Carbon Nanotubes: A New Advanced Material Rapidly Interested Scientists.

Rungsima Yeetsorn*

1. Introduction

Carbon owns three well know allotropic structures : amorphous carbon, graphite and diamond. Ggraphite can be found in carbon fibers, very light and resistant. Diamond is used for its exceptional mechanical properties, and for its strong thermal conductivity. Graphite and diamond revolutionized materials world, and large markets are currently linked to these materials.

Carbon nanotubes, new allotropics structure of carbon (Figure 1), are unique thanks to their size and properties. Carbon nanotubes (CNTs) have attracted the fancy of many scientist world wide because of small dimensions, strength and remarkable physical properties of these structures make them a very unique material with a whole range of promising applications. In this paper I briefly outline the earlier studies concerning carbon nanotubes, fabrication, properties and applications.

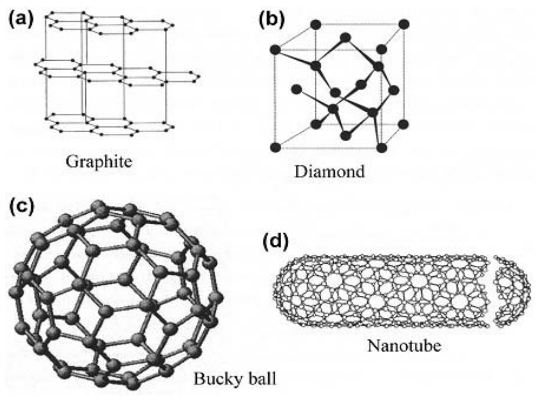
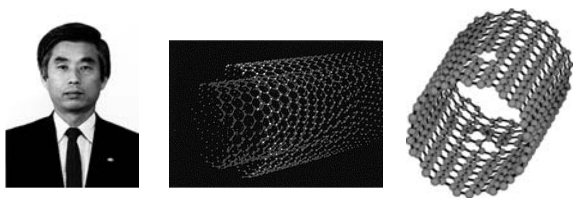


Figure 1 Different forms of carbon structures [1].

2. The Discovery of Carbon Nanotubes

The formation of carbon nanotubes could be traced back to the discovery of fullerence structure [2] or Bucky Ball; C_{60} (Figure 1) provided exciting insights into carbon nano-structures and how architectures built from sp^2 carbon units based on simple geometrical principles can result in new symmetries and structures that have fascinating and useful properties. The buckyball comprises of 60 carbon atoms arranged by 20 hexagonal and 12 pentagonal faces to form a shere, when the bucky ball is elongated to form a long and narrow tube with a small diameter, which is the basic form of carbon nanotubes [3]. Carbon nanotubes were discovered accidentally by ***Sumio Iijima*** in 1991[4]. He discovered microtubes of graphitic carbon with outer dimeters of 4 -30 nm, the inner dimeters as small as 2.2 nm and their length up to 1 mm. The carbon nanotubes consisted of two or more seamless graphene cylinders concentrically arranged and they were called muli-wall carbon nanotubes (MWNTs) because the tube diameters belonged to the nanometer order (Figure 2).



A B C

Figure 2 The picture of Dr. Sumio Iijima (A), MWNTs (B), and SWNTs (C) [7].

* Department of Industrial Chemistry, Faculty of Applied Science, King Mongkut's Institute of Technology North Bangkok.

Sing wall carbon nanotubes (SWNTs), which are seamless cylinders each made of single graphene sheet, were first report in 1993 [5]. Their diameters range from 0.4 to 2-3 nm, and there length usually of the micrometer order. SWNTs generally come to together to form bundles. In a bundle, they are hexagonally arranged to form a crystal-like structure [6].

MWNTs are collection of several concentric graphene cylinders and are larger structures conpared to SWNTs but SWNTs are more flexible than MWNTs. The angle of the rolling direction is another criterium by which can be clarified the kind of CNTs. Depending on the angle of the rolling direction, CNTs has conducting property with armchair form or semiconducting property with zigzag form (Figure 3).

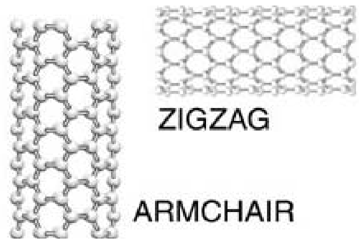


Figure 3 The forms of carbon nanotubes [8].

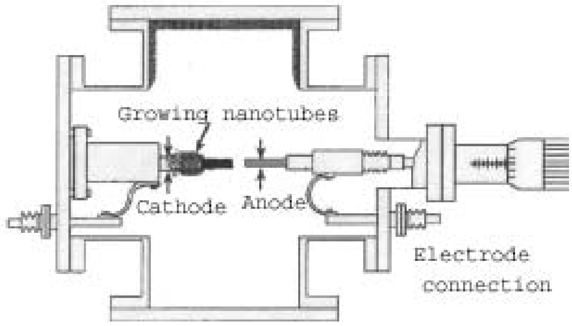


Figure 4 Schematic drawing of the direct current arc discharge method for producing CNTs [3].

3. Fabrication of Carbon Nanotubes

Carbon nanotubes are generally produced by three main techniques: arc discharge, laser ablation and chemical vapour deposition. In arc discharge, a vapour is created by an arc discharge between two carbon electrodes with or without catalyst. Nanotubes self-assemble from the resulting carbon vapour. In the laser ablation technique, a high-power laser beam impinges on a volume of carbon containing feedstock gas (methane or carbon monoxide). At the moment, laser ablation produces a small amount of clean nanotubes, whereas arc discharge methods generally produce large quantities of impure material. The chemical vapour deposition (CVD) results in MWNTs or poor quality SWNTs. The SWNTs are produced with CVD which have a large diameter range, and can be poorly controlled. On the other hand, this method is very easy to scale up, what favours commercial production.

3.1 Arc Discharge

This method creates nanotubes by connecting two graohite rods to a power supply, place end to end and separated by approximately 1mm apart, in an enclosure that is usually filled with inert gas (helium, argon) at low pressure (between 50 and 700 mbar). Recent investigations have shown that it is also possible to create nanotubes with the arc method in liquid nitrogen [9]. A direct current of 50 to 100 A is driven by approximately 20 V that creates a high temperature discharge between the two electrodes, at 100 A carbon vaporize in a hot plasma (Figure 4). The discharge vaporises one of the carbon rods and forms a small rod shaped deposit on the other rod. Producing nanotubes in high yield depends on the uniformity of the plasma arc and the temperature of the deposit form on the carbon electrode [10], typical yield is 30%. This method can produce SWNTs and MWNTs with few structural defects and tubes tend to be short with random sizes and directions [11] .

3.2 Laser Abalion

Smalley [11] at Rice University reported the synthesis of carbon nanotubes by laser vaporisation in 1995. The laser vaporisation apparatus used by Smalley's group is shown in Figure 5. A pulsed [12], or continuous [13] laser is used to vaporise a graphite target in an oven at 1200 °C. The main difference between continuous and pulsed laser, is that the pulsed laser demands a much higher light intensity (100 kW/cm^2 compared with 12 kW/cm^2). The oven is filled with helium or argon gas in order to keep the pressure at 500 Torr. A very hot vapour plume forms, then expands and cools rapidly. As the vaporised species cool, small carbon molecules and atoms quickly condense to form larger clusters, possibly including fullerenes. The catalysts also begin to condense, but more slowly at first, and attach to carbon clusters and prevent their closing into cage structures [14]. Catalysts may even open cage structures when they attach to them. From these initial clusters, tubular molecules grow into single-wall carbon nanotubes until the catalyst particles become too large, or until conditions have cooled sufficiently that carbon no longer can diffuse through or over the surface of the catalyst particles. It is also possible that the particles become that much coated with a carbon layer that they cannot absorb more and the nanotube stops growing. The primarily SWNTs formed in this case with a large diameter range that can be controlled by varying the reaction temperature. The yield of this process up to 70% but the most costly because it requires expensive lasers [11].

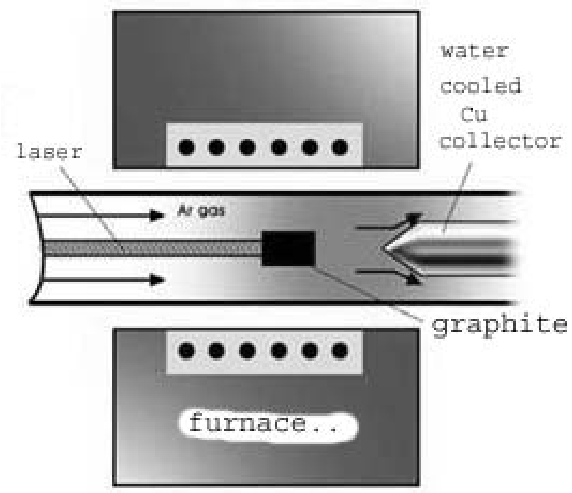


Figure 5 Schematic drawing of a laser abation apparatus [15].

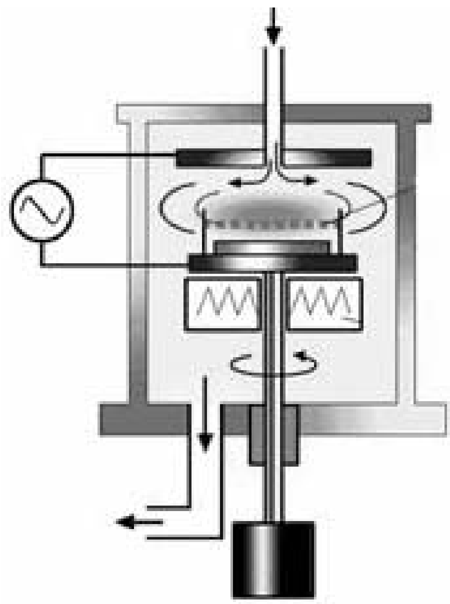


Figure 6 Schematic diagram of plasma CVD apparatus [15].

3.3 Chemical Vapor Deposition

Endo at Shinshu University illustrated carbon nanotubes can be grown by chemical vapour deposition (CVD) synthesis that is achieved by putting a carbon source in the gas phase and using an energy source, such as a plasma or a resistively heated coil, to transfer energy to a gaseous carbon molecule. The temperatures for the synthesis of CNTs by CVD are generally within the 650-900 °C range [16]. Commonly used gaseous carbon sources include methane, carbon monoxide and acetylene.The energy source is used to “crack” the molecule into reactive atomic carbon. Then, the carbon diffuses towards the substrate, which is heated and coated with a catalyst (usually a first row transition metal such as Ni, Fe or Co) where it will bind. Carbon nanotubes will be formed if the proper parameters are maintained. Excellent alignment [16], as well as positional control on nanometre scale [17], can be achieved by using CVD. Control over the diameter, as well as the growth rate of the nanotubes can also be maintained. The appropriate metal catalyst can preferentially grow single rather than multi-walled nanotubes [18]. Typical yields for CVD are approximately 20-100%.

4. Application of Carbon Nanotubes

Carbon nanotubes based materials have inspired scientists for a range of potential applications because of their unique atomic structure, very high aspect ratio, extraordinary mechanical, electrical and thermal properties with providing strong, light and high toughness characteristics. It has been estimated that the nanotubes could be designed as a longest cable in the world, i.e. a 23,000 mile cable from space station force due to its own weight at that length [3]. Only the tiny fullerence strands could sustain their weight when spanning 23,000 miles. The tensile modulus and strength of the nanotubes ranging about 270 Gpa to 1 Tpa and 11-200 Gpa, respectively, have been reported recently [19]. The use of carbon nanotubes in polymer/carbon nanotube composites has attracted wide attention [20-21] because of good properties make them ideal reinforcing fibers in nanocomposites. Carbon nanotube reinforced composites have been investigated for flame-retardant performance [22], improved electrical conductivity and electrostatic charging behavior, optical emitting devices [23], and in lightweight, high strength composites. Available as easy to be processed nanotubes macrofibers, carbon nanotubes will outerform the existing high performance reinforcement materials in aerospace, sports and industrial applications. In the last decade, many works related to nanotube composites including the investigation on the interfacial bonding properties and morphological observations through microscopy. In depth study on the stress transfer mechanism of the nanotube composites with different chemical and geometrical properties, and loading conditions are essential although many superficial works have previously addressed that the nanotubes have a good chemical bonding with typical polymeric materials. The reliability, thermal or mechanical properties and atomic relocation due to chemical interaction between carbon atoms and matrix are important issues that should be studied. The potential applications of using the nanotubes in real life applications are huge ranging from genetic probe, mechanical memory and nanoweezers, nanosensitive sensor, hydrogen and ion storage, nanotecher, nanoindentor and nano filler nanocomposite structures [24]. It is dependent on how to utilise fully the extraordinary properties of the nanotubes in different applications.

The finalization of tomorrow's fuel cells and Lithium-Ion bateries requires the development of new specialty materials. With their wide specific surface, their outstanding conductivity and their hydrophobic characteristics, CNTs are showing the way to the birth of new materials fitted for these highly innovative applications [25]. The exceptional actuating properties of the nanoledge's CNT fiber open the route to the development of new high performance actuators for medical or defense use.

5. Conclusion

In the future, there is no doubt that the nanotechnology will be one of emerging technologies that will play significant role in developing future materials. The development of a manufacturing process of nanotubes with high purity, geometrical identity and productivity, and low cost is an important factor in bringing the nanotubes to be more acceptable to the society.

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