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REVIEW

Innovations and Applications in Nanosensor Technologies: A Brief Review

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Nanotechnology represents a field of science that enables the control of matter at the atomic and molecular level. Nanotechnology has made it possible to produce new devices and systems that can be used for various applications by examining the properties and behaviors of materials at the nanometer scale, thus creating new opportunities in many fields. In this article; the historical development of nanotechnology, its basic concepts and nanosensors as a sub-branch are discussed. Nanosensors are devices made of nanometer-scale materials that can detect various biological, physical or chemical parameters and transform them into electrical, optical or mechanical signals. In this article, the properties and application areas of carbon-based nanosensors are examined. Carbon-based nanosensors consist of carbon allotropes including carbon nano-tubes, graphene, fullerene and nanodiamond. These materials have exceptional properties including mechanical strength, high electrical conductivity and chemical stability that used in many fields such as environment, health and energy. In this article, the properties, applications and developments in carbon-based nanosensors and nanomaterials are discussed.

Keywords: Nanotechnology, Nanosensor, Nanomaterials

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1. INTRODUCTION

Developments in the domain of nanotechnology, have a great importance with the developing technology. Nowadays, nanotechnology appears in medicine, engineering and many other important fields. One of the studies in the field of nanotechnology is nanosensors. Nanosensors made using different elements are used in many different fields. Carbon-based nanosensors, which will be examined in this article, are widely used especially in electronics, medicine and environ-mental fields. Carbon-based nanosensors are made using carbon nanotubes, fullerene, graphene and nanodiamond. Among these nanosensors; nanosensors made using carbon nanotubes are used in mechanical and chemical sensing, electronics and optics; nanosensors made using fullerene are used in optics, electronics and biological sensing; nanosensors made using graphene are used in mechanical and biological sensing, electronics and optics; nanosensors made using nanodiamond are used in electronics, optics and biological sensing. This study provides comprehensive information about the properties and application areas of carbon-based nanosensors.

2. NANOTECHNOLOGY AND NANOSENSORS

Nanotechnology refers to an interdisciplinary re-search field that focuses on the quantum properties of materials within the range of 1 to 100 nanometers and studies the synthesis, characterization, design and applications of these materials at the structural level. The diversity of structures at the nanoscale is related both to the dimensions being at the nanometer scale and to the fact that the smaller the size, the more pronounced the quantum properties become. In this con-text, nanotechnology examines nanoscale structures both in terms of size and properties. Nanotechnology, which has found a wide range of applications with to-day's developing technology, has significant potentials in areas such as industry, medicine and energy applications, as it offers a perspective at the molecular level as an alternative to other technological developments. These applications aim to shape the world of tomorrow by developing innovative solutions in the context of engineering and technology.

Richard P. Feynman's "There's Plenty of Room at the Bottom" [1] speech, given at the annual meeting of the American Physical Society on November 29, 1959 is generally regarded as the beginning of the nanotechnology era. In this iconic speech, Feynman highlighted that many innovative discoveries would be possible if production at the atomic and molecular scale could be realized, but he emphasized that in order for this to happen, special measurement and production techniques at the nanoscale must first be developed, and in summary, he predicted the following:

- Why cannot we write the entire 24 volumes of the Encyclopedia Brittanica on the head of a pin?

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- Information on a small scale
- Better electron microscopes
- The marvelous biological system
- Miniaturizing the computer
- Miniaturization by evaporation
- Problems of lubrication
- A hundred tiny hands
- Rearranging the atoms
- Atoms in a small world [1,2]

Although Feynman's iconic 1959 speech "There's Plenty of Room at the Bottom" [1] is generally regarded as the beginning of nanotechnology, Michael Faraday's 1857 work "Experimental Relations of Gold (and other Metals) to Light" [3], which he studied the distinctive optical and electronic characteristics of colloidal sus-pensions of nanoparticles of metals such as gold and silver, shows that the history of nanotechnology dates back much further than Feynman. The contributions of Faraday's "Experimental Relations of Gold (and other Metals) to Light" [3] work and Feynman's "There's Plenty of Room at the Bottom" [1] speech to the development of nanotechnology is an indisputable fact, but neither scientist used the term "Nanotechnology". The term nanotechnology was first coined in 1974 by Norio Taniguchi in his article "On the Basic Concept of Nano-technology" [4]. By 1981, Heinrich Rohrer and Gerd Binnig had discovered the Scanning Tunnel Microscope [5] at IBM's research laboratory in Zurich. With the Scanning Tunneling Microscope, subatomic particles that cannot be visualized with an electron microscope can be magnified 2000 times, and imaging at the atomic level has been performed for the first time. Their discovery earned Heinrich Rohrer and Gerd Binnig the Nobel Prize in Physics in 1986.

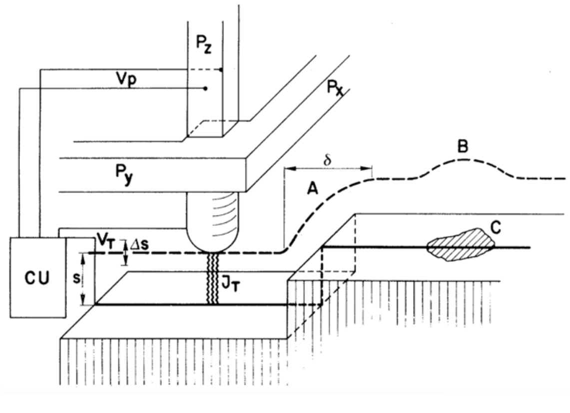

Fig. 1 – Operating principle of the Scanning Tunneling Microscope [5]

In 1985, R.E. Smalley, H.W. Kroto, and R.F. Curl synthesized a new allotrope of carbon, consisting of a molecule made up of 60 carbon atoms. This molecule has a spherical cage structure and is referred to as a "Buckyball" due to its resemblance to a soccer ball. Additionally, in recognition of the architect Buckminster Fuller, known for his geodesic dome designs, this molecule is named "Buckminsterfullerene" [6]. Buckminsterfullerene can be utilized as a building block for designing new devices and materials at the molecular scale. Consequently, it holds a key position in enabling new possibilities and applications in the field of nanotechnology. The discovery of Buckminsterfullerene [6] earned R.F. Curl, H.W. Kroto, and R.E. Smalley the Nobel Prize in Chemistry in 1996.

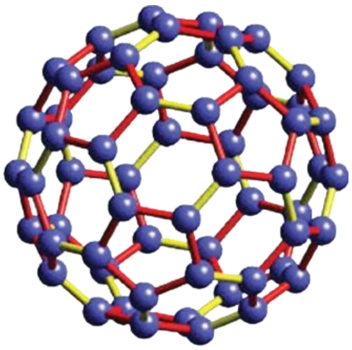

Fig. 2 – C_{60}: Structure of Buckminsterfullerene [7]

In 1986, Dr. Eric Drexler published his book Engines of Creation: The Coming Era of Nanotechnology, which is considered a classic in the field of nanotechnology. The book addresses the subject of molecular nanotechnology, drawing inspiration from Feynman's speech "There's Plenty of Room at the Bottom" [1]. In this book, Drexler states that nanotechnology is a new field of technology in which the structure of matter can be controlled, and that this field of technology can pro-vide great developments and benefits in fields such as medicine, industry, economy and the environment, but it can also pose dangers, and discusses various scenarios regarding these. Although the book is considered a classic in the field of nanotechnology, it has been criticized by scientists such as Nobel Laureate Richard Smalley and chemist George M. Whitesides for having a misleading effect on the view of nanotechnology.

Drexler also used the term "Nanotechnology" in this book, just as Norio Taniguchi did in his 1974 article "On the Basic Concept of Nanotechnology" [4]. In 1986, the same year that Dr. Eric Drexler's book "Engines of Creation: The Coming Era of Nanotechnology" [8] was published, Gerd Binnig, Calvin F. Quate, and Chris-toph Gerber discovered the Atomic Force Microscope [9]. Atomic Force Microscope is a very important discovery in terms of nanotechnology because of its ability to measure physical parameters such as surface proper-ties, electrical potential, conductivity and magnetic field at the atomic level. In 1990, D. M. Eigler and E. K. Schweizer used the Scanning Tunnel Microscope [5], invented by Heinrich Rohrer and Gerd Binnig in 1981, to create the IBM logo using only 35 xenon atoms on a nickel surface [10]. With this example, D. M. Eigler and E. K. Schweizer have demonstrated that they can position xenon atoms on a nickel surface with nanometer precision and create various patterns and structures with these positionings. They also suggested that it is possible to transfer information at the atomic level.

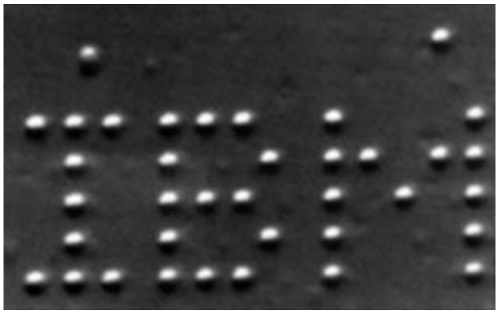

Fig. 3 – IBM logo created using 35 xenon atoms [10]

In 1991, Sumio Iijima discovered a nanomaterial called carbon nanotube [11]. Carbon nanotube is a strong and flexible structure in which carbon atoms are arranged in a cylindrical shape. Iijima's discovery of carbon nanotube aroused intense interest in the field of nanotechnology and contributed to an increase in research activities in this field. In 2000, National Nanotechnology Initiative, which encourages and directs education and research activities in the field of nanotechnology, was launched by United States President Bill Clinton [12]. The aim of this initiative is to support and coordinate research and development activities in the field of nanotechnology. In 2000, the budget allocated for the National Nanotechnology Initiative [12] was determined as 270 million dollars. On January 21, 2000, in his speech at the California Institute of Technology, United States President Clinton said, "Many of these research goals may take 20 or more years to achieve, but that is precisely why there is an important role for the Federal government [12]." The total budget allocated for the National Nanotechnology Initiative between 2000 and 2022 is approximately $30 billion, and the budget allocated for this field in 2023 is $1.99 billion. The importance of nanotechnology for the future is understood from the fact that such a high in-vestment has been made in a period of 23 years. In 2001, Andreas Hirsch discovered that carbon nanotubes could be chemically modified [13], thereby enhancing their biocompatibility, reactivity, and solubility. In 2004, Andre Geim and Konstantin Novoselov synthesized graphene for the first time [14]. Geim and Novoselov succeeded in obtaining graphene sheets by sticking and removing adhesive tape onto graphite. They observed the resulting graphene sheets with an optical microscope. Their observations and pioneering experiments on two-dimensional graphene material earned Geim and Novoselov the Nobel Prize in Physics in 2010.

The developments in nanotechnology and its growing importance have increased the significance of nanosensors in modern applications. Nanosensors are special devices that can measure the biological, physical and chemical properties of nanomaterials or nanosystems operating at the nanoscale (1 – 100 nm.) and convert these properties into signals that can be analyzed. Unlike other sensors, these specialized devices aim to provide high sensitivity and specificity. For this, it takes advantage of the unique characteristics of nanomaterials, such as quantum effects, enhanced reactivity and high surface-to-volume ratio. Nanosensors are fabricated using various methods such as molecular self-assembly, top-down lithography and bot-tom-up assembly. Nanosensors can be used in sectors such as environment and energy, medicine and health, security and defense, food and agriculture, electronics and communications.

3. NANOSENSOR CLASSIFICATION

3.1 Nanosensors by Purpose of Use

Nanosensors can be used in different fields and for different purposes thanks to their unique properties. For example, mechanical nanosensors are used to measure mechanical force, pressure, vibration, acoustic waves or displacement at the nanoscale [15,16]. Electrical nanosensors are used to measure electrical cur-rent, voltage, resistance, inductance or magnetic field at the nanoscale [15-17]. Optical nanosensors are used to measurement of light, color, spectrum or polarization at the nanoscale [17]. Thermal nanosensors are used to measure heat capacity, heat flow, entropy or temperature at the nanoscale [18]. Chemical nanosensors are used to measure chemical compounds, elements, molecules, ions or reactions at the nanoscale [18,19]. Biological nanosensors are used to measure biological struc-ture, biological function, biological interaction or biological activity at the nanoscale [18-20].

3.2 Nanosensors Based on Their Bases

Nanosensors can be created using different bases.

3.2.1. Carbon-Based Nanosensors

Carbon-based nanosensors are sensors composed of nanoscale carbon materials. Examples of carbon-based nanosensors include carbon nanotubes, fullerene, graphene, and nanodiamond.

Carbon nanotubes are structures where carbon atoms are positioned in a cylindrical shape. They can be heated to high temperatures without reacting with the oxygen in the air. This indicates that they possess very high thermal stability. They also exhibit excellent chemical stability, making them resistant to reactions with acids, bases or other chemical substances. Carbon nanotubes are resistant to magnetic fields and their electrical properties change depending on the magnetic field. This means that carbon nanotubes are diamagnetic and exhibit anisotropic sensitivity. They display nonlinear optical behaviors. The shape and size of carbon nanotubes determine how light is reflected, ab-sorbed and transmitted. Their mechanical strength is far superior to any known material. They maintain their shape under bending and tension. Carbon nano-tubes are excellent conductors of electricity with very low resistivity. They are biologically compatible with living tissues. They also demonstrate outstanding performance in heat conduction with thermal conductivity approximately 10 times greater than copper [21-24].

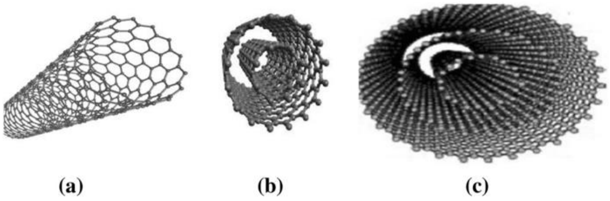

Fig. 4 – Carbon nanotubes by number of walls (a) SWNT (b) DWNT (c) MWNT [25]

Carbon nanotubes; owing to their unique properties, possess a high potential for various applications [21-24]. They have found roles in numerous modern applications such as biomedical applications [26], fiber optic chemical sensor fabrication [27], digital circuit applications [28], logic circuits [29], molecular electronics [30] and energy storage [31]. Current applications of carbon nanotubes include cathode ray lighting elements with a triode-type design, produced by ISE Electronics Company in Japan, which use carbon nanotube materials as field emitters [32], and flat panel displays that utilize carbon nanotubes as electron emission sources [33].

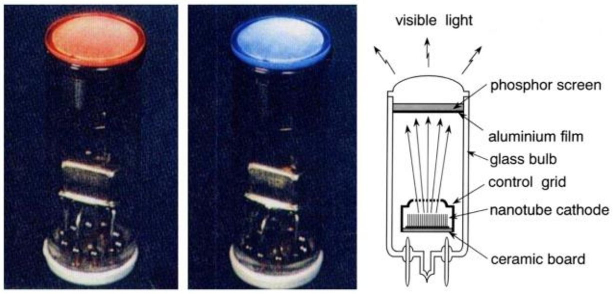

Fig. 5 – Carbon nanotube field emission cathode ray lightning element [32]

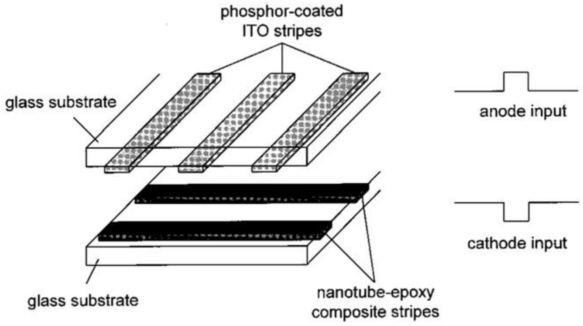

Fig. 6 – Schematic structure of the matrix-addressed nanotube display [33]

Fullerene is a molecule consisting of 60 carbon at-oms arranged in a spherical cage. Fullerene is chemically diverse and flexible. It can easily react with oxy-gen, hydrogen or other elements. Its electrical, optical and magnetic properties depend on the structure and size of the fullerene. This means that fullerene can be conductive, semiconductive, superconductive, metallic, ferromagnetic, paramagnetic, diamagnetic, photoactive, photovoltaic, or fluorescent. It also demonstrates excellent performance in heat conduction with thermal conductivity far exceeding that of diamond. Fullerene is compatible with living tissues and possesses antiviral, antioxidant, and photosensitizing biological activities. As antivirals, it can inhibit viruses such as HIV, influenza, and Hepatitis C. As antioxidants, it can capture free radicals, preventing cellular damage. As photosensitizers, it can be used to deliver light-activated drugs and genetic materials like DNA or RNA to target and destroy cancer cells [34-37].

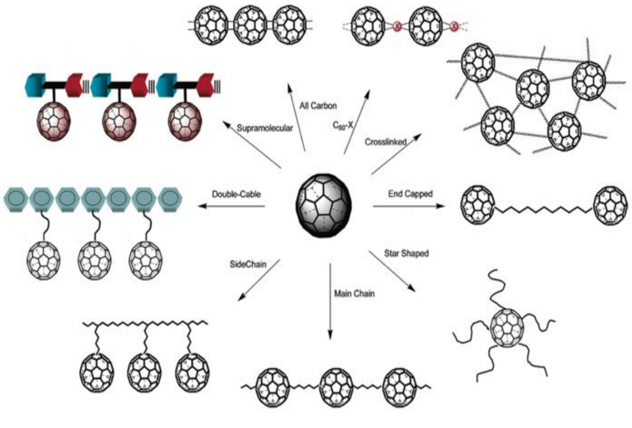

Fig. 7 – Schematic representation of C_{60}-containing polymers [38]

Fullerene; due to its unique properties, has a high potential for various applications [23,39,40]. It finds use in many modern applications such as fuel cell technologies [41], medical applications [42], energy applications [43] and sensor applications [44]. Current applications of fullerene include the use of polymers and fullerene compounds in solar cells [45] and drug delivery systems based on fullerene molecules [46].

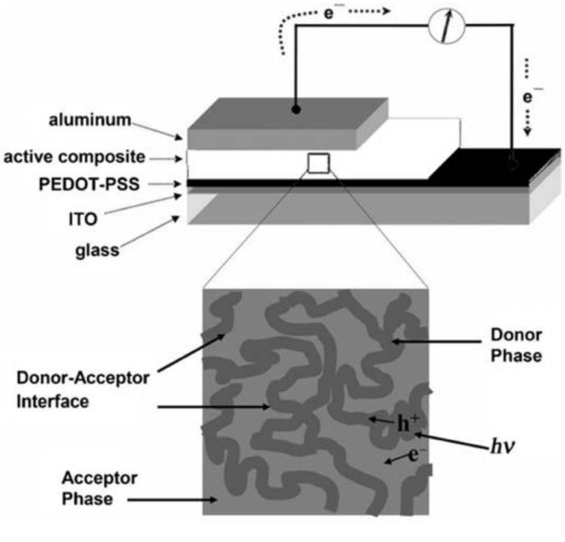

Fig. 8 – Schematic illustration of a polymer–fullerene BHJ solar cell, with a magnified area showing the bicontinuous morphology of the active layer [45]

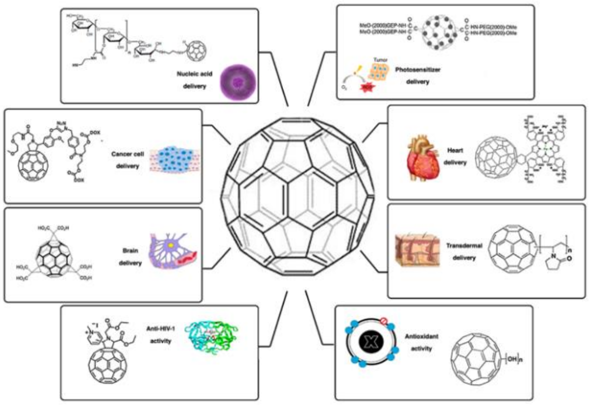

Fig. 9 – Fullerene-based delivery systems [46]

Graphene is a two-dimensional material formed from a single layer of carbon atoms arranged in a hex-agonal lattice. Graphene exhibits high thermal stability and thermal conductivity. Due to its high chemical stability, it does not easily react with acids, bases or other chemical substances. It has high mechanical strength and is also resistant to bending. It shows resistance to magnetic fields and its electrical properties change under the influence of a magnetic field. This indicates that graphene is diamagnetic and exhibits anisotropic sensitivity. It displays nonlinear optical behaviors. The shape and size of graphene determine how light is reflected, absorbed or transmitted. Additionally, it possesses optical properties such as phosphorescence, fluorescence and electroluminescence. With its very low resistivity, it conducts electricity exceptionally well. Being compatible with living tis-sues, it also demonstrates antiviral, antibacterial and anti-inflammatory biological activities [47-51].

Fig. 10 illustrates the structure of graphene. Graphene can be rolled into a Buckyball shape as shown on the left, rolled into nanotubes as shown in the middle, or stacked as graphite as shown on the right.

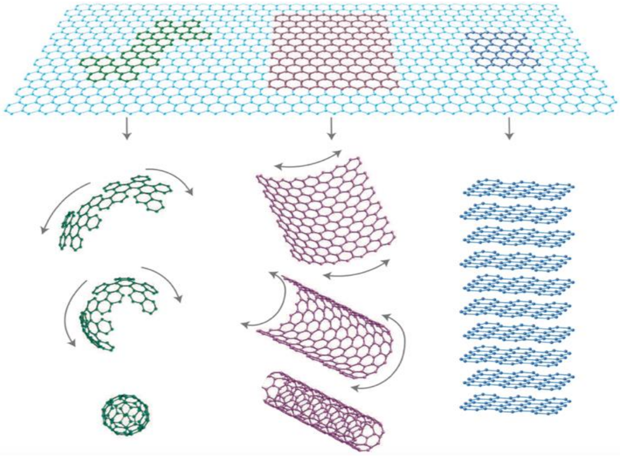

Fig. 10 – Graphene: 2D structural material that forms the basis of all graphitic forms [48]

Graphene, due to its unique properties, has a high potential for various applications [47, 48, 52]. It is utilized in many modern applications, including electronic and photonic applications [53], environmental applications [54], chemical applications [55], cellular drug delivery [56], energy storage [57] and chemical sensing [58]. Current applications of graphene include enhancing photovoltaic efficiency through heterojunctions composed of graphene and 3D semiconductors [59] and using graphene as an anti-corrosion coating [60].

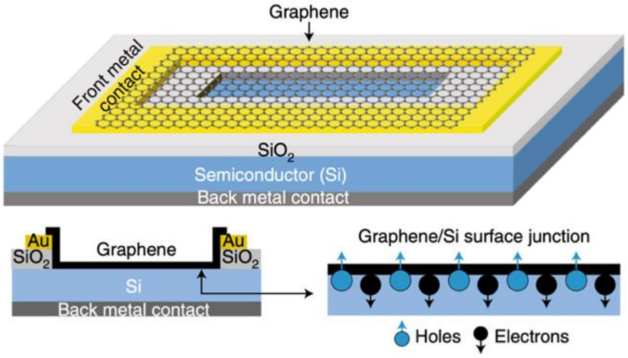

Fig. 11 – Schematic of a graphene-on-semiconductor (Si) heterojunction photovoltaic cell [59]

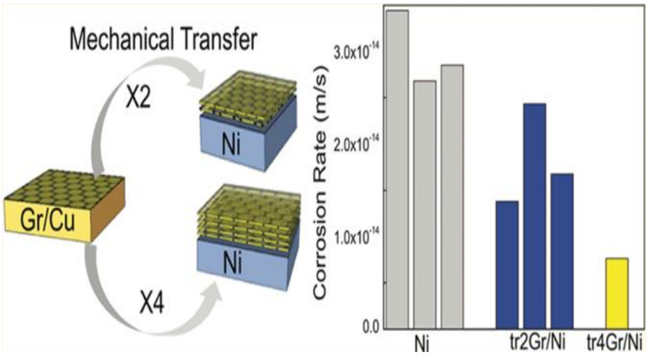

Fig. 12 – Graph showing significant reduction in corrosion with the use of graphene as a protective coating [60]

Nanodiamond is formed when carbon atoms are exposed to high pressure and temperature to form a diamond lattice. Nanodiamond possesses very high hardness and wear resistance. Under certain conditions, nanodiamond can exhibit even greater hardness than diamond, the hardest known material. It is chemically very stable and does not readily react with oxygen, hydrogen, acids, bases or other reactive substances. Nanodiamond has high thermal conductivity, allowing it to transfer heat very rapidly. It exhibits nonlinear optical properties, enabling it to reflect, absorb or transmit light and it can also emit light at different wavelengths. It is biocompatible and bioactive, allowing interaction with living tissues. Additionally, it conducts electric current well and quickly and exhibits resistance to magnetic fields [61-63].

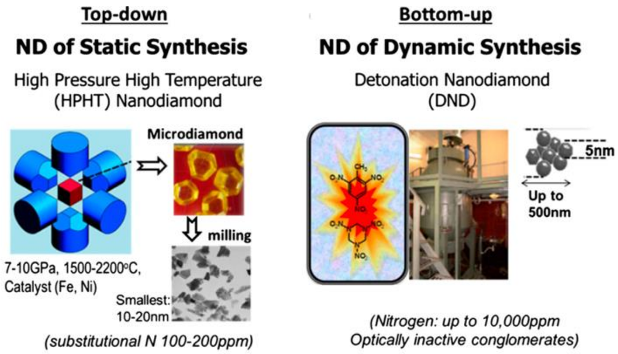

Fig. 13 – Schematic representation of the synthesis and structure of the two major types of ND particles [63]

Nanodiamond, due to its unique properties, has high potential for various applications [61,62]. It is used in many modern applications, including medical applications [64], biotechnology and tissue engineering [65] and solar cell applications [66]. Current applications of nanodiamond include its use in energy applications [67] and as quantum sensors in biological applications [68].

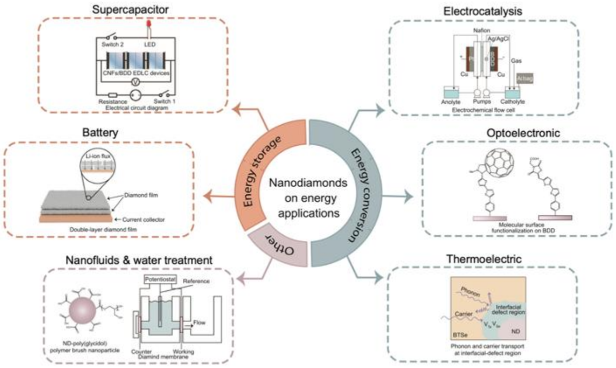

Fig. 14 – Applications of nanodiamonds on energy-related fields [67]

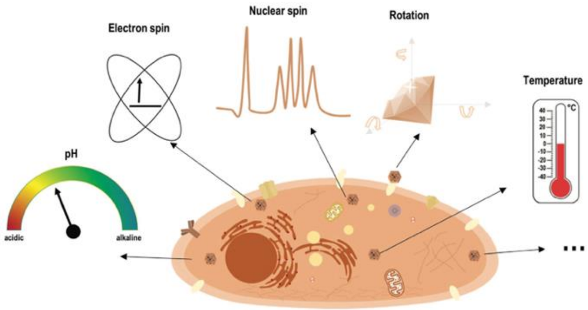

Fig. 15 – The use of nanodiamond quantum sensors in the determination of local parameters such as pH, temperature, nuclear and electron spins in biological systems [68]

3.2.2. Metal-Based Nanosensors

Metal-based nanosensors are sensors composed of nanoscale metal materials such as metal nanoparticles, nanowires or nanostructures. Examples of metal-based nanosensors include gold nanoparticles, iron oxide nanoparticles, silver nanowires and metal-organic framework-based nanosensors. Gold nanoparticles are nanoscale gold particles. They can be used in various fields such as biomedical, chemical and biological sensing, medicine, optics and electronics [69-72]. Current applications of gold nanoparticles include their use in biomedical fields and drug delivery [73].

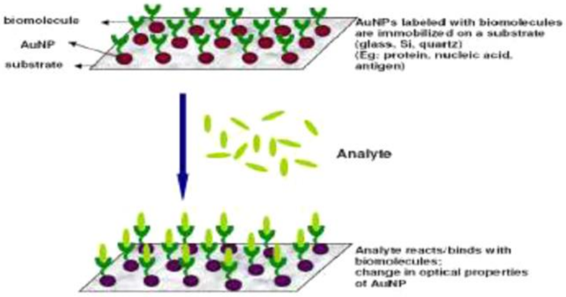

Fig. 16 – Gold nanoparticles in biosensor [73]

Iron oxide nanoparticles are nanoscale iron oxide particles that exhibit magnetic and semiconducting properties. They can be used in various fields such as biomedical applications and pharmaceutical applications [74, 75]. Current applications of iron oxide nano-particles include their use in regenerative medicine and tissue engineering [76].

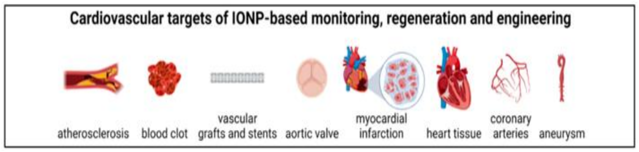

Fig. 17 – Possible targets for IONP-assisted cardiovascular tissue engineering and regeneration [76]

Silver nanowires are nanoscale silver structures with a one-dimensional form. They can be used in various fields such as electrical applications, biomedical applications and optics [77]. Current applications of silver nanowires include their use for transparent conductive films [78].

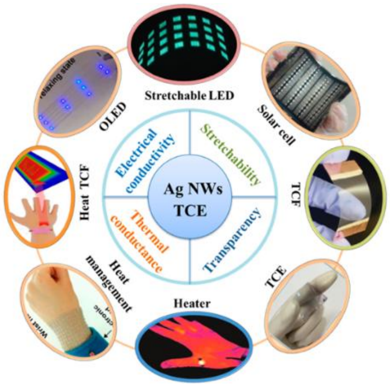

Fig. 18 – Properties and applications of recently developed devices based on Ag NWs TCE [78]

Metal-organic framework-based nanosensors are nanoscale particles with a metal-organic framework. They can be used in various fields such as biomedical applications and sensor applications [79,80]. Current applications of metal-organic framework-based nanosensors include fluorescence nanosensor developed with a metal-organic framework for the detection of copper ions [81].

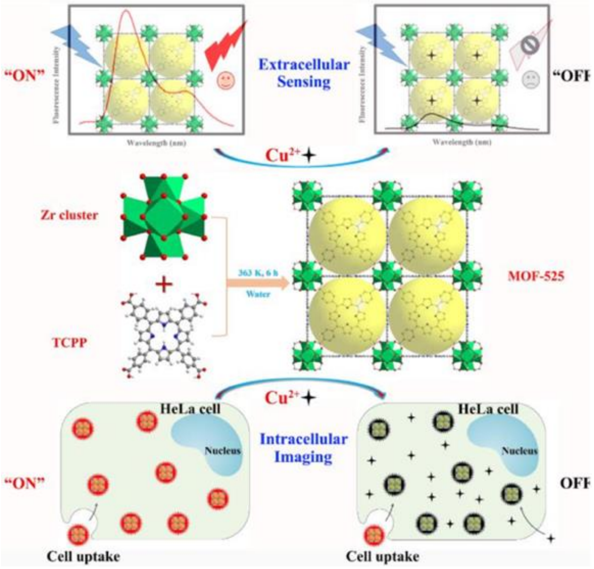

Fig. 19 – Schematic illustration of the preparation of porphyrinic MOF-525 nanoparticles and the "turn-off" fluorescence sensing mechanism for extracellular/intracellular detection of Cu^{2+} [81]

3.2.3. Semiconductor-Based Nanosensors

Semiconductor-based nanosensors are sensors composed of nanoscale semiconductor materials. Examples of semiconductor-based nanosensors include silicon nanowires. Silicon nanowires are nanoscale silicon particles with a one-dimensional form. They can be used in various fields such as electronics, optics, sensing applications, mechanical applications and thermal applications [82,83]. Current applications of semiconductor-based nanosensors include the use of obliquely aligned arrays of silicon nanowires in solar cells [84].

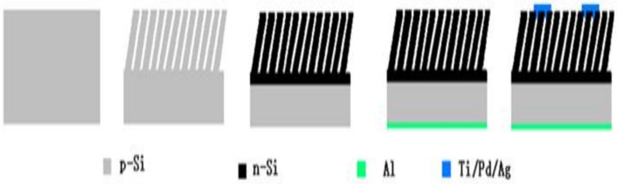

Fig. 20 – Schematic diagram of the process for fabricating SA-SiNW array solar cells [84]

3.2.4. Bionanosensors

Bionanosensors are sensors composed of nanoscale materials based on lipids, polymers, or inorganic substances. Examples of bionanosensors include DNA or RNA-based nanosensors. DNA or RNA-based nanosensors are nanoscale sensors that utilize DNA or RNA molecules. They can be used in various fields such as medicine and environmental applications [85]. Current applications of DNA or RNA-based nanosensors include the use of DNA-based photoacoustic nanosensor for the detection of interferon gamma [86].

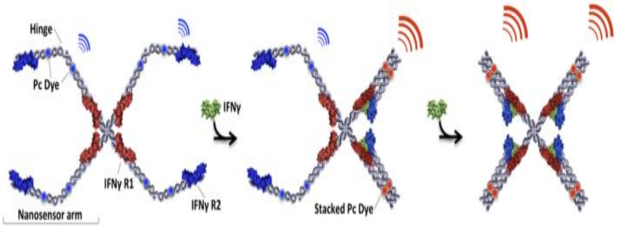

Fig.21 – Schematic representation of DNA-based photoacoustic nanosensor [86]

3.2.5. Magnetic Material-Based Nanosensors

Magnetic material-based nanosensors are sensors composed of nanoparticles with magnetic properties. Examples of magnetic material-based nanosensors include magnetoresistive material-based nanosensors. Magnetoresistive material-based nanosensors are nanoscale sensors that detect changes in the resistance of magnetic materials in a magnetic field. They can be used in various fields such as magnetic field sensing, biosensing and data storage applications [87,88]. Current applications of magnetic material-based nanosensors include position and current sensing with magnetoresistive material-based nanosensor [88].

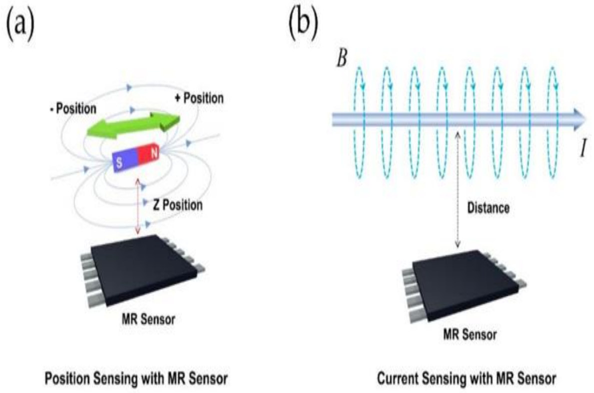

Fig. 22 – Schematic diagram of (a) position sensing and (b) current sensing with MR sensors [88]

3.2.6. Plasmonic Nanosensors

Plasmonic nanosensors are sensors that exploit the surface plasmon resonance (SPR) phenomenon, which occurs on the surface of metal nanoparticles or nanofilms. Examples of plasmonic nanosensors include plasmonic nanoparticles. Plasmonic nanoparticles are nanoscale metallic particles that can interact with electromagnetic radiation at wavelengths much larger than their particle size. They can be used in various fields such as biomedical applications, optics and nanomedicine [89,90]. Current applications of plasmonic nanoparticles include their use in chemical analysis [91].

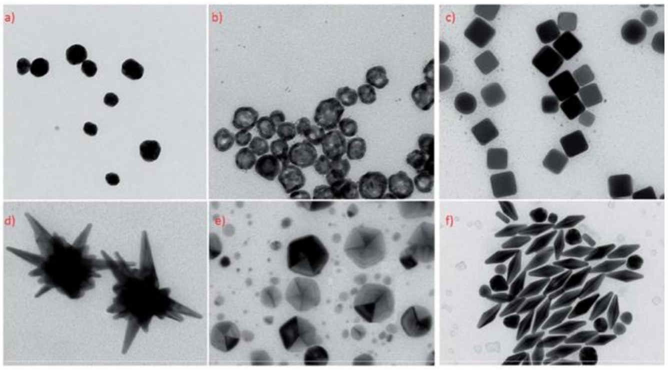

Fig. 23 – TEM micrographs presenting Ag and Au nanoparticles with different geometry and shapes practically used as electromagnetic nanoresonators for SERS measurements [91]

3.2.7. Polymeric Nanosensors

Polymeric nanosensors are sensors composed of organic material-based nanoparticles such as lipids, micelles, dendrimers or liposomes. Examples of polymeric nanosensors include conductive polymers and smart polymers. Conducting polymers are nanosensors created using organic polymers that conduct electricity. They can be used in various fields such as optics, electronics, energy applications and magnetism applications [92-95]. Current applications of conducting polymers include their use in electrochemical biosensors [96].

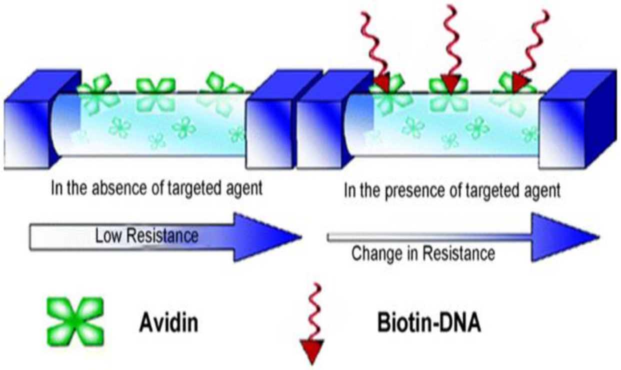

Fig. 24 – Polymer nanowire on prepatterned electrodes and its application to biosensing [96]

Smart polymers are nanosensors created using polymers that are sensitive to environmental factors. They can be used in various fields such as medicine, optics, electronics, energy applications and biomedical applications [97-99]. Current applications of smart polymers include their use in biotechnology and medicine [98].

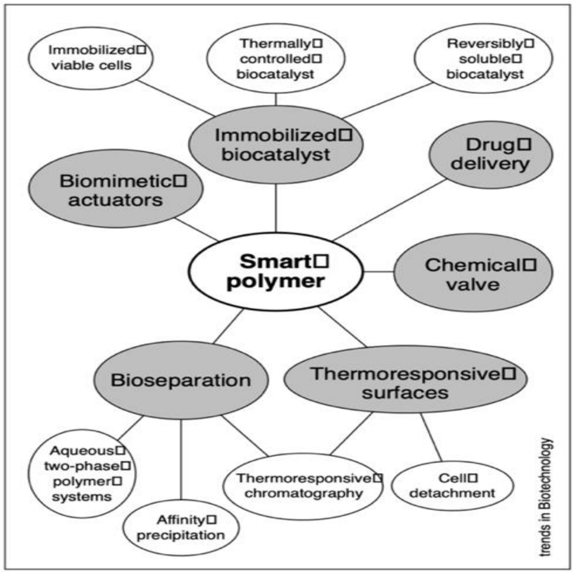

Fig. 25 – Uses of smart polymers in biotechnology and medicine [98]

4. CONCLUSION

Nanotechnology is a branch of science and engineer-ing aimed at producing new materials, devices and systems through the control of matter at the atomic and molecular level. Nanosensors are one of the most significant and exciting applications of nanotechnology. Nanosensors can detect various parameters with precision and speed by utilizing the unique properties of nanometer-scale materials. This article discusses the historical development of nanotechnology, its fundamental concepts and the classification of nanosensors. Additionally; properties, applications and developments of carbon-based nanosensors are examined in detail. Carbon-based nanosensors are composed of carbon allotropes such as carbon nanotubes, graphene, fullerene and nanodiamond. These materials are ideal for nanosensors due to their superior characteristics such as high electrical conductivity, mechanical strength and chemical stability. They are used in various application areas including the environment, health and energy. Carbon-based nanosensors play a crucial role in the future of nanotechnology. This article provides a comprehensive literature review on the properties, application areas and developments of carbon-based nanosensors. For future work, it is recommended to develop new methods and standards for the more efficient, safe and cost-effective production, testing and utilization of carbon-based nanosensors.

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Інновації та застосування у технологіях наносенсорів: короткий огляд

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Нанотехнологія є галуззю науки, що дозволяє керувати матерією на атомному та молекулярному рівні. Завдяки вивченню властивостей і поведінки матеріалів у нанометровому масштабі нанотехнологія відкрила можливість створення нових пристроїв і систем для різноманітних застосувань, що сприяло появі нових перспектив у багатьох сферах. У цій статті розглянуто історичний розвиток нанотехнології, її основні концепції та наносенсори як одну з її підгалузей. Наносенсори — це пристрої, виготовлені з нанометрових матеріалів, здатні виявляти різні біологічні, фізичні або хімічні параметри та перетворювати їх на електричні, оптичні або механічні сигнали. Особливу увагу приділено властивостям та областям застосування вуглецевих наносенсорів, які складаються з алотропів вуглецю, включаючи вуглецеві нанотрубки, графен, фулерени та нанодіаманти. Ці матеріали мають унікальні властивості, такі як висока механічна міцність, електропровідність та хімічна стабільність, що робить їх корисними у багатьох галузях, зокрема в екології, охороні здоров'я та енергетиці. У статті обговорюються властивості, застосування та останні досягнення у сфері вуглецевих наносенсорів та наноматеріалів.

Ключові слова: Нанотехнологія, Наносенсори, Наноматеріали.