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Review Article

Recent Development and Applications of Carbon Nanotubes

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Abstract

The Carbon nanotubes show one of the best innovations in the industry of the nanotechnology. CNTs have been studied by numerous researchers in various areas due to their potential in different fields. In present review properties, types and application of Carbon nanotubes have been discussed. CNTs exhibits astonishing strength as well as unique electrical, mechanical and thermal properties. CNTs are popular for their important properties like light in weight, small size with a high aspect ratio, good tensile strength and good conducting characteristics. It is concluded that these characteristics make them useful as fillers in different materials such as polymers, metallic surfaces and ceramics. Also CNTs have potential applications in the field of nanotechnology, nanomedicine, transistors, actuators, sensors, membranes, and capacitors.

Keywords: Transistors, Actuators, Sensors, Membranes, Nanotechnology

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Introduction

Nanotechnology

In 1959, a physicist Richard Feynman visualized this theoretical capability in which one can manipulate and control individual atoms and molecules. Over a period of ten year Professor Norio Taniguchi discovered the term "Nanotechnology" with the development of the scanning tunneling microscope which helps to see each atoms. He stated that "nanotechnology mainly consists of the processing steps of the sorting out, combining, and distortion of materials by one atom or one molecule [1]. According to National Science Foundation, nanotechnology has competency to understand, utilize and control matter at the level of individual atoms and molecules [2]. Nanotechnology is the study to manage the matter on an atom and molecular scale. Generally, nanotechnology deals with structures sized between 1-100 nm and at least one dimension (1D). It also include re -construct or developing materials within that size. The material developed by this technology is lighter, powerful, faster, smaller and more sustainable as compare to others. Nanotechnology stimulates the ability to frame components of molecular size and precise machine. In other words, 'nanotechnology' refers to the convertible ability to construct items from the bottom up, using tools and techniques that are being defined to make high performance products. Science and engineering are the primary operators of global technological competition. Modern science based on the unifying features of nature at the nano scale contributes a new foundation for innovation, knowledge, and integration of technology.

Nanotechnology is the construction technology to derive the absolute high accuracy and ultra-fine dimensions, i.e. the preciseness and fineness on the order of 1 nm (nanometer), 10^{-9} meter in length. The "nano" is a Greek word which means-dwarf (small); scientific therapy at the nano level (atomic level) with the help of special scientific instruments is known as nanotechnology, which has become a well-known field in the period of time [3].

Recently, the products of nanotech are in huge demand and are gradually improved using evolution nanotechnology. Nanotech products that are on the market today are mostly gradually improved products (using evolutionary nanotechnology) in which nano-enabled material like carbon nanotubes, nanocomposite structures or nanoparticles of a particular substance and nanotech process such as nano-patterning or quantum dots for medical imaging are used in the manufacturing process.

The properties of materials can be different at the nanoscale for two main reasons: one is Nanotechnology has a relatively greater surface area when compared to the same mass of material manufacture in a larger form. This can make materials more chemically reactive (in some cases materials that are inert in their larger form are reactive when produced in their nanoscale form), and affect their strength or electrical properties. Second is the quantum effects govern the behavior of matter at the nanoscale particularly at the lower end possess the optical, electrical and magnetic behavior of materials. Generally, these materials can be originated as followings ways One dimension (1D like nanowires, nanorods and nanotubes), Two dimensions (2D like plate-like shapes like nanocoatings, nanolayers, and graphene), Three dimensions (3D like nanoparticles). List of carbon isomers is given in **Table 1**.

Table 1 Carbon Isomers [4]

S.No	Dimension	Isomer	Hybridization	Density g/cm^3	Bond Length (Å)	Electronic Properties
1	0-D	Fullerene	sp^2	1.72	1.40 (C=C)	Semiconductor Eg= 1.9 eV
2	1-D	Nanotubes	sp^2	1.2-2.0	1.42(C=C)	Semiconductor or Metal
3	2-D	Graphite	sp^2	2.26	1.42(C=C)	Semi-metal
4	3-D	Diamond	sp^3	3.52	1.54 (C-C)	Insulator Eg= 5.47 eV

Carbon nanotubes

Carbon nanotubes (CNTs) are cylindrical large molecules manufacture of a hexagonal order arrangement of hybridized carbon atoms. These are large macromolecules that are distinctive for their size, shape, and extraordinary physical properties. CNTs are also known as buckytubes, are cylindrical carbon molecules having unique features that make them potentially useful in a wide variety of applications like materials science, electronics, chemical processing, energy management, and many other fields [5].

However, CNTs have outstanding electrical conductivity, heat conductivity and mechanical properties. Therefore, they are likely the best electron field-emitter as well as they have high length-to-diameter ratios. CNTs are pure carbon polymers and they can be transform using the well-known and the tremendously rich chemistry of that element.

They exhibits impressive strength as well as distinctive electrical, mechanical and thermal properties. CNTs are the members of the fullerene family, which was innovated and shows one of the most unique inventions in the field of nanotechnology. Over a time period by many researchers around the world studied CNTs because their great outcomes in different fields [6]. CNTs are cruise graphene with sp^2 hybridization materials. In view of their great properties like light in weight, small size with a high aspect ratio, good tensile strength and good conducting characteristics CNTs are significant as nanomaterials, these properties make them helpful as fillers in different materials such as polymers, metallic surfaces. CNTs also have outstanding outcomes in the field of nanotechnology, sensors, transistors, nano medicine, membrane, actuators and capacitors. Since more than twenty years CNTs materials have been studied a lot by many researchers and it has great novel applications and attractive discoveries of novel phenomena and properties. CNTs materials have significantly used in diverse areas including energy storage, molecular electronics, nanomechanical devices, composites, and chemical and bio-sensing.

Single-walled carbon nanotubes (SWCNTs) are constituted by rolling up a single sheet of graphene and multi-walled carbon nanotubes (MWCNTs) formed by rolling up multiple sheets of grapheme. Currently, great amount of research has been dedicated to understand their structures but their physical properties are still being explore and debatable. Different kinds of nanotubes show different electronic, thermal, and structural properties defined by its diameter, length, and chirality, or twist.

Types of carbon nanotubes

CNTs are generally categories in Single Walled Carbon Nanotube (SWCNT), Double Walled Carbon Nanotube (DWCNT) and Multi Walled Carbon Nanotube (MWCNT).

SWCNTs

Single-walled CNTs are made up of a single graphene sheet rolled upon with self a diameter of 1–2 nm [7]. SWNTs have a diameter nearby to 1 nm, with a tube length that can be many millions of times longer. SWNTs are the most important representatives of 1D nano-materials with 1-3 nm diameter have dependent chirality properties. As a semiconductor SWNTs have shown to contain high mobility, high current-carrying efficiency, small intrinsic capacitance, and remarkable thermal & mechanical properties. As well as SWNTs have been widely enucleated as the channel materials for radio-frequency (RF) electronics, digital electronics, and macroelectronics [8]. The structure of a SWNT can be systematic by wrapping a one-atom-thick layer of graphite called graphene into unique cylinder. The way the graphene sheet is rolled over is constitute by a pair of indices (nm) called the chiral vector.

DWNTs and TWNTs

Double and triple-walled carbon nanotubes manufactured by coaxially-nested two and three rolls of SWNTs are geometrical bridge between SWNTs and MWNTs. DWNTs and TWNTs have provided an ideal model to study the coupling interactions between different shells in MWNTs [9]. DWNTs having inner diameters of about 1.0- 2.0 nm dominate in the samples [10].

DWNTs are made of two coaxial carbon nano tubes in which the outer tube encircles the inner tube. The study of DWCNTs sheds light on inter-planar interaction effect on MWCNTs physical and chemical properties [11]. DWCNTs have small diameter, less defects compared to MWCNTs with three and more layers. Theoretically the transport properties of particular DWCNTs, which shows a considerable variation in conductance corresponding to variation of chirality of inner and outer walls. [12]

MWCNTs

Multi-walled carbon nanotube is larger and consists of many single-walled tubes stacked one inside the other. MWNTs consist of multiple layers of graphene rolled upon with self-diameters ranging from 2 to 50 nm depending on the number of graphene tubes. These tubes have an almost 0.34 nm inter-layer distance [13]. MWCNTs is composed of carbon atoms having thicker walls, which is consist of many coaxial graphene cylinders separated by a gaping which is likely to be close to the interlayer distance in that of graphite. The diameters of the MWCNTs of the outer cylinder could be ordered of 2-24 nm and the inner hollows cylinders are 1-8 nm.

MWCNTs are easy to fabricate and have better dispersibility than SWCNT because they are longer in diameter than that of SWCNT. The area occupied by SWCNT bundle is more than the MWCNTs for a specific interconnected length. MWCNTs provides chance to alter the structures and to adjust the dispersion as well as solubility. They also allow the experimental application in materials chemicals, electronics and in energy system. The properties which make the MWCNTs important for the industrial use are electrical conductivity, their mechanical properties and strength which are up to 15 to 20 times stronger than that of steel and also it is lighter then steel and their heat transmit capability which is better than diamond.

Comparison between SWCNT and MWCNT: SWNTs and MWNTs are similar in certain respects but they also have striking differences. SWNTs are an allotrope of sp^2 hybridized carbon similar to fullerenes. MWNTs consist of multiple rolled layers (concentric tubes) of graphene and some important difference is given below in **Table 2**.

Table 2 Comparison between SWCNT and MWCNT [15]

Properties	Graphene sheet	Distortion chance	Purity	Elasticity
SWCNT	Having single layer of graphene sheet.	It can be distorted during the Functionalization.	Having less purity	It can be easily re bonded and twisted.
MWCNT	Having more than 2 layer of graphene sheet.	Distortion chance is less during Functionalization.	High in purity	It cannot be easily rebounded and twisted.

Properties of carbon nanotubes

In the past few decade nanoscale science and technology have significantly studied. CNTs are one of the most interesting nanomaterials and it shows significant attention in terms of fundamental properties measurements and potential applications. It has impressive physical properties such as the electrical properties of CNT may be tuned by mechanical deformation. These materials show great attention for applicable in sensors or smart devices. These CNTs properties have been studied in multi-disciplinary and several branches of science and engineering [16].

The study of these properties involves exploring the mechanical properties and potential applications of two types of CNTs: SWCNT and MWCNT. After enormous research it is concluded that MWCNTs has specific tensile strength as high as 100 times that of steel and the graphene sheet (in-plane) is as stiff as diamond at low strain. These mechanical properties of CNTs make it useful in applications for lightweight and high strength materials. Composite materials prepared by either SWCNT or MWCNT shows significant enhancement in mechanical properties [17].

Mechanical Properties

CNTs are very strong and stiff materials yet discovered in terms of ductile strength and elastic nature respectively. This power results from the covalent sp^2 bonds formed between the singles carbon atoms [18]. Presence of C-C bonds, CNTs are considered to be very strong along their axes and have a very large Young's modulus in their axial direction. The Young modulus value of a SWNT is assumed as high as 1 to 1.8 Tpa. The high value of elastic modulus makes it suitable for the used as probe tips of scanning microscopy. The absolute value of a SWNT depends on the diameter and chirality. However, in the case of MWNT, it relates them to the amount disorder in the sidewalls. For MWNTs, it is clear by experimentally that the only outer layer is able to bear strain when the tubes are diffuse in an epoxy matrix1, 3 and for single wall nanotube bundles (also known as ropes).

The radial direction elasticity of CNTs is important characteristics for the formation of CNT nanocomposites. When a load is applied to a composite structure radial direction elasticity of CNTs helps in which embedded tubes is subjected to large deformation in the transverse direction.

CNTs have excellent capability as they are the strongest and toughest structure ever synthesized. The radial direction elasticity is important for the development of CNT nanocomposites and their mechanical properties. The composite structure has embedded tubes which are subjected to large deformation in the transverse direction when a load is applied. Among the other CNTs graphite has strong C-C bond therefore it is strongest in nature. The theoretical work on the mechanical properties of CNTs has been reported and results are found that the SWNTs could exhibit a Young's modulus as high as that of diamond [19]. Similarly, working of CNT transformation under uniaxial tension and high stress, leading to pentagon-heptagon defects in these tubes has been reported [20, 21]. It is observed that increase in diameter is proportional to the enhancement of the mechanical properties. The Young's moduli of the tubes approach those of planar graphite on the increase in diameter to a certain value.

Optical Properties

Optical properties of SWNT are related to their quasi one-dimensional nature. Conceptual studies have disclosed that the optical activity of chiral nanotubes vanish if the nanotubes become big therefore, It is await that other physical properties are impact by these parameters too. CNTs plays an important role used for optical devices [22]. 2D honeycomb molecular lattice structure of graphene with unique band structure provides unusual electric transport phenomena and valuable optical properties.

Carbon nanotube fabricated by rolled graphene sheets via various chemical vapor deposition methods (CDV). CNT has many practically useful properties like saturable absorption, pockels effect, and the DC Kerr effect (QEO). Both, graphene and CNTs have saturable absorption and optical immersion due to fast electronic transitions between energy levels. These materials also have ultra-nonlinear phenomena which make them valuable for applications like short-pulse fiber lasers, electro-optic modulators, and all-optical signal processing devices. Carbon nanotubes are mostly useful for mode locking, and graphene with broad wavelength coverage is especially handy for mid-infrareds lasers. The researchers found other new materials but standard CNTs and graphene remain the best option for short-pulse fiber lasers in terms of fabrication cost, robustness and high-power endurance [23].

Chemical Properties

The chemical reactivity of a CNT is, compared with a graphene sheet, increase as a direct result of the arch of the CNT surface. The arch reasons the mixing of the π and σ orbital, which result to hybridization between the orbitals. The degree of hybridization becomes greater as the diameter of a SWNT gets shorter. Due to increasing arch of CNT, π orbital is mismatching hence reactivity increase. Hence, carbon nanotube reactive power is directly related to the orbital mismatch caused by an increased arch. Therefore, a mismatch must be made between the sidewall and the end caps of a nanotube. For the same reason, a smaller nanotube diameter results in increased reactive power. It is possible to constructed covalent chemical modification of either sidewalls or end caps. For example, the emulsifiable of CNTs in different solvents can be managed this way. The addition of a covalent bonded species to sp^2 hybridized carbon atoms on the nanotube sidewalls proved difficult. Therefore, nanotubes can be assumed as usually chemically inert.

Electrical Properties

Not only carbon nanotubes are very strong, but also they having very interesting electrical properties. A single graphite sheet is a semimetal, which means that it has properties in between semiconductors, either it is behave as meta or non-metal (like the silicon in computer chips, where electrons have restricted motion) and metals (like the copper used in wires, where electrons can move openly). When a graphite sheet is sandwiched into a nanotube, not only do the carbon atoms have to arranged around the circumference of the tube, but the quantum mechanical have functions of the electrons must also match up [24]. It is known that copper is best conductor of electricity in metals but metallic nanotubes can conduct an electrical current density of 4 × 109 A/cm^2 which is more than 1,000 times greater than metals such as copper.

Thermal Properties

Thermal properties depend on the atomic arrangement, the diameter and length of the tubes in CNTs. The number of structural defects and the morphology, as well as the presence of impurities in the CNTs also affects thermal properties. 1D quantization of the phonon band structure in CNTs is the example of low temperature specific heat and thermal conductivity [19, 25]. However, on incorporation of different materials on pristine and functionalized nanotube the thermal property can double by only 1 % loading, therefore it was suggested that the nanotube composite is very important for thermal applications in industries.

Kim et al. (2001) reported the thermal conductivity of individual MWCNTs, which is higher than that of graphite at room temperature e.g 3,000W/K. Also they get two orders higher value for magnitude for bulk MWNTs [26]. Similarly, Yu et al. (2009) reported thermal conductivity greater than 200 W/m K for SWNTs [27]. There are many factors which effect the thermal properties like the number of phonon-active modes, the length of the free path for the phonons, and boundary surface scattering [28].

Applications of carbon nanotubes

Carrier for Drug delivery

Carbon nanohorns (CNHs) are the spherical aggregates of CNTs with desultory horn like shape. Many researchers have suggested CNTs and CNHs as a potential bearer for drug delivery system. Due to nano size and sliding nature of graphite layers bound with van der waals forces, they can be used as lubricants or glidants in tablet manufacturing [29]. CNTs have potential application in field of emitters or emission, conductive or reinforced plastics, molecular electronics, CNT based nonvolatile RA, CNT based transistors, energy storage, CNT based fibers and fabrics, CNT based ceramics, and biomedical applications etc., Some vital application of CNTs have been discussed in detail are as follows:

Genetic Engineering

In genetic engineering, CNTs and CNHs are used to frame-up genes and atoms in the development of bio imaging genomes, tissue engineering and proteomics. The open DNA (single stranded) winds around SWNT by connecting its specific nucleotides and account change in its electrostatic property [23]. In diagnostics (polymerase chain reaction) and in therapeutics CNTs make wide applications. Wrapping of carbon nanotubes by single-stranded DNA was found to be series-dependent, and hence can be used in DNA analysis. Because of their cylindrical structure CNTs used as carrier for genes (gene therapy) to treat genetic disorders and in cancer treatment. This form of carbon-nanotube proved them as a vector in gene therapy. Nanostructures have showed antiviral effect in respiratory syncytial virus (RSV), a virus with severe bronchitis and asthma. Gene slicing technologies treatment is possible by combining nanoparticles. Here RNA fragments capable of prevent a protein (which is needed for virus multiplication) is encapsulated within nanotubes and entered in the form of nasal sprays or drops.

Artificial Implants

Body shows discontent reaction for implants with the post regime pain but, small sized nanotubes and nanohorns get attached with other proteins and amino acids defer refusal. Also, they can be used as implants in the form of artificial joints without host rejection reaction [30]. Carbon nanotubes act as bone replacement because of their high tensile strength, filled with calcium and arranged/grouped in the structure of bone.

Other Medical Applications of CNT's

The single properties and characteristics of CNTs enable scientists to cultivate new areas in nanomedicine. SWNTs and MWNTs have already verified their outcomes to serve as secure and effective alternatives to previous drug delivery methods [31]. They can pass through membranes, carrying remedial drugs, vaccines, and nucleic acids deep into the cell to the substrate targets. They serve as ideal non-hazardous vehicles, which in some cases, increase the solubility of the drug, resulting in greater efficiency and safety. Overall, research studies of CNTs have shown a very favorable future for them in medicine.

Toxicity of CNTs and its Control

Due to the outstanding physical and chemical properties of CNTs, their usage in industry has been seriously considered, but there are certain problems connected with their use, especially problems related to their toxicity [32]. CNTs can have opposite effects on human health, in particular at the human pulmonary system, which is a primary route of unveiling. The certain steps are required to minimize the toxicity of CNTs. Over-exposure to CNT dust also cause irritation and oxidative stress [33].

Sensors

Sensors are important detecting tool that are now often used in different fields. The ability of biosensors and molecular sensors can be increase by connect CNTs onto them [34]. In chemical force microscopy techniques, it is possible to originate various type of sensors constituting nanotube composite pellets, which are very sensitive to gases and which can be used to identify leaks in chemical plants.

Biosensors

Biomedical industry CNT incorporated sensors are required to bring about entire changes in different fields and especially in the biomedical industry area. An example is the glucose sensing application, where steady self-tests of glucose by diabetic patients is required to measure and control their sugar levels. Another example is monitoring of the exposure to dangerous radiation like in nuclear plants/reactors or in chemical laboratories or industries [35]. The main purpose in all these cases is to find out the exposure in different stages so that appropriate treatment may be administered. CNT-based nanosensors are highly suitable as embed sensors for monitoring pulse, blood glucose, temperature, and also for diagnosing diseases we can imbed sensors.

Batteries (Lithium ions batteries)

Lithium (Li) is a useful element, as it offer distinctive properties due to its low-most electro-negativity and because electrons are easily donated from Li. Thus, it is the best for the fabrication of light weight and efficient batteries [36]. However, anyway the above advantages, the high reactivity of Li limits its applicability, as the metal loses its efficiency. This problem can be sort out by the combining an application of CNTs and Li by intercalating Li ions within CNTs fabrication of efficient battery can be done. This enables Li^+ ions to migrate from a graphitic anode to the cathode.

Carbon Nanotube in Protective Fabrics

CNT is a very adorable material with incredible properties suitable for various applications. The importance of CNTs as ballistic materials are discussed, starting from different application of CNTs in textile industries and the employment of CNTs in different ways to make composites for ballistic protection i.e. spread of CNTs in polymer matrix which is used as plural impregnation of ballistic fabrics, broadening of CNTs on ballistic fabrics and finally CNTs based fabrics. It has been predict that and this will help in reducing the weight of existing ballistic protective fabrics significantly without hampering their performance by few layers of CNT fabrics can replace the several layers of ballistic fabrics [37].

CNTs are the unique and important substance in nanotechnology owing to it exceptional properties, but their low diffusion in polymer and aqueous media prevent their development in textile industries. Therefore, researchers are working on the property of uniform increase surface growth method over fiber surface [38]. They developed an extremely fast growth method to synthesize CNTs over carbon fiber by using microwave irradiation method.

CNT use in supercapacitors

The requirement for flexible and keep energy storage devices such as solar cells, batteries or super capacitors has been enhanced in last ten years to cover the growth of advanced electronics. Flexible super capacitors have presented hopeful outcomes because of their long cycle life, easy fabrication, high capability and low cost [39]. However, to reach high capacitance with power and energy densities better than those of batteries and traditional capacitors, super capacitor expected electrodes having thinner dielectrics and high specific surface area. Because of their malleable super capacitors owing to their superb electrical, mechanical, optical properties and high stability of electrochemical which are considerable for producing high-performance energy devices ,carbon nanotube are compatible as electrode material**.**

Preservative

Since carbon nanotubes and nanohorns are antioxidant in nature therefore they are used to dehydrate herb which are prone to oxidation. Because of this assists, they are used in anti-aging cosmetics and as sunscreen dermatological with the help of zinc oxide to obstruct oxidation of important skin components [15]**.**

Carbon Nanotubes in Protective Fabrics

Carbon nanotube (CNT) is a very absorbing material with outstanding properties**.** CNTs in textile industries and the exhaustion of CNTs in different ways to make composites which is used as impregnation of ballistic fabrics, growth of CNTs on ballistic fabrics and finally CNTs based fabrics**.** Due to its light weight, high strength and high energy absorption capacity CNTs are assumed as futuristic material for protective cloths and have created an interesting field in textile industry for continuous investigation. For fabricating light weight multi-purpose protective fabric, CNT is a promising candidate [40].

Functionalization of CNT for Medical Application

Carbon nanotubes (CNTs) are strongest transporter of bioactive including drug, genes and proteins. They analyze several techniques that have been come about for fabricating, purifying and functionalizing CNT structures**.** For medical applications, Functionalization is necessary to solubilize CNTs in aqueous solvent in surface chemistry increase biocompatibility and to minimize the toxicity of CNTs to the normal cells. Carbon nanotube generally contains a huge amount of impurities like metal particles, amorphous carbon, and multi-shells. So it was proposed that purification is needed before attachment of drugs onto CNTs [41]. The effect of polyaniline and amine functionalized carbon nanotube on the properties of composite nanofibre. Conductive polymers such as polyaniline and conductive nano particles such as CNTs have very important outcomes on the polymer composition. Although there are many research carried out for just only PANI filler or carried out for just only CNT filler but there are no research performed to see the symbiotic outcomes effects of both PANI and functionalized CNTs on polymer matrix**.** Insulator PAN became antistatic material with the use of CNT and PANI. An increase in conductive filler did not increase the conductivity [42].

CNT as Super Capacitors

From last ten years the demand for flexible and feasible energy storage devices such as solar cells, batteries or super capacitors has been increased**.** To enhance the capacitance efficiency as well as improve the stability of PANI combines PANI/CNT. CNT/PANI electrodes and other materials deposited with CNT/PANI have been examined and showed an outstanding enhancement in the capacitance and energy [43].

Conclusion

The properties and characteristics of CNTs are still being researched heavily by researchers because of highly potential of single walled carbon nanotube and multi-walled carbon nanotube. In previous drug delivery methods it is confirmed that single and multiwalled nantube are safer. It is highly likely that low-cost gas sensors, nanotube fabrics, three-dimensional composite materials, heat exchangers, biological microfilters, and virus inhibitors will be produced using CNTs in the future. It was also found that the nanotube that are functionalized which disperse CNTs well lead to less toxic CNTs than pristine CNTs.

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