NANOELECTRONICS DEVICES: DESIGN, MATERIALS, AND APPLICATIONS PART II

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Gopal Rawat
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Bentham Books

Nanoelectronics Devices: Design, Materials, and Applications (Part II)

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Nanoelectronics Devices: Design, Materials, and Applications (Part II)

Editors: Gopal Rawat & Aniruddh Bahadur Yadav

ISBN (Online): 978-981-5179-36-1

ISBN (Print): 978-981-5179-37-8

ISBN (Paperback): 978-981-5179-38-5

Published by Bentham Science Publishers Pte. Ltd. Singapore.

First published in 2023.

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PREFACE

This volume is a continuation of the first volume of this nanotechnology book. The two volumes are an integral part of the book "***Nanoelectronics Devices: Design, Materials and Applications"*** and were necessary for easy handling of the whole book. The second volume is organized as:

ORGANIZATION OF PART II

Chapter 1 explains the waveguides' L shape defects and how they help in optical interconnection and optical signal amplification. Photonic crystal waveguide geometry such as one dimensional and higher dimensions and photonic crystal controlling index guiding mechanism, band gap mechanism, computational methodology, FDDT, various structure defects, and its simulation results are also provided.

Chapter 2 deals with the nanotechnology application in a power grid where power is transmitted from 8kW to 80kW with simple energy storage systems. A nano grid power frame is illustrated here that contains a smart transformer, smart sensors, smart electrical meters, capacitors, commutators, converter, communication, etc. Issues associated with nano power grid are identified, and a suitable solution is also proposed. Fuel cells for energy harvesting are also discussed and classified with other energy harvesting processes like wind energy and bioenergy. Nano grid reconstruction and restructuring are also listed with a proper illustration.

Chapter 3 deals with the use of nanomaterials photodetectors for artificial retina implants, a biomedical application of nanomaterials. Two-dimensional material and based heterojunction like MoS_2 /graphene, MoS_2 /CNT, and MoS_2 /WS_2 that have excellent carrier mobility, large surface area, thermal stability, and optoelectronic features introduced and identified as potential materials for the artificial retina. For this specific application, some biomaterials are also listed. Density functional computational technique, an effective method to identify a vast property of materials, is introduced. The density of states and optical properties of MoS2 simulated and illustrated will help readers decide on the use of this material for retina implants.

Chapter 4 presents fifth-generation communication possible because of the advancement in the nanoelectronics devices that provide efficient radio frequency power amplifiers, oscillators, amplitude modulators, etc. Amplifier classes, their performance comparison, and the Doherty amplifier classification are correctly explained.

Chapter 5 identifies carbon as an effective material for energy harvesting and is widely used for most solar cells. With active material for the optical to electrical conversion solar pannel different types and connection, multilayers, nanocomposites, junction box also illustrated.

Chapter 6 nanoelectronics and nanodevices have potential applications in the medical field called biotechnology. In addition, this chapter illustrates the use of polymers, polymer conductors, composites, graphene, and corban nanotube applications in biosensors, drug delivery, and such medical applications. Metallic nanowire liquid metals, wearable devices, electronic skin, intelligent wound bandages, tattoo-based electrochemical sensors, PEDOT: PSS-based EEG, etc. are presented in detail.

Chapter 7 present the application of nanomaterial in dentistry and cosmetic with a proper illustration. Nanoelectronics is able to produce restorative material in dentistry. Anesthesia, dentifrobots, orthodontic nanorobots, bottom-up and nanocomposites, glass ionomer cement, nanoceramics, and top-down implant approaches for dentistry and cosmetics, including their synthesis and fabrication by physical and biological roots, are elaborated. Information about the antibacterial properties of a gold-silver alloy, nanomedicine, ficus benghalensis root extract, Ag_2O nanoparticles, and different sensor and nanotechnology applications in surgery is given. Cosmetics are substances that improve the appearance of the skin and have been used by humans from ancient times in one form or another; here, some cosmetic materials like liposomes, niosomes, solid lipid nanoparticles, nanoemulsions, and cosmeceuticals are defined.

Chapter 8 provides information on environment monitoring using ferromagnetic materials. Types of ferromagnetic material biosensors and ferromagnetic, synthesis process, surface functionalization, application, based pesticides, and some pollutants and dangerous chemicals phenolic compounds, heavy metals, are incorporated in this chapter. Some future challenges and scopes in this field are also listed.

Chapter 9 focuses on the application of nanoelectronics, nanotechnology, and nanomaterials like a lab on chips in food processing and agriculture. Different structure of nanomaterials that are used in food processing is presented. Nanotechnology helps in crop production, animal production, food preservation, and soil fertility. The characterization techniques of the nanomaterials are also listed. Many sensors not presented in the previous chapter are also discussed, such as the Rumi watch nose band sensor.

Chapter 10 describes a cascade laser based on a nitride-based quantum dot, a one-dimensional material. Population inversion and energy band gap are explained in depth. Green function and different scattering are also discussed in depth.

Chapter 11 discusses nanomaterials' different fabrication methodologies and nanotechnology like carbon nanotube, quantum dots, *etc.* It includes photolithography, ball milling, electrospinning, sputtering, co-precipitation some fabrication methods to fabricate electronic devices

Chapter 12 presents the application of nanoelectronics in the medical field. This chapter is a review chapter that indicates the different nanomaterials in medical instruments. It also touches on carbon and based materials and their application in medicine.

Chapter 13 discuss and presents the InAs quantum dots for the fabrication of efficient solar cell, similar to the quantum dot technology used for the fabrication of the laser, and chapter 24 elaborates on them.

Chapter 14 presents the electromagnetic band gap of one, two, and three-dimensional materials in detail. Here band gap engineering is tailored by the substrate on which nanomaterials are synthesized. This chapter provides recent developments in electromagnetic radiation based on nitride materials.

This volume has all the key feature that has first volume. Hope readers find these two volumes helpful for their academic and research needs.

ACKNOWLEDGMENT

Editors special thanks to almighty god for giving light to write a book on nanoelectronics devices: design, material, and application to serve scientific society. We sincerely thank all contributors, reviewers, and colleagues who made this project successful. Editor's special thanks go to Mr. BS Sannakashappanavar for his valuable time compiling the book in its present form. Editors also thank their M.Tech and Ph.D. students for their support while editing the book.

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CHAPTER 1

Design and Analysis of L-shape Defect-based 2D Photonic Crystal Waveguide for Optical Interconnect Application With Signal Amplification

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Abstract: Photonic crystal (PhC) has witnessed an unprecedented research interest since its discovery by Yablonovitch and John in 1987. PhC has undergone substantial theoretical and experimental study because of its periodic dielectric structure and ability to guide and manipulate light at the optical wavelength scale. The photonic band gap (PBG), one of the fundamental characteristics of PhC, prohibits the transmission of light inside a definite wavelength range. The PBG property of PhC opens up enormous opportunities for envisioning a wide range of applications like communication, filtering, bio-sensing, interconnector, modulator, polarizer, environmental safety, food processing *etc*. However, a peculiar property can be observed when defects are added to PhC, the periodicity of this dielectric structure is disrupted, allowing PC to exhibit high electromagnetic field confinement, a little more volume, and feeble confinement loss. The propagation of light can be altered and engineered by altering the structural characteristics of PhC or introducing appropriate materials into the rods of PC. Among the different applications, optical interconnect is the most escalating application in a photonic integrated circuit. This chapter addresses a novel 2D photonic crystal waveguide for optical amplifier application. The proposed structure comprises 9×9 circular rods of Si with air in the background. A sequence of Si rods is removed to create a defect in the 90° shape. The finite difference time domain method (FDTD) can be adjusted to envisage the electric field allocation along the 90° bend defective region. Several geometrical factors, such as the radius of the Si rods and the gap between lattices, are judiciously optimized in order to realize strong light confinement inside the defect region. The intensity of incident light and the transmitted light is evaluated through numerical analysis, where it is found that the transmitted intensity from the

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waveguide is much higher than the intensity of incident light, which ensures that the projected construction can act as an optical amplifier. Apart from this, the bending loss close to the bending area of the photonic waveguide is investigated. A small bending loss of the order of 10^{-5} exists, which indicates efficient guidance of light along the 90º bend path. Lastly, the confinement loss along the defect region is studied, which is found to be in the order of 10^{-11}. So, the light propagation with negligible loss indicates that the future PCW could be an appropriate applicant for optical interconnect applications.

Keywords: Bending loss, Confinement loss, FDTD, Nonlinearity, Optical interconnect, Photonic crystal waveguide.

INTRODUCTION

In 1888, Lord Rayleigh initiated the era of photonics when he proposed a periodic multilayer dielectric stack to realize the mirror application [1]. However, at the time, scientists/researchers were unaware of the importance of photonics towards various societal applications. Almost a century later, in 1987, Eli Yablonovitch and Sajeev John [2, 3] came up with a revolutionary idea on photonic crystal, which completely changed the research perceptive of photonics, and the researchers began to explore the characteristics and applications of periodic structures in depth. Later, V.P. Bykov highlighted the high-dimensional photonic structures [4]. After 1987, nevertheless, the research on photonics has accelerated exponentially, and the fabrication constraints have come up as a hindrance in realizing high-dimensional photonic crystal structures. For the first time, Krauss [5], in 1996, presented the possible fabrication techniques to envisage two-dimensional photonic crystals using semiconductor materials. Besides this, works are also carried out on photonic crystal-based chips or components to communicate data between ON and OFF chips through optical signals. Afterwards, the researchers studied the impact of photonics in the healthcare sector, bioanalytics sensing, quantum computing, optical communications, the food industry, environmental hazards monitoring, display engineering, *etc*.

In earlier decades, a lot of significant steps were taken to manage the flow of electromagnetic rays in materials by regulating their optical characteristics. The introduction of optical fibers has revolutionized the optical and telecommunication industry, by allowing light guidance through the total internal reflection (TIR) effect [6]. Alternatively, the light can be controlled by using the Bragg diffraction technique, and the same has been the backbone of designing dielectric mirrors [7]. The principle of the dielectric mirror was further researched, and in 1987, scientists explored one-dimensional light reflection material, which led to the discovery of a new class of material called photonic crystal (PhC). The developments of photonic crystals were traced back to 1987, when two milestone publications were available in the journal of Physical Review Letters [8, 9], where the authors noticed the concept of the Photonic Band Gap (PBG). Even though the wave transmission in a periodic medium (containing even 2D optical lattices as well as gratings) had been identified for decades, these investigations opened up a novel avenue of experimental and theoretical inquiry. The fundamental goal of the year 1987 publications was to design the compactness of optical state in specific synthetic materials and remove natural light emanation, hence enhancing laser performance. The broadcast of electronic wave functions (*i.e.*, electron mobility) in semiconductors and electronic lattices is paralleled by the transmission of optical frequencies in a material having a periodic structure.

PHOTONIC CRYSTAL WAVEGUIDE (PCW): CONCEPT AND GEOMETRY

Photonic crystal waveguides are typically generated by a linear defect, which is composed of a row of modified lattice unit cells printed onto a high-index dielectric membrane. Photonic crystals (PhCs) can be created by periodic arrangement of dielectric materials of the varied index of refraction in 1D, 2D and 3D. A plane wave is not an Eigen function of the Helmholtz equation in PCs since they are inhomogeneous materials. An overall field in a PhC is the aggregate of the transmitted and reflected fields from the entire scattering areas (distributed Bragg reflection). DBR and the incident field might add constructively or destructively depending on the structure's period and frequency of operation. When backward transmitting waves totally terminate out forward transmitting waves, the transmission coefficient disappears, resulting in a resonance condition. As a result, photonic crystals can have a certain gap (known as photonic bandgap or PBG [10 - 12] in the band diagrams, for example, in the figure of momentum vs. photon energy. Further, some frequencies of electromagnetic rays cannot propagate in certain structures. Photonic crystal waveguides (PCWGs) are basically constructed on a silicon-on-insulator (SOI) wafer. The spectral characteristics like communication spectra and reflection spectra are used to examine the whole photonic band gap, index-guided mode and band gap-directed mode. The PCWG's mini-stop bands can be simulated using various structural parameters. The coupling properties of PCWG are theoretically explored, while flaws during the manufacturing process were taken into account. Based on the complexity of their periodicities, PhCs are classified as follows.

ONE-DIMENSIONAL PHOTONIC CRYSTAL

1D PhCs are simple to design and analyse. These structures can be solved analytically with a few steps. 1D PhC is the alternate arrangement of dielectric

CHAPTER 2

Nanotechnology in Smart Nano Power Grid

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Abstract: Smart small-scale power system accommodates Microgrid (MG) and Nanogrid (NG) with a cluster of multiple Distributed Energy Resources (DER), energy storage facilities, adjustable smart demand capabilities, and protecting and monitoring devices. The advancements in nanotechnology attracted the inculcation of nanomaterial science to resolve equipment-related issues in electrical power systems. The realization of nanotechnology to mitigate the variety of issues in the major entities of small-scale distribution systems leads to the evolution of the smart grid. From the smart grid perspective, the nanotechnology application acts as a disruptive technology in the improvement of renewable energy harvesting, storage devices, transformers, meters, insulators, capacitors, sensors, automation and communication. It provides an appropriate innovative solution for adequate and reliable electrification in MG and NG topology. In this article, the applications of nanotechnology in major equipment of small-scale distribution power systems and the possible innovation of MG and NG are discussed to inculcate a smarter electrical power system. The impact of nanotechnology applications has revitalized the Smart Power Grid in a modest way to provide an excellent opportunity for power autonomy.

Keywords: Capacitors, Insulators, Nanotechnology, Microgrid, Meters, Nano grid, Storage devices, Smart grid, Sensors, Transformers.

INTRODUCTION TO NANOTECHNOLOGY

Nanotechnology(NT) is a promising technology capable of resolving issues of a simple to complex nature in all sectors. The versatile properties of nanomaterials have accelerated their implication in the vast electrical engineering field. Nanotechnology has intruded into the research and development of power grid sector by revolutionizing changes and improvements in the material characteristics as well as in the cost of power grid devices and components. The realization of nanotechnology has been proven to mitigate a variety of issues in

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the major entities of small-scale distribution systems, leading to the evolution of Smart Grid.

Classification of Nanomaterials

The nanomaterials like Gold, Silver, Zinc, Copper, CNT, graphene, and silica have revolutionized the era of NT in a wide range of applications. Research on the carbon family of nanomaterials includes fullerenes, CNTs, graphene, carbon nanohorns, carbon-based quantum dots, and many others. Recent innovations in nanomaterials are Carbon Quantum Dots(CQD) with advancements in lower toxicity levels, environmental friendly usage, economical, improved photostability, enhanced electronic conductivity, and effortless synthesis of the protocol and have gained recognition over the traditional semiconductor quantum dot.

Method of Synthesis

The effectiveness of nanomaterials is based on the method of synthesis, appropriate functionalization, and applications. The synthesis of nanomaterials occurs through two main approaches, namely the top-down approach and bottom–up approach. In the traditional top-down approach, bulk materials are divided into nanostructured materials through a series of processes such as mechanical milling, electrospinning, lithography (etching), sputtering, arc-discharge technique, laser ablation technique and ultrasound synthesis technique. The bottom-up approach comprises nanoporous materials production, solvo-thermal synthesis, hydro-thermal synthesis, thermal pyrolysis, chemical-vapour deposition and reverse micelle methods.

Nanotechnology in Electrical Engineering Applications

In general, the building block materials of NT, like nanocrystals, nanotubes, nanowires, and nanofibers, are widely preferred in a variety of applications. The applications of nanotechnology in the electrical engineering field are vast but not limited to dielectric materials, electrical components, electrical energy storage devices, electrical transmission, energy transmission, energy conversion, optoelectronics, photochemical devices, semiconductor and sensors.

SMART NANO POWER GRID

The nano grid is a part of the power distribution structure that deals with low power in the range of 5 kW to 80 kW and lesser complexity in the structure, control strategies and optimisation techniques [1]. The structural hierarchy of the power grid, as shown in Fig. (**1**), shows that multiple nanogrids form a microgrid, and multiple microgrids form a power grid. Similar to microgrids, the nanogrid could also operate in islanded or grid-connected mode.

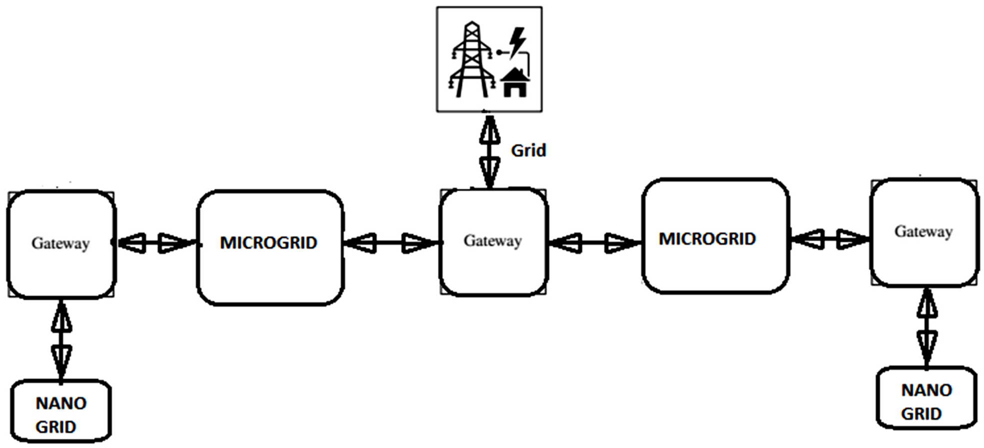

Fig. (1). General structure of the power grid.

Fig. (**2**). shows the structure of nanogrid with a variety of dependents, such as local conventional resources, renewable energy sources, energy storage system, and loads. The nanogrid can be a better option for low-power consumers like a group of houses in village, colonies or organizations that are equipped with local electricity generation to fulfill the load consumption requirements. The adoption of distributed systems may include microgrid and nanogrid along with the appropriate control architecture. Dependency on the main power grid could be reduced by the utilisation of electricity generation and storage promoted through microgrid and nanogrid.

For any kind of framework designed to satisfy a variety of loads, the nanogrid system must provide excellent energy harvesting, storage, stability, power conversion, power management, communication, and protection devices. In essence, the minimal hardware of an SNG framework comprises any renewable energy source, battery, circuit breakers, power converters, power controllers, and Ethernet local area network (LAN) based communication. Moreover, in SNG, frequent measurements of parameters like current, voltage, temperature, and phase difference are recorded to identify any fluctuation in the parameters and thereby facilitate corrective action in order to ensure the scope of grid reliability. Furthermore, the sensors facilitate the measured data in a readable form to support SNG operation.

CHAPTER 3

Theoretical Analysis and Design of Microphotodiodes Material for Artificial Retina Implant

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Abstract: As a typical member of two-dimensional TMDs, molybdenum disulfide (MoS_2) has excellent carrier mobility, a sizable surface area, thermal stability, and optoelectronic features. Due to its tunable bandgap, strong valence–conduction band bonding, and use in optoelectronic sensors, photodiodes, and phototransistors, MoS_2 has emerged as a possible substitute for graphene. For better optoelectronic properties, MoS_2-based monolayers and crystals have recently been investigated using a variety of heterostructures, including MoS_2/graphene, MoS_2/CNT and MoS_2/WS_2. It was also mentioned that MoS_2 phototransistors and sensors had poor light sensitivity because of their insufficient ability to absorb light. The right choice of material is essential for biomedical implants, including retinal implants, neuroprosthetic implants, and others where photodiodes are used to generate electrical currents in reaction to incident light Au-based nanoparticles and nanoarrays have been added to the MoS_2 monolayer to address the low absorption problem.

For increased quantum efficiency, MoS_2 monolayers based on solar cells and light-emitting diodes have also recently been created. In some of the other research, other transition metal (TM) atoms, such as Au, Ag, Cu, Nb, Tc, Ta, Re, Co, Ni, Fe, and Mn, were substituted into the monolayer of MoS_2, enhancing the material's electrical, magnetic, electrocatalytic, and gas adsorption capabilities. The combined electrical and optical properties of TM-doped and alkaline metal (AM) doped MoS_2 bulk layers haven't received much attention, though. In this study, the effects of doping MoS_2 bulk layers with TM atoms (Au, Ag, and Cu) and AM atoms (Na, Li) were investigated using first-principles DFT calculations. We investigated the density of states (DOS), band structures, structural features, optical conductivity, absorption, and reflectivity of five different doped MoS_2 bulk layers. The results show that AM atom doping narrows the MoS_2 bulk layer's bandgap more than TM doping. Bandgap values ranged from 1.42 eV for the undoped MoS_2 layer to 0.609 eV for the Li-MoS_2 layer. Additionally, it

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was discovered that bulk layers of MoS_2 doped with AM had higher optical conductivity and absorption qualities and lower reflectivity. In applications of MoS_2-based photodiode/phototransistor sensors, doping of AM atoms may show to be a successful substitute for conventionally used TM (Au) doped arrays.

Keywords: Absorption, Artificial vision, Conductivity, Density Functional Theory, Dielectric coefficient, Reflectivity.

INTRODUCTION

In the last few years, after successfully understanding the behaviour of retinal nerve operation, the response of electrodes to the retinal cells, and communication between external computing devices and retinal tissues, the artificial retinal implant has shown promising results. Adult mammalian cells that have been injured cannot regenerate; as a result, replacements are used to cure them. As cochlear implants can create a sensation, which is not only useful but also through one channel, whereas, in the case of retinal implants, a sequence of electrodes is needed, its feasibility has made the success of artificial retinal implants much more difficult. In order for the technology to become accessible and practical for the general public, it is very much required that scientists and engineers working at the global level must come along and work in coordination. This is the only way by which the initial success can be converted into some practical solution.

Relevance of this chapter to this book: This chapter is dedicated to the design and analysis of a suitable material for a very crucial nanoelectronic component, *i.e.*, photodiode. Photodiode being the key device in artificial retinal implant chips, has the challenge of efficient conversion of light into electricity that can stimulate the degenerated retinal tissues. Hence, the material which is employed in designing the photodiode is of paramount importance. The techniques of density functional theory have been utilized to analyse the MoS_2 material, and doping of various transition and alkaline metal atoms is also considered. Further, the important electronic and optical properties of these materials are analyzed to see the attributes suitable for retinal implant technique.

However, countries like the United States, Japan, and Germany achieved some success in the implantation of retinal chips in animals and a few in human beings that have worked as an inspiring force [1, 2]. Despite encouraging outcomes in clinical trials in animals, the success in the case human is at a very initial level and needs correction. There are 191 million and 285 million visually impaired persons worldwide, respectively, according to two separate reports from the years 2010 and 2012; however, the data available from WHO shows the worse scenario. It says 3.14 billion people are facing one or the other problem of blindness, out of which approximately 0.45 billion are severely blind. The majority of blind patients are located in poor nations, which is an interestingly unfortunate fact. The two major causes of diseases responsible for blindness are Age-related macular degeneration (AMD) and Retinitis Pigmentosa. In South Asia, the West of Europe and northern parts of the USA are dealing with this issue [3, 4]. It was then followed by other diseases. About 17,000 people in Germany lose their vision each year, many of them as a result of the degeneration of cones and rods in the retina. In comparison with the other technological advancements, such as pacemakers and cochlea, which are readily in use in society, the electronic/technical solution or implant for the problem of blindness is still not viable. This is seriously a big concern and challenge.

Retina, an exceptional neuroprocessor that is in charge of receiving and processing enormous amounts of complicated information *via* its neuroepithelium sensor, is the source of vision. The principle behind the retinal implant procedure is the electrical elicitation of nerves within the retina with the assistance of rods and cones. The photoreceptor cells and retinal ganglion cells (RGC) actually transform chromatic and achromatic colour images into their equivalent form of electronic/chemical/electrical signals. These signals are then categorized on the basis of resolution, known as spatial and temporal resolution. Finally, the brain's cortex receives this electrical information *via* the geniculation muscles, allowing the human to view the image.

With the sole purpose of sensitizing the degenerated retinal tissues known as rods and cones in the photoreceptor cell so that the conversion of light into its equivalent electrical form can be done, the subretinal implant works on the principle of replacement. The above-said structure is replaced by one or the other electronic aid such as microphotodiodes, charged coupled devices and CMOS imagers. This replacement technique helps in reducing surgical trauma, the need for stimulation current, and the need for mechanical fixation; yet, the absence of external light might lead to serious disorders. Additionally, the positioning of electronic devices in vulnerable body regions runs the risk of excessive bleeding and damage from overheating [5].

Epiretinal implants, in contrast to subretinal implants, focus on processing the need for external visualization. They don’t repair the degenerated cells. Hence, external tools like cameras, digitizers and transducers are important here, as they act as a converter of image information into the electrical output. The advantage here is that the presence of external elements effectively reduces the surgical needs, and because the vitreous serves as a heat sink, the control over the environment also improves. The task at hand is to create a lengthy and complex

CHAPTER 4

Fifth Generation Mobile Communication: Devices and Circuit Architectures

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Abstract: With the tremendous expansion in communication in recent years, contemporary communication techniques must improve quickly. The requirement is data-driven, driven mainly through users for content consumption and the expanding number of other mobile users who require quick access to the network for personal and professional needs, resulting in a massive growth in data traffic. However, because services and daily requirements are conducted over the internet, 5G demands pose new obstacles. As a result, device count and connections in wireless networks will grow, resulting in increasing demand for total data and the requirement to manage a large number of physical connections.

In any modern wireless communication system, power amplifiers are essential components. For many years, the general problem has been to reduce the amount of energy consumed, which is DC in nature concerning the amount of radio frequency delivered. The fifth generation (5G) wireless communication system is intended to connect billions of devices at a very high data transfer rate. However, it has prompted worries about the fast-rising global energy consumption, necessitating urgent innovation in the creation of energy-efficient wireless transmitter systems.

Efficiency, as well as linearity, are two important parameters of power amplifiers. It is unavoidable to make trade-offs among parameters like efficiency and linearity, and attaining both is incredibly challenging. In most cases, lowering the requirements of nonlinearity, which are linked to power efficiency, results in transmitting the signals with the highest amplitudes below the amplifier's compression level. The linearity of PAs, in addition to their efficiency, can be quite substantial. Some strategies include as Doherty power amplifier, Outphasing technique Envelope Tracking (ET), Kahn Envelope Elimination and Restoration (EER), and Linear Amplification with Non-linear Components (LINC).

Keywords: Doherty Amplifier, Outphasing Amplifier output back-off, Power Amplifier.

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INTRODUCTION TO FIFTH-GENERATION MOBILE COMMUNICATION

In general, a Radio Frequency Power Amplifier (RFPA) is an electrical amplifier capable of converting an RF signal which is low power in nature, into a signal which is high power which is appropriate for communication. The RFPA's inability to sustain high power efficiency over large frequency bandwidths is a typical issue. There exists a trade-off between linearity with power performance. Different exploration projects are carried out to solve this problem. Power amplifiers are classified based on their electrical characteristics, circuit architecture, and operation mode.

The data rate, radio access, bandwidth, and switching mechanisms are the four key areas where cellular generations differ from one another. Depending on the system type and service, the 1G (First Generation) cellular networks, which were primarily analog, had a bandwidth that ranged from 10 to 30 kHz. After converting from analog to digital, the offered data speeds were around ten kbps. The FDMA radio access protocol and all-circuit switching suited it for voice services. The data rate of the 2G (Second Generation) GSM networks was 9.6 kbps in the first phase, and it climbed to more than 300 kbps with 200 kHz bandwidth in the second and third phases. The peak data rate for 3G (Third Generation) networks started at 2 Mbps in the first phase and increased to 50 Mbps in the later phases, all while maintaining a continuous wide bandwidth of 5 MHz.

The 3G access method allowed was CDMA, and the switching remained circuit and packet. However, 3.5G was first focused solely on packet switching with the HSDPA technology and only on packet switching after that. Peak data rates for 4G (Fourth Generation) cellular systems began at 100 Mbps.

Different access techniques, including WLAN, WMAN, and cellular, are merged in 4G mobile systems and work together to provide various services in various radio situations. A transceiver is an electronic system that includes a transmitter and a receiver. Strong RF current is generated by a radio transmitter and passes through the antenna. Electromagnetic waves (EMWs), often radio waves, are emitted by a transmitter antenna. Information that requires to be transmitted over vast distances is transmitted through transmitters that are used in radio along with other transmission devices. Modulating the waveform at which the information wave typically appears in the form of a digital signal, video signal from a camera, or audio signal from a microphone. Phase-modulated (PM), as well as Amplitude-modulated (AM) with high peak-to-average ratios (PAR), are applied to current wireless communication systems. Following, Fig. (**1**) shows the evolution of broadband generation.

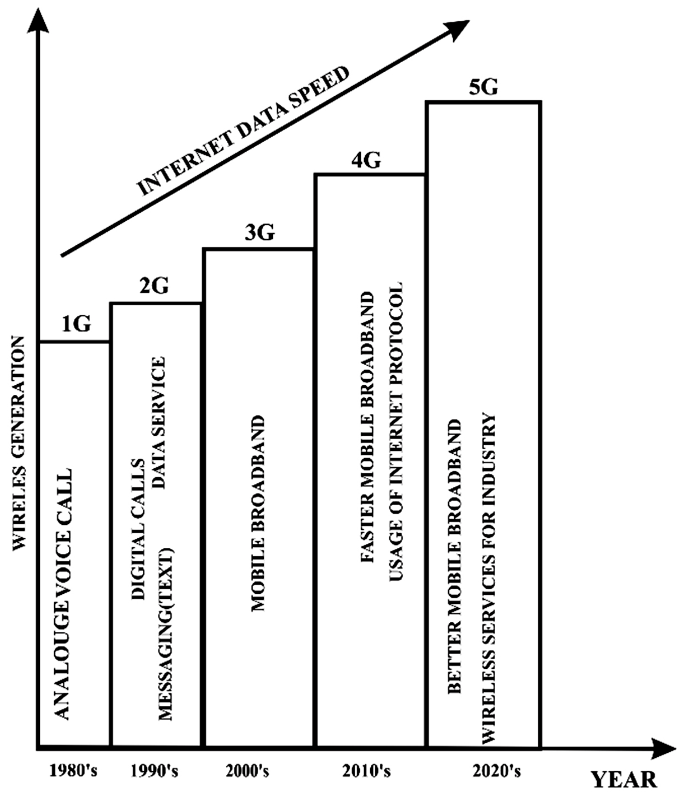

Fig. (1). Evolution of broadband generation.

It is challenging to design a transmitter with highly efficient and excellent linearity. When the signal shows both amplitude and phase modulation, linear amplification is essential. The amplified signal is generated wrongly because of nonlinearity. To effectively design a wireless communication system, a power amplifier is an important device [1]. The power amplifier's primary aim is to enhance the signal's power level. Transmitters ought to be linear to minimize interference and spectrum regrowth. Regardless of its physical form, a PA's function is to boost a signal's input power value at a specific frequency range to a predetermined value at the output.

Therefore, the power amplifiers should be seen as non-linear structures. Under higher waveform operating situations, a PA frequently experiences negative effects that distort the output waveform, a copy of the input waveform. On the other hand, small-signal amplifier design approaches cannot directly be applied to

CHAPTER 5

A Novel Nanotechnological Approach Towards Solar Panel

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Abstract: The significance and benefits of using solar energy for making use of power are notable. Still, the pace of introducing photovoltaic panels for creating power in domestic and private enterprises is still low. The explanation is the high establishment cost of the Photovoltaic arrangement, decreased productivity of the as-of-now involved solar panels and the huge space required for introducing solar panels. In this chapter, the authors have proposed an innovative Photovoltaic arrangement that resolves the previously mentioned issues. The proposed innovative multi-layered Photovoltaic model integrates nanotechnology with the present model of the panel. Various nanocomposites and nano polymers are compared, and the best-suited one is used to propose a novel solar panel with the help of nanotechnology. It was found that the integration of nano-technology improved the transmission rate of sun rays in the proposed panel. Lastly, a detailed comparative analysis between the existing Monocrystalline panel and the proposed set-up is done. It is found that the technical, economic and environmental performance of the proposed Photovoltaic Set-up exceeded that of the existing technology.

Keywords: Dye-Sensitized Solar Cells, Nanocomposites, Nanotechnology, Nanopolymers, Nanocrystals, Nanowire, Photovoltaics, Substrates, Solar Energy, Solar Panels.

INTRODUCTION TO NANOTECHNOLOGY

Nanotechnology is the science of fabricating, constructing, and studying materials on the nanometer-scale. The ideas and concepts that serve as the basis for the term date back to the 29th of December, roughly around the 1950s, when the great physicist named Richard Feynman delivered his speech entitled "There's Plenty of Room at the Bottom". Long before the term "Nano Materials or Nano Techno-

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logy" was coined, the American Physical Society held a meeting. In his talk, Richard Feynman provided a mechanism for manipulating and controlling specific parts of matter, namely: atoms and molecules. While researching ultra-precise machining after 10 years, the term was coined by Professor Norio Taniguchi [1, 2]. The invention of the specific microscope called the scanning tunnelling microscope was necessitated by modern nanotechnology, which was not invented until 1981. The resulting microscope was capable of separating individual atoms. Scientists are now debating whether nanotechnology will have positive or negative effects. The technology is believed to be capable of producing an extensive array of novel materials and technologies for use in numerous industries, including energy generation and medicine. There are two significant nanotechnology methods (Fig. **1**):

1. Bottom-up Approach: It consists of the technological developments which are made up of atomic or subatomic components which chemically fabricate themselves using molecular recognition principles.

2. Top-down Approach: It consists of the technological developments which are formed from bigger things without consideration of molecular control.

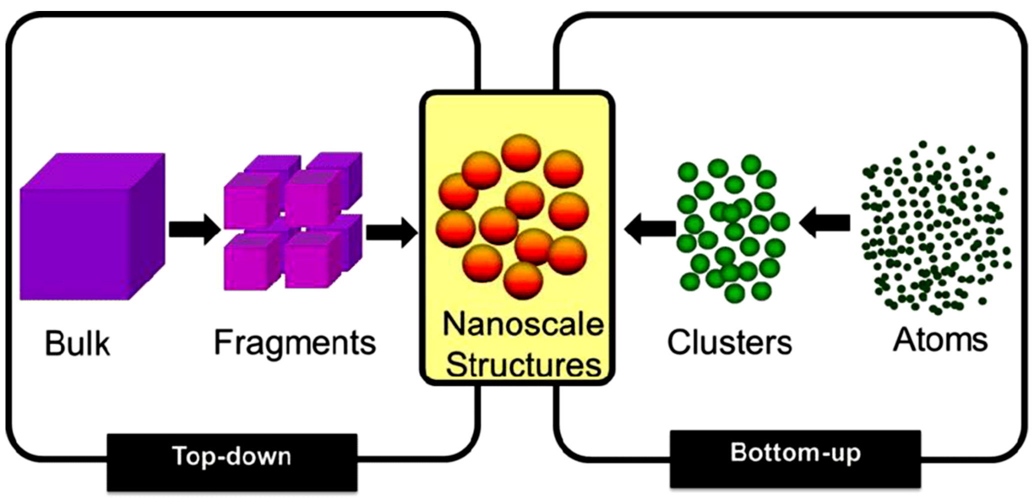

Fig. (1). Different approaches for a nanotechnological generation [2].

Companies in this new era of global competitiveness are able to meet the challenges of competition by enhancing their production processes *via* the use of technological advances. These innovations are the means by which these companies are able to overcome the problems of competition. The competition to make technological advancements has grown increasingly visible in recent years, particularly over the past ten, when product life cycles have substantially shortened. There have been significant advances made in a variety of fields, including medical, communications, robotics, computing, and energy, to name just a few of these fields' respective fields [3 - 5]. The emergence of new technology like hand held devices, medicinal imaging systems, and other such developments are particularly significant when considered in light of the function that the internet has substituted. In point of fact, customers and enterprises alike started putting their faith in newly developed technology and innovation strategies, respectively. On the other hand, it is not easy to determine how significant this is [1]. It is a known fact that certain individuals and businesses perform better professionally than others in a market that is characterised by a high level of competition. Notably, the capacity for innovation is a trait that is shared by both the individuals and the organisations that thrive in both of these contexts.

Traditional solar cells suffer from a number of drawbacks, including high production costs and poor overall performance. The utilisation of silicon cells is the root of the issue, which is that the problem of decreased efficiency is virtually unavoidable. (Fig. **2**). The reason for this is that both the energy of the photons produced by the sun and the energy of the band gap are sufficient to eject an electron from its orbit. When a photon's energy is less than the band gap, any remaining energy is dissipated as heat. Solar cells typically lose roughly 70% of the sun's energy that reaches them on an ordinary day due to factors like these. This fictitious scenario enables us to draw attention to one of the most significant technological developments in the annals of human history: nanotechnology. This field of study possesses incredible potential for a diverse spectrum of scientific and practical applications. Today, nanotechnology is having an effect on a wide variety of business sectors, such as agriculture (for the purpose of pest control), medicine (in the form of the implantation of nanorobots), and a great many more [4 - 7]. These industries provide a plethora of career paths to choose from. In order to explain how nanotechnology might be used in the manufacturing processes of many industries, this article uses the electricity generated by photovoltaic panels. It is of utmost significance for businesses operating in this sector of the market to take advantage of the competitive advantage offered by the utilisation of nanotechnology in the generation of solar energy. NANOSOLAR, a start-up based in the USA, has taken the lead in the competition to generate electricity using nanotechnology. This study is being funded in part by the United States Department of Energy as well as by notable companies such as Google and IBM. Nanophotovoltaic panels are the name given to this innovative concept. The utilisation of this product has shown a reduction in total business expenses when compared to the utilisation of alternative types of solar energy [3]. When taken as a whole, it satisfies the conditions set forth by the government for the utilisation

CHAPTER 6

Developments in Ultra-Sensitive Nanoelectronic Devices for Medical Applications

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Abstract: The interface between nanotechnology and biotechnology is emerging as one of the latest technology with the utmost comprehensive and active areas of research, bringing together the medical science and engineering field. Scientifically a disease or an illness is mostly caused by molecular or cellular damage, and sensing these changes through nanoelectronics can play an important function in assisting medical demands for early detection and diagnosis. Implantable nanoelectronics devices create numerous applications in medical observation of specific signs, bio-physical investigations of impulsive tissues, implantable devices for different body organs, solving the previous shortcomings of conventional bioanalytical techniques in terms of sensitivity, throughput, ease-of-use, and downsizing. The advancement of nanobioelectronic systems that can activate enzyme activity, the electrically triggered medicine release, an electronic circuit-based retina for colour vision, nanotech-founded breathalyzers as an assessment tool, nanogenerators to control self-sustaining biological systems and implantation arrangement are some of the applications of nanoelectronics, and in future, we may even use nanoelectronics circuit within the body tissues to regulate its functioning. In this chapter, we give a summary of the latest advances in nanoelectronics based on nanostructures, on-chip and electronic integration, microfluidics, biochemistry, and data science toolkits, we highlight the possibility for improved performance and additional functionality.

Keywords: Biosensors, Graphene, Nanotubes, Nanosphere, Nanowires, Nanotechnology, Nanoradios, Nanophotonic.

INTRODUCTION

Science and technology are making tremendous progress in many sectors, especially with the remarkable expansion of applications in numerous fields. One of the applications of electronics has been crucial to many facets of biomedicine during the last decade, extending from essential biophysical investigations of functions in tissues like the heart and brain to their monitoring and treatments.

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The medical community has now accepted the use of electronic technologies not just to assist patients in recovering from disease, but also to replace medically stained/disabled body parts. The resultant electronic technologies have the potential to incorporate onto or into the human body for diagnosis, medical, or therapeutic purposes, with the opportunities to enhance people's health and expand knowledge of biological systems. Scientists have concentrated their efforts on rebuilding every part of the human body in order to live a long and healthy life [1].

The vast possibilities of implanted electronics in the human, including pacemakers, defibrillator devices, deep brain stimulation, electrical interfaces with tissues, artificial retina, biosensors *etc*., have shown enormous applications, as shown in Fig. (**1**). The advancement of such technological developments, as in many other domains of research, will need the creation of novel materials and methodologies to allow greater tissue integration, interrogation, and stimulation with other functionality. In this regard, nanoscience provides several options for advancement. As nano-size materials are the cutting edge of this technology, which are rapidly evolving and are vital in the biomedical industry. These materials have exceptional properties and are essential in different areas due to their distinctive size-dependent features, and fascinating properties, such as enhanced surface area and unique quantum effects. Such advancements in artificial structures have also been made feasible by the development of flexible and delicate electronic substances that can easily incorporate within the body. An electronic organ is a device that is inserted into the body and interacts with biological cells to imitate or augment a specific function of a natural organ. Electronic devices or implants, on the other hand, may experience electrical and magnetic intervention, erosion, and wear and tear over time [2]. Furthermore, owing to repetitive functions, batteries must be replaced. Developing corrosion-resistant and longer-lasting electrical devices that can be powered by movements or even other sources of power from the body could be the answer.

This chapter discusses the role of nanoelectronics in biomedical sciences, focusing on creating electrical nanodevices that not only heal cell damage and diseases but can also assist in the replacement of contaminated human organs. To meet the requirement for soft, curvilinear, and constantly growing human body features, modern nanoelectronic systems are being produced with the help of advanced and intelligent materials with a variety of functions [3]. The chapter will begin with a brief introduction of the polymers necessary for the fabrication of nanoelectronic devices, as these materials are critical in the development of flexible bio-nanoelectronics. The insertion of liquid metals and nanoelectronic components into such polymers will next be discussed since we believe that the study and development of such composite systems may soon be led to a new scientific development in this sector. We will first concentrate on the application of these materials in various health monitoring devices. As a new perspective, we have also analysed current advancements in research and potential new routes that this burgeoning profession may go in the future.

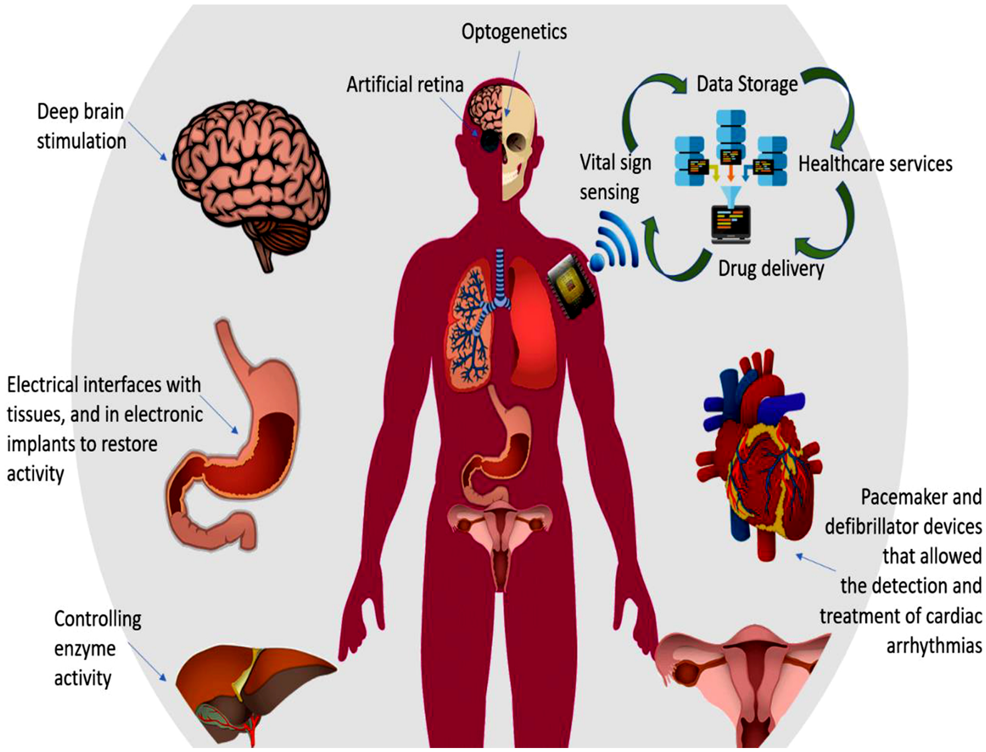

Fig. (1). Nanoelectronics-based devices and biosensors for health monitoring applications.

NANOSTRUCTURE BUILDING BLOCKS

Conventional electrical equipment was hard, flat, and physically static, but the human body is soft, curvilinear, and constantly developing. This discrepancy between traditional electronics and the human body eventually obstructs adequate physiological interaction with biological cells and serves as a controlling component for effective device functioning. To address this issue, flexible bioelectronics have arisen, allowing for extraordinarily simple and close combinations with natural tissues. The latest research has produced a comprehensive collection of new materials, production methods, and designs that overcome this significant disparity in attributes. The resultant gadgets have the ability to closely incorporate into the human body for providing significant exceptional capabilities in medical research and clinical treatment.

CHAPTER 7

Applications of Nanotechnology in Dentistry and Cosmetic Industry

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Abstract: The application of nanoparticles and nanoelectronic devices is a vast area of research in the medical field. This is with respect to the efficiency of nanoparticles to competently aim and pervade specific tissues within the body. Whereas nano electronic devices can perform real-time analysis of several parameters related to the disease condition. Medical devices and drug therapies at the nano level, eventually ensure a much higher level of precision in medicine. Therefore, the healthcare industry is leveraging this technology for diagnostics and nanomedicine. Various nanoscale devices are available that can monitor the disease condition of the body either *in vivo* or *in vitro*. Nanotechnology in dentistry has revolutionized the advancement of restorative materials.

This chapter deliberates nanointerfaces that compromise the durability of dental restorations, and how nanotechnology has been utilized to adapt them for delivering long-term effective restorations. Recently, cosmetics have been immensely used with the development of innovative cosmetic formulations through the incorporation of the latest technologies. Nano cosmeceuticals is the name given to these products, which incorporate biologically active ingredients having therapeutic benefits on the surface applied. Using nanomaterials in devices makes it possible to enhance the mechanical strength and efficiency of the systems. They have high entrapment efficiency and good sensorial properties and are more stable than conventional cosmetics. Most of the nanoparticles are suitable for both lipophilic and hydrophilic drug delivery. Nanomaterials are widely used in the preparation of anti-wrinkle creams, moisturizing creams, skin-whitening creams, hair-repairing shampoos, conditioners, and hair serums. Promising results have been achieved with nanotechnology cancer theranostics and targeted drug delivery. Apart from high sensitivity, specificity, and multiplexed measurement capacity, nanodevices have been effective in the detection of extracellular cancer biomarkers and cancer cells, as well as in *in vivo* imaging. The chapter highlights the applications, and research status of nanodentistry and provides an intuition about future, ethical and safety concerns of nanotechnology. Nanodentistry is an offshoot of nanomedicine. Its emergence will aid in the maintenance of perfect oral

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health care using nanomaterials, biotechnology, and nanorobotics. This review abridges the latest developments in nanoelectronic devices for dentistry & cosmetics. In addition, the challenges in the translation of nanotechnology-based diagnostic methods into clinical applications have also been discussed.

Keywords: Nanotechnology, Nanodentistry, Nanoelectronic devices, Nosmeceuticals, Nanomedicine.

INTRODUCTION

Electronic devices are a group of devices involving the control of electrical flow and their applications in different domains. The objective of electronic components is mobility control and signal processing in a device. For example, the development of bioelectronics and bio-devices has significantly advanced the field of biomedical engineering, allowing numerous applications from basic research to clinical research and implants. In this regard, scientists all over the world, have been studying and working with nanoparticles for the betterment of mankind. The effectiveness of their work has been hindered by their incompetence to visualize the structure of nanoparticles. With the development of high-end microscopes, the nanoparticles can be observed as small as atoms and have allowed scientists to look at what they are dealing with. The ability to manipulate nano-sized materials has launched a world of prospects in many industries and scientific attempts. Nanotechnology has paved ways to explore unique properties of nanoparticles, where a set of techniques have allowed for highlighting these properties at a very small scale. The role of nanotechnology in dentistry and cosmetic application has been remarkable and innovative in its own essence, therefore, this topic was chosen to be contributed as a chapter for this book which entails the theme of biomedical application of nanomaterials. It is well known that nanotechnology finds applications in drug delivery, the creation of specialized fabrics, the reactivity of materials and microelectromechanical systems. In the field of electronics, nanotechnology has offered various nanoelectronic devices or nanodevices. They upsurge the abilities of these devices by improvising the memory of silicon chips, reducing the power utilization and the weight of transistors employed in integrated circuits. Nanotechnology has played a noteworthy role in communication engineering which has benefitted the telecom industry in several ways [1].

Under the aegis of nanotechnology or nanoscience, atomic or molecular-level applied science research and development are the rules of the day. The contribution of nanotechnology has revolutionized, creating a milieu for collaborative work between chemists and other experts in the fields of biology, physics, and engineering and, support from material and industrial scientists elevated their scientific verve in various fields. Therefore, it is necessary to understand the requirements of other sciences to accomplish efficient partnerships. These actions substantially impact practically every aspect of human health. In this chapter, a detailed study has been performed covering the application of nanotechnology in the field of dentistry and in cosmetic innovation. The field of nano-dentistry has grown due to all the ways nanotechnology has been used in dentistry [2, 3]. The recent advances in nanodentistry and innovations in oral health-related diagnostic, preventive, and therapeutic methods required to maintain and obtain perfect oral health, have been discussed. A brief overview of biosensors used in dentistry as well as in the cosmetic industry have been covered. A detailed analysis of the synthesis, properties and dental & cosmetic applications of nanomaterials has been performed. Also, current innovations and future predictions, a general commentary on essential toxicological aspects and recent developments in mechanisms have been included.

BACKGROUND

Biosensors have become very useful in the medical fraternity, and tremendous research is going on in the development of new sensors by research scientists. They are utilized in medical societies to test water and food, manage biological processes, and determine precise health diagnoses. Medical practitioners and researchers involve safe and cost-effective methods for conducting research. They ensure the safety of the public and provide patients with healthy options like personalized medicine. Research in diagnostics has resulted in a boon to the medical profession. Early detection of diseases, screening of clinical manifestations, chronic disease therapy, health management and well-being tracking are some major applications of biosensors. Advanced biosensor technology allows for the detection of disease and the monitoring of the body responds to treatment and medicines [4]. Another aspect of nano is nanomedicine which involves the utilization of nanoparticles for drug delivery, *in vivo* imaging, and diagnoses. Nano dentistry is a subset of nanomedicine. It has given rise to a brand-new scientific subject called nano dentistry. The advancement of nano dentistry will help to maintain excellent dental health care using nanomaterials, biotechnology, and nanorobotics. Top-down and bottom-up applications of nanotechnology are available in dentistry (Table **1**) [5, 6].

While the top-down approach creates smaller devices by using bigger ones to regulate their assembly, the bottom-up strategy arranges smaller components into more complex assemblies. This approach usually adopts a broad perspective on nanotechnology, emphasizing its societal implications above the technicalities of how such items might be produced. The terms speculative approach and functional approach have been used to describe how mechanisms of the intended

CHAPTER 8

Ferro-Magnetic Nanoparticles-based Biosensors for Environmental Monitoring

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Abstract: Nanotechnology is a new technology that has attracted more and more attention in biomedicine, electronics, industry, and environmental applications. Nanoparticles (NPs) have several applications in a number of social fields because of their exceptional optical, catalytic, thermal, and electrical capabilities. Magnetic NPs (MNPs), which feature exceptional superparamagnetism, a sizable specific surface area, simplicity of surface modification, chemical stability, biocompatibility, and high mass transfer, are one of the most crucial key types. Owing to these features, ferro-MNPs (FMNPs) have received large consideration because of their applications in medicine, biosensing, catalysis, agriculture, and the environment. This chapter briefly introduces the main synthesis methods of FMNPs and describes the characterization and composition of nano-biosensors. Then, the potential applications of FMNP-based nano-biosensors in diverse fields are discussed through typical examples. Finally, the research status, challenges, and development prospects of FMNP-based nano-biosensors are summarized.

Keywords: Environmental monitoring, Magnetic nanoparticles, Nano-biosensor.

INTRODUCTION

Recently, the progress of nanotechnology has promoted progress and revolution in various fields. The advantages and applications of nanotechnology are rapidly expanding. MNPs are a kind of unique magnetic nanomaterials, which are widely used in biomedicine, energy, engineering and the environment [1]. Numerous metals (separately or in combination) and their oxides come together to generate MNPs. Nowadays, MNPs are attracting more and more consideration due to their remarkable assets, such as chemical inertness, special magnetic target, thermal stability, non-toxicity, excellent biocompatibility properties and better contact between biocatalyst and its substrate [1].

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Biosensor devices have gotten an enormous awareness in the field of modern analytical chemistry in recent decades. A biosensor is a tiny analytical tool that contains biosensor elements and is linked to a sensing system. In most cases, a combination of biological receptor compounds (enzymes, antibodies, nucleic acids, and so on) and sensors can detect specific biological events in real-time [2].

The integration of MNPs and biosensing devices further improves the detection selectivity and sensitivity of many analytes and solves biomedical, chemical, pharmaceutical and environmental problems. Integrating MNP as a biocompatible element into a biosensor can solve the shortage of biocompatible element stability thereby enhancing its application potential for further commercialization in the industry [2].

As a nanocarrier, MNPs are widely used in nano-biosensors to immobilize biomolecules. Enzymes immobilization has abundant benefits, counting increased enzyme activity and reduced mass transfer processes related to enzyme recognition substrates. Additionally, for electrochemical equipment, iron oxide NPs provide a suitable microenvironment. The electrochemical biosensor's sensitivity and selectivity are improved by the electron exchange between the enzyme and the transducer [3].

In particular, because of its great biocompatibility and low toxicity, superparamagnetic magnetite (Fe_3O_4) has become the most widely utilized iron oxide [3]. Iron oxide MNPs have gained a lot of attention recently as a result of improved knowledge and widespread use [1].

Moreover, metal oxide NPs (including Fe_3O_4 NPs) are often used to immobilize biomolecules, which is a crucial factor in the biosensor’s creation. Based on the biocompatibility, bioactivity and low toxicity, Fe_3O_4 NPs have been used to immobilize biomolecules.

Recently, several reviews on the latest applications of FMNPs in the biosensing field have been published [2, 4-12]. However, there is no report directly related to the application of FMNPs in environmental biosensing strategy. There is a dearth of thorough literature reviews on the development of ferro-nano-biosensors in the fields of environmental monitoring due to the ongoing expansion of application fields. We begin this chapter by providing a succinct summary of the complexities of the synthesis technique, which is usually used to achieve the most beneficial FMNP adaptive process. Then, we present many applications for nano-biosensors in the study of environmental monitoring. The objective recommendations for creating the most appealing and sensitive biosensors for particular applications are presented after the consideration of the most recent developments and major problems of FMNP biosensors.

TYPES AND COMPOSITION OF BIOSENSORS

Biosensors are research instruments that convert biological events (changes in charge, pH, mass, light or heat) into quantifiable output signals (optical or electrical signals). Biosensor is mainly composed of three parts: bioreceptor (biometric element), transducer (detector) and signal processor (reader). According to the types of transducers, biosensors can be divided into mechanical, piezoelectric, optical, electrochemical, field-effect transistors, *etc*. (Fig. **1**).

The main factors affecting a sensor's specificity, affinity, reaction time, and longevity are its receptors [13]. In biosensors, the receptors are typically biological and include cells or tissues from animals and plants, as well as microorganisms, enzymes, antibodies, crude extracts, DNA, and oligonucleotides that bind to particular analytes in a particular environment and reveal their existence and concentration [13, 14] (Fig. **1**). These biosensors have been effectively used in several disciplines, involving environmental protection, medical diagnosis, food and drug analysis, and military science [14].

NANOTECHNOLOGY AND BIOSENSING

The combination of nanotechnology and biosensor enables reliable detection equipment to identify and control environmental pollution effectively [15]. The employment of NMs in the design and development of nano-biosensors can improve their functioning because the features of NMs are different from bulk materials.

NMs fundamentally change the performance of biosensors by providing stable carriers, easy attachment, efficient signal transduction, signal amplifiers, labels and sometimes sensor receptors for biomolecular receptor attachment. Various signals (such as optical, electrochemical, magnetic, thermal, *etc*.) can be processed or provided by it in line with the anticipated measurement phenomena [16]. Furthermore, the main advantages of NMs in biosensor fabrication are their size, morphology, functionality, adsorption capacity, effective surface area and high electron transfer properties [17]. Different NMs have been utilized to enhance the selectivity, sensitivity, stability, rapidity, efficiency and, more generally, the biosensor performances for pollutants detection (Fig. **2**). Additionally, different nanostructures can be utilized, including self-adhesive monolayers, nanocomposites, nanopores, nanotubes, and nanowires [18].

CHAPTER 9

Nano Engineering Concepts, Principles and Applications in Food Technology

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Abstract: Nanobiosensor technology is a powerful technology that fulfills the requirement of specificity and sensitivity. It is an important prerequisite for agriculture, health care, food processing, and packaging. Highly miniature sensors have been designed and achieved based on nanotechnology. Nanobiotechnology is an interdisciplinary invention of nanosciences (Materials, Electronics, Mechanics, Computers, and Biology) to create biosensors with highly reliable detecting competence. Nanobiosensors are nanosensors with immobilized bio-receptor analyses that are selective for target analyte particles. Being in the nanoscale, the data are sensed, processed, and analyzed at an atomic scale. Their applications consist of the recognition of organic analytes like microorganisms/ pathogens and pesticides and observing metabolites. They can also be used to facilitate molecular analysis by integrating with other technologies, such as lab-on-a-chip. Nanobiotechnology is a newly explored research area that gears up real bioanalytical applications. This chapter is a journey of philosophy, understanding and setting a pattern for using nanotechnology in agriculture. This episode is a presentation of the essence of nanomaterials and their applications of nanomaterials for agriculture. The significance and importance of nanomaterials in the food industry are added.

Keywords: Agriculture, Bio-Nano sensor, Characterizing tools, Electronic Nose, Food Processing, Nanomaterial.

INTRODUCTION

Progressing nanotechnologies can provide potentially substantial profits in numerous sector that include water, food, and agriculture. New tools include

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evolving structures, such as water purification systems, rapid pathogen and chemical pollutant recognition systems, and nano-renewable energy technologies. The challenges in food security and safety that countries are facing today – in specific developing nations pertaining to sustainable agricultural development are needed to be addressed now with new nanotools.

Both the public and private sectors in developed and developing nations have seen an increase in research and development in nanoscience and nanotechnology. It is becoming obvious that the global community must ensure that direct, open global governance of these technologies is handled in order to realise the expected goals offered by nanotechnology. In light of these advances, it is necessary to learn and update the required knowledge towards nano-tech in biological sciences – particularly in agriculture.

Nanometer-scaled particles are manipulated as nanotechnology produces new products of more durable, longer lasting, more effective, and more economical. As a comparison of realizing the size, it is likely compared with the human hair diameter which is 80,000-100,000 nm. Nanotechnology has proved to be a highly interdisciplinary field that caters to engineering, technology, and scientific fields.

Nanoscale phenomena are anticipated to be significant in the field of Nanosciences & Nanotechnology, Organic Electronics &Nanomedicine. Bringing together experimental and computational experts in the areas of nanosciences, nanoelectronics, organic electronics, and nano medicine to explore collaborative challenges and opportunities in the field is the need of an hour.

Emerging nanotechnologies may provide significant advantages in a number of industries. The applications are widespread, like water purification systems, quick pathogen and chemical pollutant detectors, and nano-enabled renewable energy technologies are examples of new instruments. New nanotools must be used right away to address the issues on food security and safety that nations, particularly developing nations, are facing in relation to sustainable agricultural development.

The usage of nanotechnology is widespread in almost all fields, including medicine, energy, agriculture, water purification, automobile, construction, computation, *etc*., The field of agriculture finds its need for technology in improving soil fertility, crop quality, yield quantity, remote sensing of the land, and so on. The agricultural sector, compared with other sectors of nanotechnology, is still marginal and has not yet reached the market in applications. The quantity of chemicals released and the injury to nontarget plant tissues, which in turn disturbs the environment, can be reduced by applying target-specific nano materials. For easy biochemical sensing and control, soil analysis, pesticide and nutrient delivery, water management, and delivery, nanobiosensors also have significant suggestions for application in farming. The researchers and scientists must explore their knowledge regarding the part of nanoelectronics applications in cultivation.

In the olden days, the remains after harvesting are fired partly before the next cultivation. This is a technique to enrich the soil with organic compounds. The biomass thus produced, will have a combination of carbon, hydrogen, oxygen, nitrogen and other elements. The burnt residues are rich in carbon nanoparticles that benefit from smaller dimensions for increasing the availability and highly porous compact structures. This results in a slow release of nutrients to the soil.

The profits are not limited. Today, knowingly, the technology is named, but it is not new; instead, the technology is rediscovered. This chapter reviews nano biosensors and their significant role in food technology. This starts with the introduction to the significance of agri-nano technology in Section "**Nanotechnology in Agriculture**". Nanotechnology depends on its materials and characteristics. So, in a short account of the nanomaterials and its type has been discussed. A synthesized nanomaterial has to be characterized to study its properties. In this regard, a few important characterization tools have been noted in proceeding sections. To start the study of nano-bio-sensor, the basic biosensor, classification of biosensors and the prerequisites for a biosensor are mentioned in Section Types of Materials. Next follows the Nano biosensors in agriculture and their classification in Section Characterization Tools. The significance of Bio Nanomaterials and analyte detection is being surveyed, with the applications of nanofibers in table form. Nanosensors' potential application in the agriculture and food industry, *i.e.*, Nano sensor for animal health care (cattle) and Nano materials in food processing allowed to meet the objective of the chapter. The chapter ends with a conclusion.

Fig. (**1**) illustrates the role of nanotechnology in agriculture, which can be thought of in three aspects. They are agriculture crops production, animal production and food preservation.

Agriculture-crop production includes the growth of various crops like grains, legumes/pulses, flowers, vegetables, fruits, fodder, spices, cash crops, and sugar crops. Here, vegetables, fruits, and fodder crops come under the horticulture subsection. Meanwhile, poultry, fishery, dairy, meat, camels, lamas, and yaks are incorporated under animal production. In addition, food preservation is the third and finds an important role in post-harvesting procedures. It can be of both plant and animal origin. Moreover, food storage and food safety transportation are two challenging issues involved in food management.

CHAPTER 10

Far-infrared Gallium Nitride-based Quantum Cascade Laser

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Abstract: Gallium nitride semiconductors are considered as optimal candidate materials for terahertz quantum cascade lasers to achieve room-temperature operation and to fill the terahertz frequency gap of 6-12 THz, owing to the large longitudinal optical phonon energy (90meV, >21THz) which is 3 times that of gallium arsenide. However, the inter-subband lasing signal from gallium nitride cannot be easily obtained, with limitations such as the lack of a reliable design prediction model and the consistent epitaxy of a thick superlattice. In this chapter, the non-equilibrium Green's function model is introduced to study the various scatterings in gallium nitride-based quantum cascade lasers and subsequently to predict the optical gain at different terahertz frequencies. In addition, thick GaN/AlGaN superlattice structures were grown using both techniques of *in-house* low-pressure metalorganic chemical vapor deposition and radio-frequency plasma-assisted molecular beam epitaxy.

Keywords: III-nitride, Lasers, Intersubband transition, Epitaxy, Nonequilibrium Green's function, Superlattices.

INTRODUCTION

The far-infrared spectrum range (terahertz, THz) comprises approximately 0.3-10 THz frequencies (corresponding wavelength range is 30-1000 μm), as shown in (Fig. **1a**) [1]. Extensive applications have been developed for both scientific and commercial applications, including those in remote sensing in astronomy-related to planets/stars/galaxies formation, and the earth planet atmosphere [2 - 4]. Owing to the low energy, THz photons can be easily thermally excited for passive emission spectroscopy and imaging for non-destructive detection, such as explosives, drugs, and weapons [5, 6]. This is because many types of materials (*i.e.*, paper, plastics, and ceramics) demonstrate non-transmission in the visible spectrum but transparency at THz wavelengths. Meanwhile, for imaging, compared to microwaves, THz frequencies entail significantly improved spatial

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resolution owing to their shorter wavelength [7]. Further, they exhibit a noninvasive nature and better contrast in terms of identification of different materials than X-rays because of the very different absorption and refraction indices for materials across the terahertz spectrum [8]. Consequently, THz imaging has also been used in the fields of biology and medicine [9], for example, in cancer research, label-free DNA sensing, and non-destructive evaluation of pharmaceutical products. In fact, an increased variety of applications in the fields of information and communications technology, quality control of food and agricultural products, ultrafast computing, *etc*., have been undertaken. Historic achievements and fundamental principles of THz technologies can be found in many studies [10 - 13]. However, the applications remain significantly limited, primarily because of the lack of solid-state THz sources with compact and coherent, continuous wave (c.w.), and high-output power (milliwatt levels) features, comparable to the conventional semiconductor laser diode in the visible and infrared spectra, or to microwave transistor oscillators and amplifiers.

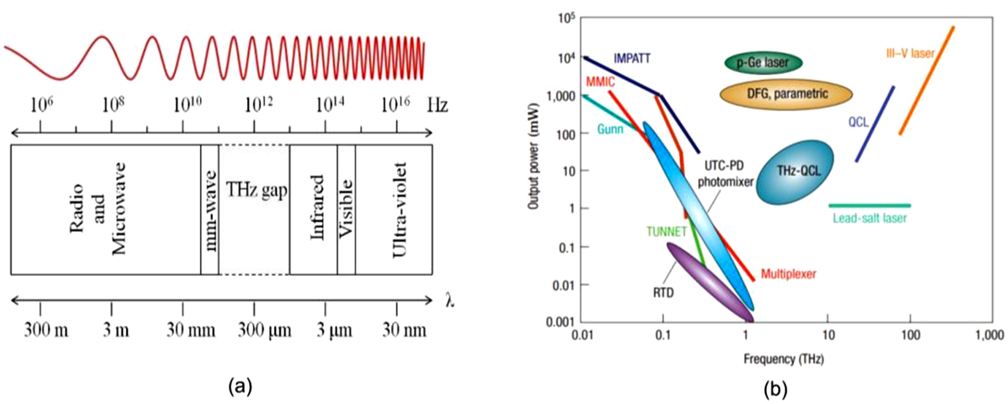

Fig. (1). The THz spectrum range roughly covering the wavelength of 30-1000μm (a); The representative developed THz radiation sources (emission power as functions of frequency) [13].

(Fig. **1b**) provides a summary of different types of THz radiation sources where the output power is shown as a function of the frequency. There are three approaches for realizing THz emission: electronic devices, optical generations, and THz quantum cascade lasers. The use of solid-state electronic devices (*i.e*., Gunn oscillators, transistors and Schottky diode multipliers) is plagued by low output power at high frequencies (*i.e*., smaller than 1 mW at THz frequencies more than 1 THz [14, 15]) because of the effects of transit-time and the resistance-capacitance [16, 17]. The optical THz generation method can be roughly divided into two categories. The first is the photoconductive switch, semiconductors employing the electric-filed carrier acceleration, or the photo-Dember effect generating ultrafast photocurrents [18, 19]. The second is based on non-linear optical effects, such as optical rectification [20], different-frequency generation (DFG) [21], or optical parametric oscillation [22]. Thus, THz radiation is analogous to compact semiconductor lasers, which have been well-developed in the visible and near-infrared frequency range. However, because the THz photon energy is excessively small (several or several tens of meV), there remains a lack of appropriate materials that can perform THz interband recombination. In fact, previous developments of semiconductor lasers at THz frequencies were mainly based on more exotic gain mechanisms, for example, the p-Ge hot hole laser [23, 24], or lasers based on impurity-state transitions [25]. Recent continuous improvements in compact THz light sources can be attributed to quantum cascade lasers, where the THz photons are generated following the electron relaxation between sub-bands that are confined in quantum wells or superlattices. The electrons can cascade through the stacked repeating unit and thus result in high output powers (hundreds of mW, or even above 1 W).

QUANTUM CASCADE LASERS

Physics of Inter-subband Transition

Quantum cascade lasers benefit from quantum mechanical phenomena, and the experimental realization of this type of laser relies on active region fabrication techniques with nanometer-scale control. The major step is the introduction of molecular beam epitaxy (MBE) for semiconductor quantum wells and superlattices, which enables the growth of epitaxial structures with one-monolayer-level flat interfaces [26]. Owing to the sharp interfaces well below the de Broglie wavelength of the charge carriers in the semiconductor, quantum states can be created and then engineered intentionally. In fact, the modulation of the sequence-layered quantum wells (or superlattice) can enable an interband transition where the minimum of the conduction band and the maximum of the valence band occur in the same material (Fig. **2a**). This results in an emission *via* the recombination of electrons in the conduction band and holes in the valence band. The transition energy for this process is simply the sum of the bandgap of the quantum well material and its confined energy for the electrons and holes. Therefore, the emitted photons are inherently limited by the bandgap of the semiconductor material; however, as mentioned above, such material for THz radiation is still lacking.

Further, transitions are also possible between quantum states that belong to the same band (thus, with the same in-plane dispersion) (Fig. **2b**). The exact transition energy is approximately equal to the separation energy of the doublet subband states (at both the valence or conduction band; here, the latter one is used as an example). This energy separation can be freely engineered by controlling the

CHAPTER 11

Novel Approach in Nanomaterial Synthesis for Nanoelectronics Devices

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Abstract: The field of electronic devices has become more significant during the past 40 years. However, the laws of quantum mechanics and the limitations of fabrication techniques have revolutionized modern technology. Many investigators in the field of electronic devices have found that nanotechnology has been used to improve electronic components and electronic research. Moreover, the devices with at least one overall dimension in the nanoscale are characterized in the category of nanodevices. These devices will impact modern society concerning computers, networking, medical services, defence, and surveillance systems. These devices will impact modern society in various applications such as computing, communications, health care, security, and environmental monitoring. Nanoelectronics aims to reduce the size, weight, and power consumption of electronic devices and displays while increasing their functionality. Device weight and power consumption are reduced as a result. To synthesize these devices, a suitable material is always needed. The nanotechnology industry is advancing steadily, and robust characterization and synthesis methods are available to manufacture nanomaterials with precise dimensions. Nanotechnology's influence on the development of nanoscale systems is sustainable and has begun to have a substantial positive impact. The rise of the nanodevice sector has been sparked by developments in nanomaterials, which are briefly covered in this chapter. We specifically outline and define several terms associated with nanomaterials. The top-down and bottom-up approaches to nanomaterial production, as well as other techniques, are reviewed. The chapter also highlights the distinctive properties of nanomaterials. Finally, we conclude by discussing the difficulties and prospects of using nanomaterials in the nanodevice sector.

Keywords: Electrospinning, Layered Structure, Nanomaterials, Nanodevices, Nanomaterials Carbon.

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INTRODUCTION

Due to their various uses in transportation, heating, manufacturing, and power, fossil fuels like coal, natural gas, and petroleum are experiencing a moderate crisis of quick depletion [1 - 3]. This problem has been exacerbated by the world economy's rapid growth [1 - 3]. The World Energy Council discovered that China and the United States are the most prominent two energy users. The USA's energy consumption is around seven times more than India's, so a significant rise in energy consumption is predicted during the following years [4].

In this context, renewable energy sources like solar, wind, and hydro are receiving much attention. However, their propensity for delivering power intermittently raises serious concerns [1 - 4]. To address the abovementioned issues, energy storage systems must be combined with renewable energy sources. Batteries, fuel cells, and electrochemical capacitors (ECs) are effective energy storage technologies that transform chemical energy into electrical energy. These energy storage technologies are now widely employed in a variety of electronic products, including laptops, cell phones, digital cameras, electric vehicles (EV), emergency space doors, aircraft, and hybrid electric vehicles (HEV) [5, 6]. In all of these devices, where diverse forms and sizes of materials were created using various procedures, nanotechnology plays a crucial role in boosting the effectiveness of all electric appliances. Fundamentally, nanotechnology involves creating and using materials with structural qualities between atoms and bulk substances, with at least one dimension falling within the range of 1 to 100 nanometers. As the number of atoms on a material's surface becomes more important for its ability to store energy as its size approaches the nanoscale, nanostructure materials are emerging.

Additionally, nano tailoring the particle size can produce reduced conduction route lengths (electronic and ionic transport), which facilitates electric characteristics. Additionally, an increase in the flow of ions *via* the interface between the liquid electrolyte and the nanoscale electrode material is attributable to the large surface area of nonmaterial that gives high rate capability [7]. Furthermore, nanoparticles are reported to offer a variety of routes for ions and electron transport at the electrode/electrolyte interface, resulting in nanostructures exhibiting excellent cyclic stability with good rate capability.

Different nanostructured electrode materials, including 0D, 1D, 2D, and 3D materials, have been produced in this context utilizing various methods [8]. However, some of the barriers to using the full benefits of nanotechnology include the challenge of developing nanostructures and nanophases, the inability to control their size and form, the poor degree of repeatability, and the intolerably high manufacturing costs. However, compared to atoms or bulk materials, the characteristics of materials with nanometric dimensions are significantly different. By effectively controlling the characteristics of nanometer-scale structures, new scientific findings and inventive goods, techniques, and technology may result. The relevance of nanotechnology's core idea, underlined by Feynman in his famous 1959 address, "There is plenty of room at the bottom." Moore's law must be defied to fit 1000 CDs in a wristwatch [9]. Nanoscience and technology have grown during the past ten years due to new methods for creating nanomaterials and tools for characterizing and manipulating them. Several state-of-the-art methods exist now for producing nanoparticles, nanotubes, and assemblages. Specific semiconductors, metals, and other material nanostructures' size-dependent electrical, optical, and magnetic properties are now better understood. Scanning probe microscopies, in addition to the well-known methods of electron microscopy, crystallography, and spectroscopy, have generated useful instruments for investigating nanostructures. Devices, manufacturing procedures, and cutting-edge methods for producing patterned nanostructures are constantly being developed [9]. As they can withstand highly demanding treatment while maintaining a small size, nanostructures are also the best option for computer modeling and simulation. Not all aspects of nanoscience, however, are novel; for instance, catalysis and photography are well-known instances of nanoscale processes used in contemporary technology [10]. However, the ability to synthesize, arrange, and manipulate bespoke materials at the nanoscale is a comparatively recent innovation. The study and production of solitary nanostructures, the fundamental building blocks of nanomaterials and their ensembles and assemblages, must be the immediate focus of nanomaterials science and technology.

TYPES OF NANOMATERIALS

Nanomaterials are materials whose dimension lies in 1–100 nm [11 - 13]. A significant surface area to volume ratio is the main factor contributing to how differently nanomaterials behave from bulk materials [14]. Nowadays, different kinds of nanomaterials are synthesized. However, nanoparticles are categorised as (i) carbon-based NPs, (ii) metal-based NPs, (iii) dendrimers, and (iv) composites-based NPs on their construction [15].

Carbon-Based NMs

Carbon is a well-known electrode material for energy storage devices with a high surface area (~ 2000 m^2 g^{-1}), excellent porosity, economical, easy processing, good electronic conductivity, non-toxicity, natural abundance, high stability, and environmental friendliness [16 - 19]. Carbon materials exhibit high surface area

CHAPTER 12

Application of Nanomaterials in the Medical Field: A Review

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Abstract: Nanomaterials are particles in sizes from 1-100 nm. Nanomaterials have a wide field of applications in aviation and aerospace, chemical industries, optics, solar hydrogen, fuel cell, batteries, sensors, power generation, aeronautic industry, building-construction industry, automotive engineering, consumer electronics, thermoelectric devices, pharmaceuticals, paints, and cosmetics. Also, efforts are being made to develop friendly alternate energy sources using nanomaterials. In this chapter, the main focus will be on the application of nanomaterials in various aspects of the medical field.

Nanomaterials are used in various medical devices. Some of the nanomaterials used in the area of optical imaging are quantum dots, and in MRI are superparamagnetic iron oxide nanoparticles. Also, nanomaterials are applied in ultrasound imaging and radionuclide imaging. Due to the small size of batteries (*e.g.*, for pacemakers) or electronic circuits and sensors utilized in medical devices presently made using nanomaterials. New ceramics consisting of materials derived from sintered nanopowders (comparable to 3D-printing) or having a specially designed surface are made from so-called nanostructures for teeth filling or screws for dental implants. For bio-detection of pathogens, detection of proteins, and phagokinetic studies, nanomaterials are also used.

For fluorescent biological labels, drug and gene delivery, probing of DNA structure, tissue engineering, tumour destruction *via* heating (hyperthermia), separation and purification of biological molecules and cells, MRI contrast enhancement, osteoporosis treatment, infection prevention, bone regeneration are some of the applications of nanomaterials used in medicines. Cancer therapy, neurodegenerative disease therapy, HIV/AIDS therapy, ocular disease therapy, respiratory disease therapy, sight-restoring therapy, and gene therapy are various therapies nanomaterials are used Nanomaterials used in various surgeries are surgical oncology, thoracic surgery, replacement of heart with an artificial heart, vascular surgery, neurosurgery, radiosurgery, ophthalmic surgery, plastic and reconstructive surgery, maxillofacial surgery, orthopedic surgery, intracellular surgery by nanorobots.

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Although all applications of nanomaterials have pros and cons, care should be taken so that the cons can be minimized.

Keywords: Medical, Medicines, Nanomaterials, Surgery, Therapy.

INTRODUCTION

Nanomaterials are extremely small in size. Hence it can be used in applications where the effect of applications is small in areas. The present chapter deals with the application of nanomaterials in the medical field. Although nanomaterials have the opportunity to be used in diverse fields like astronomy, robotics, and various engineering fields, the present chapter is confined to the application of nanomaterials in the medical field.

WHAT ARE NANOMATERIALS?

Nanomaterials are materials having characteristic dimensions from 1 and 100 nm. According to European Commission, it states that minimum of half of the particles should be in the numerical size distribution and must have a size of 100 nm or less. Nanomaterials might be naturally occurring, may be produced as byproducts of combustion reactions', or may be intentionally designed for performing specialized functions. These materials might have different physical and chemical properties than their bulk counterparts.

Credit goes to their ability to create materials in specific ways and for performing specific roles; the usage of nanomaterials extends to a broad range of industries, starting from healthcare and cosmetics to environmental protection and purification of air. For example, nanomaterials are used in various ways in health care, with drug delivery being one of its main applications. As an example of this process, nanoparticles have been developed to deliver chemotherapy drugs directly to cancerous tumors or areas of damaged arteries for fighting against cardiovascular disease. Carbon nanotubes are developed for usage in various processes, such as adding antibodies to nanotubes, thereby creating bacterial sensors. In the aerospace industry, carbon nanotubes are used to change the dimension of airplane wings. Nanotubes are applied in composite form for bending in response to voltage application. Elsewhere, environmental protection processes also apply nanomaterials. Applications have been developed by using nanowires like (zinc oxide nanowires) in solar cells, which are flexible and also purifies polluted water.

The application of nanomaterials has become common in a variety of goods related to industries and consumers. In the cosmetics industry, inorganic nanoparticles such as titanium dioxides are applied in sunscreens. This is because traditional chemical UV protection offers less stability over time. Similar to bulk materials, TiO nanoparticles might improve UV protection besides showing the added benefit of eliminating the unattractive cosmetic whiteness which is associated with nanoform sunscreens. The sports industry manufactures baseball bats from carbon nanotubes, which reduce bat weight and improve performance. Some other applications of nanomaterials in the industry are being observed in the usage of antimicrobial nanotechnology in towels and pads to be used by athletes to prevent bacteria-causing diseases. Nanomaterials are also developed for use in military purposes. For example, the usage of mobile pigmented nanoparticles produces better camouflaging by injection of these particles into the materials of the military's uniform. In addition to this, the military people designed sensor systems by the usage of nanomaterials such as titanium dioxide that help to sense biological agents. The usage of nano-titanium particles in coatings is also used to create surfaces that are auto-cleaning in nature, such as plastic lawn chairs. A closed film of water forms on the cover, thereby dissolving the dirt in the film, whereas another shower removes the dirt and cleans the seat [1].

Advantages of Nanomaterials

- The nanomaterials' size offers various advantages in comparison to bulk materials, and their versatility highlights their usefulness in terms of their ability to adapt to specific needs. Another advantage is that it has high porosity, thereby demanding an increase in applicability in many industries.
- In the field of energy, the usage of nanomaterials in existing energy production methods like solar panels can be made efficient and effective and open the latest techniques to use and store energy.
- Nanomaterials have the chance to bring many beneficial effects to the electronics and computing industry. Their usage increases the accuracy of electronic circuits' design to the atomic level, leading to many electronic products' development.
- The property of nanomaterials with a high surface-to-volume ratio makes them particularly beneficial for use in the field of medicine and enables them to bind cells and active substances. This advantage helps in increasing the chances of success in fighting numerous diseases [1].

Disadvantages of Nanomaterials

- Inhalation exposure is currently considered the major disadvantage associated with nanomaterials. This issue stems from animal studies which show that nanomaterials like carbon nanotubes and nanofibers may cause harmful effects of pulmonary like pulmonary fibrosis. Other potential health hazards include exposure to ingestion and hazards of explosion due to dust.

CHAPTER 13

Submonolayer InAs Quantum Dot Based Solar Cell: A New Approach Towards Intermediate Band Solar Cell

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Abstract: This chapter summarizes the progress of InAs submonolayer (SML) quantum dot (QD) based intermediate band solar cell (IBSC). A brief background of intermediate band solar cells (IBSC) will be presented. Different IBSC prototypes will be discussed. The importance of quantum dots (QDs) for IBSC prototyping will be illustrated. An alternative of the most extensively used Stranski-Krastanow (SK)-QDs named SML QDs will be introduced. The fabrication of SML-QD-based IBSC will be discussed from the material point of view. We will also discuss the physics behind the improved performance of these SCs. Important research in this field will be reviewed. Finally, the future direction will be suggested to further improve the performance.

Keywords: Efficiency, Intermediate band solar cell (IBSC), InAs, Quantum well, Quantum dot (QD), Solar cell, Sub-monolayer (SML), SK-QD, SML-QD, III-V semiconductors.

INTRODUCTION

At the moment, more than 80% of the total global energy demand is supplied by fossil fuels. By 2040, a 28% increase in global energy demand is expected [1]. With the increase in energy demand and huge dependency on fossil fuels, the mere idea of running out of fossil fuels raises a pertinent question: How long will fossil fuels last? In addition to the problem of these resources getting extinct, there are other issues related to the use of fossil fuels, such as global warming, pollution, storage, *etc*. To provide relief to the environment from the burden of fossil fuel and the resulting pollution, and to provide alternate everlasting energy solutions, renewable energy research must be extensively propelled.

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Solar energy reaching the earth is more than 1000 times the projected energy demand in 2040. There are multiple ways by which solar energy can be harvested, such as photovoltaics, thermal energy harvesting, solar water heater, molten salt solar power, *etc*. Out of these, photovoltaics is the most promising technology for energy harvesting from the sun. In photovoltaics, sunlight is converted to electrical energy using semiconductor material. The speedy development of commercially feasible photovoltaic technology with enhanced performance is warranted for sunlight (as an alternative renewable source) to replace fossil fuels.

The feasibility of photovoltaics to compete with conventional energy sources and replace their calls for greater efficiency and minimal cost. The current energy efficiency of the commercial solar cell (SC) is not sufficient to replace nonrenewable energy sources. The calculation (published by Schockley and Queisser, hence called the Schockley-Queisser (SQ) thermodynamic limit) places the theoretical limit of maximum energy conversion efficiency of approximately 33.7% utilizing a single connection and a material with a 1.4 eV band gap (using an AM 1.5 solar spectrum) [2]. Non-absorbing photons of lesser energy, is one of the main efficiency limiting factors for single-junction SCs. The solar cell with the middle band (IBSC) theory was introduced to improve the energy conversion efficiency above SQ limiting junction SC [3]. According to the IBSC concept, the efficiency increase could be made possible by increasing the semiconductor-spectrum of solar absorption by absorbing sub-bandgap light across a constrained range of electronic states that are contained in the semiconductor's (SC) energy band gap (EBG). Theoretical calculation promises the enhancement in efficiency and a solar cell's Shockley-Queisser efficiency limit that is exceeded by IBSC.

Not many reports have experimentally shown the efficiency improvement by IBSC. One such actualization of an IBSC makes use of InAs Stranski-Krastanov (SK) QDs stacked vertically implanted in the inherent section of a GaAs p-i-n diode [4] for the electronic states occupying the sub-bandgap area. Subsequently, sub-bandgap photons imbibed in these (solar) cells foster the limited states with carriers. Then, these carriers may draw into the bands of the barrier through tunneling, thermal escape, or a second photon absorption. It follows that the short-circuit current (I_{SC}) is improved by broadening the solar absorption spectrum. Unfortunately, devices using this technique have seen a decline in open circuit voltage VOC, finally leading to led to a decline in efficiency in the IBSC based on SK QD. As a result, relatively few studies have demonstrated even a marginal improvement in efficiency in comparison to the benchmark pin solar cell. The QD IBSC efficiency can be raised, nevertheless, if the VOC degradation could be reduced.

Recently, an alternative to the periodic repeating of sub-monolayer (SML) InAs fully crowned with a few ML of GaAs is used in the InAs SK-QD that has been proposed. Experimentally, it has been shown that this multi-stacking results in a QD-like structure due to indium segregation and vertical InAs ordering caused by localized strain. These QDs have been reported to be smaller and more uniform with higher areal densities [5]. IBSC SCs based on SML-QD have shown improved performance (better than SK-QD-based IBSC and reference solar cell, which does not employ any quantum-confined region). Increased recombination in the SC sub-band gaps, increased recapturing or trapping of excess carriers, the low optical absorption of the intermediate band material, and a decrease in the SC open circuit voltage are some of the mechanisms that lead to decreased SC performance in SK-QD-based IBSCs [7 - 9]. Trapping is primarily influenced by QD size, with smaller QDs resulting in less trapping [6]. For this reason, SML-QD-based SCs have shown superior performance over SK-QD-based SCs, as reported in our earlier publication [7].

This chapter will cover the fabrication of SML-QD-based IBSC from the material point of view. We will also discuss the physics behind the improved performance of these SCs. Important research in this field will be reviewed. Finally, the future direction will be suggested to further raise the bar on performance. Solar cell has been seen being among the promising candidates for renewable energy sources. Efficiency and cost have been the barrier that must be overcome for the successful commercial implementation of this technology. The use of QD for solar cell applications has the potential to break this barrier. Hence, this chapter which is based on SML QD-based IBSC, is very relevant both for this book and for the advancement of renewable energy technology.

UNDERSTANDING SOLAR CELL

When a pn junction is illuminated with light, excess carriers are generated. Photogenerated carriers within the diffusion length and the depletion region (DR) on both sides of DR are parted by the (built-in) internal electric field in the junction region. This results in current even at no applied bias and voltage at zero current condition. The appearance of forward voltage across an illuminated pn junction is known as the photovoltaic effect. Fig. (**1a**) shows the IV characteristics of a typical pn junction with and without illumination. Under the light, IV characteristics shift in a negative current direction because of the additional current due to photogenerated carriers. This results in the development of open circuit voltage (V_{OC}) and generation of short-circuit current (I_{SC}), depicted in Fig. (**1b**). The solar cell works in the fourth quadrant of IV characteristics where voltage and current have opposite polarity. In Fig. (**1b**), the fourth quadrant opera-

CHAPTER 14

Electromagnetic Bandgap Structure: A Review

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Abstract: This chapter reviews different technologies for tailoring Electromagnetic BandGap (EBG) of some materials and their primary applications. Recently, nitride-based materials have been widely used because of their high emission efficiency. $In_xGa_{1-x}N$/GaN heterostructures (Gallium nitride) play a significant attraction due to the terahertz (THz) emission. $In_xGa_{1-x}N$/GaN heterostructures can be tailored in a wide emission range by the variation of structure, size, and composition, resulting in excellent laser and light-emitting devices. Ultrafast optical excitation of such types of structures leads to large THz electromagnetic emissions. In some cases, the EBG of graphene has adopted a square open-loop shape with a ground plane, which displays good characteristics in dynamically adjusting the electromagnetic wave propagation in the THz range. The EBG structure is being progressively used because of its unique electromagnetic features. Due to the distinguished features of the bandgap for the emission of electromagnetic waves, it is used in various applications, such as high-performance microstrip antennas and low-profile antennas.

Keywords: Electromagnetic bandgap (EBG), Graphene, Negative refractive index, Nitride materials, Terahertz emission.

INTRODUCTION

In recent technology, electromagnetic bandgap (EBG) materials have been very promising in photonics, radiofrequency, and microwave applications. The perception of EBG structure is created from the optical domain and solid-state physics. In general, the photonic bandgap is used in optical technology, and when it is used in the microwave domain, it is named an electromagnetic bandgap. The initiation and development of metamaterials got enormous attention from researchers [1]. The metamaterials concept covers the optical applications to nanotechnology and materials science to antenna engineering. The concept of meta-materials shows a unique feature that is not shown in naturally occurring materials. Metamaterials are arranged in a repeating manner at scales that are

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smaller than the wavelength of the phenomenon they influence. Depending on their shape geometry, orientation and size, it is capable of manipulating electromagnetic waves by absorbing, blocking, bending, or enhancing the wave to achieve in device applications.

By the exhibition of electromagnetic waves in different ways, the material structure has presented their different names such as (a) negative refractive index, material, (b) double-negative material, (c) left-handed material, (d) magneto material, and (e) artificial conducting material. Researchers have explored this unique feature and applied it to various electromagnetics and antenna applications [1]. Nowadays, nanoelectronic devices are very useful, as it finds use in various fields such as biosensing, medical applications, antennae engineering, *etc*. Hence, it is a relevant topic for discussion. Nanoelectronics inspect the electronic and magnetic properties of systems at the nanoscale, and these properties can be tailored by using EBG materials.

EBG materials have a periodic array of metallic and dielectric materials which are in a 3D, 2D, and 1D manner depending on their periodicity [2]. The formation of EBG bandgap using macroscopic and microscopic resonances which based on periodic structures and satisfies Bragg's conditions. Using different dimensions, the electromagnetic propagation will be able to propagate in their selective direction [2]. By stacking various EBG layers, a 3D structure is formed like a tripod and multilayer metallic array. It has been mentioned as photonic band-gap material, which is found in nature. Formation of 2D EBG structure, such as a uni-planar design in the absence of vertical *via* and a mushroom-like structure, depends on the arrangement of a unit cell of EBG in two dimensions on a plane. For antenna design, a 2D type of EBG structure is preferable. One-dimensional EBG is established by organizing a unit cell of EBG in 1-D to set up a transmission line in the company of two ports, like a transmission line design [3].

EBG is also known as an "artificial magnet connector" (AMC). For every incident angle and each polarization state, some periodic/ non-periodic entities known as "artificial periodic" of EBG structures that are in a specific frequency band have been debar/support the propagation of electromagnetic waves [4, 5]. Again, EBG is named a "photonic band-gap" (PBG), because of microwave application; the EBG structure is valuable because of its periodic nature, which terminates the propagation of definite electromagnetic wavelengths. Based on the periodicity of the structure, a band gap is created in the EBG material, which basically consists of periodic changes of low and high dielectric regions. The propagation of surface waves can be restricted by the EBG surface within a frequency band of a particular range (Bandgap), and thus reduces the level of back lobe radiation that is undesired on the way to the human body [5].

Although there are a number of various planar EBG configurations, the 2 main essential configurations, *i.e*., uniplanar electromagnetic bandgap (UC-EBG) and mushroom EBG are very important. The UC-EBG is more accepted and preferred due to its simplicity in the manner of wearable antennas (no vias), less manufacturing budget, and compatibility, along with better quality planar circuitry [6]. To date, to change the band-gap width and decrease the periodic size, lots of UC-EBG structures have been incorporated. For real-time applications in multiband, it introduces multiband Ebg structures such as multi-layer EBG [7], fractal EBG [8], and interdigitated units [9]. Furthermore, the wearable EBG structure is favorable to designing simple structures on account of the limitations of textile materials, along with the difficulty of fabrication. In spite of the contentions that certain complex structures offer better performance than mushrooms like EBGs structure. Due to that, it is beneficial for the users because it is easily fabricated, which mitigates the cost, and the reliability is very high, which gains the most attention.

EBG has two salient properties with respect to the frequency band [10]. Firstly, the incident wave and the reflected wave of EBG remain in the same phase, for which the EBG surface becomes similar to the PMC structure with a 0° reflection phase, although it does not have any real existence. And secondly, the propagation of surface waves is not supported here. These two properties make EBG able to overcome a few of the problems occurring in common antennas and optimize the antenna operation. This way, the EBG structure expands over a wide range of applications in antenna design. EBG structures have properties such that, in a particular frequency band, they stop the propagation of surface waves and reflect any incoming wave with no phase change [10].

3D EBG STRUCTURE

For the first time, a 3D periodic EBG structure was obtained by Iowa State University [11]. The structure is very similar to the woodpile, which is depicted in Fig. (**1**) In 1993, by the drilling of holes into a dielectric material block, a 3D periodic EBG structure was formed by Yablonovitch *et al*., which was working at microwave frequencies [12]. In the general case, the 3D structure blocks microwave propagation in all three directions of the EBG materials. Although in real-world applications, it is very difficult to block the propagation of waves in particular directions, and it is very difficult to grow such a structure. For so many years, scientists have been trying to use another pathway to get a similar propagation using different forms. One of the better solutions was the 2D structure, which is able to maintain similar wave propagation.

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