, the field of forensic science has witnessed advancements in the detection of latent fingerprints on various porous and nonporous substances through the application of fluorescent nanoparticle powder. These powders exhibit excellent adhesive properties, ensuring reliable results, and they are cost-effective [23, 24]. This review focuses on elucidating the process of developing latent fingerprints using fluorescent nanoparticles. Subsequent sections delve into the discussion of different types of nanoparticles employed for this purpose.

3.3 ZINC OXIDE NANOPARTICLES

Zinc oxide nanoparticles exhibit a range of advantageous physical and chemical properties, making them highly desirable for various applications. One notable attribute is their wide band gap energy, which allows for efficient electron excitation and facilitates electron transitions even at room temperature. This characteristic is particularly valuable as it enables the utilization of zinc oxide nanoparticles in diverse electronic and optoelectronic devices. Moreover, these nanoparticles possess a high excitation binding energy, further contributing to their exceptional electron transfer capabilities. This property ensures that electrons can be effectively excited and moved within the material, enabling efficient charge transport. Consequently, zinc oxide nanoparticles find applications in electronic components that require rapid electron movement and high

conductivity. Another significant advantage of zinc oxide nanoparticles is their remarkable adhesive ability with lipids and proteins. This property plays a crucial role in latent fingerprint development, as it allows for enhanced interaction with the organic components present in fingerprints. By utilizing the adhesive properties of zinc oxide nanoparticles, latent fingerprints can be effectively visualized and developed.

Several studies [19, 24, 25] have demonstrated the efficacy of zinc oxide nanoparticles in the nano-powder form for developing fresh and aged fingerprints on nonporous surfaces. When exposed to UV irradiation, the ridge features of the developed fingerprint become distinctly visible. This property makes zinc oxide nanoparticles a valuable tool in forensic investigations, aiding in the identification and analysis of latent fingerprints. To further enhance their capabilities, researchers have incorporated fluorescent characteristics into zinc oxide nanoparticles. This modification [26, 27] has significantly improved the development of latent fingerprints on various substrates. By introducing fluorescence, the visualization and detection of latent fingerprints are greatly enhanced, even on different surfaces. In addition to their standalone applications, the combination of zinc oxide with silicon dioxide (SiO_2) has proven to be an effective method for developing latent fingerprints on both porous and nonporous surfaces. The incorporation of SiO_2 further enhances the adhesive properties of zinc oxide nanoparticles, facilitating improved interaction and development of ridge features on a wider range of surfaces [19, 25].

In summary, the exceptional physical and chemical properties of zinc oxide nanoparticles, including their wide band gap energy, high excitation binding energy, adhesive ability with lipids and proteins, and their fluorescent characteristics, make them invaluable for latent fingerprint development. Whether in nanopowder form or in combination with other materials such as SiO_2, zinc oxide nanoparticles offer a versatile and efficient approach to visualizing and analyzing latent fingerprints on various surfaces, aiding forensic investigations.

3.4 CARBON DOTS FOR FINGERPRINT DEVELOPMENT

The CDs are tiny nanoparticles composed of carbon atoms, known for their excellent water solubility. When dissolved in water, they form an aqueous solution. This solution is utilized in the process of latent fingerprint

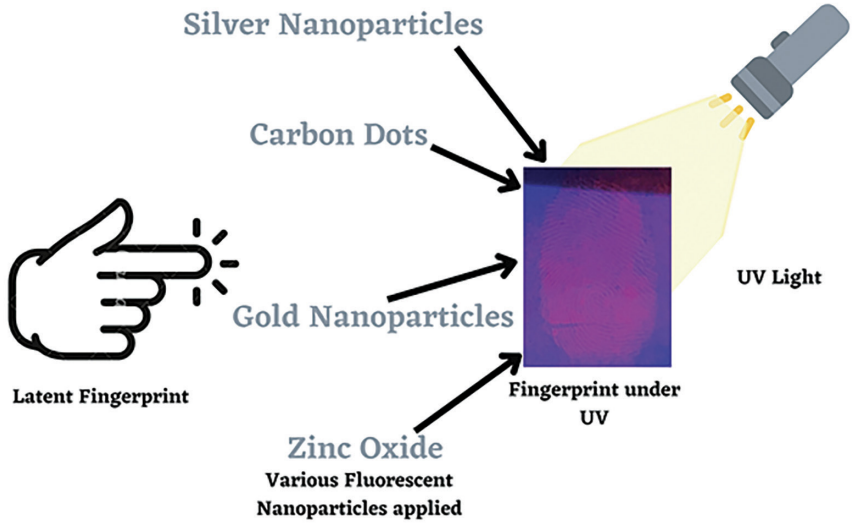

FIGURE 3.1 Development of latent fingerprint by various types of fluorescent nanoparticles.

development, where it plays a crucial role in producing identifiable fingerprint images. Under UV light irradiation, the aqueous solution of CDs generates a distinct blue image, aiding in fingerprint analysis and identification [28]. To detect fingerprints on various surfaces, CDs are combined with different solutions. By employing a CD solution in dichloromethane, fresh or aged fingerprint images become visible under UV light. The resulting fingerprint image exhibits white emission, allowing for enhanced visibility and analysis [29]. Another intriguing application involves incorporating carbon nanoparticles (CNPs) into a starch nanocomposite. This unique combination provides the nanocomposite with increased luminescence and robust chemical properties, making it an excellent candidate for detecting latent fingerprints on porous and nonporous substrates. The introduction of CNPs into the starch nanocomposite greatly improves the clarity and visibility of fingerprint ridges, thereby enhancing fingerprint identification [14]. Silica nanoparticles coupled with carbon are utilized in fingerprint detection as well, offering various fluorescence characteristics. These C-SiO_2 luminescent materials are employed to enhance the detection of latent fingerprints and minimize background contrast. Compared to traditional methods, the use of C-SiO_2 results in improved fingerprint visibility while maintaining low levels of background interference.

Moreover, C-SiO_2 is nontoxic, cost-effective, and capable of producing high-quality photographs [30].

3.5 SILVER NANOPARTICLES FOR FINGERPRINT DEVELOPMENT

Silver nanoparticles have gained significant attention as a highly appealing powder in the realm of latent fingerprint production due to their exceptional affinity for the chemical components present on fingerprint residues. This affinity arises from the intricate interplay of electrostatic forces between amino acids and fatty acids found in the residue left behind on the skin and the silver nanoparticles themselves. Scientific investigations have shown that these nanoparticles possess an innate ability to selectively bind with the organic substances present in latent fingerprints, facilitating their visualization and enhancement. The process of utilizing silver nanoparticles for fingerprint detection involves an intriguing physical mechanism. As part of the procedure, iron salt is employed as an oxidant, initiating oxidation and reduction reactions. During this process, the silver present in the form of metallic compounds or ions undergoes a transformation, giving rise to the formation of silver nanoparticles. This transformation is a result of the interplay between the oxidant and the silver, enabling the creation of nano-sized particles that exhibit unique properties. One of the remarkable attributes of silver nanoparticles is their ability to generate clear and distinct images of fingerprints on various types of surfaces, particularly porous ones. The nanoparticles, once formed, interact with the organic residues of the fingerprint, binding to them and producing highly contrasting patterns. This interaction is responsible for the development of crisp and discernible images, even on challenging surfaces where fingerprints are typically difficult to visualize. Furthermore, the resulting silver nanoparticles exhibit shades of grey and dark hues, adding to their versatility in fingerprint detection. The distinctive colors enable enhanced contrast against the background surface, aiding in the identification and differentiation of the fingerprint ridges and patterns. In summary, the utilization of silver nanoparticles as a powder for latent fingerprint production is driven by their remarkable affinity for the chemical components found in fingerprint residues. Through electrostatic attraction and the involvement of oxidant substances, silver is transformed into nanoparticles, which exhibit unique properties conducive to fingerprint detection. These nanoparticles allow for the visualization of fingerprints on porous surfaces, generating clear

and contrasting images. The grey and dark hues of the nanoparticles further contribute to their effectiveness in enhancing the visibility and distinctiveness of latent fingerprints [32].

3.6 GOLD NANOPARTICLES FOR FINGERPRINT DEVELOPMENT

Gold nanoparticles possess significant characteristics that greatly enhance the detection of latent fingerprints on various surfaces, including porous and nonporous materials. These nanoparticles exhibit exceptional sensitivity, excellent selectivity, and facilitate long-term storage of developed latent fingerprints, owing to their inert properties [33]. One of the primary reasons for the efficacy of gold nanoparticles in latent fingerprint detection is their inherent sensitivity. These nanoparticles are capable of detecting even trace amounts of fingerprint residue, enabling the identification and visualization of latent fingerprints that may otherwise go unnoticed. The high sensitivity of gold nanoparticles ensures that even the faintest impressions left behind by a person's fingertip can be effectively detected and analyzed. Additionally, gold nanoparticles demonstrate remarkable selectivity in identifying and binding with the specific compounds present in fingerprint residue. The presence of an amine functional group on the surface of gold nanoparticles allows them to readily absorb and interact with the chemical components found in fingerprints. This selectivity enables gold nanoparticles to differentiate between the target compounds in fingerprints and other extraneous substances, enhancing the accuracy and reliability of latent fingerprint detection. Moreover, the inert nature of gold nanoparticles facilitates the preservation and long-term storage of developed latent fingerprints. Due to their inherent stability, gold nanoparticles ensure that the fingerprints do not degrade or undergo significant changes over time. This inertness prevents the alteration or deterioration of the fingerprint patterns, allowing for their reliable retention and subsequent analysis even after prolonged periods. Furthermore, the lipophilic attraction between the fatty acid compounds present in fingerprint ridges and the amine functional group on gold nanoparticles contributes to their effectiveness in latent fingerprint detection [34]. The fingerprint ridges, which contain fatty acids, exhibit a strong affinity toward the amine functional group on the surface of gold nanoparticles. This interaction leads to the selective absorption and binding of the fingerprint residue by the gold nanoparticles, further enhancing the visibility and clarity of latent

TABLE 3.1 Comparison of Various Types of Fluorescent Nanoparticles and Their Advantages and Disadvantages.

S. No.	Fluorescent Nanoparticle	Size	Advantages	Disadvantages	References
1	Carbon nanoparticles	The size of carbon nanoparticles is generally less than 10 nm.	It gives superior fluorescence performance and cheaper synthesis. It is nontoxic in nature. Water-soaked evidence can also be used to create a latent print.	Many problems are faced during the preparation of CDs.	[11]
2	Fluorescently doped silica	The size of the silica nanoparticles is in the range of 114–164 nm.	It can substantially enhance the detection limit and dramatically increase the sensitivity and nontoxicity.	It is difficult to functionalize.	[17]
3	Quantum dots	The size of quantum dots is in the range of 8–100 nm.	It provides high contrast, extreme stability, high intensity, and minimal or borderline surface adjustment.	The generated fluorescence decreases significantly with time due to the high oxidation quality of quantum dots. It causes a loss of contrast and poor long-term fingerprint preservation.	[11]
4	Gold nanoparticles	The typical size of gold nanoparticles with a spherical form is 2–3 nm.	When compared to the usage of Ag-PD alone, these nanoparticles greatly improve the clarity and intensity of the generated prints.	It is ineffective for developing prints on crime scene surfaces such as floors and walls, as well as on anything that is too big for use in a desktop bath.	[11]
5	Silver nanoparticles	The site has a range of 1–200 nm.	The physical developer (Ag-PD) approach may also be used to remove fingerprints left on surfaces after many hours of exposure to direct sunshine. Furthermore, it may remove fingerprints from wet things.	This approach is more expensive, time-consuming, and insecure. The fingerprint processing operation is also damaging, leaving permanent stains or marks on the papers.	[11]
6	ZnO nano powder	The mean particle size of the ZnO nano powder is 1–3 nm.	This method works well for creating fresh and old fingerprints placed on nonporous surfaces, nonpoisonous, cheap cost, and excellent outcomes.	The development of fingerprints on porous surfaces using this method does not yield good results.	[11]

TABLE 3.1 *(Continued)*

S. No.	Fluorescent Nanoparticle	Size	Advantages	Disadvantages	References
7	Fluorescent starch-based carbon nanoparticles	The size ranges from 10–40 nm.	It is one of the easiest and most eco-friendly methods in nature. Its chemical composition has a special UV fluorescence characteristic that can be extremely beneficial in the formation of latent fingerprints.	This method gives poor results for the development of aged fingerprints.	[17]
8	Europium oxide nanoparticles	Nanoscale europium particles are typically 10–45 nm.	These functionalized nanoparticles are easy to prepare. These nanoparticles are not prone to photobleaching.	It emits short-lived fluorescence.	[11]

fingerprints. In summary, gold nanoparticles possess crucial characteristics that significantly enhance the detection of latent fingerprints on both porous and nonporous surfaces. Their sensitivity, selectivity, and inert nature enable them to effectively identify, visualize, and preserve latent fingerprints, thereby aiding forensic investigations and contributing to the field of fingerprint analysis.

Apart from conventional methods like powder dusting and other chemical methods, fluorescent nanoparticles are emerging as an advanced and promising approach for developing latent fingerprints. These nanoparticles possess unique optical properties, high sensitivity, selectivity, and are less toxic in nature. Their exceptional characteristics make them a preferable choice over other methods. Furthermore, fluorescent nanoparticles have a wide range of applications, including bioimaging and biolabeling, which further enhance their appeal as a fingerprint development technique. Fluorescent nanoparticles offer several advantages compared to traditional methods. Firstly, their unique optical properties enable them to emit a bright fluorescence upon excitation with specific wavelengths of light, making it easier to visualize latent fingerprints. This fluorescence emission enhances the contrast and visibility of the fingerprints, aiding in their detection and identification. Additionally, the high sensitivity of these nanoparticles allows for the detection of even trace amounts of latent prints, which might not be visible using conventional methods. Moreover, fluorescent nanoparticles offer excellent selectivity toward the components present in fingerprints, ensuring accurate identification and minimizing false positives. This selectivity is attributed to the specific interactions between the nanoparticles and the chemical components of the fingerprints, which enable efficient detection and imaging. One significant advantage of using fluorescent nanoparticles for fingerprint development is their reduced toxicity compared to some chemical methods. Traditional chemical methods often involve the use of hazardous substances that can be harmful to both the environment and individuals handling them. In contrast, fluorescent nanoparticles generally have a lower toxicity profile, making them a safer option for forensic applications. Additionally, the applications of fluorescent nanoparticles extend beyond fingerprint development. These nanoparticles find widespread use in bioimaging, where they can be used to visualize and track various biological processes and structures. Furthermore, their biolabeling capabilities make them valuable tools for tagging specific biomolecules or cells, facilitating their

identification and study in biological systems. These versatile applications further highlight the advantages of utilizing fluorescent nanoparticles for latent fingerprint development. To provide a comprehensive overview of the different methods available for latent fingerprint development, a comparative table will be presented in a further section. This table will compare various parameters such as effectiveness, sensitivity, selectivity, toxicity, and other relevant factors for each method, allowing for an informed evaluation of their respective strengths and limitations.

TABLE 3.2 Comparison of Methods for the Development of Latent Fingerprint.

S. No	Using the powder approach, a latent fingerprint may be created.	Using the Chemical approach, a latent fingerprint may be created.	Using the fluorescent nanoparticles approach, a latent fingerprint may be created.
1.	One of the earliest and most popular techniques for creating latent fingerprints is powder dusting.	The chemical approach works by converting any specific element of sweat and oil residue into a colourful derivative.	The usage of fluorescent NMs such as QDs and UCNMs for the creation of fingerprints has recently drawn a lot of interest due to their distinctive optical properties and nontoxic nature.
2.	The watery or oily components in the latent fingerprint remain attached to the tiny fingerprint powder particles.	Sweat ingredients are selectively fixed by various chemical reagents in order to reveal latent fingerprints.	Fluorescent NMs produce bright fluorescence when exposed to a certain light, highlighting the latent imprint.
3.	At crime scenes, powders such as standard powder (charcoal, gold, and white powder), metallic powder, magnetic powder (black and silver), and fluorescent powder are commonly employed.	Silver nitrate, iodine fuming, ninhydrin process, cyanoacrylate fuming method, and other chemical methods are utilized.	Quantum dots (QDs) and rare earth fluorescent nanomaterials (UCNMs, caron dots, gold nanoparticles, silver nanoparticles, and other fluorescent nanomaterials) are employed.
4.	Applying the powder to latent fingerprints is a straightforward method that involves careful brushing and removal of excess powder.	The type of surface that generates the latent fingerprint—porous, semiporous, and nonporous—as well as its texture, state—dry or wet—and color—all have an impact on the technique.	One of the most effective uses of fluorescent NMs for the creation of latent fingerprints is biolabeling and bioimaging.

TABLE 3.2 *(Continued)*

S. No	Using the powder approach, a latent fingerprint may be created.	Using the Chemical approach, a latent fingerprint may be created.	Using the fluorescent nanoparticles approach, a latent fingerprint may be created.
5.	It's inexpensive and effective, and it can produce fingerprints on practically any porous or nonporous surface quickly and simply.	It is time-consuming and expensive, although a cost-effective version is also available.	It takes time as it is not a field test.
6.	It is potentially health hazardous in nature at a crime scene.	It can also be toxic and hazardous in nature.	These are eco-friendly and nontoxic.
7.	The issue of potential DNA sample contamination due to transfer from the development fingerprint brushes may come up.	The repeatability and consistency of fingerprints formed are determined by elements such as force exerted, angle, area, and time of contact. It might also have an impact on the quality of latent finger marks found at the crime scene.	NIR light is significantly less destructive to DNA in fingerprint residues when used for UCNM excitation, which is advantageous for DNA analysis.
8.	Low contrast, low selectivity, and low sensitivity.	Low contrast, low selectivity, and low sensitivity.	High contrast, sensitivity, and selectivity are all possible with these nanoparticles. In nature, it is less harmful.

3.7 CONCLUSIONS

Nanomaterials play a crucial role in the advancement of finger-like structure images that can be printed. This chapter primarily focuses on the utilization of fluorescent nanoparticles, which are instrumental in the development and detection of latent fingerprints. Silver and gold nanoparticles are employed to enhance fingerprint applications and features, specifically for crime scene investigations. ZnO (metal oxides) nanoparticles are utilized to demonstrate the development of latent fingerprints, highlighting ridge features and minimizing background interference. Their exceptional visibility of fingerprints, ridge patterns, and sweat pores make gold nanoparticles widely preferred in latent fingerprint detection compared to other materials. In addition to silver, gold, and ZnO nanoparticles, other

nanomaterials such as QDs, CDs, and conjugated polyelectrolytes are also employed in the field of latent fingerprint detection. Rare earth upconverter nanomaterials, which include aggregation-induced emission luminous molecules, exhibit improved detection capabilities for latent fingerprints on both non-porous and porous surfaces compared to commercially available alternatives. Another notable nanomaterial, fluorescent-doped silica nanoparticles powder, enhances the quality of latent fingerprint pictures, enabling better distinction under UV light radiation.

KEYWORDS

- **Fingerprint**
- **fluorescent**
- **gold**
- **nanoparticle**
- **optical**
- **selectivity**
- **zinc oxide**

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CHAPTER 4

Advancements in Forensic Science: Expanding the Frontiers of Latent Fingerprint Development Through Gold Nanoparticles

SUDHANSHU SHEKHAR TIWARI[1], DIPAK KUMAR MAHIDA[2], PRATIKSHA NIMBKAR[3], and ANKITA PATEL[2]

[1]*Directorate of Forensic Science and Laboratory, Ranchi, Jharkhand*

[2]*Department of Biochemistry and Forensic Science, Gujarat University, Ahmedabad, Gujarat, India*

[3]*Gujarat Technological University, Ahmedabad, Gujarat, India*

ABSTRACT

Gold nanoparticles (AuNPs) have been used to detect various evidence collected during crime scene investigations. One of the most sought-after applications of gold nanomaterials is latent fingerprint development. The ability to absorb light in three electromagnetic spectrum regions (ultraviolet, visible, and near infrared) makes gold a go-to choice for analysts. The chapter discusses and focuses on the development of latent fingerprints from AuNPs along with the different types of synthesis and characterization methods used for their functionalization. AuNPs exhibit a range of properties which has proven beneficial for their successful application in forensic science. They offer a higher selectivity and sensitivity toward the sweaty secretions present in the fingerprint residues as well as a good contrasting image from the background. Due to the inert nature of

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gold, the developed fingerprint can be preserved for a longer period while maintaining its crucial features and not compromising on the quality of the print. AuNPs of different shapes and morphology that had been exploited in fingerprint development so far by employing different visualization methods are reviewed and the results of these studies are highlighted. The advantages and shortcomings of the AuNPs are also critically discussed. It is therefore imperative to tap the full potential and ability of gold nanomaterials to address the existing research gaps in the development of latent fingerprints present at the crime scene.

4.1 INTRODUCTION

The uniqueness of the fingerprint is what makes it evidence of importance. Fingerprints or finger impressions are the characteristic and peculiar marks left behind by an individual when there is contact between the fingers and a surface [6]. AFIS classifies fingerprint patterns through three stages. Stage 1 involves the classification of the fingerprints into four main categories: arches, loops, whorls, and composites. The occurrence of these types is a class characteristic and can be the same in multiple individuals or be present on the surface of various fingers of the same individual. The second stage involves the identification of minutiae or ridge characteristics such as bifurcation, ridge ending, dot, and spurs to name a few. Based on the frequency and location of these minutiae are used as a filter to narrow down the samples. The last stage of fingerprint identification is also called poroscopy, wherein the prints are examined and compared to determine the position and frequency of sweat pores within the sample and reference prints [17].

Fingerprints are composed of complex combinations of biomolecules such as lipids, proteins, and peptides along with numerous secretions through the apocrine, sebaceous, and eccrine glands containing metabolic and catabolic products, namely, inorganic salts, urea, creatinine, lactic acid, choline, sugars, and water [6, 21].

These fingerprints, whether latent, patent, or visible, can act as adequate information about the absence or presence of an individual at a particular place. Fingerprint evidence is accepted around the world for the individualization of suspects if a set number of minutiae are present for comparison [1]. Fingerprints can be defined as the ridge patterns found on the fingertips. They are frequently present in latent forms and are one of the numerous pieces of evidence discovered at the crime scene. Latent

fingerprints are ones that need to be observed by a third party and are invisible to the human eye. Numerous techniques have been developed for the development of these prints because it is difficult to see them with the naked eye. These techniques are based on the characteristics of the surface on which they are present (e.g., porous, semi-porous, or nonporous), the nature and composition of the prints, as well as environmental factors and ease of visualization [19].

In regular use, conventional methods for fingerprint development include using various fingerprint powders such as black powder, white powder, fluorescent powder, and magnetic powder; iodine fuming; ninhydrin; silver nitrate; and small particle reagent and cyanoacrylate development methods [2, 19]. The use of conventional methods is a two-edged sword with advantages such as availability, use of less skill, and being economic. However, to keep up with the sensitivity and accuracy requirements, the limitations such as large particle size, less efficiency in detection of older fingerprints, and poor and temporary contrast with the surface on which the fingerprint is deposited have started to weigh in and the need for more robust methods have led to the research, development, and use of techniques such as the use of nanoparticles in fingerprint development [6, 16, 21].

4.2 NANOPARTICLES IN LATENT FINGERPRINTS (LFP) DEVELOPMENT

Nano-forensics is an amalgamation of nanotechnology and forensics with an emerging branch being nano-fingerprinting within forensic fingerprinting. It is a niche and developing area for research with a wide variety of applications. The focus of study in the field includes synthesizing different highly selective, more environmentally friendly, and economical nanoparticles so that they can be brought into a routine and replace the existing methods [16].

4.2.1 SYNTHESIS OF NANOPARTICLES

According to ISO and ASTM, nanoparticles are defined as particles with sizes ranging between 1 and 100 nm with one or more dimensions [8, 16]. Nanomaterials synthesized are of various shapes and dimensions [6, 8]. The unique properties of nanomaterials include their stability

and adjustable mechanical, electrical, and optical properties, which are different from their bulk materials. The size of the nanoparticles aid in latent fingerprint development by adhering to the minute pore excretions, thereby creating a much clearer and more accurate image of the print on the surface as compared to the conventional techniques [6].

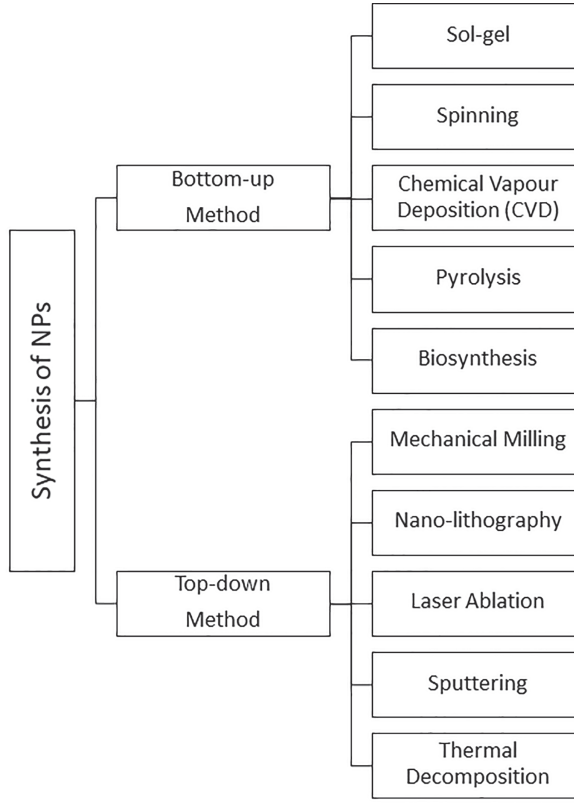

FIGURE 4.1 Methods for nanoparticles synthesis.

The synthesis of nanoparticles can follow one of the following two approaches:

1. **Bottom-Up Methods**

   Through a variety of processes, including sol–gel, spinning, chemical vapor deposition (CVD), pyrolysis, and biosynthesis, the nanoparticles are created in this method from atoms [7, 8].

a. Sol–Gel Method: This method involves the preparation of nanoparticles through submersion of macromolecule in a solvent. The nanoparticles formed are then recovered using sedimentation, filtration, centrifugation, and drying.
b. Spinning: It involves the spinning of liquid precursor with water through the use of a spinning disc rotator and maintaining parameters affecting nanoparticle characteristics such as liquid flow rate, disc rotation speed constant, and pumping of the instrument with nitrogen or other inert gases. The process causes atoms to form segregates and precipitate. The particles thus formed are collected and dried [8].
c. Chemical Vapor Deposition (CVD): The method employs depositing a thin layer of the gaseous reactant on a heated surface from which they are then recovered and used. The advantages include high purity, uniformity, and robustness in the synthesized nanoparticles [8].
d. Pyrolysis: The burning of a precursor with flame, laser, or plasma is known as pyrolysis. The combustion or byproduct gases from which the nanoparticles are collected before usage contain the particles [8].
e. Biosynthesis: It involves an eco-friendly nanoparticle synthesis method through green precursors such as plant extracts, fungi, plants, and so forth. The properties of the nanoparticles have applications in the biomedical industry [8].

2. Top-Down Methods

Also referred to as destructive-type methods, the bulk material is reduced down to the nanoscale through mechanical milling, nanolithography, laser ablation, sputtering, and thermal decomposition. The protocols consume huge amounts of energy thereby making the methods tedious for application [7, 8].

a. Mechanical Milling: The method involves milling the bulk materials in an inert atmosphere [8].
b. Nanolithography: Nanolithography translates to the synthesis of nanoparticles through processes such as optical, electron-beam, multiphoton, nanoimprint, and scanning probe lithography. The technique's appreciated feature is synthesizing

individual nanoparticles of desired size, shape, and dimensions [8].

c. Laser Ablation: In this, a metal precursor immersed in a liquid is subjected to a laser for breakdown into the corresponding nanostructure [8].
d. Sputtering: Sputtering removes excess particles from a surface leaving the surface with a thin layer of nanoparticles [8].
e. Thermal Decomposition: In this process, the precursor is provided with enough heat required to break the chemical bonds within thereby synthesizing the nanoparticles. The reactions involved are chemical and highly endothermic leading to the formation of secondary products along with the desired nanoparticles [8].

The synthesized nanoparticles can either be synthesized in solid, liquid, or gaseous phase [8], and can be free particles, immobilized [4, 22], in the form of nanocomposites [15, 23], in nanoshells, nanocages, and nano frames [10].

4.2.2 CHARACTERIZATION OF NANOPARTICLES

Post synthesis, characterization of the synthesized nanoparticles is essential for understanding their properties and determining the effectiveness and possible applications in various industries. The instrumentation methods, for example, absorbance, emission and excitation spectroscopy, surface plasmon resonance (SPR), localized surface plasmon resonance (LSPR), X-ray diffraction spectroscopy (XRD), surface-enhanced Raman scattering (SERS) spectroscopy, ultraviolet laser simulated surface scattering (UV-SERS) spectroscopy, scanning electron microscopy (SEM), transmission electron spectroscopy (TEM), high-resolution transmission electron microscopy (HRTEM), Fourier transform infrared (FTIR) spectroscopy, electron energy loss spectroscopy (EELS), selected area electron diffraction (SAED) spectroscopy, centered dark field (CDFD), thermogravimetric analysis (TGA) coupled with FTIR spectroscopy, superconducting quantum interference device (SQUID) microscopy, small-angle X-ray scattering (SAXS) spectroscopy, extended X-ray absorption fine structure (EXAFS) spectroscopy, magnetic measurements and quartz crystal microgravimetry provide a characterization of the nanomaterials [7]. Size,

charge, surface area, composition, crystallography, concentration, and surface morphology are the parameters evaluated for the characterization of the nanoparticles [8].

The significance of each character along with their available methods for characterization are mentioned as follows:

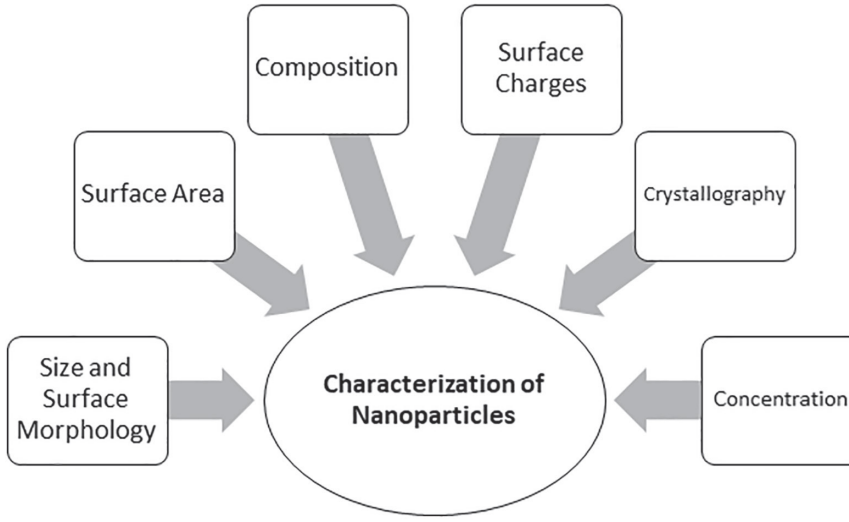

FIGURE 4.2 Characterization of nanoparticles.

1. Size and Surface Morphology: They are two of the most important factors considered and which highly affect the application. Different surface morphologies, such as cylinder, tubular, spherical, conical, and so on, can have rough or smooth surfaces. For the determination of size and surface morphology in solid-phase nanoparticles, electron microscopy methods such as SEM, TEM, and laser diffraction are used for bulk samples. For liquid-phase samples, photon correlation spectroscopy and centrifugation are employed for size determination, whereas for gaseous phase nanoparticles, scanning mobility particle sizer (SMPS) is used for size determination and surface morphology, and the gaseous phase is captured using filtration or electrostatic methods and then imaged using electron microscopy [8].

2. Surface Area: There can be numerous surfaces for a nanoparticle, and therefore, it influences the applicability and properties of the particles. For solid-phase nanoparticles, Brunauer-Emmett–Teller (BET) Isotherm is used; for liquid phase, simple titration or neutron magnetic analysis (NMR) is used. For gaseous phase particles, modified SMPS and differential mobility analyzer (DMA) are used for surface area determination [8].
3. Composition: Nanoparticles can have nanoshell, nanocages, or nano frame structures wherein the synthesized nanoparticle can be a single element or can be an amalgamation of two or more elements. The presence of impurities can also damage the efficiency and effectiveness of the nanoparticle. The composition of solid-phase nanoparticles is determined using X-ray photoelectron spectroscopy (XPS). For solid as well as liquid phase samples, chemical digestion followed by wet chemical analysis using mass spectrometry, atomic emission spectroscopy, and ion chromatography can be used. For the gaseous phase, the particles first need to be collected by filters or electrostatically and then analyzed using spectrometric or wet chemical techniques [8].
4. Surface Charge: The charge on a nanoparticle determines the nature, applicability, and interaction that can take place with the help of the particle. For solid- and liquid-phased nanoparticles, the surface charge is determined using Zeta potential; and for gaseous phase particles, a DMA is employed for surface charge determination [8].
5. Crystallography: Crystallography studies the crystal structure of solids by using X-ray, electron, or neutron diffraction [8].
6. Concentration: The concentration of nanoparticles is a property measured only for gaseous phase nanoparticles and is measured using a condensation particle counter (CPC) [8].

Knowledge of the characterization and synthesis of nanoparticles is essential to nano-forensic experts as it influences the selection of a particular nanoparticle for specific applications. In the branch of forensic fingerprinting, nanoparticles are paving breakthroughs. Nanotechnological methods for the synthesis of stable nanoparticles in fingerprint development are focused on developing clean and immaculate ridge characteristics through the use of numerous types of nanoparticles customized to

specifications for obtaining high-quality fingerprints that can be stored for a long time [22] and with applicability upon a wide variety of surfaces.

4.3 AU NANOPARTICLES FOR LFP DEVELOPMENT

The various nanoparticles found to be used in forensic science primarily include inert elements such as gold and silver. Other materials used include aluminum, zinc, silica, and carbon [16]. The inert metals have the advantage of nonreactivity for long periods making the developed fingerprints stable and resistant to environmental damage.

This chapter intends to highlight the evolution, applicability, significance, and use of gold nanoparticles (AuNPs) for latent fingerprint development.

In 1980, the silver physical development technique was remodeled to the multimetal deposition (MMD) technique through the additional use of AuNPs before the use of silver particle developer for developing latent fingerprints from a paper surface. The year 2012 marked the use of bifunctional reagents with AuNPs for developing latent fingerprints from the porous paper surface along with the usage of AuNPs with adhered antibodies for the identification of the drug and their metabolites in latent fingerprint development.

Concerning AuNPs, the nanosizing results in the development of unique characteristics that make them excellent vehicles for developing latent fingerprints. AuNPs or nanostructures synthesized nanoparticles exhibit a wide range of colors due to SPR and within the visible range based on their concentration; and shape and the colors observed are visually distinguishable [6, 14].

4.3.1 EVOLUTION IN USE OF AUNPS FOR LFP DEVELOPMENT

The history of the use of AuNPs can be dated back to the 1980s, wherein Saunders et al. were the first to test and employ AuNPs for the development of latent fingerprints (Yu et al., 2017). Since then, steady research has undergone in the synthesis and development of various types of AuNPs such as Au nanoclusters, Au nanocomposites, Au nanopowders, colloidal Au [23], Au nanoshells, Au nanocages, and nano frames [10].

Leonardo et al. (2015) elaborated on the various methods for the synthesis and visualization of AuNPs. They also mentioned the necessary precautions required to be taken to obtain good-quality AuNPs. The water quality, its pH, the chemical supplier, glassware conditions, and the quality of the stock solutions are a few of the critical factors that are generally not studied in-depth but can alter nanoparticle synthesis. They mention a step-by-step protocol for Au nanorod synthesis through three different protocols. The interpretation and significance of the different characterization techniques are also mentioned within the paper [20]. Kia-Quang et al. (2016) studied the effect of SERS on Au nanorods by using single nanoparticle LSPR-SEM-SERS techniques. They synthesized gold nanorods of three different sizes with equal, or almost equal, LSPR values by controlling the size and aspect ratio of the nanorods. The synthesized nanorods were then checked for dark-field scattering and it was observed that the strength of the scattering increased with an increase in the size of the nanorods. When the Au nanorods were checked for the effect of the SERS signal using malachite green isothiocyanate (MGITC) as a probe molecule, the results indicated that small-sized Au nanorods exhibited a stronger SERS signal which proportionally decreased with the increasing size of the nanorods [13]. Maryam et al. (2016) carried out a galvanic replacement for the synthesis of a noble metal mobile core within a hollowed shell. They employed Wulff-shaped core particles of Au formed through the dewetting of ultrathin films that were then entrapped through the reduction of Ag^{+} ions on their surface creating a core-shell structure of Au-Ag. The structure was then subjected to galvanic replacement wherein the Ag was replaced with Au in a multistep process. The process resulted in the formation of three distinct stages wherein the Wulff core was present in a shell, which, after partial GR, resulted in the core being entrapped in a cage; and further galvanic replacement finally resulted in the Wulff core being entrapped in an Ag frame. The synthesis resulted in the synthesis of a family of nanostructures that have extraordinary properties of a well-defined gap between the core and the shell or frame and core nanoparticle connected to the outer environment through a mesoporous cage [10]. Min et al. (2016) synthesized aqueous Pd@AuCu core-shell planar tetrapods by preferential overgrowth on Pd cubic seeds. The synthesis of the tetrapods was controlled and the size ranged between 33 and 70 nm by changing the number of Pd seeds used for synthesis. The SERS spectra observed were excellent as the synthesized nanostructures were branched and thus

represented an important factor in the controlled synthesis of desired nanostructures [15].

Yanlin et al. (2017) synthesized nontoxic and luminant Au Nanoclusters@Montomorillonite nanocomposite powders for latent fingerprint development. The synthesis was carried out using a microwave-assisted synthesis protocol. The synthesized nanoclusters had strong red fluorescence and were immobilized on sodium MMT clay matrix through the use of electrostatic interaction. Characterization of the nanoclusters was performed through UV-visible absorption spectroscopy, fluorescence spectroscopy, infrared spectroscopy, TEM/HRTEM, SEM, and XRD for determining their physical properties. The synthesis of the nanocrystals through the protocol is environmentally friendly with low production cost, fewer time requirements, and the development of an efficient UV-visible-dependent photoluminescence with a good affinity toward fingerprint residues [23].

Gurvinder and Jasjeet (2017) have reviewed the MMD method for latent fingerprint development. The paper reviews the MMD technique and its modified versions (MMD-II, MMD-III, MMD-IV). The MMD is a process wherein the latent fingerprint is first deposited with a layer of colloidal gold particles with a size of 30 nm having a negative charge get adhered to the biomolecules bearing a positive charge present in the sweat composition. Further, over the AuNPs, a layer of silver is deposited forming dark grey to black coloured developed impressions. In the modified MMD (MMD-II), colloidal AuNPs of a uniform size of 14 nm are used leading to more clearer and detailed ridge characteristic development. The pH range at which the modified method operates is between 2.5 and 2.8. MMD III and IV use the reagents used in the conventional protocol, the difference being, in MMD-III, the size of AuNPs used is 30 nm in concert with silver acetate and hydroquinone redox reaction, and in MMD-IV, 14 nm AuNPs are used along with silver(I) iron (II) redox couples. The advantage of the method is its versatility to develop latent fingerprints present on porous, semi-porous, and nonporous surfaces. The limitations of the method include satisfactory results on cartridge cases and subsequent firearm examination, non-applicability of the technique in case the surface has been treated with ninhydrin and zinc chloride and high costs [21].

George et al. (2018) synthesized immobilized gold nanostructures for catalysis and latent fingerprint development. The synthesized nanostructures

included nanoclusters and nanospheres on thiol-organofunctionalized silica gel (MPS). The magnetic nanoparticles (MPS) were subjected to spectroscopic analysis which revealed that the immobilization surface was able to reduce Au^{3+} *in situ* and emitted orange-red light for GNCs. For GNS reduction with $NaBH_4$ was an additional step to be performed. Characterization of the nanostructures using TEM, SRD, and UV-visible-NIR revealed the presence of spherical particles with face-centered cubic structure and plasmon resonance band. The prepared nanostructures showed properties to reduce azo dyes in aqueous solutions. The GNS/MPS and bare MPS are versatile and can develop fingerprints on both porous and nonporous surfaces. The developed fingerprints were compared with three conventional development techniques for comparison advantageous as they are reusable, thermally stable, durable, and fast-responsive [4]. A. Cid and J. Simal-Gandara [7] have reviewed the various protocols that have been adopted for the synthesis of metal nanoparticles with the focus being on nanoparticles containing copper, nickel, and palladium. The paper provides a critical analysis of the reviewed literature and mentions numerous methods used for characterizing nanomaterials. The article also provides a brief on the factors, such as chemical reduction, thermal reduction, lithography, vapor deposition, temperature, specific reductants and stabilizers, and atmosphere affecting the synthesis and structure of metal nanoparticles. Future trends in the NPs-based system are also provided for reference by the researchers [7].

Concerning the periodic table, Eugene et al. (2019) have presented a viewpoint of the elements used in nanoparticle synthesis and their relation to the periodic table. The frequency of the nanoparticles that are in use and compared to their occurrence in the periodic table. It was observed that the majority of the nanoparticles in use belonged to the p-block followed by the s- and d-block elements. The article aimed at providing a different approach to determining the occurrence of the nanomaterials in the periodic table to their relevance and application [9].

Aida et al. (2019) provided a review of the various visualization methods used in forensic science for latent fingerprint development on wet surfaces. The paper provided an overview of the significance and evidentiary value of fingerprints in forensic science and criminal investigation. Further, the authors have provided a brief on the formation, composition, and categorization of fingerprints. The various physical and chemical methods routinely used for the development of latent fingerprints are

discussed in detail, including small particle reagent, powder suspension and iodine fuming, physical developer, MMD and single-metal deposition (SMD), and Oil Red O (ORO), respectively. Comprehensive data is provided in the article highlighting the advantages and limitations of each method of fingerprint development [5]. Almheiri et al. [3] evaluated the effect of diazonium gold (III) salts in latent fingerprint development from three metallic surfaces—Cu, Pb, and Al. The study provides the application of aryldiazonium salts as chromogens in forensic science. The study conducted employed stabilized diazonium salts with gold (III) anion adhering to the components of the sweat and thereby developing a thin layer of Au through a reduction reaction. Different concentrations of the salt along with another sample containing non-gold aryldiazonium salts were used to compare the clarity of deposition and visualization obtained for the said concentrations. The reaction observed was spontaneous and did not require external intervention for the redox reaction. The results were observed using stereomicroscope, EDS, and XRF and were promising. The advantage of the one-step technique was that it can be applied to developing latent fingerprints of children which are considered to be volatile [3]. Vandana et al. (2020) have reviewed the role of nanomaterials in forensic investigation and latent fingerprint development and detection. The authors have provided a detailed description and comparative analysis of the different nanoparticles and their size along with the merits and demerits of each type. The paper provides a brief history of the use of nanoparticles and the evolution of their use in the field of forensic fingerprinting. The authors have also provided brief information about the application of nanotechnology in the various branches of forensic science [16]. Kajol and Divya (2020) have discussed the synthesis of nanoparticles through conventional and modified methods and mentioned their applications in detail highlighting their significance, advantages, limitations, and the effect of the different nanomaterials and their sizes on latent fingerprint development [6]. Shuoyn and Xiaohu (2021) synthesized AuNPs on immobilized fibrous nano-silica termed KCC-1 for developing latent fingerprints. The synthesized nanostructures were designated stable and highly effective, highly selective, and stable structures. They were able to develop enhanced fingerprints up to the third stage of fingerprint classification from various objects of daily use containing both porous and nonporous surfaces. The synthesized nanoparticles were in powder form and could hence be easily used on a routine basis as an alternative

to commercially available options. The nanostructures adhered to the fingerprint residue through electrostatic interactions and as compared to commercially available powders. They were able to enhance the ridge details with no background staining, depicting higher sensitivity and selectivity. High-quality prints were developed from smooth substrates and showed stability upon storage for six months [22]. Eswaran and Kriveshini (2021) reviewed the various nanomaterials that have been used for latent fingerprint detection, namely, metal nanoparticles, metallic oxide nanoparticles, semiconductor quantum dots, carbon dots, polymer dots, fluorescent silica nanoparticles, fluorescent silica nanoparticles, conjugated-polyelectrolyte dots, aggregation-induced emission luminous molecule incorporated nanomaterials, and uncommon earth fluorescence nanoparticles. Various examples of the nanoparticle categories are explained in detail with their methodology for use, advantages, limitations, and disadvantage concerning latent fingerprint development. The paper also reviewed the principle of latent fingerprint detection and the use of nanotechnology in forensic science [18]. Suliman and Ezzeddin (2022) have reviewed the conventional techniques to detect latent fingerprints on surfaces. The review paper provided a brief on the use of conventional fingerprint development techniques and the use of gold and silver nanoparticles for fingerprint development [1].

4.3.2 CHEMISTRY BEHIND LFP DEVELOPMENT BY AUNPS

AuNPs are one of the earliest nanoparticles to be synthesized and employed for various purposes. AuNPs have shown good affinity and selectivity toward binding with the components present within the latent fingerprints [1] through electrostatic forces [18]. The amine functional groups in AuNPs have shown binding properties with the fatty acids present in the latent fingerprints through lipophilic attraction. AuNPs have been experimented with for latent fingerprint development on both porous and nonporous surfaces and have produced positive results for both surfaces [18].

The most widely cited protocol for use of AuNPs for the development of latent fingerprints is the MMD method. The protocol is based on the principle wherein there is an interaction between the fingerprint residues and the colloidal solution of AuNPs in a medium of citrate ions which is further treated by a silver physical developer. The silver physical developer binds to the AuNPs; thus the system deposits two metal layers over

the fingerprint residues. The developed impression is silver in color. The reaction occurring between the fingerprint residues and the AuNPs is electrostatic. There are a few demerits associated with the protocol since the sample, from which the latent fingerprint needs to be developed, needs to be bathed in the colloidal gold solution and hence fingerprints from large objects cannot be developed by the method. The other demerit is that the protocol is not economical and works in a very narrow pH range [6, 16, 18].

AuNPs have also been used as molecular recognition reagents. AuNPs have been coated with antibodies through the use of deposition protein for proper binding of the antibody such as anticotinine–antibodies that can bind to the cotinine antigen present in the sweat and turn in the fingerprint residue. The antigen–antibody reaction caused the deposition of the AuNPs onto the fingerprint residues. The protocol is a modification of the MMD with the integration of the immunoassay technique [16, 19].

AuNPs coated with bifunctional reagents including tetrabutylammoniumbromide (TOAB) stabilized with a sulfur group at the end of the chain. The resultant structure has a high affinity to cellulose present in paper veiled by fingerprint residues. The bifunctional reagent along with the AuNPs bind to the fingerprint residues using paper as an attachment which leads to the development of the latent print [16].

Aptamer-based core-shell nanoparticles have also found various applications in latent fingerprint development as they are highly modifiable, highly specific, and have a high affinity toward targeted molecules. Aptamers are short and single-stranded oligonucleotide sequences that can fold into 3-D structures. Au/PNTP/SiO_2 lysozyme-binding aptamer nanoparticles have been synthesized by Fren and Zhao et al. Modified sandwiched SERS probes have been synthesized that have effectively detected and developed latent fingerprints for all three levels of classification [6]. Another example of the use of aptamer-based identification is the detection of cocaine metabolites from latent fingerprints which was carried out using cocaine-specific DNA aptamer which was cut into two pieces and bound to AuNPs [16].

4.3.3 CURRENT STATE OF AFFAIRS OF AUNPS FOR LFP DEVELOPMENT

As per the synthesis carried out by Becue et al. (2007), AuNPs were synthesized without the addition of thiolate cyclodextrin and then added with a dye

solution which was used for the detection of a latent fingerprint from porous as well as nonporous surfaces. The simplified version of MMD, known as the SMD, is where only AuNPs are utilized for developing latent fingerprints and the method has a broader pH working range compared to MMD [19].

The use of Aryldiazonium gold (III) salt has been compared with its non-Au-containing counterpart for comparing the efficiency of latent fingerprint development from metal surfaces. The aryl-diazonium gold (III) salt was synthesized using the existing protocol involving the addition of 0.691 g (5 mmol) of NO_2-4-$C_6H_4NH_2$ to 28 ml of 6.0 M HCl and stirred till the dissolution of nitroaniline. The reaction mixture was allowed to be cooled to 4°C. 0.345 g of 5 mmol of $NaNO_2$ was dissolved in 5 mL of deionized water was added to the mixture and stirred for 30 min at 4°C, Further, 1.7 g, 5 mmol of H[$AuCl_4$] was dissolved in 10 mL of water at 4°C and added dropwise into the reaction mixture resulting in the formation of a yellow precipitate which was then stirred for an hour at room temperature before filtering and washing thrice with 10 mL of cold water and vacuum drying. The dried product was then weighed and dissolved in a 5% acetonitrile: 95% ethanol solvent mixture to form a 0.001 M solution of the salt. The salt solution was used to develop latent prints and results were obtained at varying time intervals of 30, 60, 90, and 120 min. The samples were then left to dry and the results were recorded [2].

For the synthesis of immobilized AuNPs on fibrous nano-silica, 5 g of TEOS was dissolved in a solution of 60 mL cyclohexane and 3 mL of 1-pentanol. To this, a solution containing 2 g acetyl pyridium bromide (CPB) and 1.2 g urea dissolved in 60 mL of water was added. Next, the mixture was stirred for 30 min and then heated at 90°C for 10 h after which the product was filtered and washed with deionized water and acetone to obtain a pure product which was then calcinated at 550°C for 6 h in the air. For the synthesis of KCC-1-NH_2, 0.2 g of KCC-1 and 0.36 g of 3-APTES were mixed in 100 mL of toluene and refluxed under a nitrogen atmosphere for 12 h. The product was white and solid obtained through filtration and successful washing with ethanol; 0.2 g of KCC-1-NH_2 was ultrasonically dispersed in 100 mL H_2O was prepared and 0.0099 g, 3 mL of $HAuCl_4.3H_2O$ was added and stirred for 3 h and the excess $NaBH_4$ solution was removed. During the 3 h of stirring, the AuNPs get immobilized onto the KCC-1, and the resultant nanocomposites are obtained by filtration and dried in a vacuum [22].

George et al. synthesized gold nanocrystals (GNCs) and gold nanospheres (GNSs) on mercaptopropyl groups with silica gel 60 (MPS). The mixture was prepared with 5 mL of the organosilane grafting agent in 50 mL of dry toluene containing 5 mg of SG60. To prevent the oxidation of SH groups, the mixture was refluxed at 120°C for 24 h under an N_2 atmosphere; the product obtained thereafter was washed with toluene and dried in a vacuum oven at 45°C. For the preparation of GNCs and GNSs, the procedures are the same with just an additional step for the preparation of GNCs. The basic protocol includes the addition of 150 mg of MPS to 1 mL of an aqueous solution of $HAuCl_4$ and stirring it for 1 h in a rotary shaker. The product is then washed with Milli-Q water under centrifugation and dried overnight in an oven at 45°C. The additional step for the preparation of GNCs includes adding 1 mL of an aqueous solution of $NaBH_4$ to the mixture with continuous stirring. The author compared the effects of reaction time and concentration of $HAuCl_4$ and $NaBH_4$ with Milli-Q water and dried them overnight in an oven at 45°C [4].

Au nanoclusters have been synthesized on montmorillonite (MMT) powders through the modification of the one-pot microwave-assisted hydrothermal protocol. The steps for synthesis of AuNPs include the addition of 1 mL of 65 mg/mL BSA to 1 mL 10 mmol/L $HAuCl_4$, along with 0.10 mL of 1 mol/L NaOH solution, which is then transferred to a Teflon high-pressure sure digestion tank and heated at 800 W microwave programme radiation for 30 s until turned brown; 2.0 mL of the formed product is then mixed with 0.25 g of NA^+- MMT powder and stirred magnetically for 10 min. The precipitated final product formed is then centrifuged and dried at 35°C in a vacuum [23].

For the synthesis of monodisperse Au Nanorods (AuNRs) by using an improvised seed-mediated growth method, 5-bromosalicylic acid was used as an additive [21].

For the synthesis of Ag@Au-DTTC, 0.1 mM 50 μL of the ascorbic acid solution was added into 47.5 mL of boiling deionized water and then boiled for 1 more minute. Prepare 1 mL of 1% w/v of $Na_3C_6H_5O_7$ 0.25 mL of 1% w/v $AgNO_3$ and 50 μL of 0.06 mM KI into 1.25 mL of deionized water while stirring for 5 min. Add this mixture to the Ascorbic Acid solution and then boil for 1 h. The prepared Ag nanoparticles are collected through centrifugation followed by washing three times using deionized water and then redispersed in 50 mL deionized water. From the prepared Ag Nanoparticles, 0.75 mL was added into 9 mL deionized water

with constant stirring along with dropwise addition of 50 µL of 0.1 mM DTTC to form Ag-DTTC nanoparticles. 7.5 µL of 0.1 M HCl and 1 mM of $HAuCl_4$ was added after 10 min along with simultaneous addition of 60 µL of 10 mM $AgNO_3$ and 50 µL of 100 mM Ascorbic acid with vigorous stirring. Further after 30 s, dropwise 15 µL of 0.1 mmM DTTC was added with constant stirring for 10 min. Another one-step method for Ag@Au-DTTC synthesis involves the synthesis of Ag@Au nanostars and then adding 200 µL of 0.1 mM DTTC with stirring for 10 min. The obtained Ag@Au-DTTC nanostars were modified with mPEG-SH by adding 20 µL of 2 mM mPEG-SH in an aqueous solution to the prepared Ag@Au-DTTC nanostars under stirring. After 30 min, the product is collected by centrifugation, washed thrice with water, and then redispersed in 10 mL deionized water [24].

For the synthesis of gold nanorods, Lin et al. mixed 5 mL of 0.5 mM $HAuCl_4$ with 5 mL of 0.2 M CTAB solution in a round bottom flask. Further 0.6 mL of fresh 0.01 M sodium bromide ($NaBH_4$) was diluted to 1 mL with water and then injected into the $HAuCl_4$ – CTAB solution to obtain the seed solution. For the synthesis of AuNRs, 0.90 g CTAB and 0.15 g Sodium oleate (NaOL) were dissolved in a 50 mL cuvette. After cooling to 30°C, 1.8 mL of 4 mM silver nitrate solution is mixed with 25 mL of 1 mM $HAuCl_4$. 150 µL of (37% w/v) HCL is added to adjust pH.ng 125 µL of Ascorbic acid and 200 µL of the seed solution were added and the mixture was left undisturbed overnight at 30°C. The amount of the reagents added such as CTAB, NaOL, $AgNO_3$, HCl, and seed solution determine the LSPR peak of the nanorods [13].

Using ultrasonic-microwave heating, 20 mL of 0.01 mol/L of $HAuCl_4$ was added to 20 mL 50 mg/mL of BSA and mixed evenly. To this, 2 mL of 1 mol/L of KOH was added through vigorous stirring for 5 min with the pH of the mixture rising to 12. This mixture was further ultrasound for 1 h at 40 kHz frequency and 80 W power and was then kept in the microwave for the 50 s at 800 W till the color of the solution turned light brown. For the preparation of nanocluster powder, the solution was adjusted to pH 6 and centrifuged and dried under a vacuum at 37°C [11]. For the preparation of Aryldiazonium Tetrachloroaurate salts, 0.691 g of 5 mmol of 4-Nitroaniline was dissolved in 28 mL of 6 M HCl and was allowed to cool to 4°C. to this, 0.345 g, 5 mmol of $NaNO_2$ dissolved in 5 mL deionized water was added and then stirred for 30 min at 4°C, followed by the dropwise addition of $H[AuCl_4]$ dissolved

in 10 mL of water at 4°C to the mixture. The mixture is stirred at room temperature for 1 h. The bright yellow precipitate is recovered through suction filtration and then dried. The final working solution used for fingerprint development involves dissolving the product in water to form a 0.001 M solution [3].

After optimization of the protocol for the synthesis of GSH-Au Nanoparticles, 3.2 mL of 1% (w/v) of $HAuCl_4$ dissolved in 0.15 mL deionized water was added dropwise to 0.018 g of reduced GSH dissolved in 4.35 mL of deionized water through continuous stirring and controlling the dropping rate at 1 drop/min. The mixture was then ultrasonicated at 40 kHz frequency and 80 W power for 10 min followed by incubation in the thermostat box for 40 min at 75°C. The GHS-Au NCs were obtained after repetition of the process 12 times. For the synthesis of Fe_3O_4-PEI nanoparticles, 7.5 mL of 2 mol/L KNO_3 along with 1 mol/L of NaOH was dissolved in 60 mL deionized water. To this, 2 mL of 1.4 mol/L $FeSO_4$ solution was added under vigorous magnetic stirring at room temperature. With a drop rate of 1 drop/min. The particles formed are then centrifuged and washed alternately with deionized water and anhydrous ethanol 2–3 times after discarding the supernatant and eventually dispersed in deionized water. Further 4 g of PEI was dissolved in 16 mL water and ultrasonicated for 15 min. This solution is then dropped into the previous mixture under vigorous magnetic stirring at 80°C with a drop rate of 1 drop/min. The formed product was washed with deionized water. For assembly of $FeSO_4$@GSH-Au NCs core-shell nanospheres, equal volumes of GSH-Au NCs solution and magnetic $FeSO_4$ are mixed and transferred for ultrasonication for 10 min and then incubated in a thermostat box at 45°C for 20 min. The final product is obtained after repeating the steps eight times [12].

4.4 CONCLUSION

One of the major priorities in forensic science is the identification of latent fingerprints (LFP). It is a straightforward and reliable method for identifying people. An important use of nanotechnology in LFP detection is the creation of nanoparticles that optimize the surface contact with endogenous chemicals on the ridges to enhance the contrast of the fingerprints. These nanosized particles have several advantages over conventional ones when

used as a developing technique in latent fingerprinting. These nanoparticles provide a wide range of possibilities for more accurate finger ridge etching and can easily be employed to reveal fingerprints on a wide range of surfaces. It is because materials for fingerprinting have been produced using nanoparticles, which have greater capabilities over commercially available conventional powders. Over time, various nanostructures of gold such as nanospheres, nanorods, nanoprisms, and nanostars are utilized in latent fingerprints development. Gold nanorods are the most potential nanoparticle agents because of their easy optical tunability, probable noncytotoxicity, and simple production. In contrast to the presumed ionic contact in the "traditional" procedure, the AuNPs are likely to adhere to the ridges via hydrophobic interactions.

4.5 FUTURE SCOPE

While additional study is required before any of the strategies discussed may be applied in typical casework, nanotechnology is anticipated to play a significant role in the development of future methods for improving and enhancing fingerprints. Smokers' prints and those from non-smokers have been distinguished using nanoparticles functionalized with antibodies. Latent finger-mark analysis has revealed significant variations between adults and children that have already been used in forensic casework. We may anticipate future developments as equipment development, which not just aid in the viewing of latent prints but also help in deriving the additional "lifestyle" data about the individuals from their prints.

KEYWORDS

- **AuNPs**
- **crime scene investigations**
- **fingerprint**
- **gold**
- **nanoparticles**

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CHAPTER 5

Enhancing Latent Fingermark Development Through Zinc Oxide Nanoparticles: A Promising Approach for Forensic Applications

PRIYA SHARMA[1], RUBY KUMARI[2], and MONA[3]

[1]*Forensic Science Department, University Institute of Allied Health Sciences, Chandigarh University, Mohali, Punjab, India*

[2]*Forensic Science Laboratory, Haryana, India*

[3]*Department of Applied Science, Galgotias College of Engineering and Technology, Greater Noida, Uttar Pradesh India*

ABSTRACT

One of the most promising technologies in various forensic science fields is nanotechnology. This method uses a cutting-edge strategy to address the problems associated with the emergence of latent fingermarks on various surfaces. Due to their wide surface area and strong adhesive properties, many metal nanoparticles and metal oxide nanoparticles, such as tin oxide and zinc oxide (ZnO), have been used in the detection of latent fingermarks. Throughout the world, non-hazardous ZnO, which has photo-oxidizing and photocatalytic capabilities, is being used to create nanoparticles (NPs). Due to their fluorescent nature, ZnO NPs are useful for creating high-quality latent fingermarks on a variety of surfaces. This chapter will cover the synthesis, properties, and

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characterization techniques of ZnO NPs for the development of latent fingermarks. Besides, the merits and demerits of ZnO NPs over other NPs will also be discussed.

5.1 INTRODUCTION

The most frequent type of evidence obtained at a crime scene is fingerprints. Fingermarks are spontaneous sweat traces that are left behind when someone touches something with their bare hands or feet. One of the most common ways to connect a suspect to his physical presence at the crime scene is through personal identification based on fingerprints. Fingerprints discovered at the crime scene may be 3D, plastic, or latent in nature. Since they cannot be seen with the naked eye, the latent fingerprints must be visualized using a variety of ways. For the production and visualization of latent fingermarks from diverse surfaces under varied circumstances, there are numerous methods available. Conventional techniques like physical, optical, and chemical techniques are available for the detection of latent fingermarks. The physical method, namely the dry powder method, is most frequently utilized at crime scenes to create latent fingermarks. Powder particles stick to the sweat stains left on any surface and aid in their visibility. Sadly, not all latent prints discovered at the crime scene produced conclusive results. The admissibility of a developed latent fingermark depends on its quality. There are numerous factors that affect fingermarks detection like unusual substrates, and environmental factors (humidity, heat, and light), which can decrease the efficiency of these techniques. Therefore, it is very important to develop good quality latent fingermarks [8].

The developed fingermark should have clearly visible ridge details which can be further compared with known fingerprints. Fingerprints are characterized into three levels: first, second, and third-level details. The first level details include the pattern of fingerprints and the second level includes visualization of ridge characteristics like dot, bifurcation, and ridge ending. Then, the third level includes sweat pores and contours of ridges. The conventional latent fingermark development methods only help in the visualization of first level details of the fingermark. These conventional fingerprint powders also adhere to the background hindering the clearer picture of the fingerprint ridge patternClick or tap here to enter

text. [33]. Thus, we might have to compromise somewhere for good resolution latent prints. This is where nanomaterials are utilized to overcome these problems and increase the efficiency of fingerprint development. Nanoparticles are emerging as promising materials for latent fingerprint development, which can develop very high-quality latent fingermark because of its unique properties such as very small size, large surface area, and good optical properties. Nanoparticles (NPs) can be easily modified by doping with some agents [30]. The surface area factor of NPs facilitates their adherence to the sweat residue of the fingermarks [22, 30].

Metal oxide-based NPs like zinc oxide (ZnO) NPs provide good contrast and high resolution of fingermark [30]. Metal oxide NPs are chemically stable and also have strong spectral absorption in the UV region [19]. Zinc oxide has emerged worldwide to synthesize NPs due to its broad spectrum applications. Zinc oxide, an inorganic nanomaterial, has been studied in varied forms such as quantum dots, nanorods, and nanowiresClick or tap here to enter text. [3]. ZnO as compared to other metal oxides provides better fingerprint results due to its low size and high reflectivity [22].

5.2 ZINC OXIDE NANOPARTICLES

Inorganic nanomaterials have received a lot of attention recently in the past years because of their size and morphology-dependent optical, electrical, and other physiochemical properties. Zinc oxide is a promising n-type semiconductor with a relatively direct wide bandgap of 3.37 eV, electron affinity of 4.2 eV, and high exciton-binding energy of 60 meV [7, 26, 36], allowing it to be employed in various applications such as solar cells, photocatalysis, gas sensors, biosensors, photodetectors, varistors, and nanogenerators [9, 24, 25]. Additionally, they are cost-effective, easily available, non-toxic in nature, durable, and highly resistant. They have adhesive characteristics that help in their interaction with proteins and lipids present in the fingerprint residue in ambient conditions. Hence, ZnO NPs could also be used as fingerprint powders at the scene of crime [30].

To date, enormous efforts and approaches have been made to synthesize ZnO NPs with various forms and proportions using diverse approaches like wet chemical, hydrothermal, sol-gel, solvothermal, microwave, chemical microemulsion, sonochemical technique, direct precipitation, and green synthesis methods. Here, we are going to discuss various

synthesis methods of ZnO NPs. Furthermore, there will be a discussion on the characterization and properties of ZnO NPs.

5.2.1 SYNTHESIS OF ZINC OXIDE NANOPARTICLES

5.2.1.1 SOL-GEL METHOD

It is a wet chemical method in which precursors of zinc metal like zinc acetate dihydrate ($Zn(CH_3COO)_2.2H_2O$), and zinc nitrate hexahydrate ($Zn(NO_3)_2.6H_2O$) is dissolved in distilled water. This solution is mixed with an amount of sodium hydroxide (NaOH) solution with continuous stirring. Afterward, this zinc precursor is converted to gel by continuous stirring and heating at around 70°C by the addition of ethanol, known as alcoholysis. It results in white precipitates of ZnO NPs, which are isolated by centrifugation. The following chemical reaction represents the formation of ZnO NPs from zinc solution and NaOH.

$$ZnX_2 + 2NaOH \rightarrow ZnO + NaX + H_2O \ (X = NO_3^-, CH_3COO^-)$$

The formation of ZnO NPs is a result of equilibrium between the condensation and hydrolysis reaction of the zinc precursor solution. Zn precursor solution undergoes hydrolysis during heating and results in the formation of Zn^{2+} ion and counter ion [16].

5.2.1.2 HYDROTHERMAL METHOD

This process, which involves a chemical reaction in a sealed pressure vessel while water is present, is environmentally benign. In this procedure, distilled water is used to dissolve a zinc salt in order to create a zinc solution. Once the pH of the solution reaches 12, NaOH solution is added dropwise while swirling continuously. The solution is then put into Teflon-lined sealed stainless-steel autoclaves and kept in a hydrothermal oven for 2 h at a particular temperature (between 100 and 150°C). The resultant mixture is then filtered, rinsed with distilled water, and cooled to room temperature. The morphology of the resultant nanoparticle can change depending on the temperature, reaction duration, and solution concentration [27].

5.2.1.3 SOLVOTHERMAL METHOD

It is similar to the hydrothermal method, but there is a chemical reaction in the presence of solvent instead of water. In this synthesis method, zinc solution is prepared by dissolving Zn salt into the desired solvent system, such as ethylene glycol, ethanol, or a mixture of both. The synthesis temperature can be varied from 100 to 200°C [14]. By altering the reaction temperature as well as the volume combined with different solvents, one may change the size and shape of the ZnO nanostructures. The creation of ZnO NPs and their numerous characterization methods have been presented in Figure 5.1 schematically.

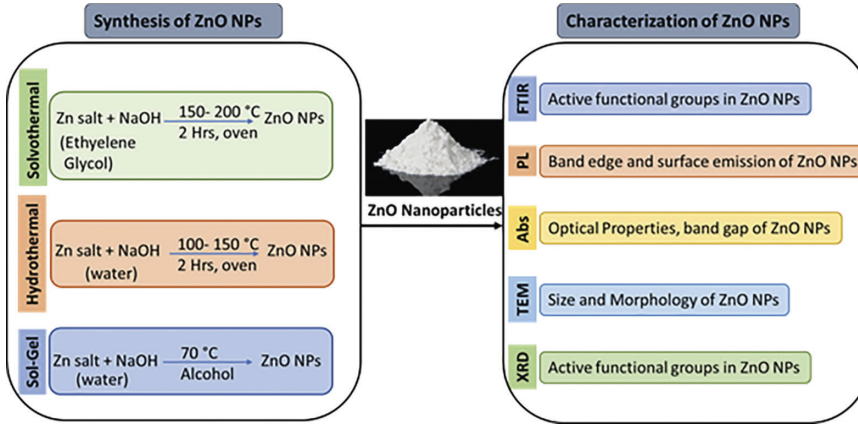

FIGURE 5.1 A schematic representation of the synthesis and characterization of ZnO NPs.

5.2.2 CHARACTERIZATION OF ZINC OXIDE NANOPARTICLES

Powder X-ray diffraction (PXRD) examinations of ZnO NPs can be used to identify their crystal structure and average crystallite/grain size. Estimating sample purity and dislocation-induced lattice strain are both aided by PXRD. According to Barhoum et al. [2], the ZnO NPs have a hexagonal wurtzite structure with the strongest peak corresponding to the 101 planes. The sample's crystallinity is shown by the PXRD pattern's strong peaks. The average crystallite size, d, can be calculated by the Debye-Scherrer Equation [17].

$$d = 0.89\,\lambda/\beta\,\cos\theta$$

where λ corresponds to the wavelength of incident radiation, β is the full-width half maximum of (101) peak, and θ is the diffraction angle corresponding to 101 planes.

The size and morphology of ZnO NPs can be obtained by transmission electron microscopic (TEM) measurements. The crystallinity of the ZnO NPs can also be determined from high-resolution TEM images. The nanostructure of ZnO NPs can also be investigated by scanning electron microscopy (SEM), which will determine the size, morphology, and nanostructure of micro-sized particles. The size of ZnO NPs increases by increasing the reaction time and decreases with an increase in reaction temperature. The reaction temperature also affects the morphology. For example, hydrothermal synthesis of ZnO NPs provides ZnO nanostructures of various shapes, such as nanoflowers, nanorods, and nanospheres at 100, 120, and 150°C, respectivelyClick or tap here to enter text. [27].

The size and band gap of the ZnO NPs can be determined by the position of the excitonic or absorbance band in UV–Vis absorption spectroscopic measurements. The band gap of ZnO NPs increases with a decrease in their size due to quantum confinement. It can be visualized by the blue shifting of the absorbance band in the absorption spectra with the decrease in the size of ZnO NPs. Zinc oxide nanoparticle shows an absorption band in the range of 350–370 nm, depending on their size, which is also a characteristic of their wurtzite crystal structure.

According to fluorescence spectroscopy, ZnO NPs have visible luminescence or fluorescence. Two emission peaks can be seen in the photoluminescence spectra of ZnO NPs, one in the UV area (370–395 nm) and the other in the visible region (530–600 nm). Band edge emission is the cause of the UV region's strong emission peak. The band edge emission is consistent with the 3.3 eV band gap of ambient ZnO NPs. Due to oxygen vacancies on its surface, the visible region experiences a large surface emission peak. As a result of extensive surface emission, ZnO NPs glow green when exposed to UV light [35]. This visible fluorescence of ZnO NPs makes them promising candidates for the detection methods of latent fingerprints on porous as well as non-porous surfaces.

Fourier transform infrared (FT-IR) spectroscopy can be used to verify the cleanliness of the sample and the ZnO bonding. The 400–4000 cm^{-1} range of bond vibration in the ZnO crystal lattice is what causes the IR bands to appear. Fourier transform infrared spectroscopy can also be used to identify the active functional groups that are present on the surface of ZnO NPs.

5.3 COMPOSITION OF LATENT FINGERMARK RESIDUE

A latent fingermark typically consists of natural secretions from glands, compounds present on the outer layer of skin of a palmer surface, that is, the epidermis, and some contaminants from the environment. An individual skin ridge consists of a chain of sweat pore openings. These pores lead to the ducts of secretion glands. Sweat including organic and inorganic components secreted from glands and deposited on the surface of the skin which further leaves an invisible impression of the fingers' ridge pattern. Eccrine glands are located throughout the body and are the only glands to be present on friction ridge skin of palmer and planter surfaces. Sebaceous glands are also present throughout the body, with the exception of the friction ridge area, and are associated with hair follicles, with the highest concentration being found on the forehead and on the back. As previously mentioned, the palmer side skin is covered with only eccrine glands, so eccrine gland secretions will be present. Furthermore, sebaceous gland secretions may be present due to frequent touching of face and hair. Sometimes, apocrine gland secretions may be present in certain crimes like sexual assaults. The composition of latent fingermark residue can be affected by the following factors:

1. Age, gender, diet, and medication of donor
2. Any contact with extraneous material like food, dust, and cosmetic products
3. Handwashing and frequent use of hand sanitizer
4. Pressure applied during deposition of fingermark
5. Temperature Conditions of Substrate: Sebaceous secretions have more adherence to the cooler surface than the human body.
6. Environmental Conditions: Humidity, light exposure, exposure to dust or pollution, and bacterial invasions
7. Surface Structure: Rougher surface has greater adhesive power than a smoother one.
8. Porosity of Surface: Higher porosity enhances the adhesion forces and thus facilitates the movement of fingermark residues into the substrate [29] Click or tap here to enter text.and higher smoothness causes a lower depth of penetration [8].

The gland secretions consist of organic and inorganic constituents. The inorganic and organic components of eccrine, apocrine, and sebaceous glands are depicted in Figures 5.2 and 5.3. Water is the major constituent,

that is, more than 98% followed by other organic and inorganic componentsClick or tap here to enter text. [12].

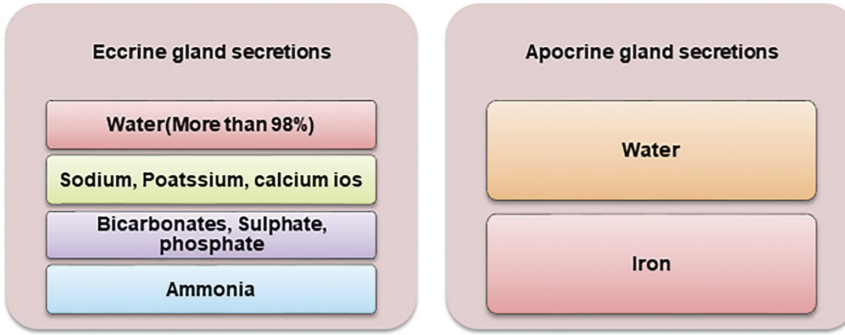

FIGURE 5.2 Constituents of inorganic secretions of latent fingermark.

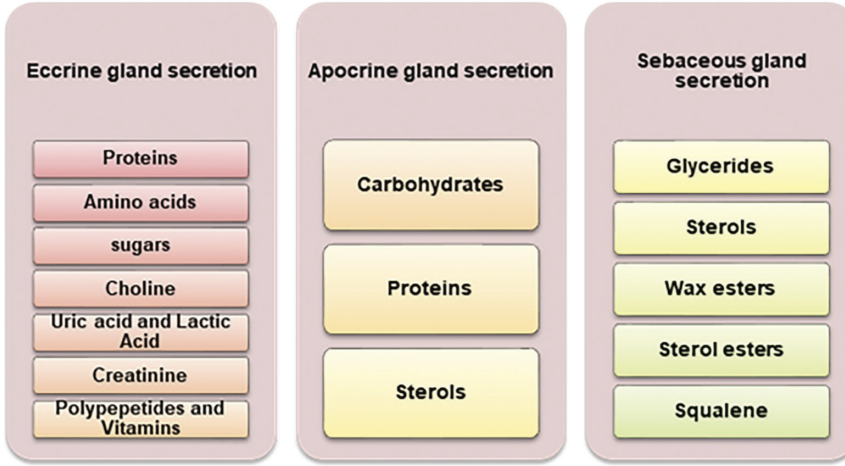

FIGURE 5.3 Constituents of organic secretions of latent fingermark.

The latent fingermark development using powder methods involves the adhesion of powder particles to the sweat residue, that is, the fingerprint ridges and having less affinity to the background substrate. The adherence of powder particles depends on particle size, shape, surface chemistry of powder particles, electrostatic charge on the particle, higher affinity for fingermark residue, and low affinity for background or substrate [13]. Nanoparticles form electrostatic and hydrophobic interactions with latent fingermarks deposited on the substrate [30].

Latent fingermark developer performance is measured on the basis of three main parameters which include resolution, stability, and brightness [30]. The developed latent fingermark should be of high resolution so that level-2 and level-3 details are clearly visible, which are shown schematically in Figure 5.4. This high resolution is possible with NPs owing to their good adhesive nature. Secondly, some of the latent print residues may be lost with aging and in extreme environmental conditions. So, the fingerprint developer should be able to develop these unstable latent fingermarks. Also, the developer should be able to provide good contrast from the substrate color. Lastly, the brightness of the developed fingermark is also one of the important factors to assess the efficiency of fingerprint developers. Fluorescent NPs have strong luminescence properties which develop good contrast and bright colored latent fingermarks [30].

FIGURE 5.4 Friction ridge detail levels in fingerprint identification. ⏎

5.4 ZNO NPS AS A LATENT FINGERPRINT DEVELOPMENT AGENT

Zinc Oxide has been used as a base for various colored pigments. Due to its photoluminescence properties, ZnO was used as a white pigment. As zinc has a luminescence property, it can provide contrast between developed latent prints and surface substrate. Powder methods are very common to develop latent prints on non-porous surfaces. Zinc oxide nano powders have good properties to be used as fingerprint powders. Also, ZnO has been used in small particle reagent formulations to detect latent prints on wet non-porous surfaces [11]. ZnO was reported to be more effective as compared to other commercial fingerprint powders. Nanostructured ZnO powder was found to develop sharper and clearer fluorescent latent fingermarks on non-porous surfaces without staining the background/substrate [10, 13].

Zinc oxide has been used as a coating instead of gold-zinc coating for the visualization of latent fingermarks using the vacuum metal deposition (VMD) method. Vacuum metal deposition technique is utilized for the latent fingermarks development on a wider range of plastic surfaces. The process of VMD method involves first the coating of gold vapors followed by the coating of zinc metal vapors over gold coating. It was reported that ZnO can produce as good quality latent prints as zinc-gold coatings in VMD [37].

The pure form of zinc is not effective as a fingerprint developer as compared to ZnO. The VMD process involves the thermal evaporation of metals. Zinc oxide and zinc have different condensation properties. Thermal evaporation of zinc generates clusters of few atoms only which do not have affinity for plastic surfaces. At the time of thermal evaporation, ZnO breaks down into zinc atoms and oxygen species, which is more reactive than zinc clusters. Also, oxygen species changes surface chemistry and further enhance adhesion between Zn and plastics [37].

Various studies show that ZnO NPs are highly effective as fingerprint powders on non-porous surfaces, semi-porous, and dry substrates [30, 31]. Researchers found good results of fingerprints on non-porous surfaces like steel, aluminum, black paperboard, and black glass under UV light [15, 33]. Even the older prints of more than a month can be developed using ZnO NPs. Zinc oxide nanoparticles are also well applicable on wet and dark surfaces [21].

ZnO NPs can be used in pure form or doped with other materials. Bumbrah et al. synthesized spherical-shaped ZnO NPs and developed good quality latent fingermarks (fresh and after 24 h) on wet and dry non-porous surfaces [6].

The effectiveness of ZnO NPs can be further improved by doping them with some other material. In previous studies, ZnO doped with various metals was synthesized and its performance was evaluated for the development of latent fingerprints. Figure 5.5 shows various doped ZnO NPs as fingerprint developers. Choi et al. synthesized and evaluated the performance of pure ZnO and Lithium-doped ZnO nano powders for the development of latent fingermark [10]. No significant differences were found between the pure and doped forms of ZnO NPs. Manganese-doped ZnO NPs [23] and Lanthanum-doped zinc [32] were also used for latent fingermark development. Copper-doped ZnO NPs increase the adhesive properties on various surfaces and enhance the resolution of fingerprints. This ZnO doped with Cu when brushed on various surfaces produces green color ridge details. The

details developed can clearly show various levels of ridge patterns, ridge details, and sweat pores enabling the identification of fingerprints at levels 1, 2, and 3, respectively. Sweat pores level 3 identification which is otherwise not visible with conventional powders can be clearly visible. These sweat pores are also unique to various individuals and help in poroscopy. Utilizing nitrogen functionalized carbon dots coated on ZnO NPs, a unique technique was created for creating latent fingermarks on various non-porous surfaces [28, 30]. These nanocomposites offer high-contrast ridges with great clarity when exposed to UV radiation. By utilizing yellow filters and light sources with wavelengths of 415 and 450 nm, these traits are improved. Due to its great efficacy, low toxicity, new optical features, and successful results in the production of latent fingermarks, this nanocomposite is outstanding [15]. Arshad et al. synthesized ZnO–Si–O_2 nanopowder as fingerprint developer on non-porous surfacesClick or tap here to enter text. [1]. It was observed that this nano powder produced better quality, showing even third-level details latent prints. In 2022, Bouaziz studied the effect of Iodine-doped ZnO NPs on latent fingermark detection. Iodine doping promotes optical constants of ZnO and thus develops high-quality latent fingermarks [5].

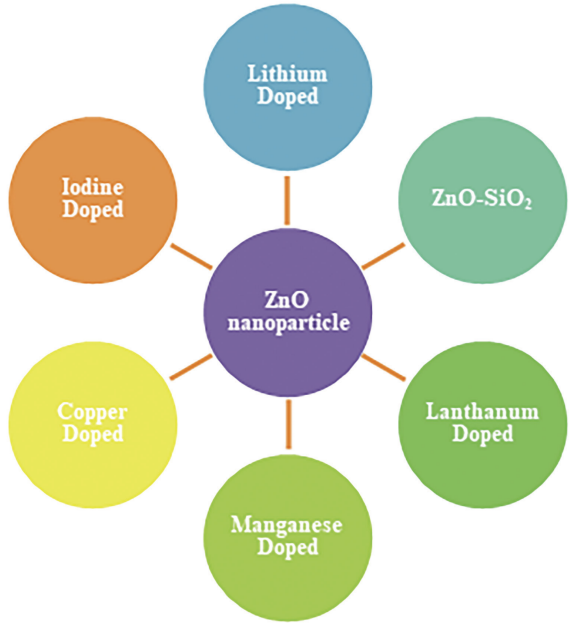

FIGURE 5.5 ZnO NPs used in the development of latent fingermarks. ⏎

The synthesis of ZnO NPs both physical and chemical methods utilizes toxic chemicals and extreme surroundings. Therefore, NPs are being synthesized using green techniques. Green techniques are eco-friendly and adopt plants, bacteria, fungi, or algae for the synthesis of NPs [18]. The ZnO NPs produced using plant materials for fingerprint development again provide a better environment-friendly approach toward its application. Luthra and Kumar synthesized ZnO NPs using barbiturates through simple combustion methods and visualized the latent fingermarks on various surfaces [22]. The developed fingermarks were clear and free of any background noise.

5.5 MERITS AND DEMERITS OF ZINC OXIDE NANOPARTICLE

Zinc oxide nanoparticles are non-hazardous, cost-effective, chemically stable, and photoluminescent. Among other metal oxide NPs, it is a low-toxic material. It can develop fresh and old latent fingermarks. Zinc oxide nanoparticles can develop high-resolution fingerprints, and help in the visualization of even third-level details. It has low background staining so clear fingermarks can be developed and further analyzed. Zinc oxide nanoparticles were found to be effective on a wider range of non-porous surfaces only. On a porous surface, it may not produce promising results. There is very little or no study available on the development of fingermarks on porous surfaces using ZnO NPs. The physical and chemical synthesis processes are toxic in nature. Though green synthesized NPs are utilized in some studies. But still, there is a need to develop standard procedures for the synthesis of NPs. The ZnO particle is active under UV luminescence only and to increase its efficiency, it is doped with other metals or semiconductors. Zinc oxide acts as an anti-inflammatory, antioxidant, and antimicrobial but in some studies, it has been mentioned that ZnO may cause hepatotoxicity, pulmonary toxicity, neurotoxicity, and immunotoxicity [20]. Zhu et al. studied the eco-toxicological impact of ZnO on Zebrafish (Danio rerio) at an early developmental stage with other metal oxides [38]. It was observed that ZnO is toxic and inhibits the growth of Zebrafish. The toxicological effect of NPs varies from one organism to another. There is a scarcity of studies on the toxic effect of metal oxide NPs [4]. Nanoparticles may enter the body via dermal contact or inhalation. The experts may be exposed to NPs through inhalation. Further, it can be disseminated in the body through the circulatory system. The size of a nanoparticle is small enough to enter the cell. Once ZnO enters the

cell, it disintegrates into Zn^{2+} ions and eventually leads to cell death [34]. Therefore, during the usage of ZnO nano powder masks should be used by experts.

5.6 FUTURE PROSPECTS

On a variety of porous and non-porous surfaces, latent fingermarks have been created using ZnO NPs. The latent fingermarks, however, were created in a perfect environment. Due to the variety of crime scenes, latent fingerprints are subjected to harsh environmental conditions. The quantity and quality of latent fingermarks are influenced by a number of variables, including ambient circumstances, donors, and substrate types. Latent fingermarks discovered in extreme environmental circumstances should be able to be developed by a skilled fingerprint developer. Instead of creating latent fingermarks from crime scene-like conditions, there is more emphasis on synthesizing unique ZnO NPs. So it is possible to replicate crime scene-like circumstances in order to evaluate the effectiveness of recently synthesized ZnO NPs. For the creation of latent fingermarks, ZnO has been employed both in its purest form and in combination with different dopants. A standardized method for the synthesis and characterization of ZnO NPs does not exist, though. Future research can compare the efficacy of ZnO NPs with those of other techniques now in use. Zinc oxide nanoparticles can be produced in a variety of sizes, from 3 to 50 nm. In order to create latent fingermarks, ZnO NPs are currently synthesized in a variety of shapes, including hexagonal, spherical, oval, and flower-like geometries [6]. ZnO NPs come in a variety of forms and sizes and have produced excellent latent fingermarks. But there is no study available where the significance of size and shape of NPs have been addressed with respect to latent fingermark development. Further, additional studies are required to study the toxicological effect of ZnO-based nano powder on fingerprint experts.

5.7 CONCLUSIONS

Apart from its applications in various fields, ZnO has been proven to be a good fingerprint developer. The adhesive characteristics of ZnO NPs facilitate its interaction with proteins and lipids present in the fingermark

residue. There are diverse approaches to the synthesis and characterization of ZnO NPs in varied forms. Zinc oxide exhibits fluorescence which helps in better visualization of developed latent fingermarks. Zinc oxide can be doped with other materials like nitrogen, copper, and lanthanum for further enhancement of developed latent fingermarks. Contemporary studies on the development of latent fingermarks using ZnO NPs suggest that second level and third-level ridge details can be visualized without any background staining of the substrate. Even the wet and dark non-porous surface could be brushed with the ZnO powders in place of other conventional fluorescent powders. With great advantages in powder as well as suspension form, it is one of the good options for fingerprint experts. With the novel properties of luminescence, good adherence, low cost, and capacity to produce high-resolution latent fingermark, ZnO nano powders must be included in crime scene fingerprint kits. Although there are many advantages of ZnO nano powders, a fingerprint expert should take proper precautions while using them. The inhalation of ZnO particles may lead to health hazards. The simulations of crime scene-like conditions including environmental factors, substrates, and donor conditions for the development of latent fingermarks using ZnO nano powders may lead to draw forensically relevant conclusions.

KEYWORDS

- **Latent fingerprints**
- **metal oxide**
- **nanoparticles**
- **nanotechnology**
- **zinc oxide**

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CHAPTER 6

Green Synthesis of Nanoparticles for Enhanced Latent Fingerprint Development: A Sustainable Approach

SNEHALATA U. SHENOY[1], ANUJ SHARMA[2], VAIBHAV SHARMA[1], VARAD NAGAR[3], APOORVA SINGH[1], KUMUD KANT AWASTHI[4], MAHIPAL SINGH SANKLHLA[5,6], and GARIMA AWASTHI[4]

[1]Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India

[2]Department of Forensic Science, ITM University (SOS), Gwalior, Madhya Pradesh, India

[3]Department of Forensic Science, Banaras Hindu University, Varanasi, Uttar Pradesh, India

[4]Department of Life Sciences, Vivekananda Global University, Jaipur, Rajasthan, India

[5]Department of Forensic Science, (UIAHS), Chandigarh University, Mohali, Punjab, India

[6]University Centre Research for Development, (UCRD), Chandigarh University, Mohali, Punjab, India

ABSTRACT

The development of latent fingerprints plays a pivotal role in forensic investigations by providing critical evidence for identifying individuals involved in criminal activities. However, traditional fingerprint

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Kumud Kant Awasthi, Mahipal Singh Sankhla, Chandra Shekhar Yadav, and Anjali Awasthi (Eds.)

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development methods often rely on chemical reagents that are environmentally harmful and pose potential health risks to forensic investigators. In recent years, there has been a surge of interest in eco-friendly and sustainable techniques for fingerprint enhancement. Green synthesis involves the utilization of natural compounds, such as plant extracts and microorganisms, to fabricate nanoparticles with enhanced properties. These nanoparticles offer numerous advantages, including biocompatibility, cost-effectiveness, and minimal environmental impact. Furthermore, the role of different types of green-synthesized nanoparticles, such as silver, gold, and magnetic nanoparticles, in enhancing the visibility and quality of latent fingerprints. It discusses their unique properties, synthesis methods, and interactions with fingerprint residue components. It also discusses future research directions and potential advancements in this emerging field, with the aim of promoting sustainable and environmentally friendly approaches for forensic fingerprint analysis. Overall, the incorporation of green-synthesized nanoparticles in latent fingerprint development holds tremendous promise for advancing forensic science while mitigating the negative impact on the environment and human health. By embracing these eco-friendly techniques, forensic investigators can enhance their capabilities in fingerprint analysis while upholding sustainable practices.

6.1 INTRODUCTION

Despite the recent progress of DNA technology, using fingerprint imprints to identify physical evidence and provide generalized identity confirmation is still a more practical and rudimentary method. This clearly demonstrates that each individual's friction ridge pattern is distinct, and even two of the same person's fingers cannot have the same pattern. As it develops in the deepest layer of the skin and leaves impressions on every item handled with bare hands, the ridge pattern is a fundamental attribute of an individual and is permanent [1].

The development of forensic sciences contributes significantly to public safety and security, which are among not only the most fundamental human necessities but also the foundation of economic stability and progress. According to the National Crime Record Bureau (NCRB) data, India saw 12,500 violent crimes per day on average in 2016 [2]. Fingerprints are a crucial piece of physical evidence in forensic investigation of physical

evidence. The majority of crime scenes have fingerprint evidence. It is a common challenge for crime scene investigators to develop fingerprints on different surfaces [3, 4]. A latent fingerprint is a fingerprint that is left on a surface unintentionally, and it is not visible to the naked eye. The formation of a latent fingerprint depends on various factors such as the surface of the object, the conditions of the environment, and the physical characteristics of the finger. Eccrine, apocrine, and sebaceous are the three main types of glands that produce the skin's natural secretions [5]. The ridges on the finger transfer the substances in the form of a pattern onto the surface. The ridge pattern contains friction ridges, which are raised lines, and pores, which are tiny openings on the ridges that emit sweat. For the creation of latent fingerprints, common techniques include silver nitrate procedure, cyanoacrylate fuming, and powder dusting. Metallic and non-metallic powders are used in the traditional powder dusting technique to create latent fingerprints [6].

Different kinds of nanoparticles have been created in a variety of morphologies during the past 20 years and employed in forensic applications. In particular, nanoparticles of silver (Ag) and gold (Au) as metal nanoparticles, titanium dioxide (TiO_2), zinc oxide (ZnO), iron oxide, europium oxide, and silica nanoparticles as metal oxides nanoparticles, cadmium sulfide quantum dots (CdSQDs), cadmium selenide quantum dots (CdSeQDs), cadmium telluride quantum dots (CdTeQDs), carbon dots (CDs), and polymers [7, 8]. The following is a description of the rationale for using these nanoparticles in fingerprint detection: The target molecules of metabolites and explosives are primarily addressed by the Ag and Au nanoparticles, which correspond to antibodies and aptamers, respectively. They have also demonstrated a number of other qualities, including a high surface area, a compact size, thermal conductivity, and electrical conductivity [9]. These chemicals are used to positively identify perpetrators at crime scenes and have been employed in fingerprint detection [10]. In the fields of optics, electronics, biomedicine, mechanics, drug-gene delivery, the chemical industry, optoelectronic devices, nonlinear optical devices, catalysis, space industries, energy research, and photoelectrochemical applications, nanoscale structures (also known as nanoparticles) are used [11].

Due to their enormous surface-to-volume and other physical and chemical alterations in their properties relative to the majority of the same chemical composition, nanoparticles are the subject of excessive attention [12, 13]. Numerous nanoparticle materials demonstrated toxicity at the nanoscale level, yet many researchers and scientists have shown

considerable interest in their unique qualities and determined that, while they have remarkable uses in diverse industries. To create eco-friendly nanoparticles that are resistant to toxicity, green chemistry and nanotechnology are combined [14]. Researchers have created several synthetic processes for creating nanoparticles that have revealed a significant advantage for the environment and nature through "green chemistry" processes that use clean, non-toxic, and ecologically suitable organisms including bacteria, fungi, and plants [15]. The manufacture of metal nanoparticles has already been studied extensively utilizing bacteria like *Bacillus subtilis* [16], as well as other bacteria including *Penicillium* sp. [17], and *Fusarium oxysporum* [18]. This chapter focuses on the most widely used green synthesis process, which uses plant extracts to create a variety of nanoparticles, and their application in the field of fingerprint.

6.2 GENERAL OVERVIEW OF GREEN-SYNTHESIZED NANOPARTICLES DEVELOPED IN RECENT YEARS

The three most important requirements for the synthesis of nanoparticles include the selection of an environmentally friendly solvent, a good reducing agent, and an appropriate stabilizing substance. In general, the chemical processes utilized are very expensive and use poisonous and harmful substances that pose a number of threats to the environment [19, 20]. The biosynthetic pathway uses plants and microbes to create nanoparticles that are safe, biocompatible, and beneficial to the environment for use in biomedical applications. This synthesis could be carried out by several organisms, including algae, fungi, bacteria, and plants. Due to the presence of phytochemicals in their extract which serve as a stabilizing and reducing agent that is several plant parts including leaves, fruits, roots, stems, and seeds, have been used in the synthesis of different nanoparticles [21]. Plants are seen as the low-maintenance, cost-effective chemical factories of nature. Due to the fact that even minute amounts of these heavy metal traces can be harmful at very low concentrations, plants have demonstrated exceptional potential in heavy metal detoxification and accumulation [22]. Plant extracts can be used to make nanoparticles, which has advantages over other biological processes like microorganism-based synthesis since they can be used to preserve microbial populations. Plant-assisted nanoparticle synthesis has the benefit that its kinetics are

much higher than those of other biosynthetic methods that are comparable to chemical nanoparticle development. By using a green approach, many nanoparticles, including Au, Ag, ZnO, and iron, have been easily synthesized. Metallic ions are reduced by the plant extract's phytocompounds, which include polyols, terpenoids, and polyphenols [11, 23]. In recent years, there has been a growing interest in the development of green-synthesized nanoparticles due to their numerous advantages over traditional synthesis methods. Green synthesis refers to the environmentally friendly fabrication of nanoparticles using natural, renewable, and non-toxic materials. This approach aims to reduce the reliance on hazardous chemicals and energy-intensive processes, making it a sustainable alternative for nanoparticle production. Several methods have been employed for the green synthesis of nanoparticles, utilizing various natural sources such as plants, bacteria, fungi, and marine organisms. These sources contain bioactive compounds that act as reducing agents, stabilizers, and capping agents for nanoparticle synthesis. By harnessing the inherent properties of these natural sources, researchers have been able to develop a wide range of green-synthesized nanoparticles with diverse compositions, sizes, and shapes.

Green-synthesized nanoparticles have found applications in various fields, including medicine, agriculture, energy, and environmental remediation. In the medical field, green-synthesized nanoparticles have been explored for drug delivery, imaging, and therapeutic purposes. Their biocompatibility and potential for targeted delivery make them attractive for biomedical applications. In agriculture, green-synthesized nanoparticles have shown promise as environmentally friendly pesticides, fertilizers, and growth regulators, minimizing the use of harmful chemicals and reducing the environmental impact. Furthermore, green-synthesized nanoparticles have demonstrated excellent catalytic, optical, and magnetic properties, which have been utilized in energy-related applications. They have been employed in solar cells, fuel cells, and batteries to enhance efficiency and performance. Additionally, green-synthesized nanoparticles have been used in environmental remediation for the removal of pollutants from water and soil, offering a sustainable approach to pollution control. Researchers have also focused on characterizing and understanding the properties of green-synthesized nanoparticles, including their stability, size distribution, surface chemistry, and reactivity. Characterization techniques such as spectroscopy, microscopy, and X-ray diffraction have been employed to analyze and optimize the synthesized nanoparticles. Overall,

the development of green-synthesized nanoparticles represents a significant advancement in nanotechnology, combining sustainability with novel materials synthesis. Continued research in this field holds tremendous potential for addressing current environmental challenges and promoting the use of eco-friendly materials in various applications.

TABLE 6.1 Overview of Green-Synthesized Nanoparticles from Different Plant Origins Used in Different Applications.

Type of Nanoparticle	Plant Origin	Morphology of Nanoparticle	Size (nm)	References
Palladium (Pd)	*Rosmarinus officinalis*	Semi-Spherical	15–90	[24]
	Cotton coll peels	Spherical	9.44	[25]
Silver (Ag)	*Nauclea latifolia*	Irregular	12	[26]
	Cestrum nocturnum	Spherical	20	[27]
	Elaeagnus umbellata	Spherical	40	[28]
	Dionaea muscipula	Quasi-Spherical	5–10	[29]
Copper (Cu)	*Hagenia abyssinica*	Hexagonal, Spherical, and Triangular	34.76	[30]
	Orobanche aegyptiaca	Spherical	<50	[31]
Zinc oxide (ZnO)	*Calotropis gigantea*	Hexagonal and Pyramidal	31	[32]
	Prosopis juliflora	Irregular	31.80–32.39	[33]
	Urtica dioica	Spherical	20–22	[34]
Platinum (Pt)	*Nigella sativa L*	Spherical	1–6	[35]
	Tragia involucrata	Spherical	10	[36]
Gold (Au)	*Croton sparsiflorus*	Spherical	16.6–17	[37]
	Desmodium gengeticum	Spherical	16 ± 4	[38]
	Hibiscus sabdariffa	Spherical	15–45	[39]
	Gelidium pusilium	Spherical	12 ± 4.2	[40]
Titanium dioxide (TiO_2)	*Ledebouria revoluta*	Tetragonal	47	[41]
	Mentha arvensis	Spherical	20–70	[42]
	Lemon peel extract	Spherical	80–140	[43]
	Alcea and *Thyme extract*	Irregular and Polyhedron	10	[44]

6.3 SCOPE OF GREEN-SYNTHESIZED NANOPARTICLES IN LATENT FINGERPRINT DEVELOPMENT

The development and analysis of latent fingerprints offer a vast array of unexplored possibilities beyond forensic applications, including the identification of illegal drugs and clinically significant metabolites. Most latent fingerprints represent surface-based phenomena, and the utilization of nanomaterials opens up new avenues in surface-based sciences. Nanoparticles can be employed to enhance the visibility and contrast of latent fingerprints, simplifying their detection and examination. Green nanoparticles synthesized through environmentally friendly processes present a safe and cost-effective alternative to traditional methods as shown in Figure 6.1. Compared to conventional techniques, green-synthesized nanoparticles have demonstrated enhanced sensitivity and selectivity in detecting latent fingerprints. They have the capability to identify even the tiniest traces of fingerprints that may be overlooked by other methods. These nanoparticles can be utilized in combination with chemical treatments and physical approaches, making them applicable to various surfaces such as metal, glass, plastic, and paper. To obtain a more comprehensive understanding of the latent fingerprint, green-synthesized nanoparticles can be employed in conjunction with other imaging techniques like fluorescence and Raman spectroscopy. This synergistic approach improves the accuracy of analysis and aids in identifying the chemical components of the fingerprint. Green-synthesized nanoparticles possess unique optical characteristics that can be leveraged to enhance fingerprint visibility. For instance, Au nanoparticles can be utilized to increase contrast and visibility through their strong light scattering effect. By reducing the likelihood of false positives or false negatives, green-synthesized nanoparticles contribute to higher precision in fingerprint development. The integration of green-synthesized nanoparticles in latent fingerprint analysis not only promotes eco-friendly practices but also expands the capabilities and accuracy of forensic investigations. Moreover, it opens up new avenues for research in the identification of substances and compounds beyond the realm of forensics, thus broadening the impact of this technology.

The scope of green-synthesized nanoparticles in this field is significant and encompasses various aspects of fingerprint analysis and enhancement.

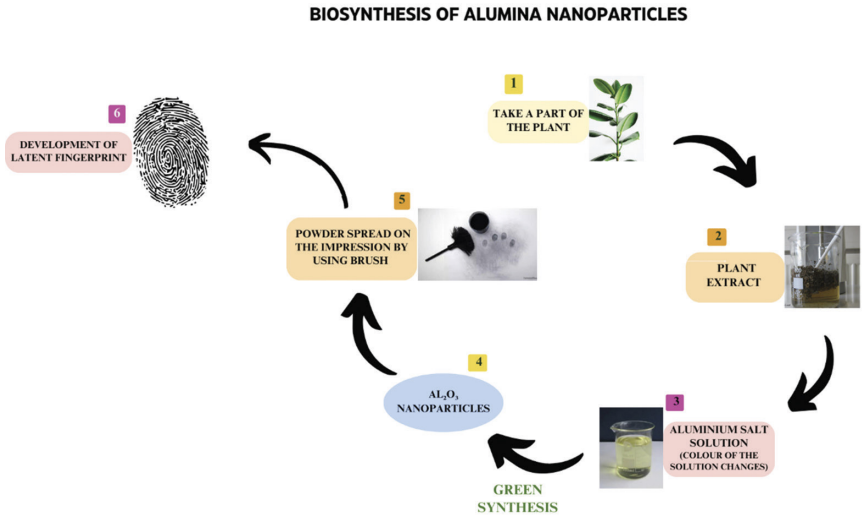

FIGURE 6.1 Synthesis and characterization methodology of silver nanoparticles (AgNPs) for utilization in friction ridges analysis. ⏎

Enhanced Visibility: Green-synthesized nanoparticles can improve the visibility of latent fingerprints by providing better contrast and increasing the signal-to-noise ratio. Nanoparticles with specific optical properties, such as plasmonic nanoparticles (e.g., Au and Ag nanoparticles), can enhance the contrast of latent fingerprints when illuminated with appropriate light sources.

Development on Challenging Surfaces: Latent fingerprints are often found on complex and challenging surfaces such as porous materials, rough surfaces, or substrates with low contrast. Green-synthesized nanoparticles can be tailored to have specific surface properties and adhesion characteristics, allowing them to adhere effectively to these surfaces and enhance the visibility of latent fingerprints.

Development of Aged or Degraded Prints: Latent fingerprints that have aged or undergone degradation over time may become faint or difficult to detect using conventional methods. Green-synthesized nanoparticles with enhanced sensitivity and selectivity can be utilized to detect and develop these aged or degraded fingerprints, leading to improved success rates in forensic investigations.

Selective Enhancement: Green-synthesized nanoparticles can be functionalized or modified to selectively interact with specific components of

latent fingerprints, such as amino acids, lipids, or proteins. This selectivity enables targeted enhancement of different components of the fingerprint, aiding in the identification and differentiation of overlapping or distorted prints.

Non-Destructive Analysis: Green-synthesized nanoparticles offer the potential for non-destructive analysis of latent fingerprints. Traditional fingerprint development methods often involve the use of chemicals that can alter or destroy the fingerprint pattern. Green-synthesized nanoparticles, on the other hand, can be designed to interact with the fingerprint without damaging its integrity, allowing for subsequent analysis and comparison.

Environmental Friendliness: As the name suggests, green-synthesized nanoparticles are produced using eco-friendly and sustainable methods, reducing the reliance on toxic chemicals and energy-intensive processes. This aspect aligns with the principles of sustainable forensic science and promotes environmentally conscious approaches in latent fingerprint development.

6.4 CLASSIFICATION OF BIOGENIC NANOPARTICLES DEVELOPMENT

6.4.1 ZINC OXIDE

Because of their special qualities, including a large surface area, high catalytic activity, and photocatalytic capabilities, ZnO nanoparticles have been found to have potential uses in the creation of latent fingerprints. Green synthesis of ZnO nanoparticles is an eco-friendly approach to latent fingerprint development. The average particle size of green-synthesized ZnO nanoparticles ranges between 10 and 100 nm. They are an effective approach to latent fingerprint development. They are capable to develop latent fingerprints on a wide range of porous and non-porous surfaces. Several studies have been conducted to see the abilities of green-synthesized ZnO nanoparticles to develop latent fingerprints. One such study was conducted by Shivananjaiah H et al. [45]. They synthesize La3+ doped ZnO nanoparticles using aloe vera gel by solution combustion method. The average particle size was found to be 13–20 nm. Additionally, these nanoparticles perform well as fluorescent markers in fingerprints. Another study was conducted by Rajan R et al. [46]. *Azadirachta indica*

extract-based green chemistry synthesis of nanostructured ZnO powder was synthesized and used for the development of latent fingerprint. The particle size was found to be 100 nm. Results show that for the creation of fingerprints, green chemistry-fabricated nanostructured ZnO can be used. Future research may be done to increase particle dispersion and provide the ZnO nanoparticles with robust photoluminescence. Like this, several other studies were conducted to develop green-synthesized ZnO nanoparticles capable of latent fingerprint development. Green synthesis of ZnO nanoparticles by lime leaf extract by Ref. [47] and N-CDs/ZnONPs nanocomposite prepared using melamine, potato peel waste, and zinc acetate dehydrate as precursors by Ref. [48] are some of the green-synthesized ZnONPs that are used to develop latent fingerprints.

Biogenic nanoparticles refer to nanoparticles that are synthesized using biological sources or organisms. When it comes to the development of biogenic nanoparticles, including ZnO nanoparticles, they can be broadly classified into the following categories:

Plant-Mediated Synthesis: This category involves the use of various parts of plants, such as leaves, stems, roots, flowers, or extracts, for the synthesis of ZnO nanoparticles. The plant material acts as a reducing and capping agent during the synthesis process. Different plant species, such as aloe vera, green tea, neem, and citrus fruits, have been used for the synthesis of ZnO nanoparticles through this method.

Microorganism-Mediated Synthesis: In this classification, microorganisms like bacteria, fungi, yeast, or algae are employed for the production of ZnO nanoparticles. These microorganisms either secrete enzymes or produce metabolites that facilitate the reduction of Zn salts into nanoparticles. Bacterial strains like *Escherichia coli*, *Bacillus subtilis*, and *Pseudomonas aeruginosa*, as well as fungal species like *Aspergillus niger* and *Fusarium oxysporum*, have been commonly used for ZnO nanoparticle synthesis.

Enzyme-Mediated Synthesis: Enzymes extracted from biological sources can be used to synthesize ZnO nanoparticles. Enzymes like urease, cellulase, and alkaline phosphatase have been employed for the biogenic synthesis of ZnO nanoparticles. These enzymes act as reducing agents, converting Zn precursors into nanoparticles in a controlled manner.

Biowaste-Mediated Synthesis: This classification involves the utilization of agricultural waste, food waste, or other organic waste materials for the synthesis of ZnO nanoparticles. Examples of biowaste sources include

fruit peels, tea waste, rice husk, and sawdust. These waste materials contain bioactive compounds that facilitate the reduction and stabilization of ZnO nanoparticles during the synthesis process.

Each of these classifications offers unique advantages and can be tailored for specific applications. Biogenic synthesis methods are generally considered eco-friendly, cost-effective, and sustainable compared to conventional chemical methods. The resulting ZnO nanoparticles exhibit varied properties depending on the synthesis approach, such as particle size, shape, crystallinity, and surface characteristics.

It is worth noting that the choice of synthesis method for ZnO nanoparticles should consider factors like scalability, reproducibility, and desired nanoparticle properties for the intended applications. Additionally, thorough characterization techniques should be employed to assess the physicochemical properties and performance of the synthesized ZnO nanoparticles.

6.4.2 CARBON DOTS

The carbon-based nanoparticles known as CDs have special optical characteristics including fluorescence that make them valuable in a variety of applications, including bioimaging and sensing. Recently, CDs have also been researched for their possible application in the creation of latent fingerprints. In comparison to conventional fingerprint creation techniques, CDs have benefits including being non-toxic, simple to make, and having excellent sensitivity. Several types of CD nanoparticles are green synthesized and investigated as a tool for latent fingerprint development in forensic science. As per several studies, N-CDs/ZnONPs nanocomposite was prepared using melamine, potato peel waste and zinc acetate dehydrate [48], solid-state photoluminescent carbon nanodots from grains [49], water-soluble fluorescent CDs from rosemary leaves [50] and green-emitting CDs [51] and several others [52] are investigated and impressive tools to develop latent fingerprints on several porous and non-porous surfaces. The average particle size of these ranges between 15 and 100 nm.

CDs are a class of nanoparticles composed of carbon-based materials with sizes typically ranging from a few to several tens of nanometers. They are also known as carbon quantum dots or carbon nanodots. CDs possess unique optical, electronic, and chemical properties, making them attractive for a wide range of applications.

The synthesis of CDs can be achieved through various methods, including hydrothermal methods, solvothermal methods, microwave-assisted synthesis, and pyrolysis of organic precursors. These methods involve the carbonization or fragmentation of organic compounds such as carbohydrates, amino acids, polymers, or biomass. The resulting CDs exhibit a fluorescent behavior, with emission wavelengths depending on their size, surface functional groups, and synthesis conditions.

The applications of CDs span across multiple fields, including optoelectronics, bioimaging, sensing, drug delivery, energy storage, and environmental monitoring. Some of the key applications of CDs include:

Bioimaging and Biosensing: The strong fluorescence exhibited by CDs, along with their low cytotoxicity, biocompatibility, and water solubility, make them suitable for bioimaging and biosensing applications. They can be used as fluorescent probes for cellular imaging, tracking drug delivery, and detecting biomolecules such as proteins, DNA, and ions.

Optoelectronics: CDs can be utilized in optoelectronic devices such as light-emitting diodes (LEDs), organic solar cells, and photodetectors. Their excellent optical properties, such as high photoluminescence quantum yield and tunable emission, make them promising candidates for next-generation display technologies and efficient energy conversion devices.

Energy Storage: CDs can be integrated into energy storage devices, including lithium-ion batteries and supercapacitors. Their high surface area, good electrical conductivity, and ability to store and transport ions make them useful for enhancing energy storage capacity and improving the overall performance of these devices.

Environmental Monitoring: CDs can be employed for environmental monitoring and detection of pollutants. They can act as sensors for detecting heavy metals, organic pollutants, and gases due to their selective binding and quenching properties. Their low cost, high sensitivity, and fast response make them attractive for on-site environmental monitoring applications.

Biomedical Applications: CDs have shown potential in various biomedical applications, such as drug delivery, bioimaging, and theranostics (combined therapy and diagnostics). Their small size, biocompatibility, and ability to encapsulate drugs make them promising carriers for targeted drug delivery, while their fluorescence enables non-invasive imaging and tracking of biological systems.

The versatility and tunability of CDs, along with their eco-friendly synthesis methods, make them a fascinating area of research with diverse applications. Ongoing research aims to further understand their properties, optimize synthesis methods, and explore novel applications in fields such as nanomedicine, catalysis, and environmental remediation.

6.4.3 CARBON BASED

A relatively recent field of study is the green synthesis of carbon-based nanoparticles (CNPs) for the creation of latent fingerprints. However, several researchers have looked at the usage of green-synthesized CNPs for the creation of fingerprints. Nanocarbon powder [53] investigated the use of such powders in latent fingerprinting. They used several porous and non-porous surfaces to develop latent fingerprints over them. The average particle size was found to be between 10 and 100 nm. They also conducted an aging study to see whether the synthesized nanopowder can develop latent fingerprints in unfavorable conditions.

Biogenic nanoparticles synthesized using carbon-based materials can be classified into different categories based on the carbon source and the method of synthesis. Here are some common classifications of biogenic nanoparticles developed using carbon-based materials.

Carbon Dots: CDs are fluorescent nanoparticles composed of carbon-based materials. They are typically synthesized using carbon-rich precursors such as carbohydrates, amino acids, or polymers through various methods, including hydrothermal synthesis, solvothermal methods, or microwave-assisted synthesis. CDs have unique optical properties and find applications in bioimaging, biosensing, optoelectronics, and energy storage.

Carbon Nanotubes (CNTs): Carbon nanotubes are cylindrical structures composed of rolled-up graphene sheets. Biogenic synthesis of CNTs can be achieved using microorganisms or enzymes that facilitate the growth and formation of nanotubes. Biogenic CNTs have potential applications in electronics, composites, sensors, and biomedical devices.

Graphene-Based Nanoparticles: Graphene, a single layer of graphite, can be used as a precursor for the synthesis of various graphene-based nanoparticles. Biogenic methods for graphene-based nanoparticles involve the reduction or functionalization of graphene oxide using biological

sources such as bacteria, fungi, or enzymes. These nanoparticles exhibit unique properties and have applications in energy storage, electronics, sensors, and biomedical fields.

Carbon Nanoparticles from Biomass: Biomass-derived carbon nanoparticles can be synthesized from agricultural waste, plant extracts, or other carbon-rich sources. These nanoparticles are produced through carbonization or pyrolysis processes, which convert the biomass into carbon-based nanoparticles. They can be used in sensing, catalysis, environmental remediation, and energy storage applications.

Biochar-Based Nanoparticles: Biochar, a carbon-rich material produced from the pyrolysis of organic matter, can be used as a precursor for the synthesis of carbon-based nanoparticles. Biogenic methods involve the treatment of biochar with various chemical or physical processes to obtain nanoparticles with desired properties. These nanoparticles find applications in water treatment, soil remediation, and agricultural systems.

Carbon Quantum Dots from Natural Sources: Carbon quantum dots (CQDs) are fluorescent carbon-based nanoparticles with unique optical properties. They can be synthesized from natural sources such as fruit peels, tea leaves, or biomass using green and sustainable methods. These CQDs have applications in bioimaging, biosensing, drug delivery, and optoelectronics.

These classifications highlight the various carbon-based materials that can be synthesized using biogenic methods. The choice of carbon source, synthesis method, and subsequent functionalization can significantly impact the properties and applications of the resulting nanoparticles. Biogenic synthesis offers a sustainable and eco-friendly approach to produce carbon-based nanoparticles with diverse functionalities for a wide range of applications.

6.4.4 SILVER NANOPARTICLES

In recent years, green synthesis of AgNPs has drawn attention as a viable and environmentally responsible substitute for traditional chemical synthesis techniques. AgNPs have been produced via green synthesis to establish latent fingerprints, among other uses. Acetylated cashew-gum-based AgNPs [54] are hereby green synthesized for the development of latent fingerprints over a wide range of porous and non-porous surfaces. These show the possible usage of AgNPs in latent fingerprint development.

Plant-Mediated Synthesis: This classification involves the use of plants, plant extracts, or plant-derived compounds for the synthesis of AgNPs. Various parts of plants such as leaves, stems, roots, or extracts are utilized as reducing and capping agents during the synthesis process. Different plant species including aloe vera, green tea, neem, and tulsi have been used for the synthesis of AgNPs through this method.

Microorganism-Mediated Synthesis: In this classification, microorganisms like bacteria, fungi, yeast, or algae are employed for the production of AgNPs. The microorganisms either secrete enzymes or produce metabolites that facilitate the reduction of Ag ions into nanoparticles. Bacterial strains like *Escherichia coli*, *Pseudomonas aeruginosa*, and *Bacillus subtilis*, as well as fungal species like *Aspergillus niger* and *Fusarium oxysporum*, have been commonly used for the synthesis of AgNPs.

Enzyme-Mediated Synthesis: Enzymes extracted from biological sources can be used for the synthesis of AgNPs. Enzymes like urease, laccase, and cellulase have been employed for the biogenic synthesis of AgNPs. These enzymes act as reducing and stabilizing agents, facilitating the conversion of Ag ions into nanoparticles.

Biowaste-Mediated Synthesis: This classification involves the utilization of agricultural waste, food waste, or other organic waste materials for the synthesis of AgNPs. Examples of biowaste sources include fruit peels, tea waste, rice husk, and sawdust. These waste materials contain bioactive compounds that act as reducing and stabilizing agents during the synthesis process.

Marine Organism-Mediated Synthesis: This classification involves the use of marine organisms such as seaweeds, microalgae, or marine bacteria for the synthesis of AgNPs. These organisms possess unique biochemical properties that enable the reduction of Ag ions into nanoparticles. Marine-based synthesis methods offer the advantage of utilizing abundant and sustainable resources for nanoparticle production.

Biopolymer-Mediated Synthesis: Biopolymers, such as proteins, polysaccharides, or nucleic acids, can be utilized as reducing and stabilizing agents for the synthesis of AgNPs. Biopolymers derived from various biological sources, including plant extracts, bacteria, or fungi, can effectively facilitate the reduction of Ag ions and control the growth of nanoparticles. This approach offers biocompatibility and the potential for functionalizing the nanoparticles with biomolecules.

Animal Extract-Mediated Synthesis: This classification involves the use of animal extracts, such as blood, urine, or egg white, for the synthesis of AgNPs. These extracts contain biomolecules, including proteins or peptides, which can serve as reducing agents and stabilizers during nanoparticle synthesis. Animal extract-mediated synthesis methods provide an alternative source of reducing agents for nanoparticle production.

Biomineralization: Biomineralization is a process where living organisms deposit minerals, including Ag, to form biogenic structures. This approach involves the use of living organisms, such as bacteria or plants, to facilitate the controlled formation of AgNPs through biomineralization pathways. Biomineralization methods offer the advantage of precise control over nanoparticle size, shape, and crystal structure.

Synthetic Biological Approaches: Synthetic biology techniques can be employed to engineer organisms for the production of AgNPs. This involves genetic modification of microorganisms to express specific enzymes or proteins that can effectively reduce Ag ions into nanoparticles. Synthetic biological approaches offer the potential for precise control over nanoparticle synthesis and customization of nanoparticle properties.

6.4.5 COPPER OXIDE

The possible application of copper oxide (CuO) nanoparticles in the creation of latent fingerprints has also been studied. Eco-friendly and sustainable CuO nanoparticles have been produced utilizing green synthesis techniques and plant extracts. Greener synthesis of CuO nanoparticles [3] developed is greenly synthesized to develop latent fingerprint over various substrates. More research is needed in the field so that eco-friendly methods are developed over the ones that are toxic and used to develop latent fingerprints.

Nagar et al. used copper sulfate (CuSO45H2O) as a precursor for nanoparticle synthesis with green tea leaves. A technique called FT-IR and FE-SEM was used to do an instrumental analysis of synthetic CuO–NPs, size ranges from 500 to 900 nm. The LFPs were developed on four distinct non-porous surfaces including glass, white paper, butter paper, and steel.

Biopolymer-Mediated Synthesis: Biopolymers, such as proteins, polysaccharides, or nucleic acids, can be used as reducing and stabilizing agents for the synthesis of CuO nanoparticles. Biopolymers derived from various biological sources, including plant extracts, bacteria, or fungi, can effectively facilitate the reduction of Cu ions and control the growth of

CuO nanoparticles. This approach offers biocompatibility and the potential for functionalizing the nanoparticles with biomolecules.

Animal Extract-Mediated Synthesis: Animal extracts, such as blood, urine, or egg white, can be utilized for the synthesis of CuO nanoparticles. These extracts contain biomolecules, including proteins or peptides, which can serve as reducing agents and stabilizers during nanoparticle synthesis. Animal extract-mediated synthesis methods provide an alternative source of reducing agents for CuO nanoparticle production.

Biomineralization: Biomineralization is a process where living organisms deposit minerals, including CuO, to form biogenic structures. This approach involves the use of living organisms, such as bacteria or plants, to facilitate the controlled formation of CuO nanoparticles through biomineralization pathways. Biomineralization methods offer precise control over nanoparticle size, shape, and crystal structure.

Synthetic Biological Approaches: Synthetic biology techniques can be employed to engineer organisms for the production of CuO nanoparticles. This involves genetic modification of microorganisms to express specific enzymes or proteins that can effectively reduce Cu ions into nanoparticles. Synthetic biological approaches offer the potential for precise control over nanoparticle synthesis and customization of nanoparticle properties.

Combination Approaches: Some studies have explored combining different biological sources or methods for the synthesis of CuO nanoparticles. For example, a combination of plant extracts and microorganisms, or a combination of enzymatic and biowaste-mediated synthesis methods, can be used to enhance the synthesis efficiency or nanoparticle properties.

Plant-Mediated Synthesis: This classification involves the use of plants, plant extracts, or plant-derived compounds for the synthesis of CuO nanoparticles. Various parts of plants, such as leaves, stems, roots, or extracts, are used as reducing and capping agents during the synthesis process. Plant-mediated synthesis methods utilize the phytochemicals present in plants to facilitate the reduction of Cu ions into nanoparticles.

Microorganism-Mediated Synthesis: Microorganisms, including bacteria, fungi, yeast, or algae, can be employed for the production of CuO nanoparticles. These microorganisms have the ability to bioreduce Cu ions and facilitate the formation of CuO nanoparticles. Bacterial strains like *Pseudomonas aeruginosa*, *Bacillus subtilis*, and *Escherichia coli*, as well as fungal species like *Aspergillus niger* and *Trichoderma*, have been utilized for the biogenic synthesis of CuO nanoparticles.

Enzyme-Mediated Synthesis: Enzymes derived from biological sources can be used to synthesize CuO nanoparticles. Enzymes such as cellulase, peroxidase, or laccase can facilitate the reduction of Cu ions into CuO nanoparticles. Enzyme-mediated synthesis methods offer control over the size, shape, and crystallinity of the nanoparticles.

Biowaste-Mediated Synthesis: This classification involves the utilization of biowaste materials such as fruit peels, agricultural waste, or food waste for the synthesis of CuO nanoparticles. These waste materials contain bioactive compounds that act as reducing and stabilizing agents during the synthesis process. Biowaste-mediated synthesis methods offer the advantage of utilizing renewable and readily available sources for nanoparticle production.

Marine Organism-Mediated Synthesis: Marine organisms, including seaweeds, microalgae, or marine bacteria, can be employed for the synthesis of CuO nanoparticles. These organisms possess unique biochemical properties that enable the reduction of Cu ions and subsequent formation of CuO nanoparticles. Marine-based synthesis methods offer the advantage of utilizing sustainable resources and may offer unique properties compared to other sources.

6.5 FUTURE PROSPECTS OF GREEN APPROACH TOWARD LATENT FINGERPRINT DEVELOPMENT TECHNIQUES

The future prospects of green approaches toward latent fingerprint development techniques are promising and hold significant potential for advancements in forensic science. The utilization of environmentally friendly and sustainable methods in fingerprint analysis not only addresses the pressing need for eco-conscious practices but also offers several advantages and avenues for further research and development. Green approaches using synthesized nanoparticles have demonstrated improved sensitivity, selectivity, and effectiveness in detecting latent fingerprints. As research in green synthesis techniques continues to evolve, there is the potential for even more efficient and tailored nanoparticles that can enhance the visibility and quality of latent fingerprints, including the detection of previously challenging or faint prints. The integration of green-synthesized nanoparticles with other imaging methods, such as fluorescence and Raman spectroscopy, opens up new possibilities for comprehensive fingerprint analysis. This multi-modal approach can provide a more thorough understanding

of the chemical components and spatial distribution of latent fingerprints, leading to enhanced accuracy and information retrieval. In addition, the combination of green approaches with emerging technologies, such as machine learning, artificial intelligence, and advanced image processing algorithms, can revolutionize latent fingerprint analysis.

Advancements in Green Synthesis: Green synthesis methods for nanoparticles and other materials used in latent fingerprint development are expected to evolve further. Researchers will continue to explore new environmentally friendly and sustainable routes for synthesizing nanoparticles, such as using bio-based precursors, plant extracts, or microorganisms. These methods will aim to minimize the use of hazardous chemicals, energy consumption, and waste generation.

Eco-friendly Developing Agents: The development of eco-friendly developing agents will be a focus area. Traditional developing agents, such as chemical dyes or powders, often contain toxic substances and have adverse environmental impacts. Future research will likely focus on the development of environmentally friendly, non-toxic, and biodegradable developing agents derived from natural sources.

Integration of Nanotechnology: Nanotechnology will play a significant role in green latent fingerprint development. The use of biogenic nanoparticles, such as Ag, CuO, or carbon-based nanoparticles, will continue to expand. These nanoparticles offer unique properties for enhancing fingerprint visibility and can be synthesized using eco-friendly methods. Additionally, nanoscale materials can enable selective and sensitive detection of latent fingerprints.

Sustainable Processing Techniques: The development of sustainable processing techniques for latent fingerprint development will be emphasized. This includes exploring alternative energy sources, minimizing water usage, reducing waste generation, and adopting efficient and green extraction techniques. Green processing techniques, such as supercritical fluid extraction, microwave-assisted extraction, or enzymatic treatments, may find applications in latent fingerprint development.

Integration of Artificial Intelligence (AI): Artificial intelligence and machine learning algorithms will likely be integrated into green latent fingerprint development techniques. AI can assist in automating the analysis and identification of latent fingerprints, enhancing the efficiency and accuracy of fingerprint analysis. This integration can lead to faster and more reliable results while minimizing human bias.

Standardization and Regulation: With the increasing adoption of green approaches, standardization and regulation of green latent fingerprint development techniques will become essential. Establishing guidelines, best practices, and quality control measures for green methods will ensure consistency, reliability, and reproducibility of results.

Forensic Database Development: The integration of green latent fingerprint development techniques with forensic databases will continue to expand. Green techniques can generate high-quality fingerprint images, which can be crucial for accurate matching and identification. Integration with databases will facilitate faster and more accurate criminal investigations and forensic analysis.

Biometric Integration: Green approaches in latent fingerprint development can be integrated with other biometric modalities, such as iris recognition, facial recognition, or voice recognition. This integration can provide a comprehensive and multi-modal biometric identification system, enhancing the accuracy and reliability of forensic investigations.

Multispectral Imaging: The use of multispectral imaging techniques in green latent fingerprint development is a promising future prospect. Multispectral imaging captures fingerprints using different wavelengths of light, allowing for improved visualization and identification of latent prints. This approach can provide better contrast and overcome challenges posed by different surfaces or background interference.

Portable and Field-Deployable Technologies: Future advancements in green latent fingerprint development techniques will focus on developing portable and field-deployable technologies. These technologies will enable forensic investigators to conduct on-site fingerprint analysis, reducing the need for sample transportation and laboratory analysis. Portable devices with eco-friendly processes will enhance the efficiency and speed of forensic investigations.

Integration of Smart Materials: Smart materials, such as stimuli-responsive polymers or luminescent materials, can be integrated into green latent fingerprint development techniques. These materials can selectively interact with the fingerprint residues, improving the contrast and detection of latent prints. The use of smart materials can enhance the sensitivity and specificity of the fingerprint development process.

Privacy Protection: As biometric data becomes increasingly important in forensic investigations, the future of green latent fingerprint development techniques will focus on privacy protection. Measures will be

implemented to ensure the secure storage and transmission of biometric data, adherence to privacy regulations, and protection against unauthorized access or misuse.

Rapid Screening and Analysis: Green approaches will aim to develop rapid screening and analysis techniques for latent fingerprints. This involves the use of efficient and automated systems that can quickly process large volumes of fingerprints and provide rapid identification or matching results. Rapid screening and analysis will contribute to faster criminal investigations and improved forensic efficiency.

Collaboration and Knowledge Sharing: The future of green latent fingerprint development techniques will involve increased collaboration and knowledge sharing among researchers, forensic experts, and technology developers. This collaboration will lead to the exchange of ideas, best practices, and advancements in green techniques, fostering innovation and driving the field forward.

6.6 CONCLUSION

As a sustainable and successful method, the use of green-synthesized nanoparticles in latent fingerprint formation has tremendous promise. This study has shown that it is possible to successfully synthesize nanoparticles utilizing natural resources like plant extracts and ecologically acceptable processes. The nanoparticles displayed exceptional qualities such as homogeneity, stability, and increased responsiveness toward latent fingerprints. The use of green-synthesized nanoparticles in the generation of latent fingerprints has a number of benefits over more conventional techniques. First off, their green synthesis guarantees that harmful chemicals are reduced or eliminated, reducing the impact on the environment and fostering sustainability. This is significant in forensic science, where it is crucial to preserve crime scenes and evidence. Additionally, the nanoparticles created using green technologies have shown improved performance in the creation of fingerprints. They interact with the fingerprint residue more effectively due to their tiny size and high surface area to volume ratio, which enhances visualization and increases recognition success rates. Furthermore, the nanoparticles have demonstrated compatibility with a range of surfaces and have successfully created fingerprints on porous and non-porous substrates. Additionally, the utilization of environmentally friendly synthetic nanoparticles opens up possibilities for customization

and improvement. To improve their capabilities and solve particular difficulties with latent fingerprint generation, researchers might change the synthesis method, nanoparticle composition, or surface functionalization. This adaptability stimulates creativity in forensic science and creates prospects for additional developments in the area. Despite the encouraging outcomes, further study and advancement are still needed in several areas. It is necessary to do more research to examine the long-term stability and suitability of environmentally friendly synthesized nanoparticles. To enable its practical application in real-world circumstances, nanoparticle compositions must also be optimized and integrated into standardized forensic methods. In conclusion, using green-synthesized nanoparticles offers a considerable improvement in the creation of latent fingerprints. They are a promising tool for forensic scientists and law enforcement organizations because of their enhanced performance, eco-friendliness, and ability for customization. Continued research and collaboration in this area will undoubtedly lead to the development of more efficient and sustainable techniques for the identification and analysis of latent fingerprints, ultimately contributing to the advancement of forensic science as a whole. This approach leverages biogenic sources, such as plants, microorganisms, or animal extracts, to synthesize nanoparticles with reduced environmental impact and health hazards compared to traditional chemical methods. By employing green synthesis methods, researchers can minimize the use of toxic chemicals, energy consumption, and waste generation, while still achieving effective latent fingerprint development. The classification of biogenic nanoparticle development, including ZnO, carbon-based nanoparticles, AgNPs, and CuO nanoparticles, demonstrates the wide range of biogenic sources and synthesis methods available. Each classification offers unique advantages, such as biocompatibility, precise control over nanoparticle properties, or the utilization of renewable resources. The future prospects of green approaches toward latent fingerprint development techniques are promising. Advancements in green synthesis, the development of eco-friendly developing agents, the integration of nanotechnology, sustainable processing techniques, the integration of AI, standardization and regulation, and forensic database development are among the key areas for future exploration and development. These prospects will contribute to more sustainable, efficient, and reliable methods for latent fingerprint analysis while ensuring the protection of the environment and human health. By embracing green synthesis

and sustainable practices in latent fingerprint development, forensic scientists and researchers can make significant strides toward reducing the environmental footprint of forensic investigations while maintaining high standards of accuracy and reliability. This sustainable approach not only addresses the current environmental challenges but also paves the way for advancements in biometric identification systems, portable field-deployable technologies, and privacy protection. Overall, the green synthesis of nanoparticles for enhanced latent fingerprint development represents a paradigm shift toward sustainable and eco-friendly forensic techniques. It offers a path toward greener and more responsible practices in the field, contributing to both environmental conservation and the advancement of forensic science.

KEYWORDS

- **Carbon dots**
- **fingerprint**
- **forensic**
- **morphology**
- **nanoparticles**
- **nanotechnology**
- **selectivity**

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CHAPTER 7

Enhancing Latent Fingerprint Development Using Iron Oxide Nanoparticles: A Promising Approach for Forensic Investigations

DIVYANSH JAIN[1], VAIBHAV SHARMA[1], ABHISHEK R. RAI[1], ANJALI AWASTHI[2], EUGENIO D'ORIO[3], ANUBHAV SINGH[4], and KAPIL PARIHAR[1]

[1]*Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India*

[2]*Department of Zoology, University of Rajasthan, Jaipur, Rajasthan, India*

[3]*Direttore Generale Bioforensics Research Center, Italy*

[4]*School of Forensic Science, National Forensic Science University, Gandhinagar, Gujarat, India*

ABSTRACT

Latent fingerprint study and development are crucial to resolving criminal investigations. The traditional identification of fingerprint techniques frequently runs into problems like poor visualization and low sensitivity. This work suggests a unique method using iron oxide nanoparticles as a potentially effective substitute to improve the visibility of latent fingerprints, enabling more precise analysis, and identification of crime scenes. These nanoparticles are a good choice for forensic applications because of

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their distinctive magnetic characteristics and high biocompatibility. The functionalized surface of the nanoparticles has a particular coating to aid in adherence to the fingerprint residue. A suspension of the functionalized iron oxide nanoparticles (IONPs) is carefully placed on the crime scene surface to create latent fingerprints. The components of the latent fingerprints are specifically bound by the nanoparticles, creating a distinct visual pattern. This makes it possible to discover fingerprints that would normally be impossible to find using standard techniques, such as those that are old or deteriorated. The improved fingerprints are recorded using a variety of imaging methods, including magnetic powdering, fluorescence or magnetic visualization, and scanning electron microscopy. The IONPs' high contrast considerably increases the precision and dependability of fingerprint identification by allowing forensic investigators to extract finer details and ridge patterns. According to preliminary findings, the suggested iron oxide nanoparticle-based technology improves latent fingerprint detection and visualization with improved sensitivity and selectivity when compared to conventional techniques.

7.1 INTRODUCTION

Latent fingerprints are ridged skin impressions made by human fingers or palms on materials like paper, glass, or metal [1]. These impressions, which are normally imperceptible to the naked eye, are created when oils and sweat from the skin come into contact with a surface [2]. Formation when an individual touches a surface, the sweat and oils from their fingers are deposited, creating a latent fingerprint [3, 4]. The ridges on the skin contain sweat pores that release these fluids, which help in maintaining grip and friction. Latent fingerprints are usually not visible without the aid of additional techniques [5, 6]. They can be obscured by various factors, such as surface texture, lighting conditions, or the presence of dirt or other contaminants. Specialized techniques are employed to visualize and capture latent fingerprints [7, 8]. These techniques include powder dusting, chemical methods, alternate light sources, etc. Fine powders, such as black, white, or magnetic powders, are applied to the surface to adhere to the residual sweat and oil deposits, making the fingerprint visible [9–11]. The excess powder is then carefully removed, leaving behind a clear fingerprint pattern. Various chemical reagents are used to react with the components

of latent fingerprints, producing a visible color or luminescence [12, 13]. Common chemicals include ninhydrin, which reacts with amino acids, and iodine fuming, which forms a brown color upon contact with the oils in the fingerprint [14, 15]. Alternate sources for the detection of latent fingerprints are various light sources, such as ultraviolet (UV) light, which can be used to illuminate latent fingerprints [16]. The oils and sweat on the ridges of the print absorb the light differently from the surrounding surface, making the print visible under certain wavelengths. Once a latent fingerprint is visualized, it can be photographed or lifted from the surface using various techniques [17]. Photographs or lifted prints can then be analyzed, compared to known prints in a database, and used as evidence in criminal investigations. Forensic experts analyze latent fingerprints by examining the ridge patterns, minutiae points (such as ridge endings, bifurcations, or dots), and other unique features [18]. Automated fingerprint recognition systems, including algorithms and databases, may also assist in comparing and matching fingerprints for identification purposes. Latent fingerprints play a crucial role in forensic investigations, as they can link individuals to crime scenes and provide valuable evidence [18, 19]. The study of fingerprints, known as dactyloscopy, has been an important field in forensic science for over a century [20].

Nanoparticles have shown promise in the development and enhancement of latent fingerprints. These tiny particles can be designed to interact with the sweat and oil components present in latent prints, making them visible or increasing their contrast [21]. Here is an overview of the use of nanoparticles in latent fingerprint development, along with references for further reading. This comprehensive review discusses the synthesis, characterization, and application of iron oxide nanoparticles for latent fingerprint development [22]. It covers various techniques, including magnetic powdering, electrostatic deposition, and nanoparticle-based suspensions. This chapter compares the effectiveness of different iron oxide nanoparticles, such as magnetite and hematite, for latent fingerprint development and evaluates their performance based on the visibility, contrast, and durability of the developed fingerprints [22, 23]. This chapter focuses on the preparation of superparamagnetic iron oxide nanoparticles (SPIONs) and their application in latent fingerprint development. It investigates the effects of nanoparticle concentration, pH, and particle size on fingerprint visualization [24]. This research explores the influence of synthesis parameters, including reaction temperature and surfactant concentration,

on the quality of fingerprint development, using magnetite nanoparticles. It provides insights into optimizing the synthesis conditions for improved results. This comparative study investigates the effectiveness of different iron oxide magnetic nanoparticles, including maghemite and magnetite, for latent fingerprint development. It evaluates their performance in terms of visibility, contrast, and recovery rate.

Recent developments in iron oxide nanoparticles have led to a wide range of uses in industries as diverse as biomedicine, electronics, environmental remediation, and energy storage. Here are some significant developments in the study of iron oxide nanoparticles, along with pertinent readings [25].

To present a thorough review of the subject, a chapter on iron oxide nanoparticle developments, particularly about the development of latent fingerprints, will be written. The chapter will evaluate the body of literature and emphasize the most recent developments in the creation, analysis, and use of iron oxide nanoparticles for the creation of latent fingerprints. The difficulties in their synthesis, optimization, and practical application will also be addressed. It would analyze variables including visibility, contrast, toughness, and recovery rate to offer suggestions for the best nanoparticles. It may investigate cutting-edge technologies that could improve the effectiveness of iron oxide nanoparticles in latent fingerprint creation, such as surface functionalization or combination methods.

7.2 METHODS FOR THE PREPARATION OF IRON NPS

Various procedures, such as wet chemical, dry processes, or microbiological techniques, are used to create iron oxide magnetic NPs with the proper surface chemistry. The following three techniques can be used to create iron NPs quickly and effectively.

7.2.1 PHYSICAL METHODS

These are complex processes with the drawback of being unable to regulate nanometer-sized particle size [26].

7.2.2 CHEMICAL PREPARATION TECHNIQUES

These techniques are straightforward, manageable, and effective, allowing the size, content, and even shape of the NPs to be controlled. Through the coprecipitation of Fe^{2+} and Fe^{3+} with the addition of a base, iron oxides can be created. The type of salt employed, the ratio of Fe^{2+} and Fe^{3+}, pH, and ionic strength all affect the size, shape, and composition of iron NPs produced chemically [27].

7.2.3 BIOLOGICAL PROCEDURES

Due to their high yield and low production costs, chemical-based synthesis techniques are the ones that are most frequently used. A base is often added to an aqueous solution of Fe^{2+} and Fe^{3+} chloride at a 1:2 molar ratio to create magnetites, which are then black in color [28]. Equations 7.1 and 7.2 give the chemical process of Fe_3O_4 precipitation. The general response is expressed as follows:

$$Fe^{2+} + Fe^{3+} + 8OH\text{---}Fe_3O_4 + 4H_2O \quad (7.1)$$

Under an oxygen-free environment, complete precipitation of Fe_3O_4 is likely between pH 9 and 14, maintaining a molar ratio of Fe^{3+}:Fe^{2+} (2:1). Fe_3O_4 might also be oxidized as:

$$Fe_3O_4 + 0{:}25\ O_2\text{----- } 4{:}5H_2O + 3Fe(OH)^{3+} \quad (7.2)$$

NPs' chemical and physical characteristics might change depending on the circumstances. Iron nanoparticles (Fe_3O_4 NPs) are often coated with organic or inorganic compounds to prevent oxidation and agglomeration [29]. However, it is necessary to create magnetic NPs in an oxygen-free environment, ideally with N_2 gas present. Nitrogen gas is bubbling, which not only delays NP oxidation but also shrinks it [30].

Each of the prior methods has pros and cons of its own. Physical methods are simple to use; however, it is difficult to manage the particle size. Particle size can be partially adjusted in wet chemical preparation by changing the environment. The chemical techniques include flow injection, electrochemistry, sol–gel, supercritical fluid, hydrothermal, chemical coprecipitation, sonochemical decomposition, and nanoreactors [27].

7.2.4 LIQUID PHASE METHOD

A typical method for creating iron oxide nanoparticles is the liquid phase method [31]. It includes the creation of nanoparticles in a liquid media, usually as a result of a carefully regulated chemical interaction between iron precursors and stabilizing or surfactant molecules [32].

As starting ingredients for the synthesis, iron salts such as iron chloride ($FeCl_2$ or $FeCl_3$), iron nitrate ($Fe(NO_3)_3$), or iron sulfate ($FeSO_4$) are frequently utilized [33]. The particular synthesis technique and the desired attributes of the nanoparticles will determine the solvent to use. Water, organic solvents like ethanol or ethylene glycol, or a combination of the two are examples of common solvents [34]. These substances are introduced to the reaction media to regulate the nanoparticles' size, growth, and stability. They regulate the form and dispersibility of the particles and aid in preventing agglomeration. Oleic acid, oleylamine, polyvinylpyrrolidone (PVP), and capping agents like citric acid are typical examples [35]. Iron oxide nanoparticles with the desired characteristics are formed by carefully regulating the reaction parameters, such as temperature, pH, and reaction time [36]. The particular synthesis technique and the desired properties of the nanoparticles determine the reaction conditions to be used. When reducing iron ions and promoting the creation of nanoparticles, reducing agents like sodium borohydride ($NaBH_4$) or hydrazine (N_2H_4) may be added to the reaction mixture [37]. Following synthesis, the nanoparticles are typically filtered or centrifuged to remove them from the reaction solution. To get rid of any leftover contaminants or extra reagents, they could go through additional purification processes. The characteristics of the nanoparticles can be changed by performing post-treatment activities including washing, drying, or annealing [38].

The chemical reduction method involves the reduction of iron precursors to form nanoparticles in a liquid medium. The most commonly used precursor for iron NPs synthesis is iron salts, such as iron chloride ($FeCl_2$) or iron sulfate ($FeSO_4$). The reduction of these precursors is typically achieved using a reducing agent.

Here are the general steps involved in the liquid phase chemical reduction method:

1. Preparation of the reaction solution: A suitable solvent is chosen to dissolve the iron precursor, typically water or an organic

solvent. The iron precursor is then dissolved in the solvent to form a homogeneous solution.

2. Addition of a reducing agent: A suitable reducing agent is added to the reaction solution. Commonly used reducing agents for iron NPs synthesis include sodium borohydride ($NaBH_4$), hydrazine (N_2H_4), or ascorbic acid (vitamin C). The reducing agent initiates the reduction reaction, converting the iron ions into iron atoms or clusters.
3. Control of reaction conditions: The reaction conditions, such as temperature, pH, and reaction time, are controlled to influence the size, shape, and stability of the resulting iron nanoparticles. These conditions can be optimized through experimentation to achieve the desired properties.
4. Stabilization and surface modification: To prevent agglomeration and enhance the stability of the iron nanoparticles, a stabilizing agent or surfactant may be added. Common examples include polyvinyl alcohol (PVA), polyethylene glycol (PEG), or capping agents like citrate or oleic acid. These agents also help control the size and shape of the nanoparticles.
5. Separation and purification: After the completion of the reduction reaction, the resulting iron nanoparticles are separated from the reaction mixture. This can be done through centrifugation, filtration, or magnetic separation techniques, depending on the properties of the nanoparticles.
6. Drying and characterization: Finally, the isolated iron nanoparticles are typically washed and dried to remove any remaining solvent or impurities. Characterization techniques such as transmission electron microscopy (TEM), X-ray diffraction (XRD), and Fourier transform infrared spectroscopy (FTIR) can be used to analyze the size, crystallinity, and surface properties of the synthesized iron nanoparticles.

It is important to note that the specific details and parameters of the liquid phase method can vary depending on the desired properties of the iron nanoparticles and the chosen precursor and reducing agent. Therefore, it is recommended to refer to specific research papers or protocols for detailed instructions on the synthesis of iron nanoparticles using the liquid phase method.

7.2.5 TWO-PHASE METHODS (MICROEMULSION)

Surfactant molecules stabilize the dispersion of nanoscale water droplets in the oil phase that make up a water-in-oil microemulsion. The nanocavities represent particle aggregation, growth, and nucleation. The fundamental benefit of this technology is the diversity of NPs caused by surfactants, nature, physiological circumstances, etc. [39]. Iron supply and sodium hydroxide are combined to create a nanoemulsion that is then lysed with acetone to remove the surfactant and washed with ethanol to create magnetite nanoparticles [40]. Colloidal nanoparticles (caps) typically display superparamagnetic behavior and high magnetization values [41]. The choice of surfactant (and cosurfactant) depends on the physicochemical properties of the system because there are several dissolved components in the water and oil phases. You can employ cationic, anionic, or nonionic surfactants, among others [42].

Two-phase methods, specifically microemulsion-based methods, are widely used for the preparation of nanoparticles, including iron nanoparticles. Microemulsions are colloidal systems consisting of two immiscible phases (typically oil and water) stabilized by surfactants and co-surfactants. These systems provide a suitable environment for the formation of nanoparticles with controlled size, shape, and properties.

The microemulsion method for iron nanoparticle synthesis involves the following steps:

1. Preparation of microemulsion: A microemulsion is formed by mixing an oil phase (such as an organic solvent), a water phase (containing an aqueous solution), a surfactant, and a cosurfactant. The choice of components depends on the specific system and the desired properties of the nanoparticles.
2. Dissolution of iron precursor: An iron precursor, usually an iron salt like iron chloride ($FeCl_2$) or iron sulfate ($FeSO_4$), is dissolved in the water phase of the microemulsion. The concentration of the precursor affects the size and concentration of the resulting nanoparticles.
3. Reduction of iron precursor: A reducing agent is added to the microemulsion to reduce the dissolved iron precursor to form iron nanoparticles. Commonly used reducing agents include sodium borohydride ($NaBH_4$), hydrazine (N_2H_4), or ascorbic acid

(vitamin C). The reduction reaction occurs within the microemulsion droplets, leading to the formation of nanoparticles.

4. Stabilization and control of nanoparticle growth: The surfactant molecules present in the microemulsion stabilize the formed nanoparticles by adsorbing them onto their surfaces, preventing agglomeration. The surfactant concentration and composition can be adjusted to control the size, shape, and stability of the nanoparticles.
5. Quenching the reaction: Once the desired nanoparticle size is achieved, the reaction is quenched by changing the reaction conditions. This can be done by dilution, adjusting the pH, or adding a quenching agent to stop the reduction process.
6. Nanoparticle separation and purification: The nanoparticles are separated from the microemulsion by techniques such as centrifugation, filtration, or solvent extraction. The collected nanoparticles are then washed to remove any residual surfactants or impurities.
7. Drying and characterization: The purified iron nanoparticles are typically dried under controlled conditions to remove any remaining solvent. Characterization techniques such as TEM, XRD, and FTIR are employed to analyze the size, crystallinity, and surface properties of the synthesized iron nanoparticles.

The microemulsion-based method offers advantages like good control over nanoparticle size, narrow size distribution, and high stability. However, the specific parameters and components of the microemulsion system should be optimized for each nanoparticle synthesis to achieve the desired results. Therefore, it is recommended to consult relevant literature or protocols for detailed instructions on the microemulsion method for iron nanoparticle synthesis.

7.2.6 SOL–GEL METHOD

The hydroxylation and condensation of chemical precursors in solution are the key components of this procedure. To create a three-dimensional metal oxide network, the obtained "sol" from nanometric particles is then dried or "gelled" using either solvent removal or a chemical process [43]. Water is the solvent, however, an acid or a base can be employed to hydrolyze the precursors. A colloidal gel is produced by basic catalysis,

whereas a polymeric gel is created by acid catalysis. Although the reaction takes place at ambient temperature, a heat treatment is necessary to produce the final crystalline state [44]. pH, the kind and concentration of the salt precursor, kinetics, temperature, agitation, and the characteristics of the gel are the factors affecting the synthesis. In this process, the solvent volume and phase determine the magnetic ordering, which is sensitive to dispersion and size distribution. The associated benefits include the ability to synthesize materials with a predetermined structure, pure amorphous phase, monodispersity, good control over particle size and microstructure, homogeneity of the end products, and the potential to produce embedded molecules that maintain their stability and properties within the matrix [45]. It is a simple process for creating metal oxides from salts under particular circumstances. This method is also used to create iron oxide-silica aerogel composites, which are discovered to be more reactive than regular iron oxide. Tetraethyl orthosilicate and Fe (III) solutions, which are commercial precursors, are dissolved in an alcoholic aqueous media, and the gels that result are heated to produce the final products. The high surface area of iron oxide NPs identifies the heightened reactivity [46]. The sol–gel method is a versatile and widely used technique for the synthesis of various materials, including nanoparticles. It involves the conversion of a solution (sol) into a solid (gel) network through hydrolysis and condensation reactions of precursor molecules. The sol–gel method offers control over the composition, structure, and properties of the resulting materials, including nanoparticles. Here is an overview of the sol–gel method for nanoparticle synthesis.

1. Preparation of the precursor solution: The sol–gel process starts with the preparation of a precursor solution. The precursor can be inorganic metal salts, metal alkoxides, or organometallic compounds. For example, for the synthesis of metal oxide nanoparticles, metal alkoxides like titanium isopropoxide or tetraethyl orthosilicate (TEOS) can be used as precursors.
2. Hydrolysis: The precursor solution is subjected to hydrolysis, typically by adding water or a hydrolyzing agent. Hydrolysis breaks the precursor molecules into metal hydroxide or oxide species. The rate of hydrolysis can be controlled by adjusting the pH and temperature of the solution.
3. Condensation: The hydrolyzed species undergo condensation reactions, leading to the formation of a three-dimensional network

or gel. This condensation can occur through various mechanisms, such as polycondensation or self-assembly, depending on the specific precursor and reaction conditions. The condensation process is influenced by factors like temperature, time, solvent composition, and catalysts.

4. Nanoparticle formation: During the gelation process, nanoparticles can form within the gel network. The size and distribution of the nanoparticles can be controlled by adjusting the precursor concentration, reaction parameters, and the addition of surfactants or stabilizers. Alternatively, post-gelation heat treatment or other techniques can be applied to induce nanoparticle formation within the gel.
5. Aging and drying: After the gelation step, the gel is typically aged or aged and dried to promote further condensation, remove the solvent, and transform the gel into a solid material. Aging can occur at ambient temperature or under controlled conditions, such as elevated temperature or humidity, to enhance the material's properties.
6. Calcination or sintering: In some cases, the dried gel may undergo additional heat treatment, known as calcination or sintering, to further enhance the crystallinity, remove residual organic components, and promote the desired phase formation. The calcination temperature and duration are carefully controlled to avoid excessive grain growth or phase transformation.
7. Characterization: The resulting nanoparticles can be characterized using various techniques to determine their size, morphology, crystallinity, and chemical composition. Common characterization methods include electron microscopy (TEM/scanning electron microscopy (SEM)), XRD, FTIR, and thermal analysis (thermogravimetric analysis (TGA)/DSC).

The sol–gel method provides flexibility in tailoring the properties of the synthesized nanoparticles by adjusting precursor chemistry, reaction conditions, and post-processing steps. It is commonly employed for the synthesis of metal oxides, such as silica, titania, and alumina nanoparticles, but can also be used for other materials. The technique finds applications in various fields, including catalysis, electronics, optics, and biomedical sciences.

7.2.7 GAS AEROSOL PHASE METHODS

Spray and laser pyrolysis is a productive technique for the continuous, high-volume, and direct manufacture of specified magnetic NPs [47]. With a reducing agent present, a solution of ferric salts is sprayed into the reactor. While the solvent evaporates, the solute condenses. Later, a dried residue made up of identically sized particles as the original is obtained. Various iron precursors have been used to create maghemite particles with sizes ranging from 5 to 60 nm and a variety of morphologies. The resonant interaction, reactant, and/or sensitizer are all important in the laser pyrolysis of organometallic precursors, but one of them needs to be in the gaseous phase [48]. The combination of CO_2 laser radiation transfers energy received to the reactants and excites a sensitizer. The chemical process proceeds until the required number of nuclei is reached, at which point particle nucleation takes place [49]. The gas stream entrains the reaction's nucleated particles, which are then gathered at the reaction's exit. The synthesis of reduced iron oxide NPs employs a gas phase, laminar diffusion flame process for the manufacture of iron oxide. The gas aerosol approach typically results in high-quality products despite its poor yield. By reducing gas impurities and managing the time of heating and gas concentrations, the pure product may be obtained even more thoroughly. This techniques' disadvantage is the price tag attached to them [27]. These methods rely on the vaporization of precursor materials followed by their nucleation and growth in a gas phase. Here are some commonly used gas aerosol phase methods for nanoparticle synthesis:

1. Chemical Vapor Deposition (CVD):

   Chemical Vapor Deposition is a widely used technique for synthesizing nanoparticles by the reaction of gaseous precursor molecules. The process involves the following steps:

   a. Vaporization: The precursor material, typically in the form of a volatile compound, is vaporized using heat or carrier gases.
   b. Transport: The precursor vapor is transported to the reaction chamber where the synthesis takes place.
   c. Nucleation: The vapor-phase precursor molecules undergo nucleation, where they cluster together to form small nuclei or seeds.

d. Growth: The nuclei grow by the addition of precursor molecules, leading to the formation of nanoparticles.
e. Deposition: The nanoparticles are then deposited onto a substrate or collected on a suitable surface.
f. Control: The size, composition, and morphology of the nanoparticles can be controlled by adjusting parameters such as precursor concentration, temperature, pressure, and residence time.

CVD is commonly used for the synthesis of a variety of nanoparticles, including metal, semiconductor, and oxide nanoparticles, and finds applications in fields such as electronics, catalysis, and materials science.

2. Aerosol Spray Pyrolysis:
Aerosol spray pyrolysis is another gas aerosol phase method that involves the synthesis of nanoparticles through the thermal decomposition of sprayed precursor droplets. The process is typically as follows:

a. Spray Generation: The precursor solution is atomized into fine droplets using techniques like ultrasonic nebulization or pneumatic nebulization.
b. Drying and Evaporation: The droplets are dried and evaporated during their travel through a heated reaction chamber, resulting in the formation of solid particles.
c. Pyrolysis: The dried precursor particles undergo pyrolysis, where they decompose and react to form nanoparticles. The decomposition can be initiated by heating the particles to high temperatures.
d. Nanoparticle Collection: The nanoparticles are collected on a substrate or a suitable collection device, typically by electrostatic precipitation or gravitational settling.
e. Control: The size, composition, and morphology of the nanoparticles can be controlled by adjusting parameters such as precursor concentration, drying conditions, reaction temperature, and residence time.

Aerosol spray pyrolysis is commonly used for the synthesis of metal oxides and mixed-metal oxide nanoparticles and finds applications in fields like energy storage, catalysis, and sensors.

Both CVD and aerosol spray pyrolysis offer advantages such as scalability, control over nanoparticle properties, and the ability to synthesize a wide range of materials. However, they require careful optimization of process parameters to achieve the desired nanoparticle characteristics.

3. Flame Spray Pyrolysis (FSP):

   Flame spray pyrolysis involves the synthesis of nanoparticles by the combustion of precursor droplets in a flame. The process includes the following steps:

   a. Droplet Generation: A precursor solution is atomized into fine droplets using a nebulizer or spray system.
   b. Combustion: The droplets are introduced into a high-temperature flame, where they evaporate, decompose, and react to form nanoparticles.
   c. Cooling and Collection: The nanoparticles formed in the flame are rapidly cooled and collected on a suitable substrate or filter.
   d. Control: The nanoparticle properties can be controlled by adjusting parameters such as precursor concentration, flame temperature, residence time, and carrier gas flow rate.

   FSP is a versatile method for synthesizing a wide range of nanoparticles, including metal oxides, metals, and composites. It is often used in applications such as catalysts, coatings, and functional materials.

4. Laser Ablation:

   Laser ablation involves the generation of nanoparticles by irradiating a solid target material using a high-power laser. The process can be summarized as follows:

   a. Laser Irradiation: A high-power laser is focused onto a target material, causing rapid heating and vaporization of the target.
   b. Plume Formation: The laser-induced vapor forms a plume or plasma, which contains the precursor material.
   c. Nucleation and Growth: Within the plume, nucleation and subsequent growth of nanoparticles occur due to rapid cooling and condensation of the vapor.

d. Collection: The nanoparticles are collected on a suitable substrate or carrier gas.
e. Control: The nanoparticle properties can be controlled by adjusting laser parameters, target composition, and ambient conditions.

Laser ablation is known for its ability to produce nanoparticles with excellent purity and control over size, shape, and composition. It is used in various fields, including nanomedicine, electronics, and nanocatalysis.

5. Vapor-Phase Synthesis:

Vapor-phase synthesis involves the direct synthesis of nanoparticles from vapor-phase precursors without the use of solvents or liquid phases. This method includes techniques such as physical vapor deposition (PVD), chemical vapor synthesis (CVS), and plasma enhanced chemical vapor deposition (PECVD). The specific techniques vary in their deposition mechanisms but generally involve the vaporization and condensation of precursor materials to form nanoparticles on substrates or within gas environments.

Vapor-phase synthesis offers precise control over nanoparticle properties, high purity, and scalability. It is commonly used for the synthesis of semiconductor nanoparticles, quantum dots, and thin films.

7.2.8 POLYOLS METHOD

An important way for creating well-defined NPs with regulated form and size is the polyols method. Non-agglomerated metal particles with precise form and size can be produced after manipulating the precipitation's kinetics [50]. In reactive media, heterogeneous nucleation controls the average size of the metal particles. The stages involved in synthesizing are unaffected by the uniformity of the final product. Iron hydroxide in the organic medium can produce iron nanoparticles (NPs) as small as 100 nm [51]. Due to their high dielectric constants, the solvents utilized, such as polyols and PEG, offer unique features. Due to their relatively high boiling points, these solvents have a wide operating temperature range (from 25°C to the boiling point), and they can dissolve inorganic compounds. To

regulate particle development, polyols work as both reducing and stabilizing agents. These stop the accumulation of NPs as well. The growth, form, size, and yield of the particles are influenced by the type of polyols, salt ratio, concentration, and other physiological circumstances. We find that the reduction potential of the polyols affects the production and size of Fe particles [52].

The polyol method, also known as the polyol reduction method or polyol process, is a popular technique for the synthesis of metal nanoparticles, particularly noble metal nanoparticles such as gold (Au) and silver (Ag). The method involves the reduction of metal precursors in a polyol solvent at elevated temperatures in the presence of a stabilizing agent. Here is an overview of the polyol method:

1. Preparation of the reaction mixture: The reaction mixture is prepared by combining a metal precursor, a polyol solvent, and a stabilizing agent. The metal precursor is typically a metal salt such as gold chloride ($AuCl_3$) or silver nitrate ($AgNO_3$). The polyol solvent commonly used is ethylene glycol (EG), although other polyols like glycerol or PEG can also be employed. The stabilizing agent, such as polyvinylpyrrolidone (PVP) or capping ligands, is added to control the size and stability of the nanoparticles.
2. Heating and reduction: The reaction mixture is heated to an elevated temperature under an inert atmosphere (e.g., nitrogen or argon). The polyol solvent acts as both a solvent and a reducing agent. The metal precursor undergoes a reduction in the presence of the hot polyol solvent, resulting in the formation of metal atoms or small clusters.
3. Nucleation and growth: The reduced metal atoms or clusters act as nucleation sites for further growth. The reaction temperature, reaction time, and concentration of the metal precursor and stabilizing agent are carefully controlled to regulate the size and morphology of the nanoparticles. By adjusting these parameters, it is possible to obtain nanoparticles with specific sizes and shapes.
4. Quenching the reaction: Once the desired nanoparticle size and morphology are achieved, the reaction is quenched by cooling the mixture or by adding a quenching agent. This step prevents further growth of the nanoparticles.
5. Nanoparticle separation and purification: The synthesized nanoparticles are typically separated from the reaction mixture

through centrifugation, filtration, or other separation techniques. They are then washed to remove any residual reactants or stabilizing agents. The purified nanoparticles can be dispersed in a suitable solvent or stored for further use.

6. Characterization: The synthesized nanoparticles are characterized using various techniques to determine their size, shape, composition, and surface properties. TEM, SEM, XRD, and UV–Vis spectroscopy are commonly employed to analyze the nanoparticles.

The polyol method is a versatile and widely used technique for the synthesis of metal nanoparticles due to its relative simplicity, scalability, and ability to produce nanoparticles with controlled sizes and shapes. It finds applications in fields such as catalysis, electronics, sensing, and biomedicine.

7.2.9 HYDROTHERMAL REACTION METHOD

The aqueous medium is used to conduct hydrothermal reactions in an autoclave at high pressure (>2000 psi) and high temperature (>200°C). These circumstances encourage the dehydration of metal salts and the low solubility of oxides, which causes the solution to become oversaturated [43]. The effects of temperature, precursor selection, and reaction time on the morphology and particle size of synthesized nanoparticles have been extensively studied. The results of the trials showed that, while the residence time has a larger impact than concentration alone, the particle size increases with increasing precursor concentration. Monodispersed particles typically result from short residence periods. The impact of altering the precursor concentration while holding other variables constant (such as employing ferric nitrate) was investigated through several experiments [53]. The resulting particles showed primarily spherical forms with an average particle radius of 15.64.0 nm when imaged using TEM. A few bigger rhombic particles, with an average size of 27.47.0 nm, were produced in a few trials. However, just a few tiny spherical particles were detected, and the rest of the particles were rhombic in shape [54]. The hydrothermal reaction method, also known as hydrothermal synthesis, is a technique for the synthesis of various materials, including nanoparticles, using a high-temperature and high-pressure aqueous environment. It involves the reaction of precursor materials under specific hydrothermal conditions to

promote the formation of desired products. The hydrothermal method offers advantages such as control over particle size, crystallinity, and morphology. Here is a general overview of the hydrothermal reaction method:

1. Preparation of the reaction mixture: The precursor materials, typically metal salts or other reactants, are dissolved in a suitable solvent, usually water. Additional agents such as pH adjusters, surfactants, or complexing agents can be added to control the reaction conditions and influence the particle formation.
2. Sealing the reaction vessel: The reaction mixture is transferred to a sealed reaction vessel that can withstand high temperatures and pressures. The vessel is usually made of materials like stainless steel or Teflon-lined autoclaves.
3. Heating and pressurizing: The sealed reaction vessel is placed in an oven or hydrothermal reactor, where it is heated to the desired temperature and pressurized. The temperature and pressure depend on the specific reaction and the desired properties of the nanoparticles.
4. Reaction and nucleation: The precursor materials undergo chemical reactions and nucleation within the high-temperature and high-pressure environment. The hydrothermal conditions promote the formation of nuclei and subsequent crystal growth.
5. Cooling and depressurizing: After the desired reaction time, the hydrothermal reactor is gradually cooled down, and the pressure is released. The slow cooling rate helps to prevent rapid particle growth and aggregation.
6. Nanoparticle separation and purification: The resulting nanoparticle suspension is typically separated from the reaction mixture by centrifugation or filtration. The collected nanoparticles are washed to remove any residual reactants, salts, or impurities.
7. Drying and characterization: The purified nanoparticles are typically dried using techniques such as freeze-drying or vacuum drying. The dried nanoparticles can then be characterized using various techniques such as TEM, SEM, XRD, FTIR, or UV–Vis spectroscopy to analyze their size, morphology, crystal structure, and composition.

The hydrothermal reaction method is versatile and widely used for the synthesis of a variety of nanoparticles, including metal oxides, hydroxides,

sulfides, and carbon-based materials. By adjusting the reaction parameters such as temperature, pressure, pH, and reaction time, it is possible to control the properties of the synthesized nanoparticles. Hydrothermal synthesis is applicable in various fields, including materials science, catalysis, energy storage, and environmental remediation. It is a powerful technique for producing nanoparticles with controlled properties and finding applications in diverse areas of research and industry.

7.3 CHARACTERIZATION METHODS

Comprehensive surface characterization approaches, such as surface shape, chemical composition, and spatial distribution of the functional groups, are utilized to better understand surface attributes. XRD analysis, FTIR, TEM, SEM, atomic force microscopy, XPS, vibrating sample magnetometry, and thermal gravimetric analysis are some of the fundamental methods used to study magnetic NPs. Ion-particle probe, thermodynamics, NP tracking analysis, tilted laser microscopy, zeta-potential measurements, isopycnic centrifugation, hydrophobic interaction chromatography, field flow fractionation, electrophoresis, and turbidimetry are further methods for characterizing materials [55].

7.3.1 TRANSMISSION ELECTRON MICROSCOPY

Iron oxide nanoparticles created for the generation of latent fingerprints can have their structure, morphology, size, crystal structure, surface characteristics, and dispersion behavior examined using the powerful characterization technique known as TEM. TEM offers the direct visualization of nanoparticle size, shape, and distribution, confirming effective synthesis. The exact iron oxide compositions are confirmed by TEM's use of selected area electron diffraction (SAED), which also reveals crystallographic phases like magnetite or maghemite. The interactions between the nanoparticles and latent fingerprints are influenced by surface properties such as roughness, faceting, and surface changes that may be seen in TEM images. To guarantee the creation of monodisperse nanoparticles with the appropriate properties, TEM also helps in analyzing the degree of size control, homogeneity, and dispersion behavior [56].

7.3.2 X-RAY DIFFRACTION

In the examination of iron oxide nanoparticles created for the generation of latent fingerprints, XRD is an extensively utilized characterization technique. By analyzing the diffraction pattern created when X-rays interact with the nanoparticles, XRD makes it possible to determine the crystal structure. Researchers can determine the crystal structure of the nanoparticles by comparing the measured diffraction pattern with well-known crystal structures. Through distinctive diffraction peaks, XRD also aids in identifying the various iron oxide phases present, such as magnetite or maghemite. Through examination of the width and shape of the diffraction peaks, the approach also enables the measurement of crystallite size and lattice strain. XRD makes it possible to determine the relative abundance of various iron oxide phases using quantitative phase analysis. Texture analysis can further investigate the preferred orientation or alignment of crystalline domains within the nanoparticles. Collectively, XRD provides crucial information on the crystal structure, phase composition, crystallite size, strain, and texture of iron oxide nanoparticles, contributing to their characterization and suitability for latent fingerprint development [57].

7.3.3 FOURIER TRANSFORM INFRARED SPECTROSCOPY

A mathematical technique known as the Fourier transform is used to analyze a variety of signals and data, including those pertinent to the synthesis and characterization of iron oxide nanoparticles for the creation of latent fingerprints. It allows for the detection and study of various frequency components by converting a time-domain signal into its frequency-domain representation. Fourier transform can be used to analyze spectroscopic data in the context of iron oxide nanoparticles, such as FTIR or Fourier transform Raman spectroscopy. These methods aid in the identification and characterization of nanoparticles by providing information about the vibrational modes and chemical bonds that are present in them. Researchers can create a detailed spectrum that indicates the precise frequencies connected to various chemical vibrations by applying the Fourier transform to the spectral data. This examination aids in identifying functional groups or surface modifications, confirming the existence of iron oxide phases, and evaluating the nanoparticles' chemical makeup and structural characteristics. To understand and characterize iron

oxide nanoparticles for use in the creation of latent fingerprints, Fourier transform plays a crucial role in obtaining important information from spectroscopic data [58].

7.3.4 ENERGY DISPERSIVE X-RAY SPECTROSCOPY (EDS)

Iron oxide nanoparticles can be identified by their elemental composition using the sophisticated analytical method known as EDS, which is utilized in the context of latent fingerprint formation. When a sample is exposed to an electron beam in a SEM, the energy and intensity of the X-rays that are released from the sample are measured using an X-ray detector. EDS gives qualitative and quantitative data about the elemental composition of the nanoparticles by analyzing the distinctive X-ray emissions from various elements in the sample. EDS can assist in identifying any impurities or dopants in iron oxide nanoparticles by confirming the elements that iron (Fe) and oxygen (O) are present. Additionally, elemental maps, which display the spatial distribution of various elements inside the nanoparticles and offer insights into their homogeneity and potential elemental segregation, can be created using EDS. The validation of the elemental composition and comprehension of the chemical makeup of iron oxide nanoparticles for their use in latent fingerprint development is made possible with the help of the useful elemental analysis technology EDS [59].

7.3.5 VIBRATING SAMPLE MAGNETOMETRY (VSM)

To investigate the magnetic characteristics of materials, such as iron oxide nanoparticles in the context of latent fingerprint development, VSM is an extensively used characterization approach. VSM analyzes a sample's magnetic response to an applied magnetic field. When doing VSM experiments, the sample is normally mounted on a vibrating platform, and a highly sensitive magnetometer is used to measure the magnetic moment. VSM offers useful information about the magnetic properties of iron oxide nanoparticles, such as their magnetic moment, saturation magnetization, coercivity, and remanence. These variables influence the strength of the magnetic response displayed by the nanoparticles as well as the type of magnetic ordering (ferromagnetic, paramagnetic, or antiferromagnetic). Researchers can evaluate the magnetic properties of the nanoparticles and

comprehend how these features may affect their functionality in applications for latent fingerprint formation by analyzing the VSM data. Additionally, by conducting measurements at various temperatures, VSM enables the examination of temperature-dependent magnetic characteristics. Characterizing iron oxide nanoparticles' thermal stability and magnetic phase transitions sheds light on how they behave in various environmental settings [60].

7.3.6 SEM

The surface morphology, topography, and elemental composition of materials, including iron oxide nanoparticles in the context of latent fingerprint generation, can be seen and examined using SEM, a potent characterization tool. In SEM, signals such as secondary electrons, backscattered electrons, and distinctive X-rays are detected as a focused electron beam travels across the surface of the sample. The topography, surface characteristics, and elemental makeup of the sample are all revealed by these signals. High-resolution, three-dimensional views of the nanoparticles are provided by SEM pictures, making it possible to examine their size, shape, aggregation, and surface roughness. The elemental makeup of the nanoparticles can also be determined using EDS in conjunction with SEM. Iron oxide nanoparticles' surface morphology, topography, and elemental makeup are all crucially characterized by SEM to better comprehend and evaluate them for applications involving the generation of latent fingerprints [61].

7.3.7 UV–VISIBLE SPECTROSCOPY

Iron oxide nanoparticles are one example of a material whose electronic transitions and optical characteristics can be usefully studied using the widely used characterization technique known as UV–Vis spectroscopy. The measuring of light absorption and transmission in the ultraviolet (UV) and visible (Vis) parts of the electromagnetic spectrum is known as UV–Vis spectroscopy. Researchers can create a spectrum that shows the sample's absorption behavior by shining a variety of wavelengths of light onto the sample and measuring how much light is absorbed or transmitted. UV–Vis spectroscopy is used to determine the presence and properties of electronic transitions connected to the energy levels of iron oxide nanoparticles. With the help of this knowledge, the bandgap energy of the nanoparticles can

be calculated, and several iron oxide phases can be distinguished. UV–Vis spectroscopy can also shed light on the nanoparticles' concentration, size, and surface plasmon resonance characteristics. Researchers can evaluate the iron oxide nanoparticles' durability, optical qualities, and potential interactions with light by examining the absorption spectrum. This helps to better understand and determine whether they are appropriate for applications involving the formation of latent fingerprints [62].

7.3.8 DYNAMIC LIGHT SCATTERING (DLS)

When examining the size distribution and hydrodynamic characteristics of nanoparticles, such as iron oxide nanoparticles in the context of latent fingerprint generation, DLS is a potent characterization tool. To detect the variations in scattered light intensity brought on by the Brownian motion of nanoparticles in a fluid medium, DLS is used. DLS can determine the size distribution and typical hydrodynamic diameter of the nanoparticles in solution by examining these fluctuations. When studying the stability and aggregation behavior of nanoparticles, this technique is especially helpful. The homogeneity of the synthesized iron oxide nanoparticles can be determined by DLS by determining whether they are monodisperse or polydisperse. DLS can also track alterations in the nanoparticle size distribution over time to spot any potential aggregation or growth occurrences. Understanding the behavior of nanoparticles in solution and their interactions with biological systems, such as the adsorption of latent fingerprints, depends on the hydrodynamic size determined from DLS studies. Iron oxide nanoparticle size distribution and hydrodynamic characteristics can be assessed using DLS, which is a useful tool for applications involving the generation of latent fingerprints [63].

7.3.9 THERMOGRAVIMETRIC ANALYSIS (TGA)

In the context of the development of latent fingerprints, iron oxide nanoparticles are investigated for their thermal durability, breakdown behavior, and composition alterations using the versatile characterization technique known as TGA. In TGA, a sample is put through a controlled temperature program while its weight is tracked as a function of temperature or time. The sample goes through heat breakdown, desorption, oxidation, or other chemical reactions during TGA measurements, which causes weight loss

or gain. Researchers can assess the composition changes brought on by temperature changes, identify various stages of weight loss or gain, and assess the thermal stability of the nanoparticles by analyzing the TGA data. The thermal breakdown temperature, purity, and stability of the synthesized iron oxide nanoparticles may all be evaluated using TGA. It can also be used to check the presence of surface coatings or contaminants. The amount of adsorbed water or other volatile species that are present in the nanoparticles can also be determined by TGA. Because it sheds light on their thermal characteristics and stability at various temperatures, this knowledge is essential for comprehending iron oxide nanoparticle behavior and prospective uses in the production of latent fingerprints [64].

7.3.10 X-RAY PHOTOELECTRON SPECTROSCOPY (XPS)

X-ray electron spectroscopy for chemical analysis (ESCA), also referred to as Photoelectron Spectroscopy (XPS), is a potent surface analysis technique used to ascertain the chemical states and elemental composition of materials, including iron oxide nanoparticles in the context of latent fingerprint development. By exposing the sample to X-ray radiation, the top few nanometers of the material emit photoelectrons. This process is known as XPS. The elements present and their chemical bonding conditions are revealed by analyzing the released electrons based on their kinetic energy. The individual elements, such as iron and oxygen, can be recognized by XPS, together with their oxidation states, providing information about the composition and surface chemistry of the nanoparticles. Researchers can determine the chemical species, functional groups, and surface modifications of the nanoparticles by looking at the binding energy peaks in the XPS spectrum. Furthermore, the presence of pollutants, impurities, or species that have been adsorbed on the surface of nanoparticles can be usefully revealed by XPS. Understanding the surface characteristics and chemical interactions of iron oxide nanoparticles is crucial for their evaluation and optimization for latent fingerprint development applications. XPS provides this precise chemical characterization [65].

7.3.11 RAMAN SPECTROSCOPY

To understand the vibrational and rotational modes of molecules, including those of iron oxide nanoparticles in the context of latent

fingerprint generation, Raman spectroscopy is a potent analytical tool. In Raman spectroscopy, the sample is illuminated with a laser, and the scattered light is analyzed to reveal the molecular vibrations and structural characteristics. The molecular vibrations caused by the laser light's interaction with the sample cause energy shifts, which produce the distinctive Raman scattering. Researchers can pinpoint individual chemical bonds, functional groups, and crystal structures in the nanoparticles by examining the Raman spectra. The composition, phase identification, and chemical changes of the nanoparticles are all revealed by Raman spectroscopy. Additionally, it can reveal details on the iron oxide nanoparticles' bonding environment, degree of crystallinity, and presence of impurities. Additionally, the efficiency of the nanoparticles in fingerprint development can be assessed by using Raman spectroscopy to study the interactions between the nanoparticles and latent fingerprints. Iron oxide nanoparticles can be analyzed non-destructively and without the use of labels using Raman spectroscopy, which also offers useful chemical and structural details for their characterization and use in the creation of latent fingerprints [66].

7.3.12 SURFACE AREA ANALYSIS

A popular method for evaluating the precise surface area and porosity of materials, including iron oxide nanoparticles in the context of latent fingerprint generation, is BET (Brunauer-Emmett-Teller) analysis, which is based on the principle of gas adsorption. In the BET analysis, a gas (often nitrogen) is adsorbed at various pressures onto the surface of the nanoparticles. The BET equation can be used to determine the surface area by measuring the amount of gas adsorbed. The precise surface area sheds light on how much surface area the nanoparticles have available for interacting with their surroundings, such as adsorbing latent fingerprint remnants. The pore volume and pore size distribution of the nanoparticles, as well as their porosity, are also disclosed by BET analysis. Understanding the accessibility of the nanoparticle surface and how it might affect fingerprint development depends on this information. For efficient latent fingerprint detection and development applications, BET analysis aids in evaluating the quality and performance of iron oxide nanoparticles as well as optimizing their surface properties and porosity [67].

7.4 IRON OXIDE NANOPARTICLE SYNTHESIZED TO DEVELOP LATENT FINGERPRINT

A green and cost effective method for the synthesis of iron oxide nanoparticles using Camellia sinensis leaf extract. These nanoparticles were successfully utilized for the visualization of latent fingerprints. The uniqueness and permanence of friction ridge patterns in fingerprints make them a valuable form of identification in forensic investigations. This chapter discusses the different categories of fingerprint impressions found at crime scenes, including visible prints, plastic prints, and latent prints, which are the most challenging to develop. Various traditional fingerprint development methods are described, highlighting their limitations in terms of selectivity, sensitivity, and toxicity [68].

This chapter then focuses on the application of nanoparticles as an alternative technique for fingerprint development. The small size and tunable properties of nanoparticles make them attractive for this purpose. Previous studies have explored the use of different nanoparticles such as gold, silver, silicon oxide, and quantum dots. However, these methods still face challenges related to selectivity and safety.

In this chapter, the authors describe a simple and safe green method for synthesizing iron oxide nanoparticles using a tea extract. The nanoparticles were successfully employed for developing latent fingerprints on both porous and non-porous surfaces. The experimental procedure involves preparing the tea extract, adding it to ferric chloride under constant stirring, centrifuging the resulting precipitate, and washing it to remove impurities. The dried precipitate is then transformed into unannealed iron oxide nanoparticles (UIO), which are further sintered to obtain annealed Fe_2O_3 (AIO) nanoparticles [69].

The developed nanoparticles exhibited high crystallinity and purity, as confirmed by XRD and energy dispersive X-ray spectroscopy (EDAX) analysis. SEM images revealed the morphology of the iron oxide nanoparticles. The developed nanoparticles were applied to different substrates, including porous paper and non-porous glass, resulting in clear and identifiable friction ridge patterns. The authors attribute the success of this method to the small particle size and high surface area of the nanoparticles, which facilitate interaction with the ridges present in fingerprints.

In conclusion, this chapter demonstrates the potential of biosynthesized iron oxide nanoparticles as a green and effective method for developing

latent fingerprints. The nanoparticles offer advantages such as easy fabrication, cost-effectiveness, and enhanced contrast. Further research is needed to explore their application on different substrates.

KEYWORDS

- **Calcination**
- **hydrolysis**
- **iron oxide nanoparticles**
- **latent fingerprints**
- **microemulsion**
- **monodispersity**
- **pyrolysis**
- **vaporization**

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CHAPTER 8

Detection of Fingerprints Using Nanoparticles

GAURAV KUMAR SINGH[1], PRATIK SINGH[2], MEGHA YADAV[3], SHREYA ARORA[4], and MANIK CHAND[5]

[1]*Department of Forensic Science, Sharda School of Allied Health Sciences (SSAHS), Sharda University, Greater Noida, Uttar Pradesh, India*

[2]*Amity Institute of Forensic Sciences, Amity University, Noida, U ttar Pradesh, India*

[3]*Guru Ghasidas Vishwavidyalaya, Bilaspur, Chhattisgarh, India*

[4]*College of Traffic Management, Institute of Road Traffic Education, Faridabad, Haryana, India*

[5]*Department of Forensic Science, University Institute of Applied and Health Sciences, Chandigarh University Gharuan, Mohali, Punjab, India*

ABSTRACT

Latent fingerprints, composed of imperceptible sweat, oils, and skin secretions residues, are frequently encountered as evidence in criminal investigations. Traditional methods for developing and detecting these latent prints, such as fingerprint powders and chemical reagents, often need to be revised regarding efficiency and reliability. In recent years, nanomaterials have emerged as a promising avenue in nano-forensics, offering significant potential for enhancing the quality and durability of latent fingerprints. This chapter provides an overview of the diverse applications

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of nanoparticles in developing and detecting latent fingerprints on various surfaces. The utilization of nanoparticles, including silver, gold, silica, carbon, quantum dots, zinc oxide, and rare earth metal nanoparticles, is discussed in the context of their unique properties and capabilities in fingerprint analysis. Recognizing that fingerprints are a fundamental aspect of individual identity and a crucial tool in connecting criminals to their actions, this chapter explores how nanoparticle-based approaches can address the limitations of traditional methods. Nanotechnology is poised to play a pivotal role in advancing forensic science by improving latent prints' sensitivity, versatility, and preservation. By exploring cutting-edge techniques and emerging trends, this chapter underscores the potential of nanoparticles to transform the landscape of latent fingerprint analysis in the foreseeable future.

8.1 INTRODUCTION

Fingerprints are commonly referred to as frictional ridges that reside on the palmer surface of hands; prints derived from these phalanger surfaces play a prominent role in individuality and fixing an individual's identity. The most repeated and reliable evidence sources in the discipline of forensic science are fingerprints, used for individual identification, and biometric systems for security purposes. However, the evolution of its recognition and identification has pertained since its development in a versatile manner [25]. The papillary or friction ridges are depressed on fingertips in a manner known as sweat pores. The surface density is about 4/mm^2 over the fingerprints, which occurs at a particular interval of about 0.5 mm on the dermal ridges [34]. Research over several years in fingerprints and dermatoglyphics has accepted that ridges present over the plantar and palmer surface remain the same developed during the fetal stage of development, except for any deep-rooted injury [14] which causes irreversible damage to the ridges. Only death has the eminent character to degenerate any detectable property of the corpse [25]. Fingerprint contains the secretion of fluids secreted through the body and contaminants in the atmosphere [6, 8]. Secretions are exudated from sweat glands, namely sebaceous, apocrine, and eccrine, which are most likely found in fingerprints and suitable for detecting fingerprints and identification [8]. The fingerprints have evolved from traditional to modern extraction and

evaluation in a diversified fashion, and their admissibility in the court of law has been increased efficiently. These frictional ridges have specific patterns that are significant, unique, and ubiquitously identifiable and leave behind impressions in whole or trace amounts when handled with the naked eye. The traces of impressions can help to fix the fingerprint pattern identification. The finger marks have a general pattern that has a specific representation with design and features that allow the machine to classify under given patterns and databases if present [12].

8.2 LATENT FINGERPRINT AND ITS DETECTION

Fingerprint impressions are categorized based on known, plastic, and latent prints. A latent fingerprint is a frictional ridge of a two-dimensional nature formed due to perspiration, oil, impurities, and dust that formed as a coating on the surfaces touched by fingers. Many investigators need to pay more attention to the physical evidence during the investigation process due to insufficient familiarity with physical evidence and its potential. While committing a well-planned crime, a person has controlled movement on the scene of the crime but cannot do it if he has a fear of detection in mind. Whenever a criminal touches anything, takes steps, or leaves a crime scene, regardless of every measure taken while handling any object at a crime scene, it will function as silent evidence over him. When we hold any object with our palm or finger, invisible impressions of the touch are left due to the excretion of lubrication from sweat pores, generally known as latent fingerprints because they cannot be seen through bare eyes.

Visualization and location of latent print on a crime scene is callous work. The main scheme in revealing the latent fingerprint is to preserve it for comparison and further analysis in the future when the suspect has been involved in any criminal act. A potential latent fingerprint should be examined by the investigator if present on different objects in contact with the perpetrator. A systematic search can help determine the latent fingerprint at the crime scene. The fingerprint can be found in a crime scene on a nonporous surface such as glass objects, table tops, wooden surfaces, electric bulbs, leather, and plastic wares. The other types are porous, such as textiles, shirts, pants, and bedsheets, and used for smooth walls, shoes, weapons, and so forth. Decipherment of latent fingerprints is performed

by several conventional and nonconventional methods, including physical development methods like tape lifting, and chemical development methods, including various powdered methods and fuming methods like iodine fuming, silver nitrate, and cyanoacrylate [5, 34]. However, old and contaminated fingerprints contain lesser reactivity during the application of the mentioned methods for detection [5]. Over the last decennium, nanotechnology has been used for the recognition and analysis of latent fingerprints prominently and to identify the features better than the traditional methods [7, 51].

8.3 CLASSIFICATION OF NANOPARTICLES ON THE BASIS OF ITS CLASS AND PROPERTIES

In this section, the classification of nanoparticles on the basis of their class and properties is discussed in Table 8.1. Further, different types of techniques used for the analysis and visualization of latent fingerprints and different types of nanoparticles used for the detection of fingerprints are represented in Figures 8.1 and 8.2, respectively.

8.4 NANOPARTICLES AND ITS IMPORTANCE

Forensic technology has evolved in all fields, including odontology, entomology, toxicology, pathology, and anthropology. In the last decades, the application of nanoparticles in various fields of forensic sciences has been expanded, incorporating metal nanoparticles, carbon dots, quantum dots, polymer dots, semiconductor quantum dots, silica nanoparticles, and metallic oxide nanoparticles [39]. In peculiar metal nanoparticles of gold and silver, titanium oxide, iron oxide, zinc oxide, and silica nanoparticles, like metal oxides, cadmium sulfide QD (CdsQDs), cadmium telluride QD (CdteQDs), cadmium selenide Quantum dots (CdSeQDs), conjugated polyelectrolyte dots (CPEDs), and fluorescent silica nanoparticles, rare earth metal fluorescent nanomaterials are used as an application for fingerprint detection [4, 17, 19, 22, 23, 51]. The different types of nanoparticles along with their composition efficient for the detection of fingerprints on various surfaces are listed in Table 8.2.

TABLE 8.1 Classification of Nanoparticles on the Basis of Its Classes and Properties.

Classification	Class	Properties	References
Root source of origin	Natural	Those nanomaterials are pre-existing in different spheres of the earth's surface. Biological processes can synthesize them.	[46]
	Synthetic	These are artificial nanoparticles synthesized by chemical and physical development methods and top-down and bottom-up methods. They are produced by different activities such as grinding mechanically and exhaust smoke by an engine.	[24]
Origin based on dimension movement of electrons	0D	Carbon quantum dots are categorized in this as they have no dimension in space. They are not more than 100 nm in size.	[38]
	1D	They show electron activity movement found along.	
		X-axis and persists a dimension outward of the nanoscale, for example, nanowires and nanotubes.	
	2D	They show the mobility of electrons along two axis, X and Y, which have two dimensions outward of the nanoscale. Examples are carbon nanotubes and nanosheets, and so forth.	
	3D	They show the motion of electrons along all three axes, X, Y, and Z but are not restricted in any nano-scale dimension. Examples are bundles of nanowires and bulk powder, and so forth.	
Based on the matter of origin	Carbon	Their primary material is carbon itself, and externally they persist in spherical, cylindrical, or elliptical. Examples are fullerene, graphene, and carbon nanotubes (single, double, and multiwalled), nano foil, and nanofibers.	[1, 20, 26]
	Organic	They are generally comprised of organic materials and are nontoxic and environment-friendly. They are in the form of nano-capsules and nano-spheres, collectively called polymer nanomaterial, which have remarkable contributions to medical science, specifically in drug delivery and treatment of target cells. Examples are dendrimers, micelles, ferritin, and liposomes.	[21]
	Inorganic	Inorganic matter comprises the nonexistence of carbon and is called inorganic nanomaterials, grouped in metal and oxides of metal nanomaterials. They possess an affinity with hydrogen and oxygen atoms and show interactivity among living bodies. Examples of metal nanomaterials are Cu, Al, Au, Ag, Zn, Co, Cd, Fe, and so forth. And oxides such as TiO_2, SiO_2, Al_2O_3 Fe_2O_3, and so forth.	[11, 48]

TABLE 8.1 *(Continued)*

Classification	Class	Properties	References
Composite nanomaterials		The nanoparticles of varied characteristics and dimensions are comprised in a manner and collectively form a single phase. Examples are organic, carbon, and metal-based nanoparticles. Examples are organic, carbon, and metal-based nanoparticles.	[24]
Ceramic nanomaterials		They are nonmetallic solids formed by the gradual cooling and heating of particles. Forms can vary from dense, porous, crystalline, and amorphous, substantially used in imaging, dye, photodegradation, catalysis photocatalysis, and so forth.	[21]
Biological nanomaterials		Nanoparticles of one dimension nature and have sizes varying from 1 to 100 nm, which are synthesized from a different system of living creatures and formed organically in nature, are termed bio nanoparticles. It can be classified into two groups: intracellular and extracellular. Examples of intracellular comprise magnetosomes, and extracellular bio nanoparticles contain viruses and lipoproteins.	[21]
Semiconductor nanomaterials		That matter which contains characteristics of metals and non-metals and their energy bandgap is below 4 eV are considered semiconductor nanoparticles like Gallium arsenide and Silicon Dioxide. They are categorized as intrinsic, which contains pure constituent or compound with no doping, and extrinsic, made up of doping one component with another to prepare a particular type of semiconductor with a high conductivity level.	[54]

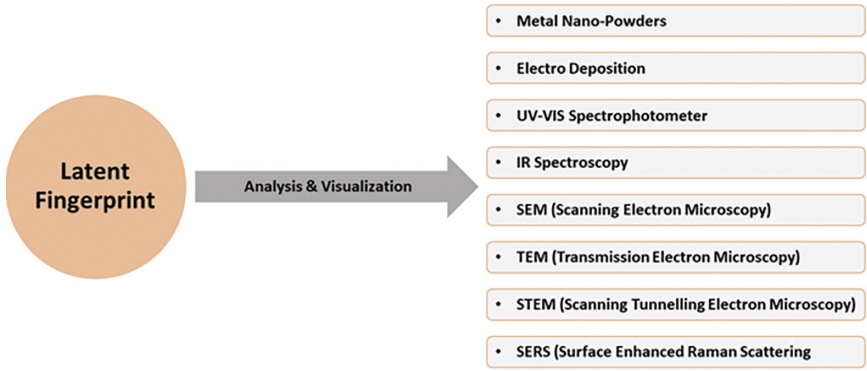

FIGURE 8.1 Different types of techniques used for the analysis and visualization of latent fingerprints.

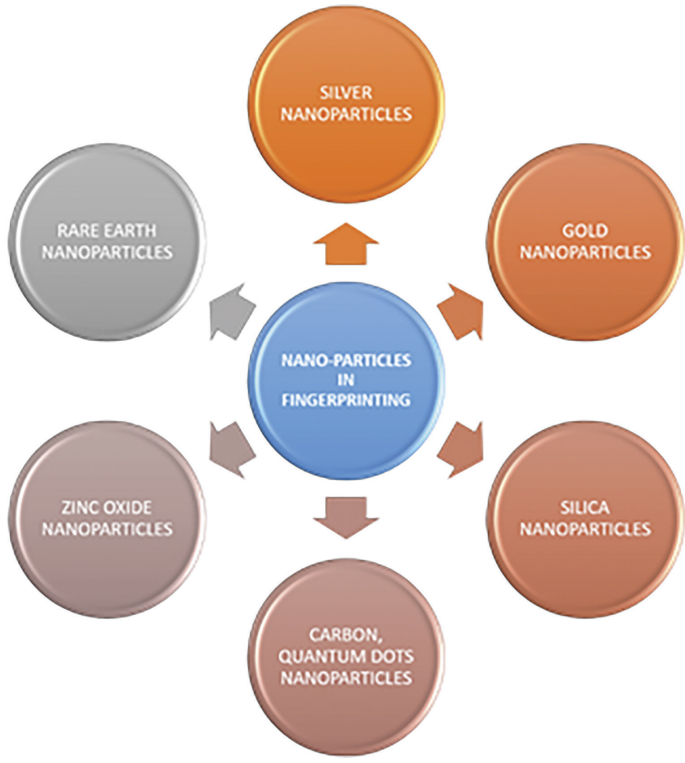

FIGURE 8.2 Different types of nanoparticles used for the detection of fingerprints.

TABLE 8.2 Different Types of Nanoparticles and Their Chemical Composition Efficient for the Detection of Fingerprints on Various Surfaces. ⏎

S. No	Type of Nanoparticles	Surface	Chemical or Reagent	References
1.	Silver nanoparticles	Porous	Ag-NPs were taken as a major reagent and physical developer method.	[5, 47]
2.	Gold nanoparticles	Porous and non-porous	Sol-gel method with multimetal deposition	[8]
3.	Silica nanoparticles	Nonporous	SiO_2:4-(chloromethyl) phenyltrichlorosilane	[19]
4.	Carbon-dot nanoparticles	Nonporous	$CdTeeCOONH_3NH_3$ p structure	[9]
5.	Carbon quantum dots nanoparticles	Nonporous	CQDs in solution phase	[55]
6.	Zinc oxide nanoparticles	Nonporous	$ZnOSiO_2$	[49]
7.	Rare earth nanoparticles	Nonporous	YVO_4:Eu and $LaPO_4$:Ce, Tb KAF:Mn_4	[15, 36]

8.5 SILVER NANOPARTICLES

Metallic compounds of silver contain the property to bind with the organic components of residual a fingerprint impression. Since 1970, silver nanoparticles have been used as a developer (Ag-PD) method for deciphering latent fingerprints on the porous surface of the paper. The reaction mechanism involves oxidation and reduction of a couple of ions, which ferrous salt reduces to an aqueous solvent of silver nitrate into metallic silver. The diameter of silver nanoparticles ranges from 1 to 200 nm [5, 47], which was helpful in detection and visualization, but visibility was poor. The latent fingerprint detection is performed by a physical approach followed by electrostatic activity between the bodily secretion and contamination such as amino acids, fatty acids, and silver steel debris [39]. The high attraction for organic constituents forms images on the porous surface [3]. Fatty acids and lipids are hydrophobic and present on the impressions for a prolonged period on the porous surface of the crime scene [33]. Analyzing latent fingerprints of several years of age can produce images under dense, generally black surroundings [37, 41]. Latent fingerprint development is planned and designed to detect fingerprints residing on humid, dry, and porous surfaces.

The evaluation and latent fingerprint development are performed through image processing on the porous surface of paper articles, tape surfaces, or clay objects [47]. Metal ions that help in latent fingerprint development are not prevalent nowadays [41]. These techniques are identified as beautiful techniques for detecting latent fingerprints due to their organic affinity with fingerprint residues [5].

8.6 GOLD NANOPARTICLES

Gold nanoparticles (AuNPs) unveiled features like inert nature, stability for a longer period, and sensitivity, and in latent fingerprint, detection can be used on nonporous substrates [31, 51]. The water-repelling group like fatty acids present on fingerprint residues reacted with the functional group of amines in AuNPs [8]. In mass spectrophotometry, AuNPs are used for imaging and evaluation of latent fingerprints [39].

Previous research demonstrated that the two major colors pink and blue enhance fingerprint detection and disclosed the surface plasmon resonance of AuNPs [2]. The ionization/laser desorption property of AuNPs by analysis of endogenous and exogenous components rooted in latent fingerprints exhibits the dispersion without blurring or scattering the fingerprint patterns. The visualization and recording of molecular images provide individual specificity and also avoid overlapped fingerprints simultaneously. The AuNPs are beneficial for exogenous and endogenous substance-coated latent fingerprints for analysis in definite and variable surfaces by laser desorption and ionization. To examine the availability of minute and trace compared in latent fingerprint detection, molecular picture, and images, information of chemical compound. As AuNPs behave as good electrical conductors which depends on the shape, dimension, and size of particles recognized by scanning electron microscopy (SEM) for latent fingerprint analysis [18]. These are beneficial in developing latent fingerprint images on the macroscopic, microscopic, and molecular levels [39]. By using the sol-gel method in the existence of multimetal deposition, AuNPs are used on various substance substrates for latent fingerprint decipherment [8]. Majorly to overcome the silver nanoparticles to metallic silver, the surface is soaked with finger marks with AuNPs [16, 43]Click or tap here to enter text.. The image of the fingerprint is visualized distinctly due to its fundamental affinity between the negative charge of AuNPs and sweat pores containing a positive charge [56].

In multimetal deposition (MMD), the nanoparticles of gold coated with silica nanoparticles is an aqueous technique to establish the fingerprint detection mechanism. The electrostatic interaction mechanism of sweat with AuNPs in the presence of acidic conditions is used extensively in the detection of fingerprints. The electrostatic interactivity between AuNPs containing the COOH functional group and the functional group amine of sweat present on fingerprint are the basic characteristics here. The amine functional nanoparticles exhibit results for latent fingerprints and enhancement of forensic nanotechnology [32]. A comparable analysis was discovered with silver nanoparticles [5].

8.7 SILICA NANOPARTICLES

For invisible fingerprints, silica nanoparticles are most preferable for an aged fingerprint on nonporous substrates such as glass, rubber, and plastic. The silica nanoparticles are made up of a discrete mass ratio of particles of silica and a compound named 4-(chloromethyl) phenyl-trichlorosilane with 700 nm of silica nanoparticles. Similar results lead to further analysis of new nanoparticles of silica for the detection of fingerprints used to alter to make it a more responsible and sensitive technique for the identification of latent fingerprints [19]. The latent fingerprint detection on the discrete surface shows high sensitivity and better image resolution due to affinity with dye and photo leaching was lessened [53]. Several varied fluorescence substances, such as CdSQDs, C-Qds, CdSeQDs, CdTeQDS, and fluorescent silica nanoparticles, are used for fingerprint detection [39]. Amphiphilic refers to a substance compound possessing a hydrophilic and hydrophobic nature [28]. Amphiphilic silica-based nanoparticles show apparent sensitivity and visibility on a nonporous surface [19]. The amphiphilic silica nanoparticles, that is, $–C_{11}H_{23}$ and $C_{17}H_{23}$ give very accurate results under visible light [10].

8.8 CARBON DOTS

Carbogenic nanoparticles, also known as C-dots, are a growing field of forensic science that provides high-performance photo luminescence, also known as nano-emitters, that can be employed in printing and bio-imaging. It outperforms more traditional methods, such as the use of dye or quantum dots with heavy metals. The synthesis of C-dots is

biocompatible, nontoxic, and cost-effective. They have a limited ability to develop latent fingerprints because they generate self-fluorescence, which causes analytical interference and makes it difficult to develop the prints. As a result, a better synthesis procedure is proposed, and the addition of heteroatoms such as nitrogen can improve the outcomes further [13].

PVP polymer is used to make N-doped carbon dots (N-CDs), which provide vivid fluorescent signals when stimulated at 350 nm. In the identification of fingerprints, these detection mediums produce clear and distinct patterns. Various functional groups, such as O=C-NH-, were also attached, resulting in distinct fluorescence patterns [30].

8.9 QUANTUM DOTS

Quantum dots (QDs) are a spectacular advancement in forensic science because of their luminous abilities. The first variant of CdS QD for the identification of latent fingerprints was designed in the year 2000. As a result, numerous additional systems, such as CdSe and even CdTe, were developed. Water-soluble fluorescent quantum dots of (CdTe) cadmium telluride coated with mercaptosuccinic acid boosted the latent fingerprint detection speed by a significant margin. With an optimal pH value, the efficiency of QDs is improved, resulting in faster detection and development time. Other forms of QDs and their prototypes exist, but semiconductor quantum dots are the ones that scientists are fascinated in. CdTe QDs have been recognized as a critical step in the detection of blood fingerprints on non-permeable surfaces [4, 27]. The latent fingerprints were identified on aluminum utilizing green (528 nm) and red (755 nm) over a period of 30 min to about 24 h when CdTe QDs were coated with thioglycolic acid (TGA). They were also modified and produced with +vely charge CdTeeCOONH$_3$NH$_3$ p structures with pH stabilizers using the usual solution method to enhance their detection and stability [42]. This modified CdTeeCOONH$_3$NH$_3$ p structure can be employed for increased fluorescence since it is based on electrostatic interaction between the positively charged synthesized chemical and negatively charged amino acids that prevail in fingerprints developed on smooth surfaces [9, 27]. Gao et al. further reported the synthesis of CdTe@-SiO$_2$ QDs which also emit fluorescence for the detection of fingerprints. He also compared the results from the conventional powder method for the development of fingerprints on smooth surfaces. It was confirmed that CdTe with SiO$_2$

QDs semiconductor powders provides better adhesive ability because of electrostatic forces and adsorption interactions which in turn gives better fluorescent results [16, 17]. Different types of quantum dots are shown in Figure 8.3.

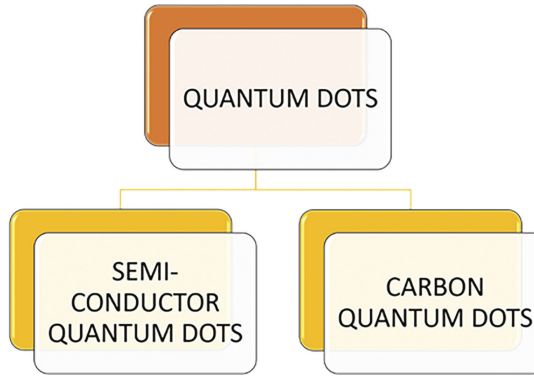

FIGURE 8.3 Different types of quantum dots.

8.10 CARBON QUANTUM DOTS

Carbon quantum dots (CQDs) have been increasingly popular in recent years because of their intense photoluminescence, ease of surface preparation, and outstanding water and chemical resilience. They are also less toxic and environmentally friendly, which adds to their usefulness. They are widely used in optical sensing, energy conservation, and imaging. Due to direct π–π interactions, CQDs are often fluorescent even in the solution state, which limits their use in the field of solid-state detection of latent fingerprints [55].

8.11 ZINC OXIDE NANOPARTICLES

The zinc oxide nanocrystals are prepared with a basic solution method which includes zinc acetate and sodium hydroxide. By heating this to 250–300°C for 3–4 h, zinc hydroxide is transformed into zinc oxide. Deepali et al. later explored how zinc oxide is a preferable alternative for latent print formation on nonporous surfaces to tin oxide [29]. Zinc oxide has a number of features, including a high excitation binding energy, which helps in easy transition, and good adhesive characteristics, which let

it bond with lipids and proteins in latent fingerprint residues even at room temperature. Zinc oxide nanoparticles, according to University of Sydney researchers, perform best on nonporous surfaces. The ZnO nanoparticles can make pretty clear prints as well as fluorescence under UV light when damp. Researchers are now working on $ZnOSiO_2$ synthesis and have discovered that it is more effective than ZnO on nonporous surfaces [49]. It has also been reported that zinc oxide deposition has considerably higher pattern visibility on fresh samples than on old samples, but results have also been obtained for samples that have been aged for one month [40]. Guzman et al discussed ZnO on aluminum and steel surfaces produces much more luminance than any other commercial powders. Another group of researchers also discussed ZnO NP combined with barbiturates also improves the fingerprints displayed in the visible light range [8, 29].

8.12 RARE EARTH NANOPARTICLES

Colloidal solutions contain nanoparticles that are not suitable for use in crime scenes due to their complicated composition and limited efficiency. As a result, fluorescent nanoparticles were considered because of their exceptional selectivity and low background interference. Rare earth nanoparticles have several benefits, including tiny particle size, large surfaces, high quantum and fluorescence yields, and high chemical stability, making them an ideal choice for producing rare earth fluorescent nanomaterials for fingerprinting. The utilization of YVO_4:Eu and $LaPO_4$:Ce,Tb rare earth fluorescent nanoparticles on diverse nonporous surfaces was described by Wang et al. [50].

Due to their small size, minimal aggregation, and bright fluorescence, these rare earth ions are one of the most attractive choices for forensic applications. This ensures better fingerprint detection. Even the creation of Y_2O_3 nano-particles doped with rare earth metals such as Tb^{3+} and Eu^{3+} results in fluorescence signals that aid in the detection of latent fingerprints. The contrast between the prints and the surfaces on which they are laid rises as a result of UV stimulation. As a result, its viability and forensic significance have increased [35]. Similarly, Thomas et al discussed lanthanum phosphate ($LaPO_4$) and lanthanum fluoride (LaF_3) nanoparticles which are doped with rare-earth ions [52]. They also stated that helium ions can be used with LaF_3 nanoparticles for fluorescent markers as compared to $LaPO_4$ due to their resilience to beam damage [15, 50].

The relevance and efficiency of KAF:Mn_4 for producing latent fingerprints were discussed by Di Peng et al. They went on to say that the hydrophobic character of OA-doped KAF:Mn_4 explains and allows for better interaction between the phosphor and organic molecules such as amino acids and lipids found on fingerprint residues. They also incorporated rare-earth phosphors in an excited state, and exhibit even fine ridge features with minimal background interference when stimulated in blue light. Even sweat pores may be seen in high resolution, suggesting its importance in forensic science as it not only displays or illuminates but also fluorescence imaging is possible [36].

8.13 EFFICIENCY OF NANOPARTICLES

Nanotechnology is a broad discipline in the sciences, and its relevance and applications in forensic science are equally diverse. The form of the surface and its relatively small size are the reasons for a large number of applications. Their size affects their chemical stability, reactivity, and excitations. This is why it is employed in a variety of fields such as chemical reaction catalysis, imaging, and drug delivery systems because it can easily penetrate any biological tissue and even be used in environmental prevention and applications. Even if detection is possible, fine ridge counting is only achievable when the technology utilized is fine and has optical properties, as stated below, latent fingerprint analysis with the use of different nanoparticles and their combinations has been described as better than the conventional methods [16, 45].

8.13.1 FORENSIC SIGNIFICANCE OF NANOPARTICLES IN ADVANCING FINGERPRINT ANALYSIS

A variety of techniques can be used to identify and develop latent fingerprints. The physical technique includes all fingerprint powders, while chemical procedures include iodine fuming, cyanoacrylate, and others. One of the numerous factors that go into the technique selection is the type of surface on which the fingerprint will be imprinted. On porous surfaces, chemical treatments are preferred, but on nonporous surfaces, the powder technique is more successful. However, the capacity of these chemicals and powders to form those prints reduces as the duration of the deposited fingerprint rises. As a result, with the old latent prints, a demand

for new approaches arises. Silica nanoparticles are simple to synthesize and a great choice for nonporous surfaces due to their prolonged shelf life [44]. They also worked well on nonporous surfaces, both with and without fluorescence. Zinc oxide nanoparticles have been reported to be a very effective powder on nonporous surfaces. In addition, diverse combinations of zinc oxide nanoparticles with other compounds are also being acknowledged for much-improved fingerprint contrast. Carbon nanoparticles are employed in a wide range of biochemical devices. Their combination with starch powder improved their fluorescence and stability, indicating that they may be used to develop and detect fingerprints on nonporous surfaces. Quantum dots come in a variety of combinations, including carbon quantum dots, which allow scientists to distinguish ridge details from latent fingerprints on nonporous surfaces. Due to their photochemical stability, rare earth metals have also been used in the field of latent fingerprint detection. They are quite beneficial since they aid in the development of fingerprints, such as aluminum foil, stainless steel, and even highlighter pens. In addition, the bright luminescence feature improves imaging. As a result, nanoparticle approaches are both a current and future research concern [40].

8.13.2 ENVIRONMENTAL IMPACT

The use of nanoparticles in fingerprint detection can have several environmental impacts, both positive and negative. On the positive side, many nanoparticle-based methods are environmentally friendly compared to traditional techniques. They often require fewer chemicals and generate less waste, contributing to reduced environmental pollution. However, there are challenges to consider. The production and disposal of nanoparticles may pose environmental risks if not managed carefully. Research in this area is essential to ensure the responsible use of nanoparticles in forensic applications.

8.13.3 CHALLENGES AND CONSIDERATIONS

1. Cost: Nanoparticles can be expensive, particularly those made from precious metals such as silver and gold. This cost factor may limit their widespread adoption, especially in resource-constrained forensic laboratories.

2. Specialized Equipment: Effective utilization of nanoparticles for fingerprint detection often requires specialized equipment, which may only be readily available in some forensic facilities. Training personnel to use this equipment is also a consideration.
3. Expertise: Skilled forensic experts are essential to ensure accurate and reliable results when using nanoparticle-based techniques. The training and expertise needed to handle these materials and interpret the results can be challenging for some forensic teams.
4. Health and Safety: Nanoparticles can pose health and safety risks to personnel if improperly handled. Safety measures and protocols must be in place to protect forensic experts working with these materials.
5. Legal Admissibility: The admissibility of evidence obtained through nanoparticle-based methods can be a legal challenge. Courts may require a clear understanding of the technology and its reliability before admitting such evidence.
6. Standardization: The field lacks standardized procedures for nanoparticle-based fingerprint detection. Standardization is critical to ensure consistent and reliable results across different laboratories.

8.13.4 FUTURE PROSPECTS

The future of using nanoparticles for fingerprint detection is promising. Here are some prospects:

1. **Technological Advancements:** Ongoing research will likely lead to improved and more cost-effective nanoparticle-based techniques. This will make them more accessible to forensic laboratories.
2. **Wider Adoption:** As the technology becomes more established and validated, it will likely be more widely adopted by forensic agencies, increasing its use in solving crimes.
3. **Interdisciplinary Collaboration:** Collaborations between experts in materials science, chemistry, and forensics will lead to innovative approaches and techniques, further enhancing the field.

4. **Enhanced Sensitivity:** Ongoing research will likely result in nanoparticles with even greater sensitivity and specificity, improving the detection of latent fingerprints, especially on challenging surfaces.
5. **Environmental Responsibility:** Research into the environmental impact of nanoparticle use will lead to more responsible practices in their production and disposal.

8.14 DISCUSSION

The use of nanoparticles to detect fingerprints has proven to be an up-and-coming and effective technique. This innovative approach could revolutionize the field of forensics by enhancing the sensitivity, accuracy, and efficiency of fingerprint analysis. After the exploration of this technology, we have uncovered several key findings and advantages:

1. **Enhanced Sensitivity:** Nanoparticles offer heightened sensitivity in fingerprint detection due to their small size and unique properties; this enables the identification of faint, aged, or contaminated prints that might otherwise go undetected using traditional methods.
2. **Quick and Reliable Results:** The application of nanoparticles expedites the development of fingerprints, reducing the time required for analysis.
3. **Versatility:** Nanoparticles can be tailored to various substrates, making them adaptable to various surfaces, including glass, plastic, and metals. This versatility extends the applicability of this technology to diverse forensic scenarios.
4. **Minimized Background Interference:** Nanoparticles can effectively bind to the amino acids and other compounds in fingerprints, reducing the potential for background interference and false positives.
5. **Improved Preservation:** Nanoparticles can aid in preserving fingerprints over extended periods, allowing for future analysis and reducing the risk of degradation.

6. **Non-destructive Technique:** Nanoparticle-based fingerprint detection is nondestructive, ensuring the integrity of the evidence for further examination or legal proceedings.
7. **Eco-Friendly Solution:** Many nanoparticle-based methods are environmentally friendly, as they often require fewer chemicals and generate less waste than traditional fingerprint development techniques.

While nanoparticle-based fingerprint detection presents numerous advantages, it is essential to acknowledge some challenges and considerations. These include the cost of nanoparticles, the need for specialized equipment, and the necessity for well-trained forensic experts to ensure accurate and reliable results. Further research and development are essential to refine the techniques and address potential limitations.

This chapter has explored the transformative potential of nanomaterials in the realm of latent fingerprint analysis. Latent fingerprints, although imperceptible, are invaluable in criminal investigations, yet traditional methods for their detection and development have often faced challenges in terms of efficiency and reliability. The emergence of nanotechnology within the field of nano-forensics has offered a promising solution to these challenges, elevating the quality and durability of latent fingerprints. In addition to this, a comprehensive overview of how diverse nanoparticles, including silver, gold, silica, carbon, quantum dots, zinc oxide, and rare earth metal nanoparticles, can be harnessed to develop and detect latent fingerprints on various surfaces has been discussed. These nanoparticles bring unique properties and capabilities to the realm of fingerprint analysis, offering heightened sensitivity, versatility, and preservation of latent prints.

8.15 CONCLUSION

Fingerprint analysis is a cornerstone of individual identity and a vital tool in connecting criminals to their actions. This chapter has shed light on how nanoparticle-based approaches effectively address the limitations of traditional methods, paving the way for a pivotal role of nanotechnology in advancing forensic science. As we peer into the future of forensic science, it becomes evident that nanoparticles hold the potential to revolutionize the landscape of latent fingerprint analysis. By embracing the latest

techniques and emerging trends, we recognize the transformative power of nanotechnology in making latent fingerprint analysis more effective and reliable. The path forward is marked by innovation, and the integration of nanomaterials promises to continue evolving forensic techniques, ultimately enhancing the pursuit of justice in criminal investigations.

KEYWORDS

- **Carbon dots**
- **gold**
- **latent fingerprint**
- **nanoparticle**
- **silver**
- **silica**

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CHAPTER 9

Synthesis of Silver Nanoparticles: Advancements and Applications in Fingerprint Development

RUHANI SHARMA[1,2], TINA SHARMA[3], ARCHANA GAUTAM[4], VAIBHAV MISHRA[4], KUMUD KANT AWASTHI[1], MAHIPAL SINGH SANKLHLA[4,5], and ANJALI AWASTHI[2]

[1]*Department of Life Sciences, Vivekananda Global University, Jaipur, Rajasthan, India*

[2]*Department of Zoology, University of Rajasthan, Jaipur, Rajasthan, India*

[3]*Department of Forensic Science, Bahra University, Shimla Hills*

[4]*Department of Forensic Science, UIAHS, Chandigarh University, Mohali, Punjab, India*

[5]*University Centre Research for Development, (UCRD), Chandigarh University, Mohali, Punjab, India*

ABSTRACT

This chapter provides a thorough examination of various techniques for the manufacture of silver nanoparticles (AgNPs, with a focus on their possible use in creating latent fingerprints for forensic research. We carefully review a wide range of approaches, including chemical reduction, biological synthesis, microwave-assisted synthesis, green synthesis, photochemical reduction, ultrasonication (sonochemical procedures), and electrochemical methods. The inherent benefits, difficulties, and uniqueness of each strategy are elaborated, based on a wide range of

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research investigations. The discussion emphasizes how different synthesis methods might affect the characteristics of AgNP, how they interact with fingerprint residues, and the quality of visualization that results. The overall story emphasizes how important it is to choose a synthesis process that is acceptable for forensic applications and urges the research community to explore more improvement and innovation in this crucial area.

9.1 INTRODUCTION

Nanoparticles have emerged as a game-changing technique in fingerprinting, providing unmatched accuracy and sensitivity. Researchers and forensic specialists may improve the accuracy and reliability of fingerprint analysis by using the unique characteristics of these small particles, such as their size, surface chemistry, and optical properties [1]. Nanoparticles can selectively stick to fingerprint residues, enabling the viewing and recognition of latent prints on a variety of surfaces, even in difficult situations. Furthermore, functionalized nanoparticles may be utilized for targeted chemical investigations, which improves the identification of individual components in a fingerprint [2]. The use of nanoparticles in fingerprinting processes is a major innovation in forensic science, with the potential to improve law enforcement skills and give crucial insights in criminal investigations [3].

Nanotechnology has revolutionized several industries, including forensics. Crime scene investigation and resolution sometimes rely on forensic analysis, which involves the use of scientific methods and tools. Nanotechnology's capacity to control and study materials at the nanoscale may lead to more precise and sensitive forensic investigations, providing a number of benefits in this context such as fingerprint analysis (Figure 9.1). The resolution and sensitivity of fingerprint analysis have increased because of nanotechnology. Nanoparticles may be utilized to improve latent fingerprints by sticking to sweat and oil residues on a surface, making them more visible and simpler to analyze. This may help identify suspects and connect them to crime sites [3].

The unique features and wide range of uses of silver nanoparticles (AgNPs) have led to a revolution in fingerprinting. Due to its exceptional physicochemical properties, this nanomaterial has been widely used to improve the speed, accuracy, and sensitivity of fingerprint analysis [4]. AgNPs are tiny particles of silver with dimensions typically ranging

from 1 to 100 nm. These nanoparticles have distinct features that make them useful in a variety of applications [5]. The excellent antibacterial activity of AgNPs is one of their most recognized features. They have been investigated and used extensively for their capacity to suppress the development of numerous bacteria, viruses, and fungi. This feature has found utility in the healthcare business, where AgNPs are employed in wound dressings, medical device coatings, and even the manufacture of antimicrobial textiles [6]. Because of their efficacy against drug-resistant microorganisms, they are a crucial weapon in the battle against diseases. AgNPs provide high electrical and thermal conductivity in addition to antibacterial characteristics. As a result, they may be used in electronics and nanotechnology [7]. They may be used to improve the performance of flexible circuits and sensors by including them in conductive inks for printed electronics. Furthermore, because of their large surface area-to-volume ratio, they are suited for catalytic applications [8]. AgNPs are utilized as catalysts in a variety of chemical processes, including organic compound reduction and the creation of valuable molecules [9]. In addition, the size and shape of AgNPs have an effect on their optical characteristics. These qualities may be changed. They have a strong surface plasmon resonance, which enables them to perform very well in the context of applications connected to optics and photonics. They are employed as components in nanoscale optical systems as well as in the construction of sensors and imaging agents [10].

Fingerprinting applications would greatly benefit from AgNPs due to their high surface area-to-volume ratio, superior conductivity, and significant affinity for biomolecules [11]. To better identify and visualize latent fingerprints, AgNPs may interact effectively with the numerous components contained in fingerprint residues, such as amino acids, proteins, and fatty acids, owing to their tiny size and vast surface area [12]. Electrostatic interactions, hydrogen bonding, and van der Waals forces all play a role in the adsorption and immobilization of AgNPs onto fingerprint residues, making it possible to detect latent prints [13].

AgNPs have been used in a number of novel ways to enhance the latent fingerprint creation process in recent years. Using AgNPs in addition to conventional fingerprint powdering is one noteworthy technique that produces improved contrast and visibility because the nanoparticles stick to the fingerprint ridges specifically [14]. Furthermore, AgNPs may be used in chemical enhancement methods to increase the visibility of latent

prints on different surfaces, such as cyanoacrylate fuming and ninhydrin treatment. These techniques make use of AgNPs' catalytic qualities to accelerate the chemical processes necessary for the formation of latent prints, producing quicker and more accurate results [15].

Moreover, fingerprint analysis now offers additional possibilities because of the addition of AgNPs to nanocomposite materials. Researchers have created nanocomposite-based fingerprint sensors that can capture high-resolution fingerprint pictures by detecting even the smallest changes in the electrical characteristics of fingertip ridges. These sensors use AgNPs as conducting components. These sensors are able to monitor in real-time and may be included in security systems for biometric authentication and access control [16]. The use of AgNPs in fingerprinting has helped solve a number of problems, including those caused by latent prints that have been damaged or deteriorated over time. AgNPs, with their better stickiness and sensitivity, have shown promise in boosting the detection of old prints on many surfaces, including paper, glass, and plastics [17]. Surface-enhanced Raman spectroscopy (SERS) and surface-enhanced infrared absorption spectroscopy (SEIRAS) are two spectroscopic methods that have been used with AgNPs to help identify compounds left behind in latent prints [18].

In the context of criminal investigations, the introduction of AgNPs has greatly improved forensic analysis. Law enforcement agencies can now rely on more sensitive and efficient methods for latent print detection, potentially leading to the identification of suspects and the resolution of cases that were previously unsolvable. AgNPs are very useful because they can be used to see latent prints in difficult situations, like when there are contaminants or when the surface is porous, where other methods might not work well [19].

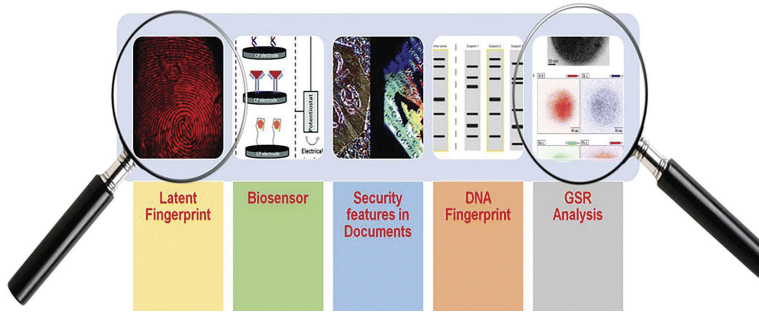

FIGURE 9.1 Use of nanotechnology in forensic science for fingerprint development.

Source: Reproduced from Ref. [66]. https://creativecommons.org/licenses/by/4.0/

9.2 SYNTHESIS AND CHARACTERIZATION OF SILVER NANO PARTICLES

9.2.1 CHEMICAL REDUCTION

The study of fingerprints has continued to be of utmost importance in forensic science and has been an integral part of numerous investigations. Despite their effectiveness, traditional methods can struggle with sensitivity and clarity. A potential revolution in this field is signaled by the creative use of AgNPs made by chemical reduction techniques. Ref. [20] detailed a thorough procedure for synthesizing AgNPs specifically designed for fingerprint recognition. They stressed AgNPs' distinctive physicochemical characteristics and their potential to improve contrast in fingerprint residues, particularly on challenging substrates. The breakthrough research of Ref. [21] examined the connection between forensics and nanotechnology. Due to the improved light-scattering and conductivity properties of AgNPs, which can be attributed to their nano-scale dimensions, their research highlighted the benefits of latent fingerprint viewing using these materials. The chemical reduction process, which includes converting silver ions in a solution to elemental silver using substances like sodium borohydride, is extremely efficient in the field of synthesis. This technique was thoroughly examined in key research by Ref. [22], which described how altering the reducing agent's concentration can fine-tune nanoparticle morphology and size. When looking at how AgNPs interact with fingerprint residues, Ref. [23] observed that these nanoparticles have a surprising affinity for certain substances that are frequently present in latent fingerprints, such as proteins and amino acids. They contend that the increased visibility provided by AgNPs is primarily due to this bonding. Authors in Ref. [24] have highlighted the adaptability of chemically-reduced AgNPs in fingerprint detection. Their research showed that AgNPs were effective at creating prints on a variety of surfaces, including porous ones like paper and nonporous ones like glass. With regard to durability and stability, Ref. [25] found that fingerprints created with AgNPs frequently preserve their sharpness and definition for protracted times, resolving a significant issue in the forensic area. It does have some difficulties though. Inconsistencies in nanoparticle size were explored in research by Ref. [26], which emphasized the need for consistent procedures. Concluding, the work of Ref. [27] echoed the sentiment that while the chemical synthesis of AgNPs presents promising advancements in fingerprint detection, continuous research is paramount to address existing challenges and further refine the technique.

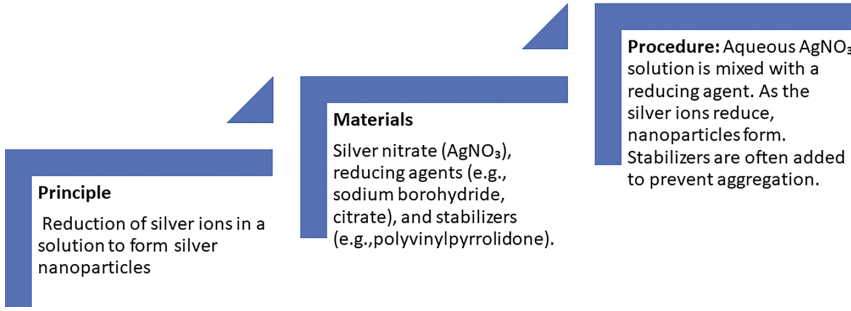

FIGURE 9.2 Preparation of silver nanoparticles with chemical reduction method.

TABLE 9.1 Depicting Different Methods of Silver Nanoparticle's Synthesis with Chemical Reduction Methods.

Method	Reducing Agent	Properties
Borohydride reduction	Sodium borohydride ($NaBH_4$)	Often used for synthesizing very small and uniform nanoparticles due to the strong reducing power of $NaBH_4$.
Citrate reduction	Sodium citrate	One of the most commonly used methods for synthesizing gold and silver nanoparticles. The Turkevich method, which produces gold nanoparticles, uses this approach.
Ascorbate reduction	Ascorbic acid (vitamin C)	Suitable for both silver and gold nanoparticle synthesis, especially in the presence of stabilizing agents or capping ligands.
Tollens process	Tollens' reagent (amoniacal silver nitrate)	Used particularly for silver mirror reactions but has been adapted for nanoparticle synthesis.
Hydrazine reduction	Hydrazine hydrate	A powerful reducing agent that can be used for various metal nanoparticles.
Polyol process	Polyols like ethylene glycol	In the presence of heat, ethylene glycol acts both as a reducing agent and a solvent, facilitating the synthesis of nanoparticles.
N,N-Dimethylformamide (DMF) reduction	DMF	Used under specific conditions where DMF can act as a reducing agent.
Hydroxylamine reduction	Hydroxylamine hydrochloride	Effective for the synthesis of gold and silver nanoparticles.
Lemon extract reduction	Lemon extract	The citric acid and other organic compounds in the lemon extract can act as reducing agents. This is also considered a green synthesis method.

9.2.2 PHYSICAL METHODS

Due to their distinct physicochemical characteristics, AgNPs have attracted a lot of attention lately. These traits are used in a variety of applications, including forensics, electronics, and medicine. Physical techniques, in particular, offer a safe way to create AgNPs because they frequently do not involve the use of hazardous chemicals. One such process that has been researched for manufacturing consistent AgNPs is the evaporation-condensation method used in tube furnaces [19]. Another intriguing method is called "laser ablation synthesis," which uses a laser pulse to remove silver from a target and create nanoparticles in a liquid media around them [20]. Although less prevalent, arc discharge and ion sputtering are examples of additional physical techniques that have been researched in the field of nanoparticle production [21, 22]. Physical approaches are appealing because they are environmentally friendly and because it is possible to regulate particle size and dispersion by adjusting the process parameters [23]. The use of physically produced AgNPs in the context of forensic applications like fingerprint detection is a developing subject of interest, albeit having scant published research as of the most recent update [24].

TABLE 9.2 Physical Methods of Silver Nanoparticle Development and Brief Description.

S. No	Method	Description
1.	Evaporation-condensation	A pure silver metal source is evaporated in a furnace, and the vaporized silver is then allowed to condense in a cooler region, resulting in nanoparticle formation.
2.	Laser ablation	A silver target is submerged in a liquid medium (like distilled water or organic solvents) and irradiated with a laser. The ablation process disperses silver atoms into the liquid, which then aggregate into nanoparticles.
3.	Sputtering	Silver is sputter-deposited onto a substrate in a high vacuum condition. The silver atoms accumulate on the substrate and form nanoparticles.
4.	Inert gas condensation	Silver is evaporated in a chamber filled with an inert gas. The evaporated silver atoms collide with gas atoms, lose energy, and condense to form nanoparticles, which can then be collected on a substrate.
5.	Thermal decomposition	Although this can also be viewed as a chemical method, the physical aspect involves heating a silver compound precursor (like silver carboxylates) under controlled conditions. The compound decomposes to yield silver nanoparticles.
6.	Physical vapor deposition (PVD)	Silver is evaporated and then deposited on a substrate in a controlled atmosphere, leading to nanoparticle formation.

TABLE 9.2 *(Continued)*

S. No	Method	Description
7.	Ion sputtering	Ions are used to sputter silver atoms from a target. These silver atoms then condense to form nanoparticles.
8.	Electrospinning	Though primarily used for the fabrication of nanofibers, under certain conditions and with the incorporation of silver salts or complexes, silver nanoparticles can be embedded within the fibers.
9.	Ultrasonication	Bulk silver can be subjected to intense ultrasonic vibrations in a liquid medium, causing the silver to disintegrate into smaller particles. While this method often requires some form of stabilizing agent in the liquid to prevent aggregation, the primary disintegration force is physical.

9.2.3 MICROWAVE-ASSISTED SYNTHESIS

Principle: Utilizes microwave radiation to heat the reaction mixture.

Procedure: A mixture of silver salts and reducing agents are subjected to microwave radiation, facilitating rapid nanoparticle formation.

When compared to normal heating techniques, microwave-assisted synthesis significantly cuts down on the amount of time needed to create nanoparticles [25]. This method has a number of benefits, such as uniform heating, quick reaction rates, and the creation of nanoparticles with precise size and shape control [26]. Because of AgNPs' distinct physicochemical characteristics, they are particularly effective in forensic applications for improving the contrast and clarity of latent fingerprints, especially on difficult surfaces [27]. AgNPs' affinity for substances frequently found in latent fingerprints, such as amino acids, fatty acids, and proteins, is one of the main advantages of employing them to create fingerprints [28]. One of the first researchers to look at the use of microwave synthesized AgNPs in forensic applications was Ref. [29]. In addition, it was found in a comparison study by Ref. [30] that AgNPs produced using a microwave have better stability and shelf life than those produced using more conventional techniques—a quality that is crucial for forensic applications. Ref. [31] emphasized the possibility for heterogeneity in nanoparticle size and shape when not properly controlling microwave settings, which might influence the outcome in fingerprint formation, but it was not without difficulties. According to Shah and coworkers [32], as forensic science develops, including nanotechnology, particularly through techniques like microwave-assisted synthesis, represents a substantial advancement. The

potential for discovering previously undetectable details is also part of the promise, which extends beyond the effectiveness of detection [33].

TABLE 9.3 Microwave-Assisted Synthesis of Silver Nanoparticles and its Brief Description.

S. No	Method	Description
1.	Microwave-assisted polyol process	Ethylene glycol or other polyols act both as a solvent and a reducing agent. Silver ions from a silver salt are reduced under microwave irradiation in the presence of polyols to form AgNPs.
2.	Microwave-assisted citrate reduction	Using citrate as a reducing agent, silver nitrate is reduced in the presence of microwave radiation. This can be viewed as a faster version of the Turkevich method.
3.	Microwave-assisted green synthesis	Natural reducing agents such as plant extracts, honey, or other biological molecules are combined with silver salts and subjected to microwave irradiation. This provides a green route for AgNP synthesis.
4.	Microwave-assisted seed-mediated growth	Initial small "seed" nanoparticles are first synthesized, which are then subjected to microwave-assisted growth in the presence of additional precursor materials. This can help in obtaining larger, uniform nanoparticles.
5.	Microwave-assisted surfactant-directed synthesis	Surfactants are employed to control the size and shape of the nanoparticles. In the presence of microwave radiation, these surfactants help in directing the growth of AgNPs in specific orientations.
6.	Microwave-assisted reduction with biopolymers	Biopolymers like chitosan or starch are used both as reducing and stabilizing agents. Under microwave irradiation, these biopolymers facilitate the synthesis and stabilization of AgNPs.
7.	Microwave-assisted core-shell nanoparticle synthesis	AgNPs are synthesized with a core of another material (e.g., gold) and then subjected to microwave-assisted growth to form a silver shell around the core.
8.	Microwave-assisted synthesis with ionic liquids	Ionic liquids can serve as solvents and stabilizers. Under microwave irradiation, silver salts dissolved in ionic liquids can lead to the formation of stable AgNPs.
9.	Microwave-assisted hydrothermal/ solvothermal synthesis	In a sealed container, silver precursors in a solvent are subjected to microwave radiation. The elevated pressure and temperature within the container promote the rapid synthesis of AgNPs.
10.	Microwave-assisted ligand exchange	Initially synthesized AgNPs with one type of ligand/capping agent are subjected to microwave treatment in the presence of a second ligand. This helps in changing the surface chemistry of the nanoparticles, potentially leading to different morphologies or properties.

9.2.4 GREEN SYNTHESIS

Principle: Uses environmentally friendly reducing and stabilizing agents.

Materials: Silver nitrate and natural reducing agents (e.g., fruit extracts, tea extracts).

Procedure: $AgNO_3$ is mixed with a natural reducing agent. The phytochemicals in the extracts reduce the silver ions and also act as stabilizers.

The development of sustainable and environmentally friendly methods for the synthesis of nanoparticles, particularly AgNPs, has gained significant momentum in recent years. The "green synthesis" approach, which capitalizes on the use of natural resources such as plant extracts, fungi, bacteria, and algae, is at the forefront of this movement [34]. When applied to the realm of forensics, particularly in the enhancement of latent fingerprints, the benefits of AgNPs synthesized through green methodologies are manifold. The rationale behind green synthesis lies in its simplicity, eco-friendliness, and cost-effectiveness. It bypasses the need for harmful reagents and high-energy input, commonly associated with traditional methods [35]. This not only reduces potential environmental and biological hazards but also produces nanoparticles with diverse shapes and unique properties, as observed by Ref. [36]. The promise of AgNPs has been recognized by forensic research, particularly when it comes to improving the clarity of fingerprints. When created, AgNPs' affinity for the proteins, fatty acids, and amino acids present in latent fingerprints results in increased contrast [37]. Reduced hazardous residue is an additional advantage of green-synthesized AgNPs, which is important when managing crime scene evidence. Ref. [38] investigated the utilization of tea and coffee extracts in the synthesis of AgNPs, revealing a quick and clean method with potential forensic applications. Similar to this, Ref. [39] used lemongrass leaf extract for AgNP production and noted that they could manipulate particle size by adjusting temperature and concentration.

The creation of fingerprints was directly connected to green-synthesized AgNPs in a ground-breaking work by Ref. [40]. On difficult substrates, they noticed improved ridge features, supporting the method's promise. Another important discovery made by Ref. [41] showed that green-synthesized AgNPs might enhance the luminescence qualities of latent fingerprints when paired with specific fluorescent dyes. But it is important to recognize the difficulties. According to Ref. [42], the biological

resource utilized can affect the consistency of nanoparticle size and form. The reproducibility of outcomes in forensic applications may be impacted by this variability. Yet, as underscored by Ref. [43], the integration of green nanotechnology in forensic science is still in its nascent stage but holds enormous promise, not just in the area of detection but also in setting sustainable practices in forensic labs.

TABLE 9.4 Green Synthesis of Silver Nanoparticle Development and Brief Description.

S. No	Method	Description	Example
1.	Plant extract-mediated synthesis	Many plants contain bioactive compounds that can reduce silver ions to AgNPs	Neem (*Azadirachta indica*) leaves or bark extract Aloe vera extract, pomegranate peel extract, green tea (*Camellia sinensis*) extract, cinnamon extract, lemongrass extract
2.	Fruit-mediated synthesis	Certain fruits and their extracts have been used as reducing agents	Banana, orange, pineapple, mango peel
3.	Microbial-mediated synthesis	Some bacteria, fungi, and algae possess the ability to reduce silver ions, leading to the formation of AgNPs	Bacteria: *Lactobacillus strains, Pseudomonas stutzeri* Fungi: *Fusarium oxysporum, Aspergillus niger* Algae: *Spirulina platensis*
4.	Biopolymer-mediated synthesis	Natural polymers can reduce and stabilize AgNPs	Chitosan, alginate, starch, cellulose
5.	Agricultural waste-mediated	Utilizing waste materials from agriculture as sources of reducing agents	Rice husk extract Coconut coir extract Peanut shell extract
6.	Animal extract-mediated synthesis	Some animal-based extracts or by-products have demonstrated potential in synthesizing AgNPs	Honey, silk cocoon
7.	Seaweed-mediated synthesis	Seaweeds contain compounds capable of reducing silver ions	*Kappaphycus alvarezii* *Sargassum wightii*

TABLE 9.4 *(Continued)*

S. No	Method	Description	Example
8.	Seed extract-mediated synthesis	Extracts from seeds of certain plants have shown potential in AgNP synthesis	Fenugreek seeds Sesame seeds
9.	Flower extract-mediated synthesis	Some flowers and their extracts have been explored for their capability to produce AgNPs	Hibiscus rosa-sinensis Moringa oleifera flowers
10.	Herbal infusion-mediated synthesis	Traditional herbal infusions or concoctions have been employed for AgNP synthesis	Ayurvedic or traditional Chinese medicine (TCM) concoctions

9.2.5 PHOTOCHEMICAL REDUCTION

Principle: Uses light energy to reduce silver ions.

Materials: Silver nitrate, light source (e.g., UV light).

Procedure: A solution of $AgNO_3$ is exposed to light, reducing the silver ions to form nanoparticles. The process can be controlled by varying light intensity and wavelength.

The ability to produce nanoparticles in ambient settings and the simplicity with which their size and form may be controlled make the photochemical reduction approach unique [44]. The utilization of AgNPs made through photochemical reduction in forensic research, notably in the area of latent fingerprint development, may provide unequaled benefits. In essence, photochemical reduction involves converting silver ions in a solution to silver atoms, which then form nanoparticles, by using light—typically from a UV source [45]. This technique has the benefit of not requiring high temperatures or pressures to produce pure, well-defined nanoparticles [46]. Its attraction is also increased by the absence of hazardous reducing agents [47]. The physical and chemical properties of AgNPs, including their size, shape, and surface charge, can play a crucial role in fingerprint development. These particles have an affinity for the various constituents of latent fingerprints, facilitating

enhanced visualization of ridge patterns [48]. Ref. [49] has emphasized the specificity of photochemically reduced AgNPs, highlighting their uniformity and sharpness in size, which can be advantageous for forensic applications. In forensic research, it has been shown that using AgNPs to improve latent fingerprints on difficult substrates, such as metallic or polymer surfaces, is efficient [50]. The capacity of photochemically generated AgNPs to attach preferentially to latent fingerprint residues, ensuring clarity and contrast in the developed prints, is one of its key benefits [51]. Ref. [52] demonstrates the superiority of photochemically reduced AgNPs over chemically reduced AgNPs, particularly in terms of their stability and reactivity, underlined the significance of the synthesis process. Yet, like all methodologies, challenges persist. Ref. [52] pointed out the susceptibility of these nanoparticles to aggregation under certain conditions, which might influence their performance in forensic applications.

However, as elucidated by Ref. [53], with ongoing advancements and a deeper understanding of the photochemical processes, the potential for AgNPs in fingerprint development and other forensic applications appears promising.

TABLE 9.5 Photochemical Methods of Silver Nanoparticle Development and Brief Description.

S.No	Method	Description
1.	UV light irradiation	Direct irradiation of silver salts like silver nitrate with UV light in the presence of a suitable stabilizing agent leads to the formation of AgNPs.
2.	Visible light irradiation	Silver salts can be reduced under visible light, especially when combined with certain photosensitizers or dyes that can absorb this light and transfer electrons to the silver ions.
3.	Laser ablation	A silver target is ablated using high-intensity laser pulses in a liquid medium, leading to the generation of nanoparticles from the bulk material.
4.	Photo-induced green synthesis	Using plant extracts combined with light irradiation, the bioactive molecules in the extracts can be activated to enhance the reduction of silver ions.
5.	Photochemical reduction with surfactants	Surfactants can be used to stabilize the nanoparticles formed under light irradiation. Depending on the choice of surfactant, it is possible to guide the size and shape of the nanoparticles.
6.	Dye-sensitized photochemical reduction	Dyes like methylene blue or eosin Y can be used to absorb light and then transfer electrons to silver ions, facilitating their reduction.

TABLE 9.5 *(Continued)*

S.No	Method	Description
7.	Titanium dioxide (TiO_2) mediated photoreduction	In the presence of a semiconductor like TiO2, which acts as a photocatalyst, silver ions can be reduced under light irradiation.
8.	Plasmon-induced photochemical reduction	Gold or other metal nanoparticles, which possess strong plasmonic properties, can be used to enhance the local electric field upon light irradiation. This can boost the photochemical reduction of nearby silver ions.
9.	Photosensitive polymer-mediated synthesis	Some polymers become electron donors upon light irradiation. Such polymers can facilitate the photochemical reduction of silver ions in solution.
10.	Silver halide-based photochemical reduction	Silver halides, used traditionally in photographic films, can be reduced to elemental silver upon exposure to light, especially when coupled with suitable developers or reducing agents.

9.2.6 ULTRASONICATION (SONOCHEMICAL METHOD)

Principle: Utilizes ultrasonic waves to produce cavitation bubbles in a liquid, leading to the formation of nanoparticles.

Procedure: A silver precursor solution is subjected to ultrasonication. As the cavitation bubbles collapse, high temperatures and pressures are generated locally, leading to nanoparticle formation.

Particularly in applications connected to forensic sciences like fingerprint creation, the sonochemical approach of synthesizing AgNPs has generated a great deal of interest. In a liquid media, ultrasonication makes it easier to create high-energy cavitation bubbles, which when they collide produce extremely intense localized heat and pressure. This unusual occurrence has the ability to trigger the synthesis of nanoparticles from their starting components [54]. Due to their unique physicochemical characteristics and interactions with fingerprint residues, sonochemically produced AgNPs are emerging as a viable method in the field of latent fingerprint detection. A quick and effective technique to create AgNPs with limited size distributions and regulated sizes is by the sonochemical process [55]. The cavitation collapse generates a significant amount of energy, which results in the formation of nanoparticles that are frequently free of agglomerates and have a high degree of crystallinity [56]. These elements may improve

how nanoparticles interact with latent fingerprint remnants, enhancing the visualization of ridge features. The method of synthesis that is selected has an impact on fingerprint development. AgNPs made using ultrasonication have shown to be more consistent and uniform than those made through other physical or chemical processes [57]. This consistency can help in getting reliable fingerprint enhancement results on various substrates. Ref. [58] and other researchers have shown the benefit of producing monodispersed AgNPs via ultrasonication. In a separate investigation, Ref. [59] highlighted the capacity of sonochemically synthesized nanoparticles to adhere effectively to fingerprint residues, facilitating better contrast and clarity in developed prints.

Additionally, the sonochemical approach can make it easier to create AgNPs when stabilizing agents are present, which might increase their affinity for particular elements of latent fingerprints [60]. The selective binding of nanoparticles is ensured by this particular interaction, which improves the visualization of ridge patterns against difficult backgrounds [61]. However, problems still exist, just like with any technique. To avoid the unexpected growth or aggregation of nanoparticles, which could decrease their effectiveness in the formation of fingerprints, some researchers have emphasized the need for adjusting ultrasonication conditions [62]. Despite these difficulties, pioneers in the field have acknowledged the ultrasonication method's potential for creating high-quality AgNPs appropriate for forensic applications, particularly fingerprint generation [63].

TABLE 9.6 Sonochemical Methods of Silver Nanoparticle Development and Brief Description.

S. No	Method	Description
1.	Direct sonochemical reductio	Silver salt solutions, like silver nitrate, are directly subjected to ultrasonic irradiation, leading to the formation of AgNPs.
2.	Sonochemical polyol process	Ultrasonication is applied to a solution of silver salts in polyols (e.g., ethylene glycol), where the polyol acts both as a solvent and a reducing agent.
3.	Ultrasonication-assisted green synthesis	Plant extracts or other natural reducing agents are combined with silver salts and subjected to ultrasonication, harnessing both the reducing power of the bioactive compounds and the sonochemical energy.

TABLE 9.6 *(Continued)*

S. No	Method	Description
4.	Sonochemical reduction with surfactants	Surfactants are added to control the size, morphology, and stability of the AgNPs. Ultrasonication helps in reducing the silver ions and dispersing the newly formed nanoparticles effectively.
5.	Sonochemical synthesis with stabilizing agents	Polymers or other stabilizing agents (like polyvinylpyrrolidone, PVP) are introduced to prevent the agglomeration of the AgNPs during and after the ultrasonic irradiation.
6.	Sequential sonochemical and thermal treatment	After initial sonochemical reduction, the AgNP solution undergoes a thermal treatment to achieve specific nanoparticle sizes or morphologies.
7.	Sonochemical seed-mediated growth	Silver "seed" nanoparticles are first synthesized and then subjected to further growth under ultrasonication in the presence of additional silver precursor.
8.	Sonochemical bimetallic nanoparticle synthesis	Alongside silver, another metal precursor (like gold or copper) is added, leading to the formation of bimetallic nanoparticles under ultrasonic irradiation.
9.	Sonochemical reduction in microemulsions	Silver precursors are mixed in a microemulsion medium, and ultrasonication induces the formation of AgNPs within the confined spaces of the microemulsion droplets.
10.	Sonochemical synthesis under controlled atmosphere	Ultrasonication is performed under specific atmospheres (e.g., inert gases) to prevent oxidation or to influence the properties of the formed AgNPs.

9.2.7 BIOLOGICAL SYNTHESIS

Principle: Utilizes microorganisms or plant extracts as reducing agents.

Materials: Silver nitrate, microbial cultures (e.g., bacteria, fungi) or plant extracts.

Procedure: Mix $AgNO_3$ with the biological material.

Silver ions are gradually reduced by the biological substance to generate nanoparticles. AgNPs can now be created biologically as an environmentally friendly substitute for traditional chemical and physical processes. The green synthesis method uses living things including plants, bacteria, fungi,

and even some types of algae to convert silver ions into nanoparticles. In addition to benefits like benign reaction conditions and less toxicity, this environmentally friendly synthesis approach offers a platform for producing AgNPs with unique features ideal for fingerprint development in forensic research. The ease and affordability of biological synthesis are what make it so appealing. Numerous phytochemicals found in organisms, particularly plants, can function as both reducing and stabilizing agents during the formation of nanoparticles [64]. For instance, Kulkarni et al. [66] reported using plant extracts to create well-dispersed AgNPs with improved binding affinity to latent fingerprint residues in their study [65]. Another interesting synthesis method is microbial pathways, which use bacteria or fungi. Due to their distinct metabolic pathways, bacteria have the ability to bio-reduce metal ions to nanoparticles either intracellularly or extracellularly [66]. Fungi might be effective biofactories for the generation of AgNP due to their strong wall-binding and intracellular absorption capacities, as noted by Ref. [67]. The spontaneously generated AgNPs can have several benefits for fingerprint development. The biogenic AgNPs showed a stronger affinity for the amino acids and fatty acids found in latent fingerprints, according to the work by Ref. [68], facilitating better visualization and pattern identification. AgNP shape and size are key factors in how they interact with fingerprint residues. It is interesting to note that depending on the organism or extract employed, biological synthesis techniques allow for adjustable nanoparticle properties. The type of plant extract and its concentration had a substantial impact on the form and size of the resultant AgNPs, according to Ref. [69]. Despite the fact that the biological synthesis of AgNPs has several benefits, issues with scalability, repeatability, and stability need to be resolved [70]. Despite these difficulties, it is clear that they have a future in forensic applications, particularly fingerprint creation. Studies like those of Ref. [71], which revealed improved fingerprint clarity utilizing biogenic AgNPs compared to chemically manufactured counterparts, have further supported this.

It is interesting to note that Mukherjee's research [72] hypothesized that the surrounding biogenic AgNPs' natural biomolecules would help them selectively bind to fingerprint residues, providing a naturally improved imaging technique. In conclusion, the function of biologically generated AgNPs in forensic applications, particularly fingerprint enhancement, becomes increasingly significant and calls for further investigation [73] as the field of green nanotechnology develops.

TABLE 9.7 Biological Methods of Silver Nanoparticle Development and Brief Description.

S. No	Synthesis Type	Description
1.	Bacterial	Several bacterial species can reduce silver ions to form AgNPs. Examples include *Pseudomonas stutzeri*, *Escherichia coli*, and *Bacillus licheniformis*.
2.	Fungal synthesis	Fungi, such as Aspergillus, Fusarium oxysporum, and Trichoderma, can produce AgNPs. Fungal processes are advantageous because they can produce larger quantities of nanoparticles compared to bacteria due to the higher amount of biomass.
3.	Plant extract synthesis	Many plant extracts have been utilized to reduce silver ions, leading to the formation of AgNPs. Examples include extracts from neem (*Azadirachta indica*), aloe vera, pomegranate, and green tea.
4.	Yeast synthesis	Yeasts like Saccharomyces cerevisiae have been employed in the synthesis of AgNPs due to their ability to produce certain biomolecules that can reduce silver ions.
5.	Algae-based synthesis	Certain algae can produce AgNPs. For instance, brown macroalgae like *Sargassum wightii* has been studied for its potential in this regard.
6.	Virus-mediated synthesis	Some viruses can bind metal ions and reduce them to nanoparticles, although this method is less explored compared to others.
7.	Biosynthesis using actinomycetes	Actinomycetes, a type of bacteria, can also be used in the synthesis of AgNPs. Strains of streptomyces are commonly studied for this purpose.
8.	Synthesis using plant pollens and spores	Certain pollens and spores can reduce silver ions to form nanoparticles. This method is less common but offers another avenue for green synthesis.
9.	Biosynthesis using animal extracts	Some animal extracts, such as those from tunicates, have been investigated for their potential to reduce silver ions and produce nanoparticles.
10.	Biopolymer-mediated synthesis	Natural polymers, such as chitosan, have been employed as both reducing and stabilizing agents in the synthesis of AgNPs.

9.2.8 ELECTROCHEMICAL METHODS

Principle: Electrolytic cells are used where AgNPs are formed at the cathode.

Procedure: In an electrochemical cell, a silver precursor is reduced to form AgNPs.

The size and shape can be controlled by varying the electrode potential and electrolyte concentration.

With control over nanoparticle size, dispersion, and shape, the electrochemical production of AgNPs offers special benefits. The intricacies of this strategy, its effectiveness, and its potential contributions to improving fingerprint visualization become clear when researchers delve deeper into the field of electrochemical synthesis. Utilizing an electrolytic cell, silver ions are reduced to produce nanoparticles at the cathode under an applied electric potential in electrochemical synthesis [74]. By adjusting the applied voltage, current density, and electrolyte composition, this technique may accurately control the nucleation and development of nanoparticles [75]. The dynamics of nanoparticle generation and stability under various electrochemical circumstances are explained in the research by Ref. [76]. Depending on their size and surface characteristics, fingerprint residues—a combination of natural secretions and foreign contaminants—can interact with nanoparticles in various ways. These characteristics may be specially tailored for use in fingerprint development applications using the electrochemical approach. Notably, Ref. [77] highlighted the improved ridge details of electrochemically generated AgNPs compared to conventionally prepared nanoparticles due to their higher adhesion to latent fingerprints. Additionally, the quality of nanoparticles produced electrochemically is frequently higher since the process avoids the use of abrasive reducing agents or stabilizers that can obstruct the visualization of a subsequent fingerprint [78]. Ref. [79] adjusted electrochemical settings to produce AgNPs that selectively bonded to specific fingerprint constituents, resulting in enhanced contrast and definition. Visualization depends heavily on the substrate that fingerprints are left on. Researchers like Ref. [80] have shown the possibility of adjusting AgNP properties to suit a variety of substrates, from porous to nonporous surfaces, thanks to the adaptability of the electrochemical synthesis. Electrochemical synthesis, like all techniques, is not without difficulties. Researchers' top concerns are electrode material, stability, and scaling-up [81]. But ground-breaking studies, like the one by Ref. [82], highlight the technique's unmatched potential for creating high-quality AgNPs, particularly for uses in fingerprint development. In conclusion, the field of electrochemical synthesis of AgNPs is poised to make significant contributions as the demand for sophisticated, reliable, and effective methods of latent fingerprint generation increases. The importance and promise of this strategy are only highlighted by recent findings and current research [83].

TABLE 9.8 Electrochemical Methods of Silver Nanoparticle Development and Brief Description.

S. No	Electrolysis	Description
1.	Potentiostatic	A constant potential is applied across the anode and cathode in an electrochemical cell containing a silver salt solution. The silver ions are reduced at the cathode to form nanoparticles.
2.	Galvanostatic electrolysis	A constant current is passed through the electrochemical cell, resulting in the reduction of silver ions at the cathode to produce AgNPs.
3.	Pulsed electrochemical deposition	Instead of continuous potential or current, pulses are applied. The intermittent nature allows for better control over the growth of the nanoparticles, often leading to uniform particle sizes.
4.	Template-assisted electrochemical synthesis	This method uses a template, such as a porous membrane, to guide the growth of the nanoparticles in specific patterns or sizes. The silver salt solution fills the template's pores, and an external potential drives the formation of AgNPs within these confined spaces.
5.	Sonoelectrochemical method	Combines ultrasonication with electrochemical techniques. The presence of ultrasound can help in the dispersion of the nanoparticles, preventing aggregation.
6.	Flow electrolysis	The silver precursor solution is continuously flowed through an electrochemical cell. The flowing nature ensures fresh reactants are always in contact with the electrode, potentially offering better control over nanoparticle synthesis.
7.	Micellar electrochemical synthesis	Surfactants form micelles in the solution, which can act as nano-reactors. In the presence of an external electric field, silver ions are reduced within these micellar structures, leading to the formation of AgNPs.
8.	Two-phase electrochemical synthesis	This method involves two immiscible liquid phases. One phase contains the silver precursor, while the other serves as the electrode where the reduction occurs. The interface between the two phases becomes the active site for nanoparticle formation.
9.	Photo-electrochemical synthesis	This method combines light irradiation with electrochemical processes. The presence of light can assist in the reduction of silver ions, often enabling the synthesis of nanoparticles at lower potentials.
10.	Wire electrode method	A silver wire electrode is partially immersed in a nonconductive solvent containing a dispersing agent. When a potential is applied, silver ions migrate from the wire into the solution, where they get reduced to form AgNPs.

9.3 APPLICATIONS OF SILVER NANOPARTICLES IN FINGERPRINTING ENHANCEMENT

AgNPs have found widespread application in the field of fingerprinting due to their unique properties and versatility. Fingerprinting, a critical component of forensic science and criminal investigations, is based on the accurate identification and analysis of fingerprint patterns left at crime scenes. With their tiny size and amazing optical, chemical, and biological capabilities, AgNPs have transformed the way fingerprints are recognized, lifted, and studied.

One of the most significant applications of AgNPs in fingerprinting is the development of latent fingerprints. Latent fingerprints are often invisible to the naked eye and need amplification to be visible [50]. When applied to surfaces with latent prints, AgNPs work as an effective contrast agent. These nanoparticles bind specifically to the chemical compounds in fingerprint residue, enhancing the visibility of ridge patterns and minutiae. This improvement increases the likelihood of successful detection and analysis in criminal investigations [51]. This could be due to metallic silver interacting with the organic component of fingerprint residue, making fingerprints on paper substrates more visible for a longer period of time.

Furthermore, nanoparticles may be used in a variety of fingerprint-detecting methods. The nanoparticle-based cyanoacrylate fuming method is one such approach. This approach combines cyanoacrylate, a chemical that emits vapors that may bind to latent fingerprints, with nanoparticles [50]. The nanoparticles interact with the cyanoacrylate vapors, increasing the visibility of the fingerprint imprints and making it simpler for forensic professionals to lift and examine them. This method works especially well on nonporous surfaces like glass, plastic, and metal [3, 52].

In addition, AgNPs have been shown to significantly contribute to the preservation of fingerprint evidence over an extended period of time. Over the course of time, the integrity of fingerprints present on various surfaces may deteriorate as a result of environmental influences, hence diminishing their efficacy in investigation [53]. The use of nanoparticles as a protective covering has the potential to alleviate this concern. A thin and stable coating is created over the fingerprint, providing protection against moisture, UV radiation, and other factors that may cause degradation [54].

AgNPs also help to create novel detection techniques in fingerprint analysis. They may be embedded in sensors and imaging systems, allowing for speedy and extremely sensitive fingerprint identification [55]. For example, sensors enhanced with AgNPs may detect even small quantities of perspiration, oils, or residues left on a surface following contact with a fingertip [56]. Furthermore, the antibacterial capabilities of AgNPs may be used to avoid fingerprint evidence contamination during collection and processing. These nanoparticles may be mixed into gloves, brushes, and other forensic instruments to help preserve evidence and reduce the chance of cross-contamination [11, 57].

AgNPs also help to create novel detecting techniques in fingerprint analysis. They are capable. Finally, AgNPs have transformed the world of fingerprinting by providing several benefits in the production, lifting, preservation, and analysis of fingerprint evidence. Their distinct features, including preferential binding to chemical substances and antibacterial properties, make them valuable forensic instruments. As technology advances, AgNPs are projected to play an increasingly important role in the advancement of fingerprinting procedures, boosting the accuracy and efficiency of criminal investigations globally [51, 54, 59–61].

9.4 ADVANCES AND CHALLENGES

Advances in AgNPs fingerprinting have brought about significant progress in various scientific fields, particularly nanotechnology, materials science, and biomedicine [58, 62]. The utilization of advanced analytical techniques, such as spectroscopy, microscopy, and SERS, has enabled researchers to precisely characterize the size, shape, and surface chemistry of AgNPs. These advances have facilitated the development of tailored AgNPs with specific properties for diverse applications, ranging from drug delivery systems to catalysis and sensing [63].

However, along with these advances, several challenges persist in AgNP fingerprinting. One significant challenge is the potential toxicity of AgNPs, as their small size and high surface area can lead to enhanced reactivity and adverse biological effects. Consequently, rigorous safety assessments and regulatory guidelines are essential to ensure the responsible use of AgNPs in consumer products and medical applications. Moreover, AgNP can easily aggregate, making their characterization and stability challenging. This necessitates the development of innovative strategies

to prevent aggregation and maintain the desired properties of AgNPs throughout their lifecycle. Additionally, the standardization of analytical methods and reference materials for AgNPs characterization remains a challenge, hindering the comparability of research results across different laboratories and studies. Addressing these challenges will be crucial for harnessing the full potential of AgNPs while minimizing their risks in various applications [64, 65].

9.5 CONCLUSION

Over the years, there has been a tremendous evolution in the production of AgNPs, with several techniques showing their distinct benefits. The method of synthesis that is chosen has a significant impact on the outcomes in the field of forensic research, particularly when improving the visualization of latent fingerprints. Electrochemical techniques stand out among the various synthesis methods because they can precisely regulate nanoparticle properties such as size, distribution, and shape. This chapter highlights the potential of electrochemical synthesis. It makes a strong case for adoption in the forensic field thanks to its precision, flexibility to various substrates, and capacity to avoid the use of potentially interfering chemicals. The potential of AgNPs generated via electrochemical methods in achieving improved clarity and definition in fingerprint visualization, a critical component in forensic investigations, is attested to by a number of research referenced below. Challenges still exist, though, as with other scientific approaches. Further research is needed in the areas of reproducibility across diverse setups, long-term stability of the produced nanoparticles, and the scalability of electrochemical approaches. It is possible that solutions to these problems will be found as this field of study develops, significantly improving the approach and securing its place in the arsenal of forensic methodologies. It is clear that the search for the ideal AgNP synthesis method is a never-ending process. However, the developments made, particularly in the Field of electrochemical synthesis, present interesting directions. It is envisaged that the employment of AgNPs in fingerprint creation will reach new heights as technology advances and as our understanding increases, pushing the limits of what is feasible in forensic research.

KEYWORDS

- **Electrochemical**
- **forensic science**
- **phytochemical**
- **silver nanoparticles**
- **synthesis**
- **ultrasonification**

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CHAPTER 10

Enhancing Fingerprint Identification: Utilizing CdS and CdSe Nanoparticles for Latent Print Development

VAIBHAV SHARMA[1], ANJALI SOY[1], ARCHANA GAUTAM[2], SNEHA LOHAR[3], POONAM KUMARI[3], BADAL MAVRY[3], RAJEEV KUMAR[3], KAMAKSHI PANDEY[4], and TINA SHARMA[5]

[1]*Department of Forensic Science, Vivekananda Global University, Jaipur, Rajasthan, India*

[2]*Department of Forensic Science, UIAHS, Chandigarh University, Mohali, Punjab, India*

[3]*Department of Forensic Science (SBMS), Galgotias University, Greater Noida, Uttar Pradesh, India*

[4]*Department of Physics and Material Research Centre, Malaviya National Institute of Technology, Jaipur, Rajasthan, India*

[5]*Department of Forensic Science, Bahra University, Shimla Hills*

ABSTRACT

This chapter presents a novel method for forensic investigations by examining the application of cadmium sulfide (CdS) and cadmium selenium (CdSe) nanoparticles for latent fingerprint formation. Criminal investigations depend heavily on fingerprint analysis, and new uses of nanotechnology have the potential to completely transform this area of study. Because of their special qualities, which include highly photoactive and programmable sizes, CdS and CdSe nanoparticles are perfect for

Nanoparticles in Fingerprinting: Advanced Methods for Development of Latent Fingerprints.
Kumud Kant Awasthi, Mahipal Singh Sankhla, Chandra Shekhar Yadav, and Anjali Awasthi (Eds.)

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detecting latent prints on a variety of surfaces. With less influence on the environment and less toxicity than conventional techniques, they provide an eco-friendly substitute. The usefulness and efficacy of these nanoparticles in raising the precision and productivity of fingerprint analysis are demonstrated by case studies and research findings.

10.1 INTRODUCTION

Due to its crucial significance in personal identification, the detection of fingermarks is a topic of great interest in forensic research. Usually, latent fingermarks are the most often discovered fingermarks at crime scenes [1, 2]. The lifelong objective of forensic scientists is to produce a sensitive, easy-to-use, and successful method for creating latent fingermarks. Generally speaking, there are three types of fingerprint evidence that may be discovered at a crime scene: latent prints, impression prints, and visible prints, often known as patent prints [3–5]. Latent prints need to be developed or enhanced in order to be visualized because they are not visible to the unaided eye [6, 7]. Although other methods for latent fingerprint detection have been developed, the powdering approach is still the standard method for processing latent prints in fingerprint detection [8, 9]. The fingerprint powder sticks to any residue, perspiration, or other elements left in a fingerprint when it is applied to the afflicted region. The application of nanotechnology to latent fingerprint detection has expanded recently, with implications for selectivity, contrast, and sensitivity improvements, among other things [10, 11]. Anatomy and physiology are the focus of forensic technology in order to get trustworthy evidence against offenders [12]. Nanotechnology is therefore developing in forensic research to effortlessly acquire evidence at crime scenes and their surroundings and present this after laboratory analysis in a court of law [13, 14].

In particular, the scientific community has shown a great deal of interest in the use of fluorescent semiconductors as labeling agents in the development of latent fingermarks [12, 15]. The synthesis of semiconductor powders and aqueous dispersions has been the subject of significant efforts, the majority of which are predicated on the employment of semiconductor nanoparticles of the II/VI type as luminescence probes, such as cadmium sulfide (CdS) and cadmium selenium (CdSe) [16–18].

Excellent luminous characteristics are well known for CdS and CdSe nanoparticles. They produce bright and easily recognizable fluorescence

when stimulated by the right light source [19, 20]. Because of this feature, they are perfect for improving latent fingerprint contrast and visibility—even on difficult surfaces [21]. The adjustable emission wavelengths of CdS and CdSe nanoparticles are one of their main benefits. Researchers can accurately regulate the color of the light emitted during synthesis by adjusting the size and content of these nanoparticles [22, 23]. This allows for customized responses to certain substrates and background materials. Enhancing the selectivity and sensitivity of fingerprint formation requires this flexibility. It is well known that CdS and CdSe nanoparticles are stable and photostable [24, 25]. They do not lose their luminescence even in the face of severe environmental conditions and prolonged light exposure. This guarantees that the generated fingerprints will always be observable and trustworthy for analysis. The latent prints that CdS and CdSe nanoparticles have produced on a variety of surfaces, including porous and nonporous materials, have shown to be versatile [26]. Their application in diverse forensic settings is increased by their versatility. In contrast to certain traditional techniques for fingerprint formation that could entail hazardous substances, CdS and CdSe nanoparticles provide a cleaner substitute [27, 28]. They usually use less potentially dangerous ingredients, which makes forensic procedures safer and more environmentally friendly. The manufacture and use of CdS and CdSe nanoparticles in latent fingerprint formation are still being advanced by ongoing research [29]. With increased sensitivity and specificity from fingerprint visualization techniques, forensic investigations should become more accurate and efficient. CdS and CdSe nanoparticles are interesting candidates for the construction of latent fingerprints because of their special mix of luminous characteristics, tunability, stability, and decreased toxicity [30, 31]. The utilization of these tools not only improves the skills of forensic specialists but also helps the criminal investigation profession adopt more ecologically friendly procedures.

10.2 NANOTECHNOLOGY IN FINGERPRINT DEVELOPMENT

For more than a century, fingerprint analysis has been an essential technique in forensic science, being crucial to both criminal investigations and person identification. This field has been supported mostly by conventional fingerprint creation procedures, including dusting and chemical

operations [32, 33]. On the other hand, latent fingerprint development is entering a new age marked by recent breakthroughs in nanotechnology. The visualization and detection of latent fingerprints have been shown to be greatly enhanced by nanomaterials, particularly semiconductor nanoparticles [34].

10.2.1 CdS AND CdSe NANOPARTICLES AND THEIR PROPERTIES TO DEVELOP LATENT FINGERPRINT

Among the many uses of nanotechnology, latent fingerprint development has drawn a lot of interest in the use of semiconductor nanoparticles like CdS and CdSe. They are very promising for improving the visualization of latent fingerprints because of their special qualities [35].

Luminescence is one of the most remarkable features of semiconductor nanoparticles. These particles glow with great intensity and distinctness when exposed to the right light source. This characteristic, which considerably increases the contrast and visibility of latent fingerprints even on difficult surfaces, is crucial to the development of fingerprints [36, 37]. One benefit of CdS and CdSe nanoparticles, in particular is that their emission wavelengths may be adjusted. Researchers can accurately alter the color of the light that is emitted by manipulating the size and composition of these nanoparticles throughout the production process [38, 39]. This tunability enhances the selectivity and sensitivity of fingerprint creation by enabling customized responses to certain substrates and background materials.

It is well known that CdS and CdSe nanoparticles are stable and photostable. They do not lose their luminescence even in the face of severe environmental conditions and prolonged light exposure [40]. This guarantees that the generated fingerprints will always be observable and trustworthy for analysis. The latent prints that CdS and CdSe nanoparticles have produced on a variety of surfaces, including porous and nonporous materials, have shown to be versatile [41, 42]. Their application in diverse forensic settings is increased by their versatility. In contrast to certain traditional techniques for fingerprint formation that could entail hazardous substances, CdS and CdSe nanoparticles provide a cleaner substitute [43]. They usually use less potentially dangerous ingredients, which makes forensic procedures safer and more environmentally friendly [44].

10.2.2 APPLICATION OF CdS AND CdSe NANOPARTICLE IN FINGERPRINT DEVELOPMENT

The use of CdS and CdSe nanoparticles in fingerprint creation has several benefits that greatly improve forensic investigation skills. Among these advantages is improved sensitivity, as these nanoparticles' luminescence greatly increases the capacity to clearly see even weak or incomplete prints [45]. Furthermore, a selective reaction to particular substances and background materials is made possible by the adjustable emission wavelengths of CdS and CdSe nanoparticles, which lowers the possibility of false positives and improves the overall accuracy of fingerprint analysis [46]. Together, CdS and CdSe nanoparticles have an impact that is not only additive but also synergistic, enhancing each of their unique properties. The optical abilities of CdSe nanoparticles are enhanced by CdS nanoparticles, which are well known for their strong contact with fingerprint residues and high-contrast imaging [47, 48]. Combining CdSe improved sensitivity and specificity with CdS strong interaction processes yields a complete latent fingerprint development solution. Because of their adaptability to a variety of surfaces, including paper, plastic, and glass, they may be used in a variety of forensic contexts [38, 49]. Additionally, using nanoparticles speeds up growth, giving forensic investigators faster results. Significantly, by providing a less hazardous and more sustainable substitute for some conventional fingerprint production techniques, these nanoparticles also help with environmental responsibility by lowering the risk of injury to both investigators and the environment [50].

10.3 CDS NANOPARTICLES

CdS nanoparticles have been used in forensic research, leading to notable improvements in latent fingerprint analysis. Recent studies have demonstrated creative approaches that take advantage of the special characteristics and methods of synthesis of CdS nanoparticles to improve latent print visibility on a variety of porous and nonporous surfaces [35]. Several CdS nanoparticle compositions have been investigated in these studies; each has unique properties that meet the changing demands of the forensic community [42].

In a work, scientists used 2-mercaptoacetic acid-capped CdS nanoparticles doped with Mn^{2+} to enhance fingerprint visibility using a unique strategy [51]. The coprecipitation process was used to create these nanoparticles,

which have a spherical average size of about 6–7 nanometers. By using the exceptional qualities of CdS nanoparticles, this novel method provided an efficient way to improve latent prints on a range of surfaces. A further line of inquiry focused on the use of photoluminescent CdS/polyamidoamine (PAMAM) nanocomposites [52] to improve latent fingerprints. These nanocomposites were created *in situ*, demonstrating their versatility and suitability for a variety of surfaces. These CdS/PAMAM nanocomposites' photoluminescent properties within the PAMAM matrix made them an extremely attractive choice for enhancing latent fingerprints. This method was a significant advancement in the search for sophisticated fingerprint analysis methods. Phthalocyanine (PPH-CN) and mercaptopropyl (PPH-SH)-functionalized porous phosphate heterostructures (PPH) were used to create fluorescent hybrid CdS quantum dots (QDs) [53]. The results showed that these water-based compounds were very successful in making latent impressions more visible on nonporous and porous surfaces. By combining the characteristics of CdS QDs with PPH, this novel hybrid structure offered a promising route for forensic applications and revolutionized fingerprint analysis [54]. Using highly photoluminescent CdS QDs integrated in a biopolymeric chitosan matrix for latent fingermark detection was yet another innovative technique. These nanoparticles, which have a diameter of around 20 nanometers and a nanospheric shape, showed how biopolymeric matrixes might improve the photoluminescent qualities of CdS QDs. This method demonstrated the efficacy of CdS QDs in a biopolymeric framework and provided a strong instrument for the generation of latent fingerprints.

All of these varied studies highlight the potential and adaptability of CdS nanoparticles in latent fingerprint analysis. Through the investigation of diverse manufacturing methods and compositions, these investigations have markedly improved the state of forensic research in this field. CdS nanoparticles have shown to be an effective tool, offering improved visibility, sensitivity, and selectivity on a variety of surfaces [36–39]. These cutting-edge techniques are essential to advancing criminal investigations and forensic science into new frontiers of accuracy and efficacy. One cannot overstate the importance of these innovative methods. They have the secret to faster, more precise fingerprint analysis, which will eventually help the legal system serve the public interest. CdS nanoparticles give forensic experts a potent toolkit to solve complicated cases and make sure the guilty are held responsible for their deeds by enhancing latent print visibility. With the ongoing advancements in technology and research,

the use of CdS nanoparticles in latent fingerprint analysis is expected to become more crucial in the pursuit of justice [29, 46–48].

10.4 CdSe NANOPARTICLES

Because of the special optical and chemical characteristics of CdSe nanoparticles, their use has attracted a lot of attention. The results of three significant investigations, each concentrating on a distinct facet of the formation of latent fingerprints based on CdSe nanoparticles, are examined and summarized in these studies. In a study, CdSe QDs are incorporated into PPH to create a fluorescent nanocomposite known as PPH-NH_2@ CdSe [55]. Amino groups provide further functionalization to the nanocomposite. This complex synthesis makes it possible to produce a material that is extremely sensitive for latent fingerprint detection. Phosphate heterostructures' porous nature improves their ability to adsorb substances, and the amino groups offer another degree of specificity when they attach to the fingerprint residues [56]. Another study used mercaptoacetic acid-stabilized CdSe nanoparticles to produce latent fingerprints [57]. This work highlights the adaptability of this nanomaterial in forensic applications by extending the use of CdSe nanoparticles to both porous and nonporous surfaces. Mercaptoacetic acid, the stabilizing agent, helps to improve the interaction between CdSe nanoparticles and latent fingerprint residues on a variety of surfaces in addition to ensuring the stability of the nanoparticles. The use of CdSe/PAMAM QDs [56] for latent fingerprint development is the subject of one research. The basic principles of CdSe nanoparticle interactions with fingerprint residues are clarified by this work. Because of their size and composition, the QDs have special optical qualities that make them perfect for selective and sensitive latent fingerprint detection. The work advances our knowledge of the fundamental processes governing the interplay between latent fingerprint chemical composition and CdSe QDs.

When taken as a whole, these investigations show how versatile and useful CdSe nanoparticles are for developing latent fingerprints. By combining the benefits of amino functionalization with porous architectures, the fluorescent nanocomposite creates a material that is specifically designed for sensitive and targeted fingerprint detection. These demonstrate the versatility of CdSe nanoparticles in actual forensic situations by expanding their applicability to a wider range of surfaces, including porous and nonporous ones [37, 38].

Forensic science places great significance on the use of CdSe nanoparticles in latent fingerprint formation for a number of reasons. First off, CdSe nanoparticles have remarkable optical characteristics, such as adjustable emission spectra and strong fluorescence. Even under difficult circumstances, these characteristics improve the contrast and sensitivity of fingerprint detection. Second, the adaptability of CdSe nanoparticles enables the effective generation of latent fingerprints on a variety of surfaces. This flexibility is essential in forensic investigations since different surfaces have different properties and conventional techniques might not work. Moreover, adding CdSe nanoparticles to porous materials allows for increased adsorption capacity, which improves latent fingerprint residue retention and visualization. In one research, the amino functionalization adds a layer of selectivity, improving the CdSe nanoparticles' specificity toward the target residues [34]. To sum up, the application of CdSe nanoparticles in latent fingerprint generation is a state-of-the-art development in forensic research. The convergence of distinct optical characteristics, surface flexibility, and customized functionalization demonstrated in these investigations leads to the creation of extremely sensitive and successful latent fingerprint detection techniques. The use of nanotechnology, especially CdSe nanoparticles, in forensic science has enormous potential to improve the precision and effectiveness of fingerprint analysis in criminal investigations.

TABLE 10.1 Application of CdS and CdSe Nanoparticles in Enhancement of Latent Fingerprint.

Nanoparticles	Size	Description	References
CdS: Mn^{2+} nanoparticles	6–7 nm	2-mercaptoacetic acid-capped CdS nanoparticles doped with Mn2+ to enhance fingerprint visibility using a unique strategy. The coprecipitation process was used to create these nanoparticles, which have a spherical average size of about 6–7 nm.	[51]
Photoluminescent CdS/ polyamidoamine (PAMAM) nanocomposites	2.4 nm and 3.4 nm	These nanocomposites were created *in situ,* demonstrating their versatility and suitability for a variety of surfaces. These CdS/PAMAM nanocomposites' photoluminescent properties within the PAMAM matrix made them an extremely attractive choice for enhancing latent fingerprints.	[52]

TABLE 10.1 *(Continued)*

Nanoparticles	Size	Description	References
Hybrid cadmium sulfide (CdS) quantum dots (QDs) nanocomposites	5–7 nm	Phthalocyanine (PPH-CN) and mercaptopropyl (PPH-SH)-functionalized porous phosphate heterostructures (PPH) were used to create fluorescent hybrid CdS QDs. The results showed that these water-based compounds were very successful in making latent impressions more visible on nonporous and porous surfaces.	[53]
CdS quantum dot/chitosan nanocomposites	20 nm	These nanoparticles, which have a diameter of around 20 nanometers and a nanospheric shape, showed how biopolymeric matrixes might improve the photoluminescent qualities of CdS QDs.	[54]
PPH-NH2@CdSe nanoparticles		CdSe QDs are incorporated into PPH to create a fluorescent nanocomposite known as PPH-NH2@CdSe. Amino groups provide further functionalization to the nanocomposite. This complex synthesis makes it possible to produce a material that is extremely sensitive for latent fingerprint detection.	[55]
CdSe/PAMAM nanocomposites	250 nm	The basic principles of CdSe nanoparticle interactions with fingerprint residues are clarified by this work. Because of their size and composition, the QDs have special optical qualities that make them perfect for selective and sensitive latent fingerprint detection. The work advances our knowledge of the fundamental processes governing the interplay between latent fingerprint chemical composition and CdSe QDs.	[56]
CdSe nanocrystals	-	The adaptability of this nanomaterial helps in forensic applications by extending the use of CdSe nanoparticles to both porous and nonporous surfaces. Mercaptoacetic acid, the stabilizing agent, helps to improve the interaction between CdSe nanoparticles and latent fingerprint residues on a variety of surfaces in addition to ensuring the stability of the nanoparticles.	[57]

10.5 FUTURE DIRECTION AND CHALLENGES

With CdS and CdSe nanoparticles, latent fingerprint development has a bright future ahead of it, especially in terms of synthesis methods. It is anticipated that further study will see developments targeted at improving and streamlining the procedures used to create these nanoparticles. There might be advancements in cost-effectiveness, scalability, and green synthesis techniques, opening the door to more widely available and environmentally friendly nanoparticle manufacturing. Furthermore, modifying the dimensions, form, and surface characteristics of CdS and CdSe nanoparticles might potentially improve their effectiveness in forensic contexts.

Although CdS and CdSe nanoparticles have shown great promise, forensic science is still in the early stages of investigating different nanoparticles for fingerprint formation. Researchers may look into the use of various nanomaterials with special qualities, such as metal oxides, hybrid nanocomposites, and materials based on graphene. Comparative research may provide forensic investigators with a more comprehensive toolset by illuminating the advantages and disadvantages of different types of nanoparticles. It may also be investigated to use the complementing qualities of different nanoparticle kinds in a synergistic way to get a more thorough latent fingerprint analysis.

There are several obstacles that need to be carefully considered when applying nanoparticle-based latent fingerprint development from the lab to actual forensic situations. Among the principal difficulties are:

1. **Standardization:** Establishing standardized protocols for nanoparticle-based fingerprint development is crucial to ensure consistency and reliability across different forensic laboratories. Efforts should be made to develop international guidelines that encompass various nanoparticle types and application methods.
2. **Sensitivity to environmental conditions:** Real-world forensic applications often involve diverse environmental conditions. Researchers need to address the challenges posed by varying humidity, temperature, and substrate types. Enhancing the robustness of nanoparticle-based methods under such conditions is imperative for their practical implementation.
3. **Ethical and legal implications:** The integration of advanced nanotechnology in forensic investigations raises ethical and

legal considerations. Ensuring that the use of nanoparticles complies with privacy rights, legal standards, and forensic ethics is paramount. Transparent communication with the public and legal stakeholders is essential to build trust in these emerging technologies.

4. **Cost-effectiveness:** For widespread adoption, nanoparticle-based methods must be economically viable. Future research should focus on optimizing the cost-effectiveness of synthesis techniques and scaling up production without compromising the quality and efficacy of the nanoparticles.
5. **Training and education:** Forensic investigators need specialized training to effectively implement nanoparticle-based fingerprint development techniques. Developing comprehensive training programs and educational resources will be essential to ensure the successful integration of these advanced methods into forensic practice.

10.6 CONCLUSION

In latent fingerprint formation, the dual use of CdS and CdSe nanoparticles tells an intriguing narrative of forensic scientific discovery. Recapitulating the synergistic benefits of their combined use, it is clear that the special qualities of CdS and CdSe, when combined, provide forensic investigators with an effective tool. In addition to using the complementing qualities of each, this nanoparticle synthesis produces an approach that is more selective, sensitive, and contrast-rich than conventional fingerprint production procedures. As we confirm that CdS and CdSe nanoparticles play a crucial role in the production of fingerprints, it is evident that their use goes beyond the lab and has great potential for the advancement of forensic research. A paradigm change in the precision and effectiveness of latent fingerprint analysis is expected, with possible ramifications for resolving crimes and upholding the rule of law. The discipline of fingerprint recognition is about to enter a new age as these nanoparticle-based techniques advance and tackle practical problems. They have the potential to become essential tools in the forensic investigator's toolbox.

KEYWORDS

- **Fingerprints**
- **luminescence**
- **nanoparticles**
- **porous**
- **semiconductor**

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