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CARBON NANOTUBES AN INTRODUCTION PROPERTIES AND APPLICATIONS

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Abstract-In this paper, carbon nanotubes have been introduced along with their unique properties and wide range of applications. CNTs have unique electrical conductivity. They are also good absorbent that have been utilized for filtration of gas, air and water. They have high aspect ratio and show field emission effect. This field emission phenomenon have been used for photoluminescence imaging. Due to their elastic property, they have been used as the tip of sanning probe microscope. CNTs have been used for treatment of cancer, activation of pletelets, generation of tissues, cardiac autonomic regulation, drug delievery, gas storage, flat panel displays, technical textiles, ultra capacitors, biosensors, improved lifetime batteries, good absorbent, micro and nano electronics, photoluminescence imaging, gene therapy etc.
Keywords: allotropy, fullerenes, graphene, carbon nanotubes,chirality.

1. INTRODUCTION

Carbon has many structural forms. In the last two decades, three forms of carbon are attracting the attention of researchers: grapheme, fullerenes and nanotubes [1]. Carbon nanotubes (CNTs) have sp^2 type hybridization. CNTs have unique properties as compare to other materials. Physical, mechanical and chemical properties of CNTs lie between graphite and diamond. These properties includes high thermal and chemical stability, high thermal conductivity etc. CNTs have high surface to volume ratio. It makes the composite processing challenging and hence it shows poor interaction at the interface [2-3].

In recent times, a number of attempts have been performed for modification of surface of CNTs. This will enhance properties of CNTs. These enhanced properties have been utilized in various fields like bio-sensing, biological imaging, drugs and molecules delivery, catalysis, nano electronic devices, filtration of air and water etc [4-5]. The most significant application includes dispersion of carbon nanotubes into numerous matrix systems. CNTs have a wide range of applications in photovoltaic energy devices. By joining photovoltaic devices with conducting polymers, organic solar cells have been established with enhanced properties[7-8].

In this paper, carbon nanotubes have been introduced along with their unique properties and wide range of applications. CNTs have unique electrical conductivity. They are also good absorbent that have been utilized for filtration of gas, air and water. They have high aspect ratio and show field emission effect. This field emission phenomenon have been used for photoluminescence imaging. Due to their elastic property, they have been used as the tip of sanning probe microscope. CNTs have been used for treatment of cancer, activation of pletelets, generation of tissues, drug delievery. These can also be used as gas storage, flat panel displays, technical textiles, ultra capacitors, biosensors, improved lifetime batteries, good absorbent, micro and nano electronics, photoluminescence imaging, gene therapy etc.

2. HISTORICAL BACKGROUND OF CNTS

Discovery of CNTs was accidental while observing transmission electron microscopy of soot generated from two electrodes of carbon. CNTs were discovered by Sumio Ijima (NEC laboratory in Tsukuba, Japan) in 1991 [9]. Efforts behind this discovery were nothing but capability and microscopic skill of Ijima. She was observing the transmission electron microscopy of C_{60} molecules, also called as buckminster fullerenes. Fullerenes were allotropes of carbon discovered by Harold Kroto and Richard Smalley in 1970 [10]. They observed that under some specific conditions, there happens spontaneous self assembling of carbon atoms into molecules of some specific shapes and sizes named buckminster fullerenes as shown in fig.1. However, Ijima discovered that under various experimental conditions, atoms of carbon can also self assemble in the shape of tubes with nano-size dimensions called as carbon nanotubes (CNTs) [11].

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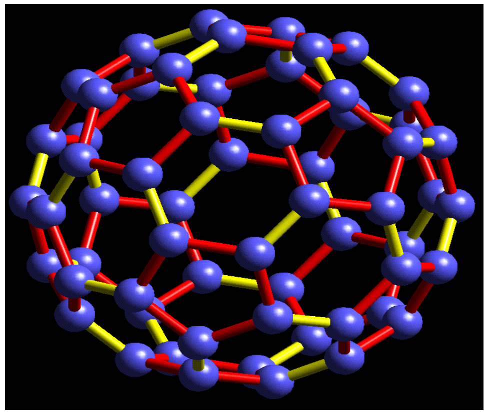

Fig.1: Structure of Buckminster Fullerene

3. STRUCTURE OF CNTS

There are a variety of allotropes of carbon atom in 0D, 1D, 2D or 3D. Graphite and diamond are the examples of carbon allotropes in 3D. In diamond, carbon atoms are sp^3 hybridized. Allotropes of carbon in low dimensions (2D, 1D or 0D) are called as carbon nanomaterials. Graphene is 2D carbon nano-material which is single sheet of graphite with sp^2 type hybridization of carbon atoms. Carbon nanotubes are allotropes of carbon in 1D and fullerenes are the examples of carbon allotropes in 0D [12].

Graphene structure has hexagonal arrangement of carbon atoms as shown in fig.2. There are four valence electrons in 2s and 2p orbitals of carbon in graphene. Three atomic orbitals of carbon, 2s, 2px and 2py are sp2 hybridized in the same plane. 2pz atomic orbital is perpendicular to other existing orbitals [13]. The bonds between adjacent carbon atoms are sigma-bonds which are formed by orbitals with sp2 hybridization whereas 2pz orbitals form pi bonds in the perpendicular plane as shown in fig.3.

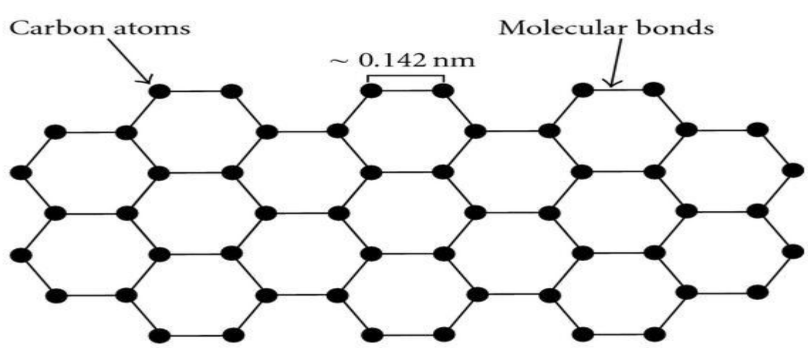

Fig.2: Layered structure of graphene

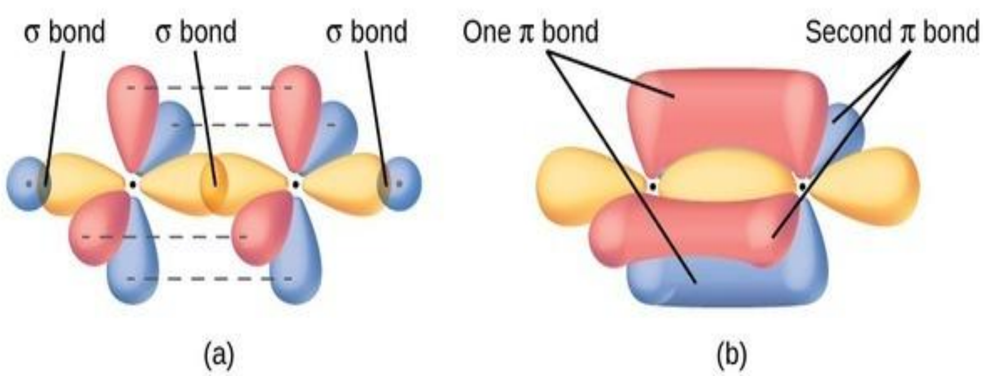

Fig.3: Sigma and Pi bonds in grapheme

Nanomaterials like CNTs are formed by rolling up of graphene sheet into a cylindrical shape. Length to diameter ratio of such nanomaterials is approximately (1.32* 108):1. This ratio is significantly large as compare to other materials. Nanotubes have diameter of the order of few nanometers while length of nanotubes can be up to 18 centimetres [14].

4. TYPES OF CNTS

CNTs are classified on the basis of number of concentric rolled grapheme sheets. These are named as single walled nanotubes (SWNT), double walled nanotube (DWNT) and multi walled nanotube (MWNT) as shown in fig.4. SWNT is formed by rolling up of single atom thick layer of graphene into cylindrical structure. DWNT is a special case of MWNT in which two graphene sheets are rolled up in concentric cylindrical shape [15].

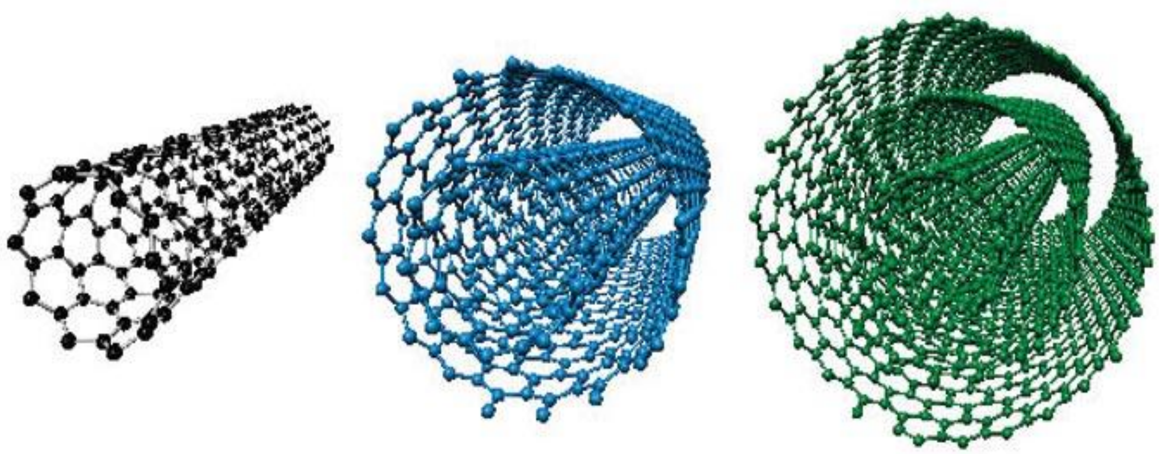

Fig.4: Structures of SWCNT, DWCNT and MWCNT

Structure of MWNT can be described by two models. According to Russian Doll model, MWNTs are arrangement of graphene sheets like concentric cylinders. Whereas, Parchment model tells that MWNTs are rolls of graphene single sheet around itself like a rolled newspaper. In CNTs, edges of graphene sheets are combined together like a seamless cylinder [16]. On the basis of direction of rolling CNT are classified as Chiral, Zigzag and Armchair form as shown in fig.5.

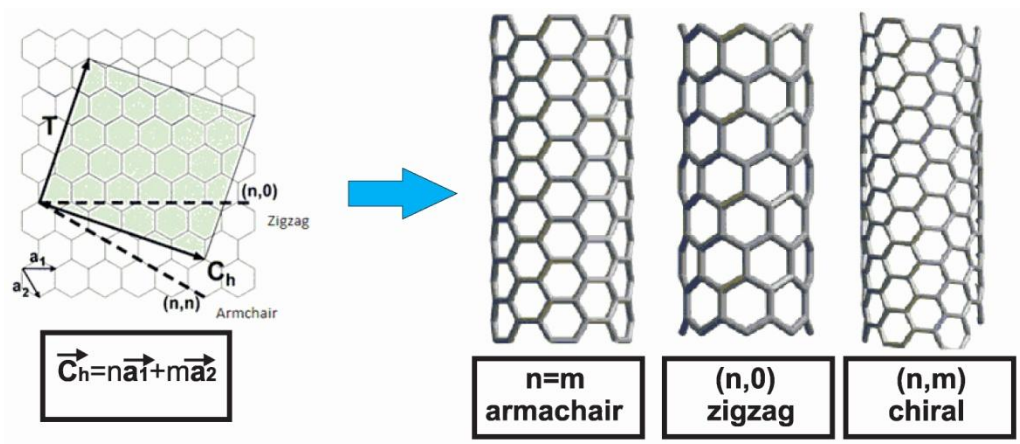

Fig.5: Different types of CNTs based on rolling direction

Rolling up direction of CNT is indicated by$\overrightarrow{C_h}$, circumferential vector. Circumferential vector is defined as $\overrightarrow{C_h} = \overrightarrow{a_1}n + \overrightarrow{a_2}m$ where$\overrightarrow{a_1}, \overrightarrow{a_2}$ are graphene lattice vectors andn, m are chiral indices. These chiral indices define different structures of CNT. For armchair CNT chiral indices are equal i.e. $n = m$. For zigzag CNTs, n or $m = 0$ i.e. one of the chiral indices should vanish. For the remaining values of indices, CNTs are defined as chiral. On the basis of different structures of CNTs, they show semiconducting or metallic behaviour. Armchair CNTs are always shows metallic properties while zigzag CNTs can behave both metallic and semiconducting depending on the condition $n - m = 3I$ where I is an integer. If any CNTs satishfies this condition then they will behave like metals otherwise the tubes will be semiconductor. It has been found that in a mixture of CNTs, $1/3^{rd}$ CNTs will behave like metals whereas $2/3^{rd}$ CNTs will show semiconducting behaviour [17].

5. PROPERTIES OF CNTS

Atomic arrangement of carbon atoms gives rise to unique thermal, electrical and mechanical properties of carbon nanotubes which are discussed below:

5.1 Electrical Conductivity

Electrical property of carbon nanotubes depends on chirality and diameter. On the basis of chirality, CNTs behave like both metals and semiconductors. As the diameter of CNTs increase, energy gap decreases and hence metallic character increases. Electrical conduction behaviour of MWNTs is complex as compare to uniform current distribution of SWNTs. The resistivity value for SWCNTs is of the order of 1μ Ω cm at room temperature. Because of low resistivity, CNTs can carry more current than metals [18].

5.2 Strength and Elasticity

In CNTs each carbon atom is covalently bonded to neighbouring three atoms. This strong bonding increases their elasticity and strength. CNTs have higher elastic modulus than steel. Also these are considered as high strength fibre. When we apply pressure on nanotubes, tip bends. On removing force, it restores its original shape. Due to this property, CNTs play significant role for scanning probe microscopy. For SWNTs Young's modulus value varies from 1.22 TPa to 1.26 TPa depending on the chirality and size of SWNTs. For MWNTs, moduli are related to extent of disorder in the walls of nanotubes [19].

5.3 Thermal Conductivity and Expansion

There are strong in plane carbon-carbon bonds in graphene. Due to these strong bonds, CNTs can have superconductivity property below 20 K temperature. This strong bond increases the stiffness and strength of CNTs. High thermal conductivity and larger in plane expansion property of CNTs plays important role in various applications like sensing and actuating device, molecular electronics at nanoscale etc [20].

5.4 Aspect Ratio

Aspect ratio gives the information about the less CNT load requirement as compare to other conducting materials for achievement of same electrical conduction properties. CNTs have very high aspect ratio. This high aspect ratio of CNTs provides unique electrical conductivity as compare to carbon black, stainless steel fibre etc [21].

5.5 Field Emission

High aspect ratio and small diameter of CNTs results in field emission phenomena in CNTs. When a strong electric field is applied on CNTs, electrons start tunnelling from the metal tip to vacuum space. This phenomenon is field emission of CNTs. In MWNTs both electrons and light are emitted in this phenomenon. Such phenomenon are significantly used in flat panel displays [22].

5.6 Absorbent

Due to light weight, high mechanical strength, more flexibility and extraordinary electrical properties, CNTs and their composites have been utilized as absorbing materials. Thus CNTs plays an important role in filtration of air, gas and water. A lot of work has been done for replacement of charcoal by CNTs for ultrahigh purifying purpose [23].

5.7 Decoration of metal nanoparticles on CNT

To enhance the properties of CNTs, organic materials like metallic nanoparticles have been deposited on the surface of CNTs. A new hybrid material forms by the combination of two different materials, CNTs and nanoparticles. Such hybrid materials have enhanced properties that can be significantly used in catalysis, nanotechnology and many more other applications [24].

6. APPLICATIONS OF CNTS

CNTs have a wide range of applications in various fields like medical science, nano-size electronic devices, nanotechnology, photovoltaic devices etc [25]. Most significant application of CNTs is in medical sciences area. CNTs have been used for treatment of cancer, activation of pletelets, generation of tissues, cardiac autonomic regulation, drug delievery [26-28]. These can also be used as gas storage, flat panel displays, technical textiles, ultra capacitors, biosensors, extra storage fibres, improved lifetime batteries, good absorbent, micro and nano electronics, photoluminescence imaging, gene therapy etc. Thus CNTs and their composites have wide range of applications in various fields [29-30].

7. CONCLUSIONS

In this paper, carbon nanotubes have been introduced along with their unique properties and wide range of applications. CNTs have unique electrical conductivity. They are also good absorbent that have been utilized for filtration of gas, air and water. They have high aspect ratio and show field emission effect. This field emission phenomenon have been used for photoluminescence imaging. Due to their elastic property, they have been used as the tip of sanning probe microscope. CNTs have been used for treatment of cancer, activation of pletelets, generation of tissues, cardiac autonomic regulation, drug delievery. These can also be used as gas storage, flat panel displays, technical textiles, ultra capacitors, biosensors, extra storage fibres, improved lifetime batteries, good absorbent, micro and nano electronics, photoluminescence imaging, gene therapy etc.

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