NANOTECHNOLOGY: A QUICK GUIDE TO MATERIALS AND TECHNOLOGIES

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PREFACE

"Nanotechnology: A Quick Guide to Materials and Technologies", is a comprehensive compendium that offers a concise yet insightful exploration of the fascinating world of nanomaterials and their diverse applications in smart devices, renewable energy, environmental sustainability, and beyond.

The rapid advancements in science and technology have revolutionized our lives, and materials play a fundamental role in driving these innovations forward. Nanomaterials, in particular, have emerged as key enablers of groundbreaking technologies due to their unique properties and versatility. This guide aims to provide a succinct overview of various nanomaterials and their remarkable applications, offering a valuable resource for both experts and newcomers seeking to understand the impact of nanotechnology on modern-day advancements.

Chapter 1 embarks on a journey through the realm of smart devices, exploring how nanomaterials are at the heart of these revolutionary technologies. From enhancing electronic components to improving energy efficiency, nanomaterials have unlocked new dimensions in the design and functionality of smart devices.

Chapter 2 delves into the world of semiconductor nanomaterials, which form the backbone of modern electronics. We investigate the unique properties of these materials, which have propelled the semiconductor industry to new heights and paved the way for quantum computing and other cutting-edge technologies.

Chapter 3 focuses on the fascinating field of photocatalysis, where nanomaterials display exceptional prowess. By harnessing the power of light, these materials can drive chemical reactions for environmental remediation, energy conversion, and much more, contributing to a cleaner and greener future.

Chapter 4 takes a closer look at polymer nanomaterials and their remarkable applications in a wide range of industries, from flexible electronics to biomedical devices, demonstrating their immense potential for shaping the technologies of tomorrow.

Chapter 5 unveils the realm of nano-catalysis, where nanomaterials act as catalytic agents with superior efficiency and selectivity, promising transformative solutions for cleaner and more sustainable chemical processes.

Chapter 6 explores the exciting world of carbon nanomaterials, such as carbon nanotubes and graphene, showcasing their extraordinary electrical, mechanical, and thermal properties that have sparked a revolution in various applications, from electronics to advanced composites.

In Chapter 7, the significance of modeling and simulation in understanding nanomaterial behaviour is discussed. The chapter provides a glimpse into the advanced techniques that underpin the design and optimization of nanotechnologies.

Chapter 8 focuses on the vital role of nanomaterials in photovoltaic applications, where they drive innovations in solar energy conversion, increasing efficiency and sustainability in our pursuit of cleaner energy sources.

Chapter 9 examines the critical role of nanomaterials in water purification, addressing the pressing global challenges of water scarcity and pollution, and offering promising solutions for access to clean and safe drinking water.

Chapter 10 explores the synergy between rare earth materials and nanotechnology, illuminating their importance in photovoltaic applications and their potential to revolutionize renewable energy technologies.

Chapter 11 showcases the fascinating realm of nanomaterials in sensing applications, enabling the creation of highly sensitive and selective sensors for monitoring environmental conditions, health parameters, and much more.

Chapter 12 unveils the innovative applications of ion beams in nanostructure development, pushing the boundaries of nanotechnology and paving the way for groundbreaking discoveries.

In Chapter 13, the realm of environmental remediation has been discussed, where nanomaterials offer ingenious solutions for mitigating pollution and addressing environmental challenges in a sustainable manner.

Chapter 14 brings us to the realm of Nano lubricants, which promise enhanced efficiency and reduced energy consumption in mechanical systems, leading to greener and more sustainable industrial practices.

This guide aims to provide readers with a concise yet comprehensive understanding of the diverse applications of nanomaterials and the significant impact they have on modern technologies. We hope that this quick guide will serve as a valuable resource for students, researchers, engineers, and anyone eager to explore the dynamic and transformative world of nanotechnology.

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CHAPTER 1

Application of Nanomaterials for Smart Devices

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Abstract: Nanomaterials have emerged as transformative agents in the realm of smart devices, enabling revolutionary advancements and applications. At the nanoscale, materials exhibit unique properties that differentiate them from their bulk counterparts, offering exceptional opportunities for enhancing the performance, functionality, and miniaturization of smart devices. The present chapter delves into the significant contributions of nanomaterials in the development of smart devices. Nanotechnology's ability to engineer materials at the atomic and molecular level has led to the creation of nanomaterials with precisely tailored properties. These nanoscale wonders have found applications in diverse fields, including electronics, healthcare, energy, and environmental monitoring. The integration of nanomaterials in smart devices has unlocked unprecedented opportunities for innovation. Nanoscale sensors with heightened sensitivity and selectivity have transformed devices into intelligent perceivers of the environment. Additionally, nanomaterials have revolutionized energy storage, enabling longer-lasting batteries and supercapacitors with higher energy density. Furthermore, nanomaterials play a pivotal role in advancing smart displays, wearable technology, and Internet of Things (IoT) devices. The seamless connectivity and improved performance offered by nanomaterials have paved the way for a more connected and efficient world. Additionally, this chapter emphasizes the immense potential of nanomaterials in shaping the future of smart devices, making them more adaptive, energy-efficient, and capable of transforming our daily lives. However, responsible implementation and safety considerations are essential for harnessing the full potential of nanomaterials and ensuring sustainable and secure technological advancements.

Keywords: Carbon, CNT, Energy storage, Flexible displays, Graphene, Metal oxide, Nanomaterials, Nanofibers, Nanoelectronics, Photocatalyst, Quantum dots, Sensors, Supercapacitors, Transistors, Wearable devices, Wireless communication.

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INTRODUCTION

In the ever-evolving landscape of technology, smart devices have emerged as transformative instruments that seamlessly integrate with our daily lives. From smartphones and wearable gadgets to smart home appliances and IoT-enabled systems, these devices have revolutionized the way we interact with the digital world. Over the last few decades, nanomaterials have emerged as the transformative agents driving the evolution of smart devices, ushering in a new era of technological advancements.

Nanomaterials are materials with at least one dimension in the nanoscale range, typically between 1 and 100 nanometres. At this scale, materials exhibit unique and distinctive properties that differ from their bulk counterparts. These properties arise from the high surface area-to-volume ratio and quantum confinement effects that become more pronounced at the nanoscale. Nanomaterials can be classified into different categories based on their dimensions, shapes, and structures. Some common types of nanomaterials include nanoparticles, nanotubes, nanowires, nanocomposites, and nanofilms, among others. At the nanoscale, materials exhibit extraordinary properties and behaviours that deviate from their bulk counterparts [1 - 3]. These unique characteristics, such as quantum confinement effects [4] and high surface area-to-volume ratio [5], empower nanomaterials to revolutionize the functionality and performance of smart devices. The convergence of nanotechnology and smart devices has unlocked unprecedented opportunities for innovation across various industries, reshaping how we interact with technology and enhancing our daily experiences [6]. The introduction of nanotechnology has enabled the manipulation and engineering of materials at the atomic and molecular levels, granting researchers the ability to design nanomaterials with precisely tailored properties. These nanoscale wonders have found a myriad of applications in the realm of smart devices, facilitating improvements in electronics, energy storage, sensors, and beyond [7 - 10]. Nanomaterials offer a promising avenue for addressing the miniaturization challenge in smart devices (Fig. **1**), as their nanoscale dimensions pave the way for more compact and efficient components. From quantum dots for vibrant displays to carbon nanotubes for flexible electronics, nanotechnology has unraveled a host of possibilities for smart device miniaturization and optimization [11].

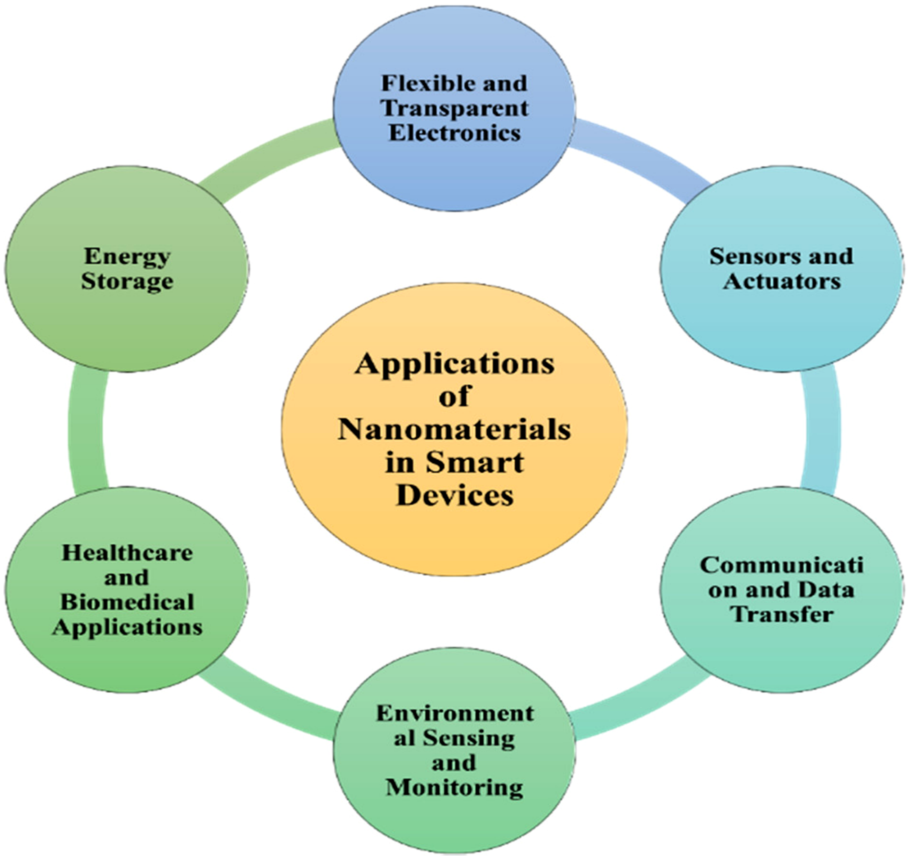

Fig. (1). Schematic representation of avenues of nanomaterials in smart devices.

One of the most significant contributions of nanomaterials in smart devices lies in their unmatched sensing capabilities. Nanoscale sensors can detect and respond to minute changes in their environment, enabling smart devices to gather real-time data and react adaptively [12]. Moreover, nanomaterials play a pivotal role in boosting the energy efficiency of smart devices. Nanostructured electrodes in batteries and supercapacitors offer higher surface area and faster ion transport, leading to improved energy storage and longer-lasting devices [13 - 15]. Additionally, nanomaterials enhance the connectivity and communication abilities of smart devices [16]. Nanoscale antennas and transceivers enable seamless wireless connectivity, enabling the Internet of Things (IoT) ecosystem and driving the interconnectedness of smart devices for a more integrated and intelligent world [17].

Moreover, the integration of nanomaterials in smart devices has catalysed a paradigm shift towards a more connected, smarter, and sustainable lifestyle. From wearable health monitors and smart textiles to energy-efficient displays and adaptive materials, nanotechnology has played a pivotal role in reshaping how we interact with technology. As research and innovation continue to push the boundaries of nanomaterials, the possibilities for even more advanced and intelligent smart devices seem limitless. However, the responsible use of nanomaterials and their potential environmental and health implications warrant careful consideration [18]. As we embark on this nanoscale revolution, a balance between innovation and ethical considerations will pave the way towards a future of intelligent, connected, and sustainable living through nanomaterials for smart devices.

Thus, the present chapter delves into the fascinating realm of nanomaterials and their pivotal role in shaping the future of smart devices. Nanotechnology, with its unique ability to manipulate matter at the atomic and molecular scale, has opened a new dimension of possibilities in device design, performance, and functionality.

NANOELECTRONICS FOR SMART DEVICES

Nanoelectronics has emerged as a revolutionary field driving the development of smart devices, ushering in a new era of intelligent and interconnected technology. At the nanoscale, electronic components exhibit distinct behaviors and properties that transcend the capabilities of traditional electronics. Nanoelectronics empowers the design of smaller, faster, and more energy-efficient devices, opening a world of possibilities for smart technologies. The integration of nanoscale materials, such as carbon nanotubes and graphene, has led to the creation of nano-electronic devices with unparalleled performance. These materials possess exceptional electrical conductivity, mechanical strength, and thermal stability, making them ideal building blocks for smart devices [19, 20]. Nanoelectronics has transformed sensors, displays, and communication systems, enabling real-time data gathering and processing with enhanced accuracy and sensitivity. Smart devices benefit from the miniaturization capabilities offered by nanoelectronics. Nanoscale transistors and circuits pave the way for smaller and more powerful devices, enabling sleek wearables, compact IoT sensors, and smart appliances that blend seamlessly into our daily lives. Moreover, nanoelectronics plays a pivotal role in addressing the ever-increasing demand for energy-efficient devices. Low-power nanoelectronic components reduce energy consumption, extending battery life and enabling the development of environmentally friendly technologies. However, the realization of nanoelectronics in smart devices demands overcoming various challenges. These include scalability, manufacturing precision, and ensuring reliability in nanoscale components. Researchers and engineers are actively exploring novel materials and fabrication techniques to tackle these hurdles and unlock the full potential of nanoelectronics.

Nanoscale Transistor and Logic Components

In the relentless pursuit of faster, more efficient electronics, nanoscale transistors, and logic components have emerged as key enablers in revolutionizing modern technology. At the nanometer scale, these electronic components exhibit extraordinary properties, such as higher switching speeds and lower power consumption, leading to significant advancements in digital devices and integrated circuits. Nanoscale transistors, including FinFETs (Fin Field-Effect Transistors) and nanowire transistors, have supplanted their larger counterparts as the backbone of digital circuits [21]. These miniature devices offer improved electrostatic control and reduced leakage currents, allowing for higher packing densities and increased integration levels. As a result, the processing power of microprocessors and system-on-chip (SoC) devices has skyrocketed, enabling smarter and more versatile computing platforms. Logic components, such as logic gates and multiplexers, play a crucial role in information processing and decision-making within digital circuits. At the nanoscale, these components have been meticulously engineered to operate efficiently in low-power environments, making them ideal for battery-operated devices and IoT applications. The advent of nanoscale logic components has led to the realization of ultra-low-power electronic systems, extending battery life, and enabling the proliferation of portable and wearable smart devices [22].

The rapid progress in nanoscale transistor and logic component technologies has unlocked the potential for innovative and disruptive applications. Quantum-dot transistors, quantum computing gates, and spintronics-based logic elements hold promise for pushing the boundaries of computation and information storage even further. Despite these remarkable achievements, the journey towards nanoscale electronics is not without challenges. The nanofabrication process demands unprecedented precision and control, requiring state-of-the-art cleanroom facilities and cutting-edge lithography techniques. Additionally, issues such as quantum effects, variability, and reliability become increasingly pronounced at the nanoscale, necessitating innovative design and optimizated methodologies. Nevertheless, the prospects for nanoscale transistors and logic components continue to excite researchers and industry pioneers alike. As we venture deeper into the nanotechnology frontier, the potential for novel electronic devices, transformative computing paradigms, and a more connected and intelligent world awaits. Embracing the power of miniaturization, nanoscale transistors, and logic components herald a new era of technology, where the boundaries of what is possible are continuously pushed, and the landscape of smart devices and computing is forever changed [23].

Nanomaterials for High-Performance Integrated Circuits

The relentless demand for faster, more powerful, and energy-efficient electronics has led researchers and engineers to explore nanomaterials as a game-changer in the realm of integrated circuits (ICs). Nanomaterials, with their unique properties at the nanoscale, offer the potential to revolutionize the design and performance of ICs, enabling a new generation of high-performance electronic devices. One of the key challenges in modern ICs is reducing transistor size to increase packing density and enhance processing speed. Nanomaterials, such as carbon nanotubes, graphene, and 2D materials like molybdenum disulfide (MoS2), have emerged as promising candidates to replace traditional silicon transistors. These nanomaterials possess exceptional electrical conductivity and mechanical properties, making them ideal for creating smaller and more efficient transistors.

Moreover, nanomaterials hold the potential to tackle the growing issues of power consumption and heat dissipation in high-performance ICs. Heat dissipation becomes a critical concern as transistor density increases [24]. Nanomaterials with superior thermal conductive properties offer an efficient solution to dissipate heat and prevent overheating, leading to improved energy efficiency and reliability in high-performance ICs. Furthermore, the unique quantum properties of some nanomaterials, like quantum dots and quantum wells, offer opportunities for quantum computing and information processing. These materials enable the development of qubits, the building blocks of quantum computers, which hold the promise of exponentially faster computing power and groundbreaking applications in cryptography, drug discovery, and more. Despite the enormous potential of nanomaterials, their integration into high-performance ICs poses challenges related to manufacturing, scalability, and material quality control. To fulfill these challenges, interdisciplinary research and collaboration between material scientists, device engineers, and semiconductor manufacturers have been required.

APPLICATION OF NANOMATERIALS IN NANOELECTRONICS

The application of various nanomaterials in nanoelectronics has opened a world of possibilities, revolutionizing the performance and functionality of electronic devices. Each nanomaterial brings unique properties and advantages, making it suitable for specific applications. Some of the prominent nanomaterials (Fig. **2**) and their applications in nanoelectronics include:

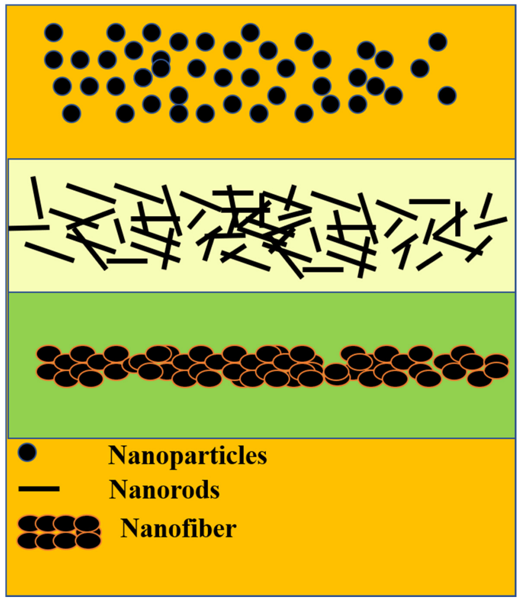

Fig. (2). Various forms of nanomaterials.

Carbon-based Nanomaterials

They have emerged as a game changer in the field of nanoelectronics by offering unique properties and exceptional performance. Among all these carbon-based nanomaterials, graphene possesses special attention nowadays due to its 2D honeycomb lattice arrangement. It shows good electrical conductivity, high electron mobility, and great mechanical strength. Due to these properties, graphene-based transistors, integrated circuits, batteries, and supercapacitors are revolutionizing industries. Moreover, carbon nanotubes are another carbon-based material, which exhibit remarkable thermal, electrical, and mechanical properties. CNT can serve as nanoscale interconnects, enhancing the efficiency and speed of data transmission in electronic circuits. Carbon-based nanomaterials also include carbon dots, carbon nanowires, and carbon nanofibers. These materials are versatile and can be functionalized to serve various electronic applications. It is an appropriate choice for nanoelectronic applications [25].

Quantum Dots (QDs)

Quantum dots are semiconductor nanocrystals with size-dependent optical and electronic properties. They find applications in displays, LEDs, and photodetectors, as their emission and absorption wavelengths can be tuned by altering their size [26].

Nanowires

Nanowires are ultra-thin wires with diameters in the nanoscale range. They are used in transistors and sensors, taking advantage of their high surface-to-volume ratio and excellent charge transport properties.

2D Materials

2D materials offer unique electronic properties, such as tunable bandgaps and high carrier mobility (*e.g*., MoS2, WS2). They are applied in transistors, memory devices, and optoelectronics, enabling new functionalities and improving device performance [27].

Nanoparticles

Nanoparticles of various materials, such as metal oxides and quantum dots, are employed in memory devices, nanoscale interconnects, and printed electronics, taking advantage of their small size and enhanced reactivity.

Nanostructured Thin Films

Nanostructured thin films, made of materials like metal oxides and conductive polymers, are used in flexible electronics, touchscreens, and transparent electrodes due to their mechanical flexibility and transparency.

Molecular Electronics

Organic molecules with specific electronic properties are utilized in molecular electronics for computing and memory applications, offering the potential for ultra-dense and energy-efficient circuits.

Nanostructured Composites

Nanocomposites formed by incorporating nanoparticles or Nano fillers into a matrix, are employed in printed electronics, sensors, and energy storage devices, enhancing the mechanical, electrical, and thermal properties of the materials.

The incorporation of these nanomaterials in nanoelectronics has paved the way for more compact, efficient, and versatile devices. Their unique properties, coupled with ongoing research and innovation, are set to drive further advancements, pushing the boundaries of what is possible in the world of electronics. However, addressing challenges related to scalability, reproducibility, and cost remains crucial for the widespread adoption of nanomaterial-based nanoelectronics in various industrial applications.

FLEXIBLE DISPLAYS AND NANOMATERIALS

Flexible displays have revolutionized the way we interact with electronic devices, offering enhanced portability, durability, and user experience. Nanomaterials have played a pivotal role in the development of flexible displays, unlocking a new realm of possibilities for this cutting-edge technology. Nanomaterials such as graphene quantum dots possess unique properties that make them ideal candidates for creating flexible and transparent electronic components [28]. Flexible displays offer numerous advantages in smart devices, transforming the way we interact with technology and enhancing user experience. Some of the key advantages of flexible displays in smart devices include:

a. **Portability and Form Factor:** Flexible displays allow smart devices to become thinner, lighter, and more portable. They can be bent, rolled, or folded, enabling compact and space-saving designs. This portability enhances the convenience of carrying and using smart devices on the go.
b. **Durability and Resistance:** Unlike traditional rigid displays, flexible displays are more durable and resistant to damage. They can withstand bending, twisting, and impact, reducing the risk of screen breakage and extending the lifespan of the device.
c. **Versatility of Applications**: Flexible displays enable a wide range of applications, from curved smartphones and smartwatches to rollable tablets and foldable laptops. Their adaptable form factor allows for innovative and versatile designs, catering to various user preferences and needs.
d. **Improved User Experience:** The flexibility of displays provides a more immersive and engaging user experience. Curved or wraparound screens offer a wider field of view, enhancing gaming, video streaming, and multimedia consumption.
e. **Energy Efficiency:** Flexible displays can be integrated with energy-efficient technologies, such as organic light-emitting diodes (OLEDs) and low-power electronic components. This results in improved battery life and reduced energy consumption, contributing to long-lasting smart devices.
f. **Enhanced Wearable Devices**: Flexible displays are particularly advantageous for wearable devices, such as smartwatches and fitness trackers. They can conform to the shape of the user's wrist, offering a comfortable fit and allowing continuous monitoring of health and fitness data.
g. **Innovative Design Possibilities**: Flexible displays encourage designers and manufacturers to explore new design possibilities. Devices can be designed to be more aesthetically pleasing, making them visually appealing and increasing their overall appeal in the market.

h. **Foldable and Multi-Mode Functionality**: Foldable displays enable multi-mode functionality, allowing users to switch between phone and tablet modes seamlessly. This enhances multitasking and productivity, making smart devices more versatile and efficient.
i. **Space-Saving Solutions**: Flexible displays can be integrated into unconventional spaces, creating new opportunities for smart devices in various industries. They can be used in wearable health monitors, automotive dashboards, and even smart clothing.
j. **Reduced Material Usage**: The flexibility of displays allows for efficient use of materials, reducing waste and environmental impact during manufacturing.

NANOMATERIALS FOR TRANSPARENT CONDUCTIVE FILMS

Nanomaterials have revolutionized the field of transparent conductive films, offering superior conductivity and transparency compared to traditional materials like indium tin oxide (ITO). These nanoscale wonders have enabled the development of flexible, lightweight, and highly transparent conductive films that find applications in various industries. The use of nanomaterials in transparent conductive films offers several advantages, including improved mechanical flexibility, enhanced optoelectronic properties, and potential cost reduction. Additionally, the tunable properties of nanomaterials allow for tailored solutions in specific applications, making them a versatile and promising choice for transparent conductive films. We can expect further advancements in transparent conductive films, contributing to the growth of flexible and transparent electronics in various industries. Some of the prominent carbon-based nanomaterials used for transparent conductive films have been displayed in Fig. (**3**) and discussed briefly below:

a. **Graphene:** Graphene, a single layer of carbon atoms arranged in a 2D lattice, boasts exceptional electrical conductivity and transparency. It is used as a replacement for ITO in transparent conductive films for touchscreens, OLED displays, and solar cells. Graphene-based films offer higher flexibility, making them ideal for flexible electronics.
b. **Carbon Nanotubes (CNTs):** CNTs are hollow cylindrical structures with excellent electrical conductivity and transparency. They are utilized as alternatives to ITO in transparent conductive films for displays, sensors, and solar cells. CNT-based films can be easily integrated into flexible and stretchable devices.

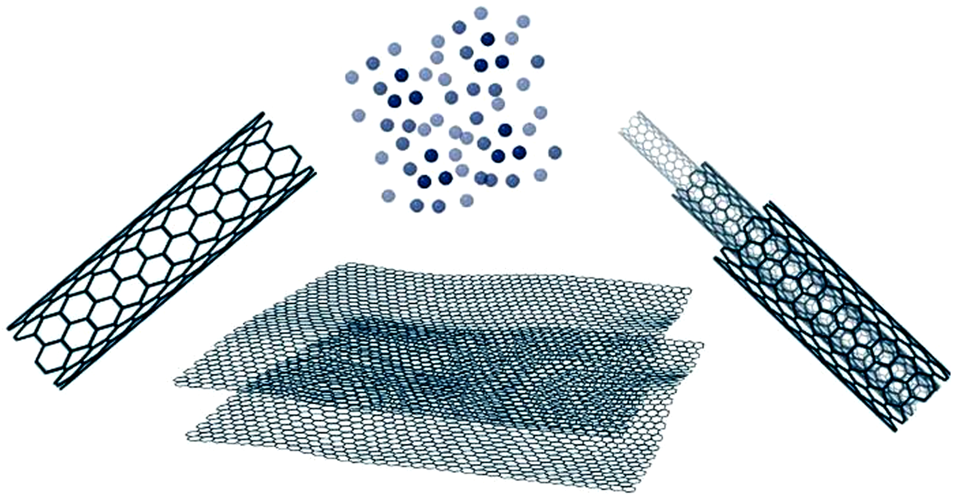

Fig. (3). Various forms of carbon-based nanomaterials used in transparent conductive films.

ROLE OF NANOMATERIALS IN BENDABLE AND ROLLABLE DISPLAYS

Nanomaterials play a crucial role in the development of bendable and rollable displays, revolutionizing the way we interact with electronic devices. These innovative materials offer unique properties that enable the creation of flexible and durable displays, opening up new possibilities for portable and wearable technologies. The role of nanomaterials in bendable and rollable displays can be summarized as follows:

a. **Flexibility and Mechanical Durability:** Nanomaterials, such as carbon nanotubes (CNTs), graphene, and silver nanowires, possess exceptional mechanical flexibility and strength. When integrated into display components, these materials allow the screen to bend and conform to different shapes without compromising on mechanical durability. This flexibility is essential for creating bendable and rollable displays that can withstand repeated folding and rolling motions.
b. **Transparent Conductive Films:** Transparent conductive films are essential for touchscreens and flexible displays. Nanomaterials like graphene, CNTs, and metal nanomesh offer high electrical conductivity and transparency, making them ideal candidates for replacing traditional materials like indium tin oxide (ITO) in transparent conductive layers. These nanomaterial-based films enable seamless touch functionality on bendable and rollable displays.

c. **Thin and Lightweight Design:** Nanomaterials are characterized by their nanoscale dimensions, resulting in ultra-thin and lightweight structures. When incorporated into display layers, nanomaterials contribute to reducing the overall thickness and weight of the display, making bendable and rollable devices more portable and convenient for users.
d. **Flexibility in Display Components:** Nanomaterials can be used in various display components, such as organic light-emitting diodes (OLEDs) and thin-film transistors (TFTs). These materials provide flexibility to the individual components, allowing them to bend and stretch along with the flexible display panel, ensuring uniform performance even in curved or rolled configurations.
e. **Energy-Efficient Displays:** Some nanomaterials, such as quantum dots, offer energy-efficient properties, enabling brighter displays with lower power consumption. Their tunable emission properties allow for improved colour gamut and better display performance in bendable and rollable devices.
f. **Printable and Scalable Manufacturing:** Many nanomaterials can be processed using printing techniques, making them suitable for scalable and cost-effective manufacturing of flexible displays. Roll-to-roll printing processes can be used to fabricate large-area bendable and rollable displays at a reduced cost.
g. **Stretchable Electronics:** Nanomaterials with high stretchability, such as stretchable conductive polymers, can be integrated into flexible displays to create stretchable electronics. This capability opens up new avenues for wearable devices with curved and conformable displays.

ENERGY STORAGE APPLICATIONS

Nanotechnology plays a crucial role in improving the performance of electrode material for energy storage devices such as batteries Supercapacitors, fuel cells, and solar cells as shown in Fig. (**4**). Here different shapes and sizes of the materials are fabricated using different techniques. Nanostructure materials are emerging as attractive electrode materials because as the size of the material approaches to nano dimension, the number of atoms present at the surface of the material becomes more significant for energy storage performance. Furthermore, these materials exhibit higher adaptability to the strain that arises during charging-discharging operation, improving electrochemical cyclability [29, 30]. Moreover, by nano-tailoring the particle size, shorter conduction path lengths (electronic and ionic transport) can be achieved, facilitating reversible electrochemical reactions. Further, the large surface area of nonmaterial provides high-rate capability due to increased ion flux through the liquid electrolyte/nanosized electrode material interface [31]. Furthermore, nanostructures are found to exhibit high cyclic stability with good rate capability because nanomaterials provide numerous pathways for ions and electron transfer at the electrode/electrolyte interface. In this context, different nanostructured electrode materials (zero-dimensional (0D), one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D)) have been synthesized using different methods [32]. However, the difficulty in the synthesis/ fabrication of nanostructure/nanophase, poor control of size and morphology, poor reproducibility, and prohibitively high fabrication costs are some of the hitches in employing the overall significance of nanotechnology.

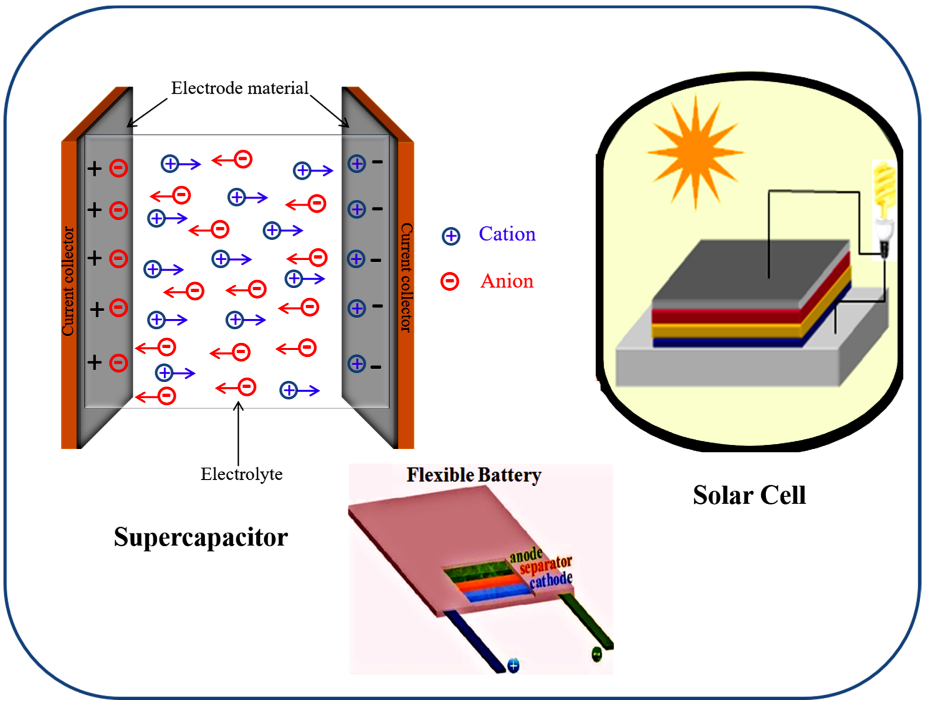

Fig. (4). Schematic representation of different energy storage devices.

Nanomaterials in High-Capacity Lithium-ion Batteries

Lithium-ion batteries (LIBs) have become the cornerstone of portable electronics, electric vehicles, and renewable energy storage due to their high energy density and long cycle life. The continuous drive for improved battery performance has led researchers to explore nanomaterials as a promising avenue to enhance the capabilities of LIBs. Nanomaterials offer unique properties at the nanoscale, such as high surface area, short diffusion paths, and improved electron transport, which can significantly impact the electrochemical performance of lithium-ion batteries. This section discusses the role of nanomaterials in high-capacity lithium-ion batteries and their potential to revolutionize the energy storage landscape.

a. **Enhanced Electrode Structure:** Nanomaterials, such as nanoparticles, nanowires, and nanosheets, can be tailored to specific shapes and sizes to form high-surface-area electrode structures. This increased surface area provides more active sites for lithium-ion intercalation and de-intercalation, leading to higher charge storage capacity and faster kinetics [33].
b. **Improved Electrochemical Kinetics:** The reduced size of nanomaterials shortens the diffusion pathways for lithium ions, enhancing the rate of lithium-ion transport within the electrode. This results in improved charge and discharge rates, allowing high-capacity lithium-ion batteries to be charged and discharged more rapidly.
c. **Mitigation of Volume Changes:** During lithium-ion intercalation and de-intercalation, some materials experience significant volume changes, leading to mechanical stress and capacity fading. Nanomaterials, particularly nanocomposites, and nanocoating, can alleviate these issues by accommodating volume changes more effectively, leading to improved cycling stability.
d. **High Energy Density:** Nanomaterials can enhance the energy density of lithium-ion batteries by enabling higher lithium-ion storage per unit mass or volume. For instance, silicon nanoparticles can store many lithium ions, providing a high theoretical capacity compared to traditional graphite electrodes.
e. **Advancements in Anode Materials:** Nanomaterials have opened new avenues for anode materials, such as silicon-based nanocomposites and tin oxide nanowires, which have shown remarkable capacity retention and rate capabilities, promising a step change in the performance of LIBs.
f. **Cathode Material Innovations:** Nanomaterials have also made significant contributions to cathode materials, including lithium iron phosphate nanoparticles and layered oxide nanosheets, resulting in high-capacity cathodes with excellent cycling stability.
g. **Solid-State Electrolytes:** Nanomaterials are being explored in solid-state electrolytes, which offer higher safety, wider operating temperature ranges, and improved energy density compared to conventional liquid electrolytes.
h. **Long Cycle Life:** The unique properties of nanomaterials contribute to reduced degradation rates, leading to prolonged cycle life and improved overall durability of lithium-ion batteries.

Nano Materials used for Supercapacitors

Supercapacitors, also known as electrochemical capacitors, have gained significant attention as promising energy storage devices due to their high power density, rapid charge-discharge capabilities, and long cycling life. To further enhance their performance and energy storage capacity, the integration of nanomaterials and nanocomposites has emerged as a promising approach. Nanomaterials, with their unique properties at the nanoscale, offer exceptional surface area, enhanced electrical conductivity, and shortened ion diffusion pathways. According to their charge storage mechanisms, nanomaterials are divided into two categories; (a) Carbon-based nanomaterials are used in EDLCs, and (b) Transition metal oxides for Psuedocapacitors (Fig. **5**). When incorporated into nanocomposites, these nanomaterials synergistically contribute to higher energy storage capacity and faster charge-discharge rates. This article explores the significance of nanomaterials and nanocomposites in advancing the field of supercapacitors, highlighting recent advancements, challenges, and prospects.

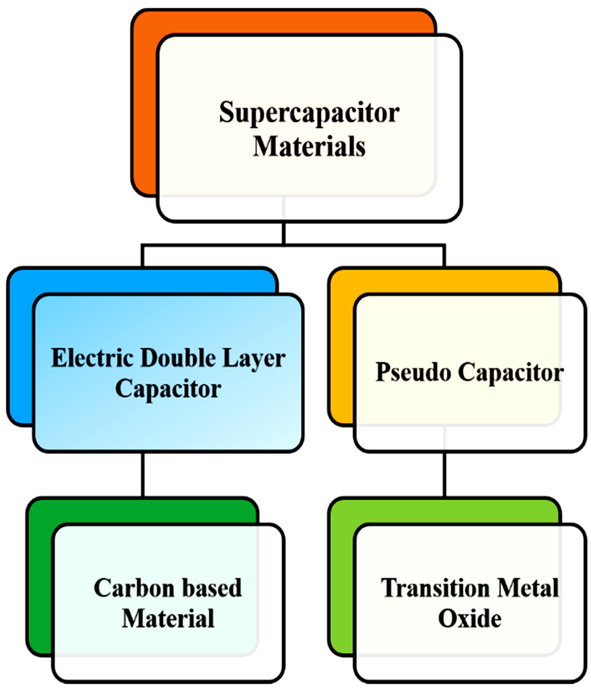

Fig. (5). Schematic representation of supercapacitor electrode materials.

Nanomaterials, such as carbon nanotubes, graphene, and metal oxides, have shown remarkable potential in supercapacitor applications. Their high surface area provides more active sites for charge storage, while their unique electronic properties facilitate rapid electron transport. Carbon-based nano materials, particularly graphene and carbon nanotubes, are widely used as electrodes due to their excellent electrical conductivity and mechanical strength. Metal oxide nano materials, on the other hand, enable pseudocapacitance, contributing to increased energy storage beyond the limitations of double-layer capacitance. Moreover, nanocomposites are created by integrating nanomaterials into the electrode structure of supercapacitors. This combination results in tailored nanoscale architectures with enhanced electrochemical properties. The synergy between the components in nanocomposites improves ion accessibility, reduces diffusion pathways, and enhances charge storage. For instance, carbon nanotubes incorporated into a conducting polymer matrix create nanocomposites that exhibit both pseudocapacitance and double-layer capacitance, leading to higher energy density and faster charging. These nanomaterials offer various advantages for improving the capacitance of supercapacitors, which are discussed below:

a. **High Surface Area:** Nanomaterials offer a high surface-to-volume ratio, allowing for more active sites for ion adsorption and charge storage, leading to improved energy storage capacity.
b. **Faster Charge-Discharge Rates:** The short diffusion paths in nanomaterials and nanocomposites enable rapid ion transport, resulting in faster charging and discharging of supercapacitors.
c. **Long Cycle Life:** The mechanical stability of nanomaterials enhances the structural integrity of electrodes, leading to long cycling life and improved durability.
d. **Tunable Properties:** Nanocomposites allow for fine-tuning of electrochemical properties by adjusting the composition and arrangement of nanomaterials, providing versatility in supercapacitor design.

Nanomaterials for Energy Harvesting in Smart Devices

Nanomaterials have revolutionized the field of energy harvesting for smart devices, enabling efficient and sustainable power solutions. One of the significant advantages of nanomaterials is their unique properties at the nanoscale, which offer enhanced energy conversion capabilities. For photovoltaic energy harvesting, nanostructured materials like quantum dots and perovskites have demonstrated exceptional light absorption and charge separation abilities, leading to improved solar energy conversion. These nanomaterial-based photovoltaic cells can be integrated into the design of smart devices, providing a reliable and eco-friendly power source for a range of applications. Thermoelectric energy harvesting, which converts waste heat into electrical energy, also benefits from the use of nanomaterials. Nanostructured materials like silicon and bismuth telluride exhibit low thermal conductivity and high electrical conductivity, making them ideal candidates for thermoelectric generators. By incorporating these nanomaterials into smart devices, the devices can capture and utilize the ambient heat from their surroundings, extending battery life, and reducing the need for frequent recharging. Another exciting application of nanomaterials in energy harvesting is piezoelectric nanogenerators. These generators convert mechanical vibrations and motion into electrical energy, and nanomaterials, such as nanowires and thin films, exhibit higher piezoelectric coefficients, enabling efficient energy conversion even from small-scale mechanical inputs. By integrating piezoelectric nanomaterials into smart devices, energy can be harvested from everyday interactions, such as tapping on touchscreens or movement from the user, making the devices more self-sustaining and less reliant on external power sources.

IMPORTANCE OF NANOMATERIALS IN PHOTOCATALYSIS

Photocatalysis is a powerful and promising advanced oxidation process that utilizes light energy to drive chemical reactions. Photocatalysis involves a semiconductor catalyst absorbing photons to create electron-hole pairs as shown in Fig. (**6**). These charge carriers participate in redox reactions with organic pollutants or substrates. The holes react with water or hydroxide ions, generating hydroxyl radicals. The highly reactive hydroxyl radicals then oxidize and degrade the targeted pollutants into harmless compounds. Photocatalyst applications of nanomaterials in small devices have emerged as a promising avenue for addressing various challenges and enhancing functionalities. Nanomaterials, characterized by their unique properties and high surface area-to-volume ratio, offer immense potential in harnessing light-induced chemical reactions for a wide range of applications in small devices. One of the significant applications is in photocatalytic air purification. Incorporating nanomaterial-based photocatalysts, such as titanium dioxide (TiO_2) nanoparticles, into small air purifiers and filters enables the effective decomposition of harmful pollutants like volatile organic compounds (VOCs) and airborne pathogens when exposed to UV light or visible light. This leads to improved indoor air quality and enhances the performance of compact air purification systems. Another critical application lies in the development of self-cleaning surfaces for small devices, such as smartphone screens and camera lenses. Nanomaterial-based photocatalytic coatings on these surfaces can break down organic contaminants, like fingerprints and oils, when exposed to light, making the devices self-cleaning and reducing the need for frequent manual cleaning. This not only ensures the longevity of the devices but also enhances user experience and convenience.

Small-scale water purification devices benefit from nanomaterials as well. Photocatalysts like zinc oxide (ZnO) and iron oxide (Fe_2O_3) nanoparticles can effectively degrade organic pollutants and disinfect water when illuminated. By integrating such photocatalysts, small water purification devices become portable, efficient, and capable of providing clean drinking water in various settings, including remote areas and emergency situations. Photocatalytic hydrogen generation is another promising application of nanomaterials in small devices.

Nanomaterials like semiconducting metal oxides, for example, TiO_2 and ZnO, can split water into hydrogen and oxygen under light irradiation. This paves the way for self-contained, portable systems capable of producing clean hydrogen fuel for small-scale energy applications and power sources for portable devices.

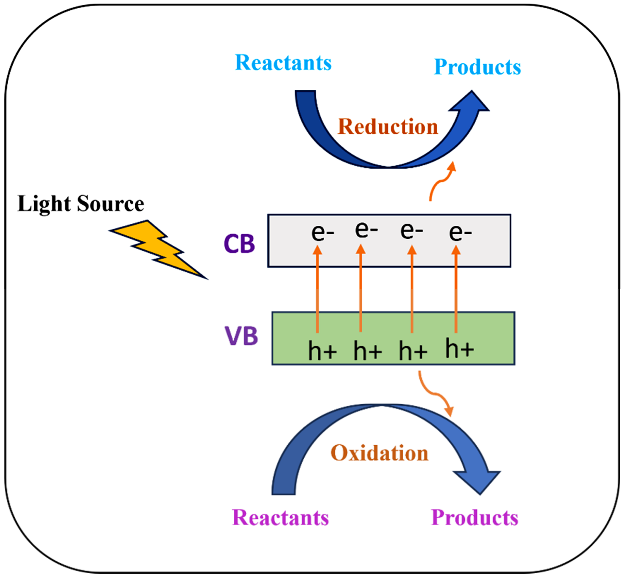

Fig. (6). Mechanism of photocatalysis.

Nanomaterial-based photocatalytic sensors have shown potential for sensing applications in small devices. These sensors can detect and quantify various analytes by measuring changes in photocatalytic activity caused by the presence of the target analyte. This enables the development of compact, sensitive, and selective sensors for use in fields such as environmental monitoring, healthcare diagnostics, and food safety. Furthermore, nanomaterial-based photocatalysts contribute to energy harvesting in small devices. They can convert light energy into electrical energy, making them valuable components of hybrid energy-harvesting systems. These systems enable small devices, such as self-powered sensors, to operate sustainably without the need for external power sources. In the realm of small-scale lithography and patterning applications, photocatalytic nanomaterials have proven useful. By selectively exposing regions of a substrate to light, intricate patterns can be created with high precision at the nanoscale. This opens up new possibilities for small device manufacturing and fabrication processes.

Photocatalytic inks and coatings based on nanomaterials find applications in small devices as well. These inks and coatings can confer diverse functionalities, such as antibacterial surfaces, enhanced UV protection, and self-cleaning capabilities, making them highly versatile for a variety of small device applications. While photocatalyst applications of nanomaterials in small devices hold great promise, it is essential to consider potential toxicity and environmental impact. Careful selection of nanomaterials and safety measures during device fabrication and usage are crucial to ensure sustainable and safe deployment of these innovative technologies in the market. As research and development in this field continue, nanomaterial-based photocatalysts are poised to revolutionize small device functionalities and drive technological advancements across various industries.

NANOMATERIALS FOR COMMUNICATIONS

In recent years, nanotechnology has emerged as a game-changer, paving the way for innovative applications in various fields, including the development of smart devices. Nanomaterials, materials engineered at the nanoscale, offer unique properties and capabilities that can be harnessed to enhance the performance and functionality of smart devices. One of the most exciting areas of application is in communications. This summary explores the significant impact of nanomaterials on smart devices' communications capabilities and their potential to revolutionize the way we interact with technology. This has been summarized in Fig. (**7**).

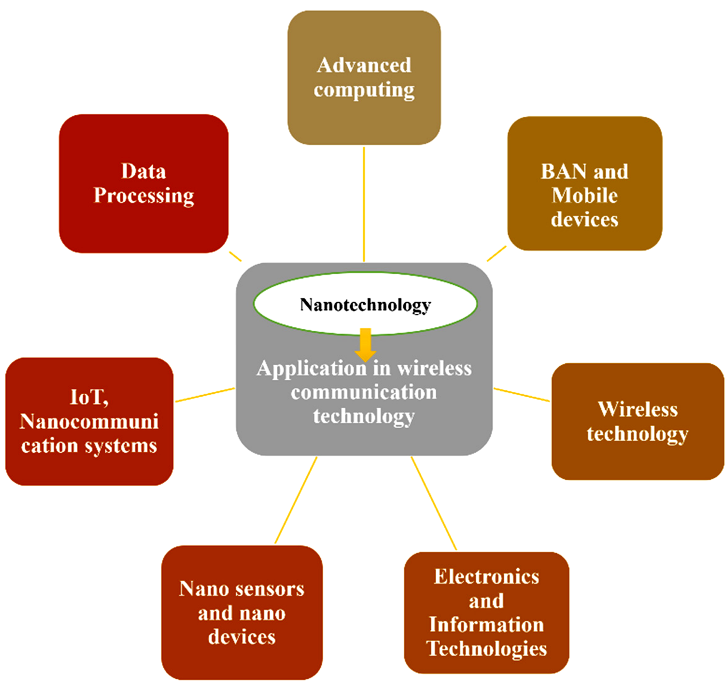

Fig. (7). Application of nanotechnology in wireless communication technology.

a. **Nanomaterials in Wireless Communication:** Nanomaterials have revolutionized wireless communication, enabling higher data transfer rates, reduced power consumption, and improved signal strength. For instance, graphene, a two-dimensional nanomaterial, has exceptional electrical conductivity, making it an ideal candidate for radio-frequency applications. When integrated into antennas and communication circuits, graphene enhances signal reception and transmission, providing seamless connectivity for smart devices, such as smartphones, wearables, and Internet of Things (IoT) devices.
b. **Enhanced Energy Efficiency:** Smart devices often suffer from power limitations due to their small form factors. Nanomaterials offer solutions by improving energy efficiency in communication components. Quantum dots, for instance, have been employed in display technologies, reducing energy consumption and extending battery life. Additionally, nanomaterials like carbon nanotubes and nanowires contribute to energy-efficient data transmission in wireless communication, thus ensuring uninterrupted connectivity in smart devices.
c. **Miniaturization and Flexible Communication Devices:** The unique properties of nanomaterials allow for the miniaturization and flexibility of communication devices. Nanomaterial-based sensors can be integrated into smart clothing and accessories, enabling seamless communication and monitoring of vital signs for healthcare applications. Moreover, flexible nanomaterials like silver nanowires and conductive polymers have revolutionized the development of bendable displays, antennas, and communication circuits in smartphones and wearables.
d. **Internet of Things (IoT) Connectivity:** The proliferation of IoT devices has driven the need for efficient and reliable communication between connected devices. Nanomaterials play a crucial role in enabling IoT connectivity by improving sensors' performance, wireless communication, and energy efficiency. Nanoscale sensors and transceivers facilitate seamless data exchange between devices, paving the way for smart homes, smart cities, and other IoT applications.
e. **Quantum Communication and Cryptography:** Quantum nanomaterials offer ground breaking possibilities for secure communication. Quantum dots and quantum key distribution systems can be integrated into smart devices to enable quantum communication, which ensures ultra-secure data transmission. Quantum cryptography based on the principles of entanglement and superposition guarantees secure communication channels, protecting sensitive data from potential threats.
f. **Nanomaterials for 6G Technology:** As the world anticipates the rollout of 6G technology, nanomaterials are at the forefront of research for its development. 6G aims to provide unprecedented data transfer rates, low latency, and

connectivity for a hyper-connected society. Nanomaterials' ability to operate at high frequencies and efficiently handle massive data traffic holds immense promise for the realization of 6G networks.

g. **Nanomaterials in Satellite Communications:** Satellite communication is critical for global connectivity, and nanomaterials can enhance satellite efficiency and performance. Lightweight and robust nanomaterials can be used in satellite components, reducing launch costs while providing better signal processing and radiation resistance. This advancement ensures improved communication in remote and underserved areas, enhancing global connectivity [34].

FUTURE PROSPECTS FOR NANOMATERIALS

Nanomaterials, which consist of nanoparticles and nanocomposites with unique properties, have opened up a vast array of possibilities in the development of smart devices. Nanomaterials have demonstrated their potential across a range of significant domains [35 - 37].

a. **Improved Energy Storage:** Nanomaterials have the potential to revolutionize energy storage in smart devices. By enhancing the performance of batteries and supercapacitors, nanomaterials can lead to longer-lasting and faster-charging devices, paving the way for sustainable and eco-friendly technologies.
b. **Flexible and Transparent Displays:** Nanomaterials can be engineered to create flexible and transparent displays, enabling the development of foldable smartphones, wearable devices, and even rollable screens. This breakthrough will redefine the form factor of smart devices, making them more versatile and user-friendly.
c. **Enhanced Sensing Capabilities:** Nanosensors composed of nanomaterials can detect and respond to various environmental stimuli such as temperature, pressure, and chemical changes. Integrating these sensors into smart devices will lead to enhanced functionality, making our devices more intuitive and responsive to user needs.
d. **Energy Harvesting:** Nanomaterials can be utilized to harvest energy from the surrounding environment, converting light, heat, or motion into usable electricity. This technology can help extend battery life or even power small devices autonomously, reducing our dependence on conventional power sources.
e. **Miniaturization and Weight Reduction:** Nanomaterials allow for the miniaturization of components, making smart devices lighter and more portable without compromising performance. This trend will pave the way for

wearables and IoT devices to become seamlessly integrated into our daily lives.

f. **Biocompatibility and Medical Applications:** With advancements in nanomaterials, smart medical devices could be developed with improved biocompatibility and tailored functionalities. Nanotechnology could revolutionize healthcare by enabling non-invasive diagnostic tools and targeted drug delivery systems [38].

However, as you venture into exploring these applications, it is crucial to keep ethical and safety considerations in mind. Thoroughly assess the potential risks associated with nanomaterials and work towards sustainable practices in their production and disposal. The future holds immense possibilities for nanomaterials in smart devices, and I am confident that your contributions to this field will drive progress and lead to groundbreaking innovations. Stay curious, collaborate, and never cease to challenge the boundaries of what is possible.

CONCLUSION

The future of smart devices is undeniably intertwined with nanomaterials and the endless possibilities they bring. From enabling ultra-fast communication and energy-efficient operations to empowering wearable healthcare monitoring and quantum computing, nanomaterials are set to shape the way we interact with technology in the coming years. Advancements in nanotechnology will likely open new avenues for innovation, leading to smarter, more intuitive, and sustainable smart devices that cater to our ever-evolving needs. However, it is crucial to address potential challenges related to safety, scalability, and ethical considerations as nanomaterials become more integrated into our daily lives. As research and development continue, the collaboration between scientists, engineers, and policymakers will be instrumental in realizing the full potential of nanomaterials in the next generation of smart devices. The applications of nanomaterials in smart devices have opened up a world of possibilities, transforming the way we interact with technology and setting the stage for a more connected, efficient, and sustainable future. As this article explored, nanotechnology has significantly impacted various aspects of smart devices, including communication, energy efficiency, sensing capabilities, and even quantum computing. The culmination of these advancements promises to unlock the full potential of smart devices, shaping a new era of technological innovation.

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CHAPTER 2

Semiconductor Nanomaterials

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Abstract: The physical and chemical characteristics of semiconductor materials radically alter as their size is shrunk to the nanoscale, giving rise to unusual traits because of their enormous surface area or quantum size effect. Despite being at the research stage right now, semiconductor nanomaterials and devices hold great promise for use in a variety of sectors, including solar cells, nanoscale electronics, light-emitting nanodevices, laser technology, waveguides, pharmaceuticals, and biosensors. The semiconductors will undoubtedly experience substantial advancements as nanotechnology continues to advance. The entire mechanism is regulated with the help of band theory, which includes valence band, conduction band and an energy gap, also considered forbidden gaps. These semiconductors when converted into nano sizes are corresponded to nanoparticles, which have the potential to accommodate various functionalities due to the reduced size, which increases the surface area for better function, adsorption, efficiency, and other things as discussed in the book chapter. This chapter also focuses on some of the most important activities now underway and problems that must be solved to enhance nanostructures and nanodevices based on semiconductors.

Keywords: Light emitting nano devices, Nanomaterials, Semiconductors, Solar cells.

INTRODUCTION

Semiconductors are substances with significant capability of conversion of their electrical properties from conductors to insulators and then to conductors. Semiconductor nanoparticles were made by various techniques to get the desired shape, size, and dimension. This is done by reducing the size of semiconductors to change their physicochemical properties to generate a quantum size effect. The entire field is so widely helpful and the most promising research for their implementations as light emitting nanodevices, laser technology, waveguide, *etc.* [1]. Majorly the conductivity and optical properties of semiconductors like

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absorption coefficient and their refractive indices have been altered to induce nanomaterial properties. Various semiconductor nanomaterials such as Si, Si-Ge, AlInGaP, CdSe, CdS, *etc*. have been significantly used in various applications such as in computers, cell phones, CD players, satellites, traffic signals, *etc*. Semiconductors are usually generated from a variety of differently rated compounds of type II-VI, III-V, or IV-VI semiconductor nanocrystals as per the modern periodic table [1, 2]. Reduction of size affects the physical properties of semiconductors such as structure, appearance, magnetic properties, optical properties, dielectric properties, and various thermal properties. This is due to surface effects and quantum size effects. Hence, because of the extremely small size of these materials, they exhibit properties that are essentially different from the original form of semiconductors and become superior in their characteristics and other viable properties [3].

In nanomaterials generated from semiconductors, electrons are confined to regions having all one, two, or three-dimensional structures, when comparing their sizes and dimensions according to de Broglie's wavelength [4]. In the subsequent history of nanotechnology, Nanosciences is subsequently gaining a lot of potential and has an impact on various research fields. However, in the 21st century, there has been subsequent production in Nanosciences between a range of diameter of 1 to 20nm [4, 5]. According to various research works, nanosciences has opened new options and availability for drug delivery, and gene therapy. Nanomaterials are also used for various diagnostic codes in medical sciences and can be used as nanocapsules and nanodevices. Nanoparticles are so widely useful for investigation purposes in forensic sciences; the major predictable uses are in fingerprints, forensic chemistry, *etc.* [6]. For decades, carbon nanotubes have been so widely used due to their thermal conductivity being twice to that of even diamonds. These nanotubes generally carry an electric current 1000 times more than in a simple copper wire, and are thermally stable in a vacuum up to 2700°C. Carbon nanotubes can be reinforced into nanocomposites, and have a wider range of other possible uses such as in electronic devices, nanocomputers, transistors, solar cells, types of diodes, such as light emitting diodes (LED), silicon-controlled rectifiers, and digital and analog circuits, hydrogen production, synthesis of silicon semiconductors and their useful devices. Various other optoelectronic devices are wide examples of semiconductor devices.

Nanotechnology has been significantly integrated with a variety of other disciplines propagating its effective and continuous use. Examples of such integrated disciplines include nanosciences, nanobiotechnology, nanochemistry nanophysics, nano-forensics, *etc*. [7, 8]. Additionally, research into nanoparticles and nanostructures is a crucial area for developing new norms, frameworks, and methods, perhaps leading to advancements in difficult logical problems. Nanomaterials formed from nanoparticles and nanocrystals exhibit unique optical and electrical properties [9] Subsequently, these nanomaterials are classified as Zero dimensional nanomaterials, quasi-one-dimensional nanomaterials, two-dimensional nanomaterials, and three-dimensional nanomaterials. All these nanomaterials have different chemical and physical properties. These are relatively different in conductivity, resistance, and uses on the nanoscale [10].

The entire book chapter presents a thorough study of semiconductor nanomaterials, their formation, hybrids of nanomaterials, their types, functionality, and applications. [11].

NANOSCIENCES AND NANOTECHNOLOGY

Nanosciences and nanotechnology deal with the manipulation of materials at the nanoscale or nano-diameter. This manipulation has been made by scientists and nanotechnologists to make various fundamentals of life possible, to create eco-friendly and sustainable products, and to emphasize eco-friendly development [12]. Since ancient times only, various chemically synthesized nanomaterials have been significant in use. Nanomaterials in the recent world have become potentially important both to scientists, and technologists, in medical sciences and practices, diagnostic activity, drug delivery systems, *etc.* [13, 14]. These materials are evident mainly due to their physical-chemical characterization and due to these characteristics, nanomaterials open new windows towards processing of other efficient high-performance materials.

The terminology nanomaterials has been a significant part of the modest term ‘nano’ which is derived from the Greek word ‘dwarf’. Nanomaterials have been significantly classified as nanoparticles, nanoclays, and nanoemulsions. Further classification of nanoparticles is as follows: organic nanoparticles and, inorganic nanoparticles as shown in Fig. (**1**) [15].

Nanoparticles have been accepted as useful materials in mega industries incorporated by nanotechnology. Nanoparticle science is a subsequent branch of substances that are dissected with various instruments and advancements in nanoparticle science. Nanomaterials made from semiconductors are crystallined with approximate sizes of 1-100nm. The majority of semiconductors are usually explained as band hole vitality, which in in turn requires an electron to move from valence vitality into empty vitality bands [16]. These nanomaterials have very few electrons in their conduction band and have more electrons in the valence band. Major fields of research in nanotechnology are summarised in tabular form in Table **1** [16 - 20].

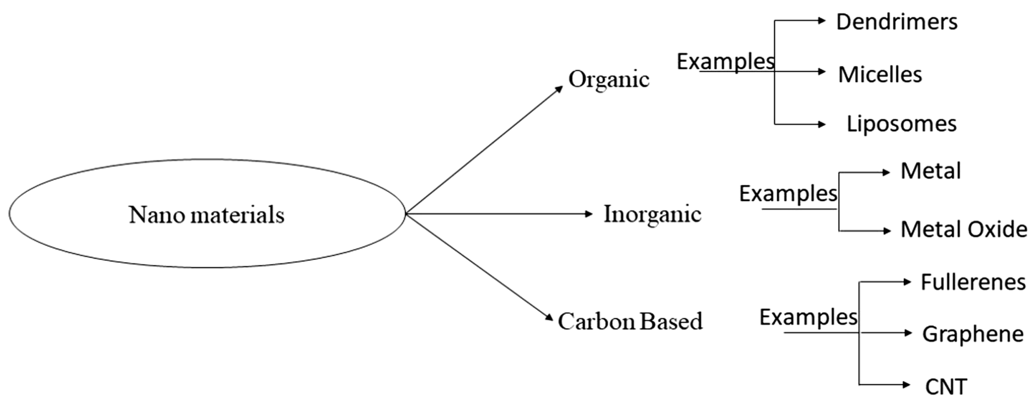

Fig (1). Classification of the Nanomaterials [15].

Table 1. Various Areas of Research Incorporated under Nanotechnology and Nanosciences.

S.No.	Areas of Research	Types of Nanomaterials	Synthesized Nanostructures	Purpose/ Usefulness of Research
1.	Agricultural industries	ZnO Nanoparticles Ag Nanoparticles ZnO Nanoparticles Cu Nanoparticles	--	Used as pesticides in agro-food industries.
2.	Nanomaterials used as nanotube membranes	C nanoparticles	Carbon nanotubes	Tubular structures are highly useful in food packaging to enhance food shelf life by reducing antimicrobial activity as various microbes get ruptured in direct contact with these nanotubes.
3.	Polymer-based nanostructures	--	Polymeric micelles Polymeric nanospheres Nanocapsules	These are specialized copolymers, nanostructures associated with synthesized nano molecules, mainly vitamins, antioxidants, and encapsulated polymeric matrix.

(Table 1) cont.....

S.No.	Areas of Research	Types of Nanomaterials	Synthesized Nanostructures	Purpose/ Usefulness of Research
4.	Lipid-based nanoparticles	--	Nanoliposomes Nanocochleates NLC (Nanostructured lipid Carrier) Archaeosomes Nanosized self-assembled structured liquid (NSSL)	These are mixtures of solid-liquid and liquid-liquid nano compartments, made at room temperature mainly used in beverages, minerals, phytotoxins, *etc*.
5.	Food industry	Solid lipid nanoparticles Selenium nanoparticles	Nanotea	Manufacturing of a selenium-containing tea increases the bioavailability of the tea.
-	-	-	Novasol	The carrier system is particularly used in the encapsulation of many food ingredients.
-	-	-	Nutri-nano	These nanoparticles convert various oil-based substances into water-admissible particles to increase their absorption.
-	-	-	Nanostructured liposomes	These nanoparticles encapture protein lytic enzymes that inhibit cheese production.
-	-	-	Zein nanostructures	Used to induce flavouring agents and essential oils in food to make them microbe resisted.
-	-	Silica nanoparticles	Nano-cluster	Utilises silica nanoparticles coated with cocoa powder to enhance the flavor and taste of the choco-based products.
6.	Nanotechnology-based food safety	-	Nanobio recognition	In this approach, useful metabolites are combined with nanomaterials to determine contamination and infection in the food.
-	-	-	Nanobarcodes	Used to detect pathogen contamination in food. Fluorescent tags are visualized using UV light when DNA barcodes get stuck to specific pathogens.