CARBON NANOTUBES – AN ULTIMATE MATERIAL FOR TECHNOLOGICAL ADVANCEMENT

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Abstract: Carbon nanotubes (CNTs) are allotrope of carbon atom having a cylindrical shape with a diameter ranging from 1nm to 100nm and theoretically possessing an ultimate intrinsic tensile strength in the 100–200 GPA range. It has a 2-D structure but with quite a bit of interesting properties such as high thermal and electrical conductivity high tensile strength.CNTs has a vast range of application in the medical field as well as in data transmission. It can be a potential alternative to metallic wires or a replacement for modern day transistors. It can also be used for energy storage as well as ceramics. Currently Carbon nanotubes are still in development phase, but initial results are very promising and gives a high hope to all of us regarding its capabilities and usages.

I. INTRODUCTION

Carbon nanotubes(SWCNTs) were discovered independently by Iijima, Ichihashi and Bethune et al. in carbon arc chambers. Carbon nanotubes are allotrope of carbon atom, intermediate between fullerene cages and flat graphene. It is an extremely large molecule of pure carbon atom having a diameter ranging from 1nm to 100nm and has a length ranging from 100 to 1000 nanometers. If considered individually a CNT molecule is about 100 times stronger than steel and is about 1/6 times its weight.

Carbon nanotubes can also refer to tubes with an undetermined carbon-wall structure and diameters less than 100 nanometers. Such tubes were discovered by Radushkevich and Lukyanovich. While nanotubes of other compositions exist, most research has been focused on the carbon ones.

Carbon nanotubes comes in two variety SWCNTs—Single-walled carbon nanotubes and MWCNTs—Multiple-walled carbon nanotubes.

SWCNTs

- Has a single layer of graphene.
- Catalyst is required for synthesis.
- Synthesis in large bulk amount is difficult
- Not fully dispersed, and form bundled structures.
- Resistivity usually in the range of 10−4–10−3 Ωm.
- SWCNT content in samples prepared by chemical vapour deposition (CVD) method is about 35–55 wt%. However high purity up to 80% has been reported by using arc discharge synthesis method.

MWCNTs

- Has multiple layer of graphene.
- Can be produced without catalyst.
- Bulk synthesis is easy.
- Homogeneously dispersed with no apparent bundle formation.
- Resistivity usually in the range of 1.8×10^{-5}–6.1×10^{-5} Ωm.
- Purity is high. MWCNT content in samples prepared by CVD method is about 35–90 wt%.

1.1PROPERTIESS OF CNTs

Some intrinsic properties of carbon nanotubes – which makes it

- It is ideal conductors of electrical energy,
- Higher tensile strength.
- Extraordinarily flexible and elastic.
- It is excellent conductor of thermal energy.
- High aspect ratio.
- Excellent electron field emitters.
- Lower thermal expansion coefficient.

Carbon nanotubes are the strongest and stiffest materials yet discovered in terms of tensile strength and elastic modulus. This strength results from the covalent sp2 bonds formed between the individual carbon atoms. Studies conducted in 2008, revealed that individual CNT shells have strengths of up to ≈100 gigapascals (15,000,000 psi),

strength of individual CNT shells is extremely high, however weak shear interactions between adjacent shells and tubes lead to significant reduction in the effective strength of multiwalled carbon nanotubes. CNTs are not nearly as strong under compression. Because of their hollow structure and high aspect ratio, they tend to undergo buckling when placed under compressive, torsional, or bending stress.

carbon nanotubes are either metallic or semiconducting along the tubular axis. In theory, metallic nanotubes can carry an electric current density of 4 × 109 A/cm2, which is more than 1,000 times greater than those of metals such as copper,[55] where for copper interconnects, current densities are limited by electromigration. Carbon nanotubes are thus being explored as interconnects and conductivity-enhancing components in composite materials, and many groups are attempting to commercialize highly conducting electrical wire assembled from individual carbon nanotubes.

II. SYNTHESIS OF CNTs

There are many synthesis methods to produce CNTs. Compared with other methods, chemical vapor deposition (CVD) is the most effective method.Other technique includes arc discharge, laser ablation, high-pressure carbon monoxide disproportionation.

2.1 ELECTRICAL ARC DISCHARGE

Arc discharge was the method used to prepare CNTs by Iijima in 1991. He used an AC plasma arc between a pair of graphite electrodes under an inert gas (helium or argon) at about 0.657 atm to produce MWCNTs. The high temperature between the electrodes causes sublimation of the carbon(graphite). This sublimated graphite is deposited at the negative electrode or the walls of the chamber where the process is carried out. These deposits contain CNTs .For achieving the single-walled CNT (SWCNT) electrodes are doped with catalyst particles, such as Ni–Co, Co–Y, or Ni–Y. Nanotubes produced by this method are generally entangled and have varying lengths. However, the tubes are of high quality with low amounts of defects.

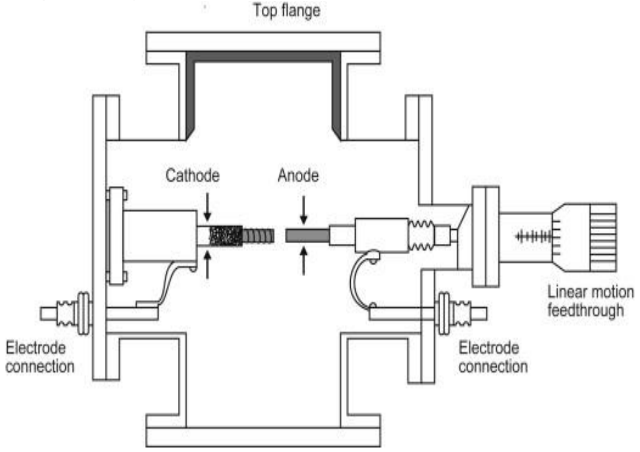

Fig: Arc discharge method for CNT.

2.2 LASER ABLATION TECHNIQUE

In the laser ablation technique, a high power laser was used to vaporize carbon from a graphite target at high temperature. Both MWNTs and SWNTs can be produced with this technique. In order to generate SWNTs, metal particles as catalysts must be added to the graphite targets similar to the arc discharge technique. The quantity and quality of produced carbon nanotubes depend on several factors such as the amount and type of catalysts, laser power and wavelength, temperature, pressure, type of inert gas, and the fluid dynamics near the carbon target. The laser is focused onto a carbon targets containing 1.2 % of cobalt/nickel with 98.8 % of graphite composite that is placed in a 1200°C quartz tube furnace under the argon atmosphere (~500 Torr). These conditions were achieved for production of SWNTs in 1996 by Smalley’s group [2]. In such technique, argon gas carries the vapors from the high temperature chamber into a cooled collector positioned downstream. The nanotubes will self-assemble from carbon vapors and condense on the walls of the flow tube. The diameter distribution of SWNTs from this method varies about 1.0 - 1.6 nm. Carbon nanotubes produced by laser ablation were purer (up to 90 % purity) than those produced in the arc discharge process and have a very narrow distribution of diameters.

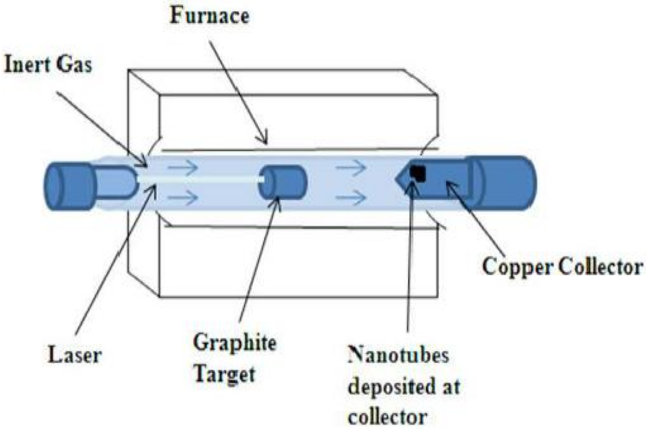

Fig: Schematic diagram of Laser ablation set-up for CNT synthesis

2.3CHEMICAL VAPOUR DEPOSITION

Chemical vapor deposition (CVD) is the most effective method. The catalyst is the most influential factor for the morphology, structure, and properties of CNTs.

The chemical vapor deposition method is to cleave a carbon atom-containing gas continuously flowing through the catalyst nanoparticle to generate carbon atoms and then generate CNTs on the surface of the catalyst or the substrate. The synthesis process is to let catalyst decompose carbon source (usually hydrocarbon gas) at a sufficiently high temperature in a tubular reactor.

Compared to other two methods, in terms of crystallinity, although the crystallinity of CVD-grown MWCNTs is low, the crystallinity of CVD-grown SWCNTs is close to that by arc or laser.

When a hydrocarbon vapor is contacted with heated metal nanoparticles, it is first decomposed into carbon and hydrogen. Hydrogen leaves with the passing carrier gas or reducing gas, and carbon dissolves in the metal catalyst. When the temperature reaches the carbon solubility limit of the metal, the decomposed carbon particles precipitate and crystallize to form CNTs. The decomposition of hydrocarbons is an exothermic process, carbon crystallization is an endothermic process, and the thermal gradient continues this process.

When the catalyst interacts weakly with the substrate, carbon decomposed from the hydrocarbon diffuses from the metal catalyst to the bottom of the metal catalyst and precipitates between the substrate and the metal catalyst, thereby promoting the growth of the entire metal catalyst nanoparticles. When the metal particle is entirely covered by excess carbon, growth stops, which is called tip-growth.

When the catalyst interacts strongly with the substrate, the carbon precipitates without pushing up the metal particles, so it is forced to precipitate from the top of the metal, which is called the “basic growth model,” also called root growth.

During the synthesis of CNTs, many parameters affect the final morphology and properties of CNTs, such as carbon source, catalyst, reactor temperature, system pressure, flow rate of carrier gas, deposition time, reactor type, the geometry of reactor, catalyst support, active metal components in catalyst, and so on.

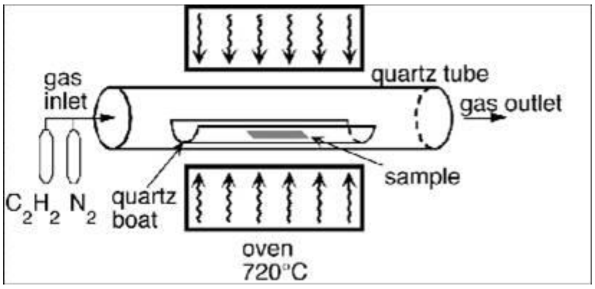

Fig: Schematic diagram of the chemical vapor deposition apparatus.

III. INDUSTRIAL USAGES OF CNTs

Industrial usages of CNTs include automotive, energy, paint and coatings, and electronics sectors.Li-ion batteries constitutes 1 - 3 weight percent of the graphite electrodes. Another example where CNTs are used in resin or plastic based industry where CNT fillers are used in base resin and thermoplastic, preventing them from becoming electrostatically charged and to increase their strength.

Advanced polymer composites used for sports equipment such as rackets, golf-clubs, and ice-hockey sticks, along with high performance bicycles, small boats and windmill blades containing CNT are on the market. In these products CNTs are used to as reinforcing agent. Composite materials other than polymers are also being investigated, e.g. aluminum CNT composites and ceramic CNT composites.

Adding CNT to textile fibers have been demonstrated to imply electronically conducting properties to the finished textiles, and products utilizing this property is known on the market in Japan.This may be either as CNT heating textiles or as part of final products. Electronically conducting textiles are used as extremely thin heating mats and has been proposed used for ‘intelligent’ clothing e.g. for winter sports applications.

3.1 CNT NANOTHREAD

Nanothread is one of the world’s thinnest man-made fiber. It is about 100 nm in diameter and was manufactured under an electron microscope. Nanothread is a new material building block that can be used at the nanoscale or can be put together to form a yarn. The resistivity of nanothread is less than 10−5 Ωm. The strength of nanothread is greater than 0.5 GPa. Made directly from carbon nanotubes and thus acquiring its superior electrical and mechanical properties, it is one of the best replacement material choice for replacing diff metals in electronic industry and mechanical industry.

CNTs used to make nanothreads are grown by the chemical vapor deposition (CVD) method in lab. They are about 10 nm in diameter and 500 µm in length. However by spinning, millimeter long CNT arrays can form CNT threads that can be km long. In the NanoWorld Lab, a micromanipulator made by Kleindiek is used to handle nanoscale materials. The micromanipulator has plug-in accessories that were adapted to prepare thread and characterize it. A rotational tip is used for twisting a CNT bundle into thread. Driven by a power supply outside the SEM, the piezo motor can rotate step by step for an unlimited angle. A tungsten probe was attached to the rotational tip. The probe is used to pick up a very small bundle of CNTs and twist the bundle into a thread.

IV. OTHER APPLICATIONS OF CNTs

4.1Field emission:

It is a phenomena when electrons are emitted under the action of strong electric field from a metal surface. As CNTs are very small in diameter and have a high aspect ratio it makes up for one of best choice for every technology based on field emission.

4.2CNT as a transistor

Nanoscale field effect transistors in the sub-10 nm regime, suffer from short channel effects such as direct tunneling from source to drain, increase in gate-leakage current and punch-through effect. Semiconducting carbon nanotubes (CNTs) because of their properties like large mean free path, excellent carrier mobility and improved electrostatics at nanoscales as the result of their non-planar structure, can be best ideal replacement for silicon. CNTs are very attractive for nanoelectronic applications and can be used to achieve high speed ballistic carbon nanotube field effect transistors (CNTFETs). Theoretically, CNTFETs could reach a higher frequency domain (terahertz regime) than conventional semiconductor technologies.

4.3 CNT as a viable replacement for electrical and data transmission medium

Carbon nanotubes (CNTs) offer opportunities for integration into wires and cables for both power and data transmission due to their unique physical and electronic properties. Macroscopic CNT wires and ribbons are presently shown as viable replacements for metallic conductors in lab-scale demonstrations of coaxial, USB, and Ethernet cables. In certain applications, such as the outer conductor of a coaxial cable, CNT materials may be positioned to displace metals to achieve substantial benefits (e.g. reduction in cable mass per unit length (mass/length) up to 50% in some cases). Bulk CNT materials possess several unique properties which may offer advantages over metallic conductors, such as flexure tolerance and environmental stability. Specifically, CNT wires were observed to withstand greater than 200,000 bending cycles without increasing resistivity. Additionally, CNT wires exhibit no increase in resistivity after 80 days in a corrosive environment (1 M HCl), and little change in resistivity with temperature (<1% from 170-330 K). This performance is superior to conventional metal wires and truly novel for a wiring material. However, for CNTs to serve as a full replacement for metals, the electrical conductivity of CNT materials must be improved. Recently, the conductivity of a CNT wire prepared through simultaneous densification and doping has exceeded 1.3 × 10(6) S/m. This level of conductivity brings CNTs closer to copper (5.8 × 10(7) S/m) and competitive with some metals (e.g. gold) on a mass-normalized basis. Developments in manipulation of CNT materials (e.g. type enrichment, doping, alignment, and densification) have shown progress towards this goal. In parallel with efforts to improve bulk conductivity, integration of CNT materials into cabling architectures will require development in electrical contacting. Several methods for contacting bulk CNT materials to metals are demonstrated, including mechanical crimping and ultrasonic bonding, along with a method for reducing contact resistance by tailoring the CNT-metal interface via electronless plating. Collectively, these results summarize recent progress in CNT wiring technologies and illustrate that nanoscale conductors may become a disruptive technology in cabling designs.

V. CONCLUSION AND FUTURE WORK

A review of the synthesis, processing, functionalization and characterization is presented in this paper. CNTs are a new class of materials having properties that can be utilized in vast amount of fields We conclude that nanotubes could have features of both NP and conventional fibers.applications of CNTs in the field of energy conversion and storage, environmental monitoring and wastewater treatment, as well as green nanocomposite design are research area of growing interest from their potential uses in future technologies point of view. Integration of CNTs in the field of energy applications has brought revolutionary developments in the conventional electrochemical devices. In solar cell technology, CNTs are employed as the conductive filler for sensitizer with the advantages of lower fabrication cost but photoconversion efficiency comparable to or higher than the conventional silicon solar cells. CNTs have attracted extensive research interest for the development of sensors and adsorbents, due to their unique structural, electronic, and mechanical properties. In gas sensing applications, CNTs are selectively functionalized with metal oxides to act as the sensing elements, which have exhibited high sensitivity and selectivity towards many air pollutants. CNTs have demonstrated advantageous potentials in energy and environmental applications with their outstanding structural, electronic, and mechanical properties. Development of CNTs integrated energy conversion technologies implement with efficient energy storage system have shown promising progress in efforts to address the energy challenge for future clean and sustainable energy source.

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