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THE EMPLOYMENT OF CARBON NANOTUBES IN BIOMEDICAL APPLICATIONS

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Abstract. Carbon nanotubes (CNTs), a prominent application of nanotechnology, find extensive use across various fields. Their electrical and optical characteristics, which are affected by the manufacturing process and any impurities introduced during production, are crucial in establishing their suitability for use. This research focuses on the utilization of carbon nanotubes in medical applications, exploring their properties both as electrical conductors and semiconductors, comparable to silicon used in precision medical equipment and devices. When functioning as electrical conductors, CNTs exhibit characteristics similar to traditional conductive materials. This property is harnessed in medical applications, particularly in targeted cancer treatments that minimize impact on healthy cells. CNTs' efficient conduction of electrical current makes them valuable components in medical devices and equipment. Furthermore, CNTs showcase semiconductor properties akin to silicon. This characteristic is crucial for developing advanced medical equipment, enabling accurate diagnostics and medical imaging. The semiconductor behavior allows the creation of intricate medical devices with enhanced precision. The research underscores the significance of CNTs in shaping the future of medical technology, especially when integrated with artificial intelligence applications. The ability of CNTs to function both as conductors and semiconductors highlights their versatility in the medical field, promising advancements in healthcare technologies. Their use holds potential for targeted cancer treatments, accurate diagnostics, medical imaging, and enhanced performance through integration with artificial intelligence.

Key words: Carbon Nanotubes, Biomedical Engineering, Nanotechnology Engineering, Bio- Nanotechnology, and Carbon Nanotube Applications

1. Introduction. Nanotechnology, emerging as an alternative to microtechnology, introduces the possibility of manufacturing nanoelectronic and electromechanical devices, drastically reducing their size compared to micro devices. This transformative innovation is anticipated to bring about significant advancements across various scientific and engineering disciplines. Enthusiasts foresee its broad influence on contemporary medicine, the global economy, international relations, and the daily lives of individuals. The potential to arrange matter particles in unprecedented ways at a lower cost sparks imaginations of supercomputers integrated into pen tips, and fleets of medical nanorobots administered to treat blood clots, tumors, and currently incurable diseases[[1], [2]]. The study highlights the contrast between micro and nano technologies, emphasizing nanotechnology's potential to revolutionize electronic and electromechanical devices. In contrast to micrometers, nanoelectronic and electromechanical devices can be reduced in size by a factor of a thousand, resulting in enhanced performance. This paradigm shift is not merely a theoretical concept; it has tangible applications across various industries. For instance, polymers in micro-devices lead to increased device longevity, while metals like gold, nickel, and aluminum contribute to the reliability of early devices [3], [4]. The discussion extends to the unique properties of nanomaterials, showcasing their exceptional hardness, transparency, and transformative effects on material behavior. Spherical nanoparticles made of silicon, ranging from 40 to 100 nanometers, exhibit hardness surpassing even that of sapphire and approaching that of diamond. Transparency, a characteristic of nanoparticles due to their dimensions being smaller than light wavelengths, opens up possibilities for applications like transparent packaging and cosmetic products [5], [6], [7].

Nanotechnology is acknowledged as the fifth generation of electronic technologies, following the progression from electronic valves to transistors, integrated circuits, and microprocessors. The development of nanoelectronic and electromechanical devices, facilitated by advancements in synthetic chemistry, holds promise for applications in health, medicine, information technology, and beyond. Notable examples include IBM's creation of a microscope for imaging and recording atoms at the Nano level and the aspiration to replace electricity with light ([8], [9], [10]) potentially leading to the advent of optical computers such as shown in figure 1.1.

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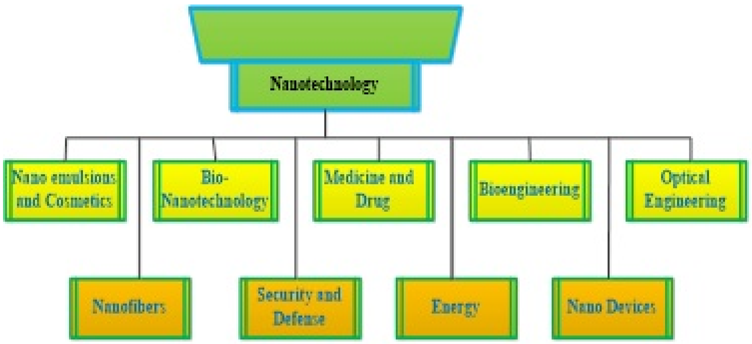

Fig. 1.1: Nanotechnology holds promising prospects and applications in many fields.

1.1. Overview of Carbon Nanotubes (CNTs). During the early 1990s, Sumio Iijima made a groundbreaking discovery of carbon nanotubes (CNTs), which brought about a significant transformation in numerous scientific and technical domains. Carbon, which is vital for human existence, serves as the fundamental building block for the bonding arrangement of diamond, graphite, nanotubes, and fullerenes. With a wide range of desirable properties, CNTs have become integral in structural science, material science, chemistry, biology, and electronics[11], [12]. CNTs, resembling stretched graphite strips, exhibit exceptional properties—tensile strength surpassing steel, superior thermal conductivity, and electrical conductivity equivalent to copper. Divided into single-wall (SWNTs) and multi-wall (MWNTs) categories, CNTs' key characteristics include diameter, chirality angle, and number of walls, each influencing unique physical and chemical properties. Fabrication techniques involve chemical methods and physical techniques such as chemical vapor deposition (CVD), arc discharge, and laser ablation. CNTs, incorporated into nanosystems like polymer electrical nano materials, possess a nanoscale diameter, contributing to their versatility. Electronic properties vary based on diameter and chirality, with approximately one-third exhibiting metallic structure and the rest being semiconducting. The optical properties of CNTs have garnered attention in photonics, showcasing a short recovery time and high third-order optical nonlinearity. Chiral nanotubes, categorized based on chiral vectors, contribute to the diverse landscape of carbon nanotubes. The interplay between valence electrons and the lattice in rigid covalent-bond materials impacts the electronic structure. Calculations show that around one-third of CNTs have a metallic structure, dependent on nanotube diameter and chiral angle [13], [11], [14] .

The structure of single-walled carbon nanotubes (SWNTs) is intricately linked to their electrical properties, particularly influenced by the chiral vector (Ch), which determines the orientation of the honeycomb lattice. This unique parameter serves as the key characteristic affecting whether SWNTs behave like metals or semiconductors. The chiral vector, represented by (n, m) indices, defines the tube's structure, with n and m being integers that influence the nanotube's diameter and chirality angle ( ). It is essential to comprehend the structure of the end of a single-walled carbon nanotube (SWNT), which is commonly described using Hamada indices (n, m), as this knowledge is critical for accurately predicting and controlling the electrical characteristics of SWNTs. The chiral angle and the specific arrangement of carbon atoms significantly impact the electronic structure. The correlation between the electrical structure and geometry, as demonstrated in fullerenes, is proposed to be a universal trait in nanostructured carbon materials such as carbon nanotubes. This reliance is attributed to the enhanced interaction between valence electrons and the lattice in rigid C-C covalent-bond materials. In materials with stiff covalent bonds, valence electrons interact more strongly with the lattice, influencing the electronic structure based on geometrical details. The electrical energy bond structure of a nanotube is intricately connected to the energy band structure generated by the 2D graphite honeycomb sheet used in the production of the nanotube. This connection highlights the significance of the underlying hexag-

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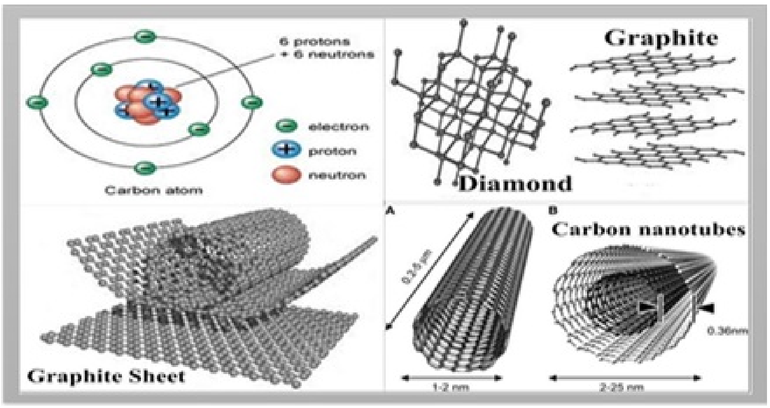

Fig. 1.2: Full carbon nanotube (CNT) manufacturing process, from atomic carbon to graphite sheets to rolled-up form tubes.

onal lattice structure in determining electronic properties. Calculations reveal that approximately one-third of carbon nanotubes exhibit a metallic structure, while the remaining two-thirds have a semiconducting structure [14][2][15]. This observation is contingent on factors such as nanotube diameter (dt) and the chiral angle (θ). Chiral nanotubes, categorized as zigzag and armchair nanotubes, represent another classification based on chiral vectors (Ch), adding to the diversity of carbon nanotube structures as observed in the figure 1.2.

Carbon nanotubes (CNTs) have potential biomedical applications in various fields. They have applications in antimicrobial materials, dentistry, drug delivery, biosensing, cancer therapy, tissue engineering, diagnostic imaging, and regenerative medicine. Carbon nanotubes (CNTs) have distinctive characteristics, including a large surface area, exceptional mechanical robustness, electrical conductivity, and thermal properties, which render them well-suited for these specific applications. Functionalization of CNTs enhances their biocompatibility and enables biomolecule loading for targeted drug delivery and immobilization support. Carbon nanotubes (CNTs) can undergo modifications with diverse functional groups to enable the concurrent transportation of many molecules, facilitating targeted delivery, therapeutic interventions, and imaging purposes. They have been employed for the delivery of tiny medicinal molecules, peptides, proteins, and genes and have demonstrated therapeutic effectiveness in both in vivo and in vitro experiments. In addition, carbon nanotubes (CNTs) have been utilised in the advancement of biosensors for the detection of biological and biomedical chemicals. However, there are challenges related to cytotoxicity and biodegradation that need to be addressed for their safe implementation in clinical trials [16], [17].

Properties of carbon nanotubes have High Strength that mains Carbon nanotubes are known for their exceptional strength, making them ideal for use in biomedical implants and scaffolds [3], [18], [19]. Electrical Conductivity is they exhibit excellent electrical conductivity, allowing for applications in bioelectronics and biosensors. Thermal Stability is with high thermal stability, carbon nanotubes are suitable for various biomedical applications, including heating-based therapies. Carbon nanotubes (CNTs) exhibit unique optical properties that make them highly valuable in various applications. Some key aspects of their optical properties include: Optical Absorption and Emission are CNTs demonstrate strong optical absorption in the near-infrared region. Their emission properties can be tuned based on the nanotube structure, offering possibilities for applications in sensors and imaging. Photoluminescence is Carbon nanotubes can emit light upon absorbing photons, a phenomenon known as photoluminescence. This property is influenced by the nanotube's diameter and chirality, providing opportunities for designing nanoscale light sources and devices [20]. Nonlinear Optical Behavior is CNTs exhibit nonlinear optical behavior, making them suitable for applications in nonlinear optics. Their response to intense light can be harnessed for developing optical switches and modulators. Optical Transparency is Depending on their structure, some carbon nanotubes are optically transparent. This transparency, combined with their excellent electrical conductivity, is advantageous for applications in transparent conductive films and coatings. Light Polarization can be Carbon nanotubes exhibit polarization-dependent optical properties. This polarization sensitivity is beneficial in designing devices for polarized light applications, such as in optoelectronics and photodetectors. Light Scattering and Reflection have CNTs can scatter and reflect light, and their interaction with light is influenced by factors like diameter and length. These properties are relevant in applications such as anti-reflective coatings and light-absorbing materials. Photoconductive Response have Carbon nanotubes can show a photoconductive response, meaning their electrical conductivity changes upon exposure to light. This property is utilized in developing light-sensitive devices like photodetectors and photovoltaic cells. Broadband Absorption: CNTs have broadband absorption capabilities, covering a wide range of the electromagnetic spectrum [13], [21], [22]. This feature is advantageous for applications in solar cells and broadband photodetectors.

Utilizing carbon nanotubes (CNTs) in biomedicine presents promising opportunities, but it also comes with several challenges and limitations that need to be addressed. Some key considerations include: Biocompatibility Concerns is the biocompatibility of carbon nanotubes is a significant challenge. Some studies have raised concerns about potential toxicity and inflammatory responses when CNTs interact with biological systems. Addressing these issues is crucial for safe biomedical applications. Functionalization and Surface Modifications are Pure carbon nanotubes may lack specific functional groups required for targeted drug delivery or interactions with biological molecules. Surface modifications are often necessary to enhance biocompatibility, solubility, and the attachment of biomolecules [3], [4], [23], [24]. Biodistribution and Clearance have Understanding the biodistribution and clearance of carbon nanotubes from the body is essential for their safe use. The long-term fate of CNTs, especially in terms of potential accumulation in organs or tissues, needs careful investigation. Regulatory Approval can be the regulatory approval process for medical applications involving carbon nanotubes is challenging. Establishing standardized protocols for testing and ensuring the safety and efficacy of CNT-based biomedical products is crucial for regulatory acceptance. Large-Scale Production is Scaling up the production of high-quality, well-characterized carbon nanotubes for biomedical applications remains a challenge. Ensuring consistency in size, structure, and purity is essential for reproducibility in research and clinical settings. Cost is the production and functionalization of carbon nanotubes can be expensive, limiting their widespread adoption in healthcare. Cost-effective manufacturing methods need to be developed to make CNT-based technologies more accessible. Limited Understanding of Long-Term Effects can be the long-term effects of exposure to carbon nanotubes, especially in the context of chronic diseases or repeated treatments, are not fully understood. Further research is needed to assess any potential cumulative impact on health over extended periods. Interaction with Immune System has the interaction between carbon nanotubes and the immune system is complex. Depending on their properties, CNTs can trigger immune responses, impacting their effectiveness and safety in biomedical applications. Intracellular Fate is understanding how carbon nanotubes behave inside cells and their intracellular fate is crucial. This includes investigating whether they remain intact, undergo degradation, or lead to the formation of toxic byproducts. Multifunctionality Challenges are while the multifunctionality of carbon nanotubes is advantageous, integrating multiple functionalities (e.g., imaging, drug delivery, and sensing) in a single platform without compromising performance remains a technical challenge. Carbon nanotubes (CNTs) possess unique properties such as large surface area, mechanical strength, electrical conductivity, and biocompatibility, making them ideal for biomedical applications. CNTs have been used as antibacterial agents, dental materials (scaffolds, bone-grafting, tissue engineering), and drug delivery systems for cancer therapy. The modifications of CNTs with metal and metal oxide nanoparticles, such as zinc oxide (ZnO), have enhanced their antibacterial properties [13], [22], [25], [26], [27] .

The graphite's hexagonal mesh structure, which serves as the basis for carbon nanotubes, can be conceptualised as a cylindrical formation resembling rolled-up chicken wire, owing to the organisation of carbon atoms in stacked layers. Within the electrical density of states (DOS) of carbon nanotubes, there are singularities called Van Hove Singularities. Each nanotube possesses four distinct energy levels – two for conduction and two for valence (CNTs). In contrast to metal carbon nanotubes, semiconducting carbon nanotubes exhibit a direct band gap that increases with the nanotube diameter, enabling them to efficiently conduct electrical current. Single-walled nanotubes generally exhibit sizes within the range of 1-2 nm, but multi-walled nanotubes can exhibit diameters ranging from 2-25 nm. Furthermore, nanotubes can vary in length, ranging from 0.2 to 5 micrometers, which provides a diverse array of structural options. Carbon nanotubes can exhibit either metallic or semiconducting properties, depending on their structure and orientation. This dual nature makes them valuable for a wide range of electronic applications, from high-conductivity components to semiconducting devices in advanced technology and nanoelectronics [7], [21], [28], [29]. The authors Mohd et al. (2023) provided information. The user's text is empty. Carbon nanotubes possess significant potential for utilisation in several biomedical applications, including the fabrication of antibacterial materials, enhancement of dental operations, drug delivery, and the advancement of biosensors. The study conducted by K. Victor et al. (2022) highlighted the several potential biomedical uses of carbon nanotubes, which encompass therapeutic, tissue engineering, diagnostic, and imaging applications. Additionally, carbon nanotubes can be utilised for drug transport and exhibit antibacterial properties. [Sarika Verma et al, (2023)] described The potential biomedical applications of carbon nanotubes include their usage in diagnoses, tissue regeneration, selective drug delivery, and as tissue engineering scaffolds. [Mahdieh Darroudi et al, (2023)] explained Carbon nanotubes have the potential to be used in several biomedical applications, such as diagnosing, treating, and preventing infectious and neoplastic disorders. They can also be used for gene transfer and anti-inflammatory therapy. [Lopamudra Giri et al. (2023)] discussed the biomedical applications of carbon nanotubes, highlighting their potential in various biological applications. [Duygu Harmanci et al. (2023)] discussed Carbon nanotubes (CNTs) show great potential for theranostic applications in various fields, including cancer diagnosis and therapy, infectious diseases, central nervous system problems, and tissue engineering. Functionalized carbon nanotubes (CNTs) have been successfully used in pharmaceuticals and medicine due to their unique properties . Study of the properties of carbon nanotube when it acts as a conductor of electric current or acts as a semiconductor, based on the materials added to the graphite material, as well as on the valence band and conduction in each nucleus and the opening between them. It is considered a carbon nanotube that is symmetrical, unlike semiconductors made of silicon, which are asymmetrical and the bias voltage is high. Compared to the effort required for carbon nanotubes. Single walled carbon nanotubes (SWNTs) have a single cylindrical wall. The typical diameter of the nanotubes falls within the range of 1 to 2 nm, although their length can vary from 0.2 to 5 um, and in some cases, even extend to a few centimeters, as depicted in figure 3. It has been processed to have optical qualities that are compatible with optical systems. The photonic and biological research communities have been paying an increasing amount of attention to the possible uses of carbon nanotubes. The latter property has given rise to dreams of using nanotubes to make extremely dense electronic circuitry and the last year has seen major advances in creating basic electronic structures from nanotubes in the lab, from transistors up to simple logic elements. The volumes of SWNTs produced are currently small and the quality and purity are variable. Multi-walled carbon nanotubes have two or more cylinders within cylinders. Nanotubes typically have diameters in the range of two to twenty-five nanometers, and their lengths may vary anywhere from two to five micrometers or a few centimeters. The gap between the walls is 0.36 nm, and the spacing between walls is 0.36 nm. In these progressively more sophisticated systems, the several SWNTs that combine to form the MWNT could have quite different architectural compositions (length and chirality). MWNTs have an average length that is one hundred times greater than their width, and their outside diameters are almost always measured in the tens of nanometers. [5], [8], [10], [13], [22]. Despite the fact that it is simpler to produce significant quantities of multi-wall nanotubes than single-wall nanotubes, the structures of multi-wall nanotubes are not as well understood as those of single-wall nanotubes due to the greater complexity and variety of multi-wall nanotubes, as shown in figure 1.3.

2. Research Methodology. When a single sheet of graphite crystal is rolled up into a cylinder, the result is a single wall carbon nanotube (SWTN). This cylinder has a thickness of one atom and a relatively low density of atoms (20–40 per micron in diameter and length) along its axis. The nanotube represented by the chiral vector *C_h*.

$$C_h = n * a_1 + m * a_2 \tag{2.1}$$

where n and m are two integers denoting the number of unit vectors n* a 1 and m* a 2 in the hexagonal honeycomb lattice contained in this vector, where $|a| = |a_1| = |a_2|$ and where $|b| = |b_1| = |b_2|$ and where $|c| = |c_1| = |c_2|$ Graphite lattice vectors a 1 and a 2 are a pair of real space vectors with the following values: * a (c-c) =0.246nm, where a (c-c) =0.142nm is the c-c bond length. As can be seen in Figure 1.3, the chiral vector may be used in conjunction with the zigzag or the direction to create an angle (the chiral angle. On a graphene sheet with a honeycomb structure, the vector connects two O and A sites that are crystallographically

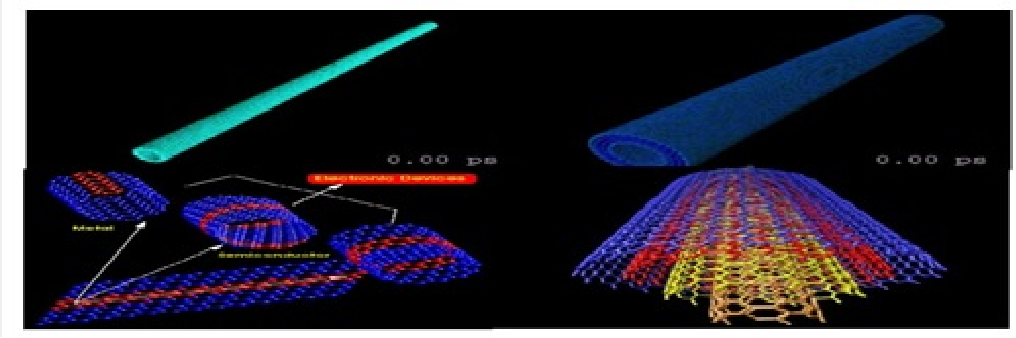

Fig. 1.3: Schematic representation of rolling graphite to create single-and multi-walled carbon nanotubes.

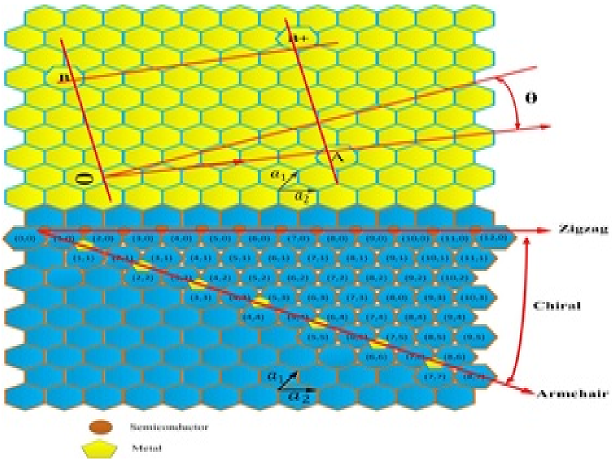

Fig. 2.1: Clarification of the process through which graphite sheets are converted into carbon nanotubes

similar to one another. Each vertex of the honeycomb structure contains a carbon atom. The axis of the zigzag nanotube is located at the value $\phi = 0$ for the parameter, the axis of the armchair nanotube is located at the value $\phi = 30$ for the parameter, and the axis of the chiral nanotube is located at a value that is 0 30. Attaching the line AB to the parallel line OB in figure 2.1 creates the smooth cylinder connection that the nanotube needs in order to function properly [30], [31], [32], [33]. The following is an equation that expresses the diameter of a nanotube, denoted by the notation d_t, in terms of the numbers n and m: equation 2.2.

$$d_t = \frac{|a| * \sqrt{(n^(2) + n * m + m^2}}{\pi} \tag{2.2}$$

The distance between the two carbon atoms of the closest neighbor is 1.421 or 0.142 in graphite, C_h is the length of the chiral vector, and the chiral angle (ϕ) may be obtained by solving the following equation 2.3.

$$\phi = \tan^- 1 \frac{\sqrt{3} * m}{2n + m} \tag{2.3}$$

Thus, the (n, m) indices or their equivalent, d_t, may be used to describe a nanotube.

Figure 2.1 shows a) The unit cell of one-dimensional nanotubes is described using the nomenclature of the unit cell of the honeycomb lattice, which is often encountered in two dimensions; b) the brillouin zone of two-dimensional graphite represented by rhombuses and a shaded hexagon; and c) The unit cell of one-

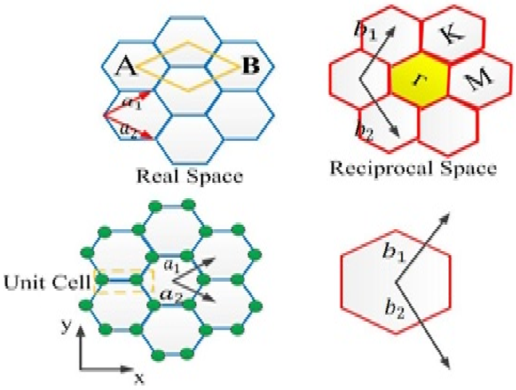

Fig. 2.2: Actual and reciprocal features of the structure's fundamental building block, the unit cell

dimensional nanotubes is described using the nomenclature of the unit cell of the honeycomb lattice, which is often encountered in two dimensions.

Figure 2.2's coordinates (x, y) are used to express the real space basis vectors a (1) and a 2, which are written as equations 2.4 and 2.5 respectively.

$$a_(1) = (\frac{\sqrt{3}}{2*a}, \frac{a}{2}), a_2 = (\frac{\sqrt{3}}{2*a}, \frac{-a}{2}) \tag{2.4}$$

and

$$b_(1) = (\frac{2\pi}{\sqrt{3}*a}, \frac{2\pi}{a}), b_(2) = (\frac{2\pi}{\sqrt{3}*a}, \frac{-2\pi}{a}) \tag{2.5}$$

where $a = |a_1| = |a_2| = 0.246$nm, a is the lattice constant of two-dimensional graphite, which is consequently the basis vectors b 1 and b 2 of the reciprocal lattice. b 1 and b 2 are the reciprocal lattice's basis vectors. The reciprocal (b=2.949nm A) hexagonal lattice has basis vectors b 1 and b2 that are rotated by 30 degrees with respect to the real space hexagonal lattice's basis vectors a 1 and a2. To do this, we choose the shaded region of Figure 2.2 to represent the first brilluoin zone, the centers of Points K and M, and the corners of Figures 2.1 and 5 to represent the highest symmetry points. Calculations have been made to determine the energy dispersion relations for the MK triangle depicted in Figure 2.1 with dotted lines. As shown in figure 1.3, the unit cell is defined by the smallest repetition distance along the axis of the 1D nanotube, which is denoted by the letter OB. This allowed us to determine the translation vector (T).

$$T = t_1 * a_1 + t_2 * a_2 \tag{2.6}$$

The equation 2.7 the variables n and m are connected to the coefficients t_1 and t_2, respectively.

$$t_1 = \frac{(2n+m)}{(dR)} t_2 = \frac{-(2n+m)}{(dR)} \tag{2.7}$$

where dR is the greatest common divisor of (2n+m, 2m+n), and the equation 2.8 for dR may be obtained by clicking here.

$$dr = \begin{cases} d, & ifn-misnotamultipleof3d) \\ d3, & ifn-misamultipleof3d) \end{cases} \tag{2.8}$$

where d is the greatest common divisor of all the other (n, m). The magnitude of the translation vector T, equal to the vertical bar symbol.

$$|T| = \frac{\sqrt{3} * L}{dR} \tag{2.9}$$

The length of the chiral vector C h is denoted by L, while the diameter of the nanotube is denoted by d t. The region bounded by the vectors T and C h is the area that is referred to as the nanotube's unit cell. The values (n,m) and the formula are used to determine the number of hexagons, N, that are contained within the one-dimensional unit cell of a nanotube. This number may be thought of as the number of individual nanotubes 2.10.

$$N = \frac{(2(n^2 + n * m + m^2))}{dR} \tag{2.10}$$

Two carbon atoms are added, which is represented by a single hexagon in the honeycomb structure shown in Figure 1.2. We chose carbon nanotubes with the following chirality ratios (17, 0), (12, 5), (10, 10), (16, 2), (15, 0), and (11, 11) based on the assumption that a (c-c)=0.142 nm. The nanotube has a larger real space unit cell compared to the 2D graphene sheet, resulting in a substantially smaller 1D Brillouin zone (BZ) for the nanotube compared to a single 2D graphene unit cell. The reason for this is that the actual spatial unit cell for the nanotube is far greater than that for the 2D graphene sheet. Brillouin Zone-folding methods have been extensively utilised to establish approximate connections between the dispersion of electrons and phonons in carbon nanotubes (n, m) possessing specified symmetry. The user's text is empty. The nanotube's crystal structure closely mimics that of a graphene sheet, which is why the Brillouin Zone is relatively modest. The vectors k 1 and k 2 may be calculated using the relationship. $R_i * K_j = 2 *_i j$, where the lattice vectors in real space are denoted by $R(i)$, and the vectors in reciprocal space are denoted by Kj. It is possible to write form k 1 and k 2 as

$$k_1 = 1/N(-t_2 * b_1 + t_1 * b_2) and k_2 = 1/N(m * b_1 - n * b_2) \tag{2.11}$$

The reciprocal lattice vectors of a graphene sheet in two dimensions are represented by the symbols b 1 and b 2, which are correspondingly indicated by the equation that describes them 2.5. Given a set of N wave vectors k (1) (=0,...,N-1), it is feasible to compute N discrete k vectors in the circumferential direction. A one-dimensional band of electronic energy appears for each of the discrete values of the circumferential wave vectors, and phonon dispersion relations extend in six distinct directions depending on the value of . Creating a nanotube from a graphite sheet by rolling it along the chiral vector C hon. The resulting nanotube is rolled (n,m). Nanotubes can be characterised by their diameter (d_t) and chiral angle (π) in relation to the zigzag axis. Single-wall nanotubes (SWNTs) may be thought of as hollow cylinders that are formed by rolling a graphite sheet. It is possible to describe it in an unambiguous manner by a vector denoted by the letter C h in terms of a set of two numbers denoted by the letters n and m, which correspond to graphite vectors a_1 anda_2. It is possible to create two standard nanotubes from a single graphite sheet by rolling it in opposite directions. The nanotubes can exist in three different configurations: zigzag (n, 0), armchair (n, m) when $n = m$, and chiral (n, m). If n is a value greater than m and less than zero, the coordinates of the chiral nanotubes are as follows: (17, 0), (15, 0), (12, 5), (16, 2), (10, 10), and (11, 11). Both the lattice constant and the intertube spacing are essential requirements for the proper creation of a bundle of single-walled carbon nanotubes (SWNTs). Experiments and theoretical studies have reached the conclusion that the average length of C-C bonds in MWNT should be 0.34 nanometers, and that the spacing between tubes should also be 0.34 nanometers. In light of this, equations 2.1 and 2.2 may be used to simulate a variety of tube architectures and interpret experimental data. They are now taking into account the energetics or the stability of nanotubes. During the fabrication of a SWNT from a graphite sheet, the strain energy is equal to $1/d_t$ per tube, or$1/{d_t}^2$ per atom.

The diameter of SWNTs that are often seen in experiments ranges from 0.6 to 2.0 nanometers, however it may be as tiny as 0.4nm or as big as 10 nanometers (3.0nm). The electrical properties of a nanotube can be determined by analysing the dispersion relation of a graphite sheet with wave vectors (k_x, k_y), in the most basic scenario.

$$E(k_x, k_y) = \gamma\sqrt{+4cos((3 * k_x * a)/2)cos((k_y * a)/2) + 4cos^2((k_y * a)/2)} \tag{2.12}$$

Considering the stated values of $a = 0.246nm,_o = 2.5eV - 3.0eV$ (the lattice constant), and $a = 0.246nm$(the closest neighbour hopping parameter), it is plausible that $_o$ originates from many sources. In order to construct a nanotube from graphite, it is necessary to maintain a periodic boundary condition either around the circumference of the tube or in the C directions. This may happen either along the circumference of the tube or along the C directions [30], [31], [32], [34], [35], [36], [37], [38]. The two-dimensional wave vector $k = (k_x, k_y)$is quantized in this direction due to the constraint $k.c = 2q$, where k that satisfies this condition is allowed when q is an integer. The following need, therefore, must be satisfied in order for metallic conductance to occur: equation 2.13

$$(n - m) = qmetallicor(2n + m) = 3q \tag{2.13}$$

2.1. Semiconducting of Carbon Nanotubes . The valence energy band is located at the lower section of the energy curve, while the conduction energy band is located at the upper section of the energy curve. When s equals zero, the valence band and the conduction band become symmetric, adopting the shape of a ball, which is described by equation 2.12, and $_o = 2.9eV$. This occurs when the electron spin is equal to zero. $2D$ graphite is classified as a zero-gap semiconductor due to the conduction and valence bands intersecting at the six corners of the Brillouin zone, which are known as high symmetry sites $E = E_{sp}$ [30], [38], [39], [40]. The positive sign is used to represent the valence band, whereas the negative sign is used to indicate the conduction band. Graphene exhibits symmetrical conduction and valence bands in terms of both structure and distribution. On the other hand, silicon, which is an indirect band gap semiconductor, exhibits dissimilar band structures for both electrons and holes. The Fermi points are the places on the edges of the Brillouin zones where the energy troughs may be found. These sites are also known as the Brillouin zone corners. The vectors serve as the foundation for the reciprocal latticesbj. The wave vectors were limited to the specified range as a direct consequence of the periodic boundary restriction that was applied in the circumferential direction .

$$k.c = 2 * \pi * q \tag{2.14}$$

where k is a wave vector that can be allowed, and q is an integer that denotes the quantum number. This may be allowed. The equation that describes the conductance of SWNT, MWNT rope, or SWNT cable is as follows 2.15:

$$G = G_O * M = ((2e^2)/h) * M \tag{2.15}$$

Since nanotubes' conductance is quantized, the resistance of nanotubes is equal to 6.5*103 ohms; M is an apparent number of conducting channels that takes into account electron-electron coupling and intertube coupling effects in addition to the intrinsic channel $G = (6.5kohm)^{(} - 1)$ which is the value of the intrinsic channel. The results of the combined STM and STS studies are consistent with the following hypotheses: 1) approximately two-thirds of the nanotubes are semiconducting, and one-third of them are metallic; 2) the density of states exhibits van hove singularities, which is characteristic of the expectations for a one-dimensional system; and 3). The energy gaps of semiconducting nanotubes are proportional to the square root of the distance traveled over time $(1/d_t)$. An inductor's E_k value is determined by the extra kinetic energy associated with the current. This represents the equilibrium Fermi energy for electrons moving between the source and the drain of a field-effect transistor. This demonstrates that kinetic inductance has a ballistic origin. Therefore, making the right option while selecting the diameter is helpful. At a temperature of 300 kelvin, the typical values for the band gap are as follows: - (1.12 eV) for germanium; (0.67 eV) for silicon; and (1.43 eV) for GaAs. Electronic density of states (DOS) is measured in terms of the equilibrium Fermi energy per unit of nanotube length, whereas avaiability is expressed in terms of the number of electron-phonon pairs per unit of nanotube length. Both of these measures are independent of one another. Both of these measurements are expressed in nanotube length units. Due to the fact that the bias window only contains right-moving carriers, the density of states must be divided by two in the calculation for the mean number of electron-phonon couplings. This is because the bias window contains only the right-moving carriers [26], [27], [41], [42], [43].

2.2. Nanotechnology Applications in the Medical Sciences. Because of its close relationship to human life and health, nanomedicine is often regarded as one of the most significant uses of nanotechnology. Some even argue that it is the most significant application of all. This is the age of nanomedical technology, when the principles of illness prevention, diagnosis, and treatment have been rewritten in light of recent advances in nanotechnology. Whereas nanotechnology, by way of illustration, opens up novel pathways for drug carriers within the human body, allowing them to specifically target different cells, and to take on some of humanity's deadliest diseases, like cancer. This has spawned a great deal of nano research and experimental applications at labs all over the world. The nanosensors, on the other hand, may be surgically inserted into the brain of the paraplegic patient to give them the ability to move and walk again. Research indicates that it will appear on the farthest extent of techniques for repairing living cells, as well as nano-neural electronic links, and if this happens, a real revolution will occur in the world of treatment and therapy. There are a lot of applications in the field of health care and the manufacture of nanomedical devices. Using this method, it is possible to capture images of the body's cells with ease, akin to taking a conventional snapshot. Furthermore, these cells can be manipulated and moulded into various configurations [13], [14], [22]. An institute in California has set a general framework for what nanotechnology can offer us in the field of medicine, for those people who suffer from certain diseases, and for older people who suffer because of the incorrect sequence of atoms.

2.2.1. Delivery of the Drug to the Tissues. Delivery of drugs to tissues is one of the priorities of research in the field of nanomedicine, as it depends on the manufacture of micro-nanomaterials that improve the bioavailability of the drug. This means that the drug molecules are located in the targeted place in the body, where they work with maximum effectiveness, and thus the rate of drug consumption decreases and its side effects are reduced, as well as the total cost of treatment. Pharmacology is one of the sciences that needs high accuracy due to its connection to human health. A drug's efficacy is diminished and it causes undesired side effects if it is absorbed by healthy tissues along with the sick ones. For instance, we see that conventional approaches such as radiation and chemotherapy have serious adverse effects and are not very successful in treating cancer [11], [21], [44], [45]. As a result, anti-cancer medications need highly targeted administration in order to have any effect at all. Therefore, scientists are studying one of the future nano applications, which is represented in the drug delivery technology using one of the nano devices called dendrimer. Methods of drug delivery are based on nanotechnology, some of which depend on very small-scale tubes that have the ability to move and can be directed to the area to be treated. Others rely on smart systems of very small size that can be implanted inside the body and have the ability to control drug doses and the appropriate time for delivery. It appeared that carbon nanotubes could be used by linking them with peptide compounds to introduce them to the immune system in the body and thus use them in the delivery of traditional vaccines [43].

2.2.2. Pharmaceuticals and Therapeutic Drugs. A new term has now been introduced into the science of medicine, nanobiotics, which is the new alternative to antibiotics. Hangbang University researchers in Seoul successfully incorporated nano-silver into antibiotics. Silver possesses the capability to eradicate 650 pathogenic pathogens while maintaining the safety of the human body. This technology will solve a lot [5], [31], [46], [47], [48]. One of the problems of antibiotic-resistant bacteria that have caused mutations that prevent the effect of the antibiotic on these bacteria is that nanobiotics puncture the cell wall of bacteria or cells infected with the virus, allowing water to enter the cells and they are exterminated. This technique will eliminate the strains of bacteria that are resistant to antibiotics that have caused mutations to prevent them from affecting them. Where the nanobiotic punctures the cell wall of the bacteria or virus, and when millions of them enter the gel membrane of the bacterium, they are chemically attracted to each other and gather in the form of long tubes or many pins that puncture the cell membrane and other groups work to expand the hole in the bacterial cell wall so that it dies within minutes as a result. They dissipate the external electrical potential of her membrane and then destroy it within minutes, and she cannot adapt her immune system with it [4,44].

2.2.3. A Nano-Sized Robot is an Assistant in Surgical Operations. For use in delicate and high-risk procedures, Corv is has developed nanoport optical transducers with nanoscale scales. By using a specialized gadget, the surgeon may direct the robot to do the procedure with more precision and less human error than is possible with conventional approaches. The surgeon manipulates the robot arm, which holds the instruments and camera, via a joystick. Through this, huge motions may be reduced to micromanipulations, enhancing the accuracy of surgical procedures. Because of its extreme hardness, scientists used carbon to create a nanoport only 1 millimeter wide, allowing it to pass through human blood arteries. Magnetic resonance imaging (MRI) and computed tomography (CT) scans may be used to track the robot while it works within the body to verify that it has reached the correct organ or sick tissue.

2.2.4. Diabetes Treatment. Niue University in the United States has successfully created a nanotechnology-based device that can regulate blood sugar levels in the body. This device offers an alternative to insulin injections for diabetic patients. Additionally, nanotechnology is being used in the treatment of kidney diseases. Specifically, researchers are studying the atomic-level formation of kidney proteins and using nanotechnology for imaging purposes. The aim was to study the biological processes that occur in kidney cells and the use of nanoparticles in the treatment of kidney diseases, where solutions to many kidney diseases can be reached by understanding the physical and chemical properties of kidney proteins, and many doctors dream of an artificial kidney using nanotechnology. The cell has the potential to improve the lives of many kidney patients significantly.

2.2.5. Medical Imaging of Medical Applications. Researchers and medical professionals now have the ability, thanks to nanoimaging, to monitor every movement that takes place inside the live tissue of the human body. This allows medical professionals to properly detect the movement of the medicine within the sick tissue. Studying some cells of the body is difficult, and from here scientists resort to coloring them. There is another problem, which is that the cells that emit light waves of different lengths do not always work in the same way or in the same way, which makes medical imaging processes face problems in terms of correct diagnosis. Scientists were able to solve this problem by using some nanoparticles that show reactions different due to the different wave frequencies arising naturally from the difference in the length of the face. Nanotechnology will contribute to advancing its development in terms of its efficiency, performance, speed of work, and increased safety, due to the entry of nanotechnology into the manufacture of electronic chips, electrical conduction circuits, and data processors used in these devices.

2.2.6. Diagnostic Applications of Nanotechnology Medical. The main goal is to discover the disease in the early stages so that it can be eliminated before it causes symptoms or complications. By using nanotechnology, biological tests to measure the presence or activity of the tested materials become faster, more accurate and flexible. The presence of specific molecules or microbes can be combined, and similarly, gold nanoparticles can be combined with short sections of DNA to identify a sequence of genes in a sample. There is also the technology of nano-holes to analyze DNA, which converts its sequence of units directly into electrical signals, and by using nanoparticles as contrast agents (as an alternative to dye), we obtain MRI and ultrasound images with better contrast and distribution, and even luminous nanoparticles can help the surgeon during the operation Surgical procedures to identify the location of the tumor and thus make the process of eradicating it more easily [4], [6], [17], [20], [25], [29], [30], [38], [45], [48], [49], [50].

3. Result and Discussion. The electrical characteristics of carbon nanotubes (CNTs) are determined by the chiral vector (C_h), which is calculated using Equation (1). Various arrangements of carbon nanotubes, such as (17, 0), (12, 5), (10, 10), (16, 2), (15, 0), and (11, 11), exhibit different chiral angles and integer pairs. For instance, the (17, 0) and (15, 0) nanotubes, known as zigzag nanotubes, can function as either metals or semiconductors, depending on the fabrication method. The focus of this paper is on chiral semiconducting nanotubes, specifically (12, 5) and (16, 2), with $n = 12, m = 5$, and chiral angles analyzed in the range of 0 to 30 degrees. Additionally, armchair nanotubes (10, 10) and (11, 11), with n=m=10 and a chiral angle (=30), operate as metals. Simulation results reveal nanotube diameters ranging from approximately 1.33 nm to 1.356 nm. The band gap in semiconducting nanotubes is determined by solving for the energy difference between the Fermi energy and electronic density of states (DOS). Equation 3.1 is employed to find the band gap (E_g) in semiconducting nanotubes by used MATLAB program. This is found by comparing the Fermi energy per carbon nanotube atomic unit cell to the electronic density of states (DOS) (unit measurement, arbitrary, unit) given by equation 3.1

$$E_g = \frac{2 * a_(c - c) * \gamma_o}{d_t} = \frac{(0.8eV)}{d_t} \tag{3.1}$$

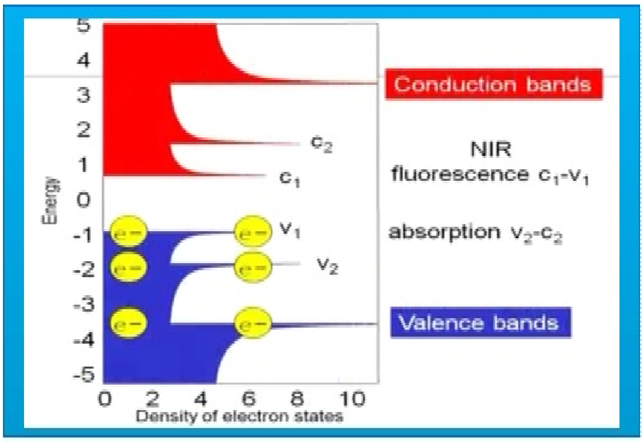

Fig. 3.1: An example of two van hove singularities in semiconductor carbon nanotubes

Figure 3.1 shows the energy band gap, denoted as E g, for a semiconductor with two conduction bands and two valence bands, where the Fermi energy is $_o = 2.9eV$, and where two van Hove singularities are handled. The semiconducting properties of carbon nanotubes are described by the equation (2/3) if the condition that 2n+m) =3q 0is equation (3.13). The minimal value, which is provided by the equation, is used to compute the kinetic energy, denoted by E_k, of the lowest subband 3.2.

$$K_(c.q) = \frac{2}{(3d_t)} \tag{3.2}$$

The equations that describe the energy output of carbon nanotubes, where d_t represents the diameter of the nanotube, are as follows: 3.3

$$(K_t) = (\frac{(3 * a_(c-c) * \gamma_o}{2}) * \sqrt{(k_t{}^2 + (2(3d_t)^2)} \tag{3.3}$$

and

$$E_o = \frac{(3 * a_(c-c) * \gamma_o)}{2} \tag{3.4}$$

where E_o is the energy gap for graphite when it is at its standard temperature. After solving equations 3.3 and 3.4, we are left with equation 3.5, which describes E_out, also known as the output energy band gap.

$$E_out = \frac{(E(k_t))}{E_o} \tag{3.5}$$

Doping the electron density of states during manufacture has a direct impact on the output energy band gap of carbon nanotubes, which may be described as an equation3.6.

$$D(E_k) = \frac{8}{(3 * \pi * a_(c-c) * \gamma_o)} * \frac{(E(k_t))}{\sqrt{(E(k_t) - (E_g 2)}} \tag{3.6}$$

The electrons in the valence band (v_2) are excited by the incident light (photon) and move into the conduction band (c_2), leaving a hole in the valence band (v_2), which allows an electron to move from the valence band (v_1) to the valence band (v_2), which in turn allows an electron to move from c_2 to the conduction band (c_1) and back to v_1 such as shown in figure 3.1.

Certainly, let's delve deeper into specific aspects of the electronic construction of carbon nanotubes (CNTs) and their implications:

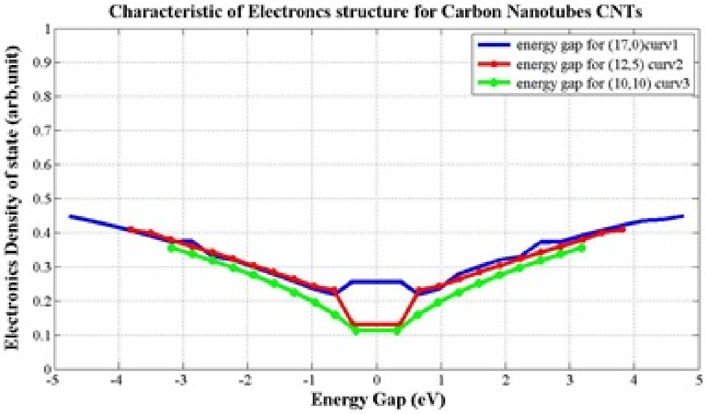

Fig. 3.2: The energy gap to the DOS in this system in order to present the results for three distinct carbon nanotubes (17, 0), (12, 5), and (10, 10)

- *Chirality and Electronic Properties:* The chirality angle (θ) determined by the chiral vector plays a crucial role. Zigzag nanotubes (=0) exhibit unique properties, potentially serving as either metals or semiconductors. Semiconducting nanotubes with specific chiral angles (e.g., (12, 5), (16, 2)) offer controlled electronic behavior.
- *Simulation and Diameter Impact:*The simulation results showing nanotube diameters are vital. Diameters influence the electronic structure, affecting band gaps and conductivity. Understanding this parameter aids in tailoring nanotubes for specific applications.
- *Energy Band Gap in Semiconducting Nanotubes:* Equation 3.1 provides a direct link between the energy band gap and nanotube diameter. This relationship is essential for predicting and controlling the semiconducting properties crucial for electronic applications.
- *Visualization of Energy Band Gap (Eg):* Figure 3.1's visualization of the energy band gap is a key element. It illustrates the distinct bands and van Hove singularities, giving a comprehensive view of the electronic structure. This understanding is fundamental for designing nanotubes for specific electronic functionalities.
- *Output Energy Band Gap* (E_out)*:* Equation (20) and the concept of E_out are critical. This parameter encapsulates the nanotube's output energy band gap, offering insights into its behavior and suitability for various applications. It aids in predicting the nanotube's response to external stimuli.
- *Impact of Doping on Electronic States:* Equation 3.6 underscores the impact of doping on the electron density of states. Doping introduces additional electronic states, influencing the output energy band gap. This insight is valuable for engineering nanotubes with tailored electronic properties.
- *Applications in Electronics*: The discussed parameters collectively contribute to the understanding of how carbon nanotubes can be harnessed in electronic devices. Their unique electronic properties, such as high conductivity and tunable band gaps, make them promising candidates for future electronic applications.
- *Challenges and Future Directions:* Despite their potential, challenges and limitations in utilizing carbon nanotubes in electronics should be acknowledged. Issues like uniformity, scalability, and reproducibility are areas of ongoing research. Future directions may involve overcoming these challenges for widespread implementation.

The electronic construction of carbon nanotubes, shaped by factors like chirality and diameter, offers a versatile platform for tailoring their behavior in electronic applications. The ability to control their electronic properties makes them valuable in the development of advanced electronic devices.

Figure 3.2 illustrates that carbon nanotubes can exhibit both positive and negative values for the energy band gap. This high level of symmetry is a unique characteristic, indicating the versatile electronic behavior

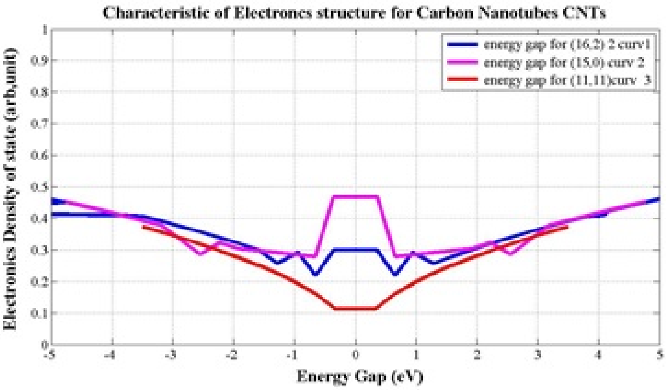

Fig. 3.3: Connection between energy gap and DOS for three distinct carbon nanotubes (16, 2), (15, 0), and (11, 11)

of nanotubes. Coordinates (17, 0) and (12, 5) in Figure 3.2 demonstrate the energy gap with two valence bands $(v1andv2)$ and two conduction bands (c_1 and c_2) according to van Hove notation. The presence of both positive and negative energy gap values highlights the tunable electronic states in these nanotubes. Unlike semiconductor nanotubes, (10, 10) nanotubes exhibit metallic behavior with only one conduction band and a valence band. The absence of a band gap in these nanotubes classifies them as metals. This behavior is critical for applications requiring high electrical conductivity.

Employing equations 3.2-3.5, another set of findings is presented in Figure 3.3, reinforcing the observation that carbon nanotubes can have both positive and negative energy gap values. This emphasizes the exceptionally high symmetry of carbon nanotubes' electronic structure. In Figure 3.3, coordinates (15, 0) and (16, 2) exhibit two conduction van Hove bands (c_1andc_2) and two valence bands (v_1andv_2). The symmetry of the energy gap in semiconductor carbon nanotubes is influenced by doping in the electronic density of states (DOS), resulting in either positive or negative energy gaps. For (11, 11) nanotubes, the band gap is zero, indicating metallic behavior. These nanotubes act as metallic carbon nanotubes with a continuous range of energy levels. Equations 3.7 and 3.8 provide insights into the behavior of carbon nanotubes as semiconductors (S) and metals (M) during a symmetric transition at p=q. The ability of nanotubes to operate in positive and negative bias with low bias is a crucial characteristic for certain applications. he equations suggest that the symmetric transition in the energy level occurs at p=q, allowing carbon nanotubes to operate under both positive and negative biases with low bias conditions (160 mV - 200 mV). This bias-dependent behavior is significant for practical electronic applications.

$$E_pp^S = \frac{(2*\pi*a_(c-c)*\gamma_o)}{d_t} \tag{3.7}$$

For semiconductance carbon nanotube,

$$E_pp^M = \frac{(6*\pi*a_(c-c)*\gamma_o)}{d_t}(6*p*a_(c-c)*_o)/d_t \tag{3.8}$$

for metallic carbon nanotube.

Figure 3.2 and 3.3 and associated equations underscores the intricate electronic properties of carbon nanotubes, including their symmetry, tunability, and diverse behavior as semiconductors and metals under different conditions. These characteristics are fundamental for leveraging carbon nanotubes in a wide range of electronic applications. The synergy between nanotechnology and artificial intelligence (AI) represents a transformative leap in technology. Nanotechnology, with its ability to manipulate materials at the nanoscale, coupled with AI's data processing and analytical capabilities, promises enhanced precision and efficiency across various domains.

In the realm of medical devices and healthcare, the convergence of nanotechnology and AI holds great promise. The precision offered by nanoscale materials, such as carbon nanotubes, can be complemented by AI algorithms for more accurate diagnostics, treatment delivery, and monitoring of health conditions. Carbon nanotubes, with their remarkable electrical, thermal, and mechanical properties, stand out as a key component of nanotechnology. Their high conductivity, strength, and unique structure make them versatile for applications ranging from electronics to biomedical devices. The discussion emphasizes the significant role carbon nanotubes will play in the future of nanotechnology. In the biomedical field, these nanotubes have shown promise for drug delivery, imaging, and diagnostics due to their ability to penetrate cell membranes and interact at the molecular level. Carbon nanotubes, integrated with AI, can revolutionize healthcare by enabling advanced diagnostics, personalized medicine, and real-time monitoring. The combination of nanoscale materials and intelligent algorithms enhances the capabilities of medical devices for more accurate and timely interventions. The collaborative use of nanotechnology and AI in medical diagnostics can lead to highly accurate and efficient diagnosis. Nanoscale sensors, possibly incorporating carbon nanotubes, can detect biomarkers at ultra-low concentrations, while AI algorithms analyze complex datasets for disease identification. The statement underscores the belief that carbon nanotubes, as part of nanotechnology advancements, will significantly shape the future of healthcare. This suggests a transformative era where nanoscale materials, guided by AI, contribute to breakthroughs in diagnostics, treatment, and overall healthcare management. Alongside the potential benefits, it's crucial to acknowledge and address challenges and ethical considerations associated with the integration of nanotechnology and AI in healthcare. Ensuring the safety, privacy, and ethical use of these technologies is paramount for their widespread acceptance and positive impact. the convergence of nanotechnology, artificial intelligence, and the potential of carbon nanotubes holds immense promise for advancing healthcare. The precision, efficiency, and transformative capabilities offered by these technologies signify a future where medical devices are more accurate, personalized, and effective in improving patient outcomes. The difference is clear in Table No. 3.1 of the specifications and properties of carbon nanotube and its use, like semiconductors, silicon, and germanium, in terms of work, heat tolerance, and working with ultra-high frequencies up to THz. as well as form figure 3.2 and 3.3.

4. Conclusion. The development of nanoparticles, their size control, and the study of their physical properties have revolutionized medical diagnostics. The advancement has opened up possibilities for incorporating nanoparticles, specifically carbon nanotubes (CNTs), into well-established diagnostic techniques such as magnetic resonance imaging (MRI), ultrasound, CT scans, and nuclear medicine equipment. The ability to control nanoparticle properties enhances diagnostic efficiency, enabling early disease detection and providing detailed information about disease location, size, and progression. Around the world, ongoing studies focus on incorporating nanotechnology advancements into medical fields. These efforts include safety assessments for human use, aiming to turn these applications into a daily reality in hospitals. Nanotechnology applications span various sectors, including technology, electronics in medicine, biology, pharmaceutical industries, and disease detection. The enormous potential of CNTs in biological applications is evident. CNTs are highly adaptable molecules that show promise in diverse contexts, acting as sensors, drug transporters, imaging aids, bioelectrodes, and reinforcement for composites. CNT-based sensors are envisioned as simple, rapid, sensitive, and cost-effective tools for monitoring various analyses. Their design flexibility allows for tailoring to specific needs, surpassing the limitations of prior analytical methods. The construction of CNT-based sensors from scratch enhances simplicity and performance. These sensors are considered more straightforward to work with, exhibiting improved detection limits, sensitivities, specificities, and repeatabilities. The potential of CNT-based sensors as effective tools for monitoring targets is recognized, offering a feasible option to meet the urgent demand for numerous analyses. Future research on CNTs-based biosensing is expected to emphasize in vivo detection methods. These methods aim for minimal cytotoxicity, high sensitivity, and long-term stability to meet the requirements for reliable point-of-care diagnostics under physiological conditions. The continuous development of CNT-based technologies underscores their significance as a transformative tool in healthcare, contributing to disease treatment and human health preservation. While silicon remains the workhorse of the semiconductor industry, carbon nanotubes offer unique properties that make them attractive for certain applications, particularly in emerging fields such as flexible electronics and advanced sensors. Ongoing research aims to harness the strengths of both materials for future semiconductor technologies. Table No. 1 in the specs outlines the

Table 3.1: Comparison Carbon nanotubes (CNTs) and silicon are both materials with distinct semiconductor properties.

Serial No.	**Criterias**	**Carbon Nanotubes (CNTs) Semiconductors**	**Silicon Semiconductor:**
1.	Structure	CNTs have a tubular structure composed of carbon atoms arranged in a hexagonal lattice.	Silicon is a traditional semiconductor with a crystalline structure.
		They can be single-walled (SWNT) or multi-walled (MWNT), and their electrical properties depend on their structure and chirality.	It is widely used in the electronics industry, forming the basis of most semiconductors
2.	Electrical Properties	CNTs can exhibit either metallic or semiconducting behavior depending on their structure.	Silicon is typically a semiconductor with an indirect bandgap.
		Semiconducting CNTs have a bandgap that varies with their diameter and chirality.	Its electrical properties can be manipulated through doping.
3.	Advantages	High electrical conductivity, comparable to or even better than silicon.	Well-established technology with mature fabrication processes
		Exceptional mechanical strength, flexibility, and thermal conductivity.	Integrated into a variety of electronic devices and circuits.
4.	Applications	Widely explored for Nano electronics, including transistors and interconnects.	Dominant material in the semiconductor industry for integrated circuits and microelectronics.
		Promising in applications like flexible electronics and high-performance sensors.	Commonly used in transistors, diodes, and solar cells.
5	Bandgap Control	CNTs offer a tunable bandgap based on their structure.	Silicon bandgap is controlled through doping
6	Mechanical Properties	CNTs have superior mechanical properties	Silicon, providing flexibility and strength.
7.	Conductivity	CNTs can have higher electrical conductivity than silicon, making them suitable for specific high-performance applications.	Silicon has modest conductivity and is affected by temperature changes
8.	Fabrication Complexity	Large-scale production of CNTs is still an evolving challenge.	Silicon has well-established and mature fabrication processes

distinctions between carbon nanotubes and their applications in semiconductors such as silicon and germanium, focusing on factors including performance, heat resistance, and operation at ultra-high frequencies up to THz. as well as the result of this work paper.

REFERENCES

[1] N. For and B. Applications, "Jurnal Teknologi RECENT MODIFICATIONS OF CARBON," vol. 2, pp. 83–100, 2023.

[2] S. Kruss, A. J. Hilmer, J. Zhang, N. F. Reuel, B. Mu, and M. S. Strano, "Carbon nanotubes as optical biomedical sensors," Adv. Drug Deliv. Rev., vol. 65, no. 15, pp. 1933–1950, 2013, doi: 10.1016/j.addr.2013.07.015.

[3] V. Harish, D. Tewari, M. Gaur, A. B. Yadav, and S. Swaroop, "Review on Nanoparticles and Nanostructured Materials : Bioimaging , Biosensing , Drug Delivery , Tissue Engineering , Antimicrobial , and Agro-Food Applications," 2022.

[4] A. Barhoum et al., "Review on Natural , Incidental , Bioinspired , and Engineered Nanomaterials : History , Definitions , Classifications , Synthesis , Properties , Market , Toxicities , Risks , and Regulations," 2022.

[5] D. Maiti, X. Tong, X. Mou, K. Yang, and K. Yang, "Carbon-Based Nanomaterials for Biomedical Applications : A Recent Study," vol. 9, no. March, pp. 1–16, 2019, doi: 10.3389/fphar.2018.01401.

[6] D. Holmannova, P. Borsky, T. Svadlakova, and L. Borska, "applied sciences Carbon Nanoparticles and Their Biomedical Applications," pp. 1–21, 2022.

[7] A. Madni et al., “Graphene-based nanocomposites : synthesis and their theranostic applications,” J. Drug Target., vol. 0, no. 0, pp. 1–26, 2018, doi: 10.1080/1061186X.2018.1437920.

[8] S. Anwar et al., “Recent Advances in Synthesis , Optical Properties , and Biomedical Applications of Carbon Dots,” ACS Appl. Bio Mater., vol. 2, pp. 2317–2338, 2019, doi: 10.1021/acsabm.9b00112.

[9] E. T. Thostenson, Z. Ren, and T. Chou, “Advances in the science and technology of carbon nanotubes and their composites : a review,” vol. 61, pp. 1899–1912, 2001.

[10] H. A. Owida, N. M. Turab, and J. Al-nabulsi, “Carbon nanomaterials advancements for biomedical applications,” vol. 12, no. 2, pp. 891–901, 2023, doi: 10.11591/eei.v12i2.4310.

[11] E. Ali et al., “Carbon nanotubes: properties, synthesis, purification, and medical applications,” Nanoscale Res. Lett., vol. 9, no. 1, p. 393, 2014.

[12] B. O. Murjani, P. S. Kadu, M. Bansod, S. S. Vaidya, and M. D. Yadav, “Carbon nanotubes in biomedical applications : current status , promises , and challenges,” Carbon Lett., vol. 32, no. 5, pp. 1207–1226, 2022, doi: 10.1007/s42823-022-00364-4.

[13] V. R. Raphey, T. K. Henna, K. P. Nivitha, P. Mufeedha, C. Sabu, and K. Pramod, “Advanced biomedical applications of carbon nanotube,” Mater. Sci. Eng. C, vol. 100, no. July 2018, pp. 616–630, 2019, doi: 10.1016/j.msec.2019.03.043.

[14] F. Liang and B. Chen, “A Review on Biomedical Applications of Single-Walled Carbon Nanotubes,” Curr. Med. Chem., vol. 17, no. 1, pp. 10–24, 2009, doi: 10.2174/092986710789957742.

[15] E. Vázquez and M. Prato, “Carbon nanotubes and microwaves: Interactions, responses, and applications,” ACS Nano, vol. 3, no. 12, pp. 3819–3824, 2009, doi: 10.1021/nn901604j.

[16] J. Nandhini, E. Karthikeyan, and S. Rajeshkumar, “Nanomaterials for wound healing: Current status and futuristic frontier,” Biomed. Technol., vol. 6, pp. 26–45, 2024, doi: https://doi.org/10.1016/j.bmt.2023.10.001.

[17] S. M. Asil et al., “Theranostic applications of multifunctional carbon nanomaterials,” no. January, pp. 1–24, 2023, doi: 10.1002/VIW.20220056.

[18] R. S. Ruoff, D. C. Lorents, S. R. I. International, and M. Park, “MECHANICAL AND THERMAL PROPERTIES OF CARBON NANOTUBES,” vol. 33, no. 7, pp. 925–930, 1995.

[19] S. Keren, C. Zavaleta, Z. Cheng, A. De Zerda, O. Gheysens, and S. S. Gambhir, “Noninvasive molecular imaging of small living subjects using Raman spectroscopy,” 2008, doi: 10.1073/pnas.0710575105.

[20] S. Gautam, D. Bhatnagar, D. Bansal, H. Batra, and N. Goyal, “Recent advancements in nanomaterials for biomedical implants,” Biomed. Eng. Adv., vol. 3, p. 100029, 2022, doi: https://doi.org/10.1016/j.bea.2022.100029.

[21] S. Beg, M. Rizwan, A. M. Sheikh, M. S. Hasnain, K. Anwer, and K. Kohli, “Advancement in carbon nanotubes: Basics, biomedical applications and toxicity,” J. Pharm. Pharmacol., vol. 63, no. 2, pp. 141–163, 2011, doi: 10.1111/j.2042-7158.2010.01167.x.

[22] W. Yang, P. Thordarson, J. J. Gooding, S. P. Ringer, and F. Braet, “Carbon nanotubes for biological and biomedical applications,” Nanotechnology, vol. 18, no. 41, 2007, doi: 10.1088/0957-4484/18/41/412001.

[23] J. Pang, A. Bachmatiuk, F. Yang, H. Liu, and W. Zhou, “Applications of Carbon Nanotubes in the Internet of Things Era Carbon nanotubes based electronics,” Nano-Micro Lett., vol. 13, no. 1, pp. 1–15, 2021, doi: 10.1007/s40820-021-00721-4.

[24] M. Asaftei et al., “RSC Advances Fighting bacterial pathogens with carbon nanotubes : focused review of recent progress,” pp. 19682–19694, 2023, doi: 10.1039/d3ra01745a.

[25] M. Ramezani, A. Dehghani, and M. M. Sherif, “Carbon nanotube reinforced cementitious composites: A comprehensive review,” Constr. Build. Mater., vol. 315, p. 125100, 2022, doi: https://doi.org/10.1016/j.conbuildmat.2021.125100.

[26] H. Cui, S. Zhao, and G. Hong, “Wireless deep-brain neuromodulation using photovoltaics in the second near-infrared spectrum,” Device, vol. 1, no. 4, p. 100113, 2023, doi: https://doi.org/10.1016/j.device.2023.100113.

[27] D. S. G and M. B, “A comprehensive review on current trends in greener and sustainable synthesis of ferrite nanoparticles and their promising applications,” Results Eng., vol. 21, p. 101702, 2024, doi: https://doi.org/10.1016/j.rineng.2023.101702.

[28] Q. Dots, M. Bechelany, and A. Barhoum, “Biomedical Applications of Carbon Nanomaterials : Fullerenes ,” 2021.

[29] M. Ul-Islam, K. F. Alabbosh, S. Manan, S. Khan, F. Ahmad, and M. W. Ullah, “Chitosan-based nanostructured biomaterials: Synthesis, properties, and biomedical applications,” Adv. Ind. Eng. Polym. Res., 2023, doi: https://doi.org/10.1016/j.aiepr.2023.07.002.

[30] G. Rahman et al., “An Overview of the Recent Progress in the Synthesis and Applications of Carbon Nanotubes,” C, vol. 5, no. 1, p. 3, 2019, doi: 10.3390/c5010003.

[31] M. R. Almeida et al., “Carbon Nanotubes for Biomedical Applications,” Mater. Horizons From Nat. to Nanomater., vol. 4, no. 2, pp. 285–331, 2022, doi: 10.1007/978-981-16-7483-9_14.

[32] M. F. L. De Volder, S. H. Tawfick, R. H. Baughman, and A. J. Hart, “Carbon nanotubes: Present and future commercial applications,” Science (80-.)., vol. 339, no. 6119, pp. 535–539, 2013, doi: 10.1126/science.1222453.

[33] N. Gupta, S. M. Gupta, and S. K. Sharma, “Carbon nanotubes: synthesis, properties and engineering applications,” Carbon Lett., vol. 29, no. 5, pp. 419–447, 2019, doi: 10.1007/s42823-019-00068-2.

[34] J. J. Shelke, A. R. , Roscoe, J. A. , Morrow, G. R. , Colman, L. K. , Banerjee, T. K. , & Kirshner and Perrine Susan, “ NIH Public Access,” Bone, vol. 23, no. 1, pp. 1–7, 2008, doi: 10.1166/jbn.2005.004.Applications.

[35] F. Kreupl, A. P. Graham, M. Liebau, G. S. Duesberg, R. Seidel, and E. Unger, “Carbon nanotubes for interconnect applications,” Tech. Dig. - Int. Electron Devices Meet. IEDM, pp. 683–686, 2004, doi: 10.1109/iedm.2004.1419261.

[36] N. Mehra, S. Pharma, A. Jain, R. Raj, D. Mishra, and S. Maharastra, “Th Au Se,” vol. 25, no. February, pp. 169–206, 2008.

[37] G. S. S. Clarence S Yah, “The use of Carbon Nanotubes in Medical Applications - Is It a Success Story?,” Occup. Med. Heal. Aff., vol. 02, no. 01, pp. 10–11, 2014, doi: 10.4172/2329-6879.1000147.

[38] S. Mohanty and A. Misra, “Sensors and Actuators B : Chemical Carbon nanotube based multifunctional flame sensor,” Sensors Actuators B. Chem., vol. 192, pp. 594–600, 2014, Available: http://dx.doi.org/10.1016/j.snb.2013.11.019

[39] S. Polizu, O. Savadogo, P. Poulin, and L. Yahia, “Applications of carbon nanotubes-based biomaterials in biomedical nan-

otechnology," J. Nanosci. Nanotechnol., vol. 6, no. 7, pp. 1883–1904, 2006, doi: 10.1166/jnn.2006.197.

[40] M. Roldo and D. G. Fatouros, "Biomedical applications of carbon nanotubes," 2013, doi: 10.1039/c3pc90010j.

[41] F. Karchoubi, R. Afshar Ghotli, H. Pahlevani, and M. Baghban Salehi, "New insights into nanocomposite hydrogels; a review on recent advances in characteristics and applications," Adv. Ind. Eng. Polym. Res., 2023, doi: https://doi.org/10.1016/j.aiepr.2023.06.002.

[42] N. H. Solangi, R. R. Karri, N. M. Mubarak, and S. A. Mazari, "Mechanism of polymer composite-based nanomaterial for biomedical applications," Adv. Ind. Eng. Polym. Res., 2023, doi: https://doi.org/10.1016/j.aiepr.2023.09.002.

[43] M. Bilal et al., "Surface-coated magnetic nanostructured materials for robust bio-catalysis and biomedical applications-A review," J. Adv. Res., vol. 38, pp. 157–177, 2022, doi: https://doi.org/10.1016/j.jare.2021.09.013.

[44] G. Gruner, "Carbon nanotube transistors for biosensing applications," Anal. Bioanal. Chem., vol. 384, no. 2, pp. 322–335, 2006, doi: 10.1007/s00216-005-3400-4.

[45] A. Mazzaglia and A. Piperno, Carbon Nanomaterials for Therapy , Diagnosis , and Biosensing.

[46] Y. Charles, "Nanoparticles with Raman Spectroscopic Fingerprints for DNA and RNA Detection," vol. 1536, no. 2002, 2012, doi: 10.1126/science.297.5586.1536.

[47] S. Law, "Mini-Review for an Electrocatalytic Application of Carbon Nanotube in Medical Fields – Tissue Engineering , Drug Delivery , Cancer and SARS-CoV-2," vol. 13, no. 1, pp. 1–8, 2023.

[48] B. K. Saikia, S. Maria, M. Bora, J. Tamuly, and M. Pandey, "Review article A brief review on supercapacitor energy storage devices and utilization of natural carbon resources as their electrode materials," Fuel, vol. 282, no. April, p. 118796, 2020, doi: 10.1016/j.fuel.2020.118796.

[49] A. Bianco, K. Kostarelos, D. Partidos, and M. Prato, "Biomedical applications of functionalised carbon nanotubes," no. November 2004, pp. 571–577, 2005, doi: 10.1039/b410943k.

[50] S. Akgönüllü and A. Denizli, "Recent advances in optical biosensing approaches for biomarkers detection," Biosens. Bioelectron. X, vol. 12, p. 100269, 2022, doi: https://doi.org/10.1016/j.biosx.2022.100269.

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