CARBON NANO-TUBES: DESCRIPTION, PROPERTIES AND APPLICATIONS
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SUMMARY
Carbon nano-tubes (CNTs) are hollow cylinders of graphite carbon atoms. These tubes are on the nanoscale (10\(^{-9}\) m), which is so small that 10,000 of them could fit within the diameter of one human hair. Carbon nano-tubes are a new form of carbon with unique electrical and mechanical properties. They can be considered as the result of folding graphite layers into carbon cylinders. These cylinders may be composed of a single shell single wall carbon nano-tubes (SWCNTs), or of several shells multi-wall carbon nano-tubes (MWCNTs). SWCNTs tend to be stronger and more flexible than MWCNTs. Their interesting electronic structure makes CNTs ideal candidates for making novel molecular devices. Metallic Nano-tubes for example, were utilized as Coulomb islands in single-electron transistors. SWCNTs are nanometer-diameter cylinders consisting of a single graphite sheet wrapped up to form a tube. They have emerged as a very promising new class of electronic materials. Both metallic and semi-conducting SWNTs are found to possess electrical characteristics that are comparable favorably to the best electronic materials available. Field emission cathodes based on CNTs are potential candidates for low-cost replacement of thermionic cathodes used in microwave tubes. The combination of Poly-methyl-methacrylate (PMMA) known as a bone cement and hydroxyl-apatite with MWCNTs has revolutionized orthopedic surgery. Due to their small dimensions and high aspect ratio, they exhibit exceptional physical and chemical properties. This paper presents a brief account of their description, properties and applications of CNTs.

INTRODUCTION
Carbon nano-tubes (CNTs) are allotropes of carbon with a nano-structure that can have a length-to-diameter ratio greater than 1,000,000. These cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nano-technology, electronics, optics and other fields of materials science. They exhibit extra-ordinary strength and unique electrical properties, and are efficient conductors of heat. Inorganic nano-tubes have also been synthesized. A CNT is a hollow tube composed of carbon atoms. Its diameter averages tens of nanometers (10\(^{-9}\) meters) and its length can vary from nano-meters to centimeters (10\(^{-2}\) meters). CNTs can be thought of as a rolled-up sheet of hexagonal ordered graphite formed to give a seamless cylinder. Due to the variety of extraordinary properties exhibited by CNTs, a large number of possible applications have been proposed.

Recent discoveries of various forms of CNTs have stimulated research on their applications in diverse fields. They are very promising for the development of novel technological applications, such as batteries, tips for scanning probe microscopy, electrochemical actuators and sensors. The high current carrying capacity and mechanical stability of metallic nano-tubes indicates applications in microelectronic interconnects whereas the reasonably large band gap of narrow SWCNTs suggests their use as nano-scale transistor elements. The outstanding properties of CNTs such as low-weight, very high aspect ratio, high electrical conductivity, elastic modulus values in the TPa range, and much higher fracture strain values make them attractive candidates for making advanced composite materials with multifunctional features. They hold promise for applications in medicine, drug and gene delivery areas.

DESCRIPTION
The nature of bonding in carbon nano-tubes (CNTs) is described by applied quantum chemistry, specifically, orbital hybridization. This chemical bonding is composed entirely of sp\(^3\) bonds, similar to those of graphite. This bonding structure, which is stronger than the sp\(^3\) bonds found in diamond, provides the molecules with their unique strength. Nanotubes naturally align
themselves into "ropes" held together by Van der Waals forces. Under high pressure, nanotubes can merge together, trading some sp² bonds for sp³ bonds, giving the possibility of producing strong, unlimited-length wires through high-pressure nanotube linking.

CNTs are categorized as single-walled carbon nano-tubes (SWCNTs) and multi-walled carbon nano-tubes (MWCNTs). Several SWCNTs can be concentrically nested inside each other, like a Russian doll, forming the so-called MWCNTs. Most SWCNTs have a diameter close to 1 nanometer, with a tube length that can be many thousands times longer than the diameter. The structure of a SWCNT can be conceptualized by wrapping a one-atom-thick layer of graphite called graphene into a seamless cylinder. SWCNTs are a very important variety of CNTs because they exhibit important electric properties that are not shared by the MWCNT variants. SWCNTs are the most likely candidates for miniaturizing electronics beyond the micro electro-mechanical scale that is currently the basis of modern electronics. The most basic building block of these systems is the electric wire, and SWCNTs can be excellent conductors. One useful application of SWCNTs is in the development of the first intramolecular field effect transistors (FETs). The production of the first intramolecular logic gate using SWCNT FETs has recently become possible as well.

MWCNTs consist of multiple layers of graphite rolled in on themselves to form a tube shape. There are two models which can be used to describe the structures of MWCNTs. In the Russian doll model, sheets of graphite are arranged in concentric cylinders. In the parchment model, a single sheet of graphite is rolled in around itself. The interlayer distance in MWCNTs is close to the distance between graphene layers in graphite, approximately 3.4 Å (330 pm). Single graphene sheets, SWCNTs and MWCNT are shown in Figure 1.

PROPERTIES
Interest in CNTs has grown at a very rapid rate because of their many exceptional properties, which span the spectrum from mechanical robustness to novel electronic transport properties. It has become clear from recent experiments that CNTs could fulfill their promise as the ultimate high strength fibers for use in materials applications. The small diameter of CNTs also has an important effect on their mechanical properties, compared with traditional micron-size graphitic fibres. Perhaps the most striking effect is the opportunity to associate high flexibility and high strength with high stiffness, a property that is absent in graphite fibers. These properties of CNTs open the way for a new generation of high performance composites. Theoretical studies on the mechanical properties of CNTs are more numerous and more advanced than experimental measurements, mainly due to the technological challenges involved in the production of nano-tubes and in the manipulation of nano-meter-sized objects. However, recent developments in instrumentation (particularly high-resolution transmission electron microscopy (HRTEM) and atomic force microscopy (AFM)), production, process and manipulation techniques for CNTs, have given remarkable experimental results.

CNTs are the strongest and stiffest materials on earth, in terms of tensile strength and elastic modulus respectively. This strength results from the covalent sp² bonds formed between the individual carbon atoms. The SWCNT is about 100 times stronger than steel, yet one-sixth of its weight. Its hollow center and chicken-wire-like structure makes it very light, being 1/6th the weight of copper, and about half the weight of aluminum. As for thermal conduction, the CNT surpasses even that of diamond, reaching almost double the value diamond.

Electrical Properties:
Rolling up a graphene sheet on a nano-meter scale has dramatic consequences on the electrical properties. Because of the symmetry and unique electronic structure of graphene, the structure of a nano-tube strongly affects its electrical properties. CNTs are regarded as molecular wires whose electronic properties are largely determined by extended molecular orbits. The chirality and diameter of a CNT is extremely important, because it influences its properties. In electrical terms, chirality and diameter determine whether a CNT will behave as a metal or a semiconductor. Depending on the specific realization, the nano-tube may be a true one-dimensional metal or a semiconductor with a gap. For metallic behaviour, CNTs can have conductivity up to

Mechanical and Thermal Properties
eight times higher than that of copper. It can carry a current density achievable by any known conventional metallic wire, thus making them as potential candidates as nano-scale wires\(^{21}\). By combining metallic and semi-conducting tubes, the whole span of electronic components ranging from wires, bipolar devices to field-effect transistors may be embodied in nanotubes\(^{22}\). On the fundamental side, a perfect metallic nanotube is supposed to be a ballistic conductor in which only two one-dimensional sub-band carry the electric current\(^{23}\).

**APPLICATIONS**

Many potential applications have been proposed for CNTs, including conductive and high strength composites; energy storage and energy conversion devices; sensors; field emission displays and radiation sources; hydrogen storage media; and nano-meter-sized semi-conductor devices, probes, and interconnects\(^{24}\).

**CNT Composites:**

The first realized major commercial application of MWCNTs is their use as electrically conducting components in polymer composites. Depending on the polymer matrix, conductivities of 0.01-0.1 S/cm can be obtained for 5% loading; much lower conductivity levels suffice for dissipating electrostatic charge\(^{25}\). In commercial automotive gas lines and filters, nano-tube filler dissipates charge buildup. This prevents explosions and helps better maintenance of barrier properties against fuel diffusion than the use of plastics filled with carbon black. Plastic semi-conductor chip carriers and reading heads made from nano-tube composites avoid contamination associated with carbon black sloughing. Similar materials are also used for conductive plastic automotive parts, such as mirror housings that are electrostatically painted on the assembly line, thereby avoiding separate painting and associated color mis-match. The smoothness of the surface finish provides an advantage over other conductive fillers\(^{24}\).

Various CNT-polymer composites have been fabricated to improve their properties such as electrical conductivity, mechanical strength, radiation detection, optical activity etc. Diverse applications in electronics, medicine, defense and aero-space have been envisioned due to their remarkable improved properties. The known applications of CNT-polymer composites include their use in actuators and sensors\(^{26-27}\). In order to realize the potential applications of these composite materials, it has been suggested to continue some work leading to developing more economical ways for mass production techniques of CNTs\(^{28}\).

**Electrochemical Devices**

Because of the high electrochemically accessible surface area of porous CNTs arrays, combined with their high electronic conductivity and useful mechanical properties, these materials are attractive as electrodes for devices that use electrochemical double-layer charge injection. Examples include “super-capacitors,” which have giant capacitances in comparison with those of ordinary dielectric based capacitors, and electromechanical actuators that may eventually be used in robots. Like ordinary capacitors, CNT super-capacitors and electromechanical actuators typically comprise two electrodes separated by an electronically insulating material, which is ionically conducting in electrochemical devices\(^{29-32}\). The use of CNTs as electrodes in lithium batteries is a possibility because of the high reversible component of storage capacity at high discharge rates.

**Hydrogen Storage:**

A major obstacle in the way of a transition to hydrogen economy has been the absence of a practical means for hydrogen storage\(^{33}\). CNTs technology represents a new direction for solid hydrogen storage especially if these materials can be altered to store large amounts of hydrogen at room temperature. CNTs discovery has generated much interest and has created extensive research activities into the properties and application of the nano-meter scale cylindrical CNTs\(^{34-36}\).
Field Emission Devices

Industrial and academic research activity on electronic devices has focused principally on using SWCNTs and MWCNTs as field emission electron sources for flat panel displays, lamps, gas discharge tubes providing surge protection, and x-ray and microwave generators. Nano-tube field-emitting surfaces are relatively easy to manufacture by screen printing nano-tube pastes and do not deteriorate in moderate vacuum (10^-8 torr). These are advantages over tungsten and molybdenum tip arrays, which require a vacuum of 10^-10 torr and are more difficult to fabricate.

Medical Applications:

CNTs have the potential to carry drugs in the organism as they are hollow and much smaller than the blood cells. The methods were developed for attaching DNA and protein molecules to the inside and outside of the nano-tubes. This gives one the ability to target and destroy individual cells that may be cancerous or infected by a virus. Nano-tubes with attached enzymes might, in the long term, be used as enzymatic bio-sensors that could simultaneously detect and measure a variety of biological molecules. Interfacing CNTs with biological systems could lead to significant applications in various disease diagnoses. Significant progress in interfacing CNTs with biological materials has been made in key areas such as aqueous solubility, chemical and biological functionalization for biocompatibility and specificity, and in electronic sensing of proteins. In addition, the bio-conjugated nano-tubes combined with the sensitive nano-tube based electronic devices would enable sensitive bio-sensors toward medical diagnostics. Furthermore, recent findings of improved cell membrane permeability for CNTs would also expand medical applications to therapeutics using CNTs as carriers in gene delivery systems.

CONCLUSIONS

CNTs have been called the “wonder material of the 21st century”. There are many potential applications of CNTs in various fields, particularly in the field of electronics. They are assumed as “the building blocks for the future of electronics”, and the “replacement for silicon circuits. There are many applications of CNTs that are now realized in products. Others are demonstrated in early to advanced devices, and one, hydrogen storage, is clouded by controversy. Nano-tube cost, polydispersity in nano-tube type, and limitations in processing and assembly methods are important barriers for some applications of SWCNTs.

Proposed medical applications of CNTs require pure nano-tube material. However, it has been established that beside nano-tubes, the reaction product contains a mixture of different carbon forms, such as amorphous carbon (which covers the nano-tubes), multi-shell carbon, as well as metal catalyst residues. These impurities affect the properties of the CNT reaction product and make its application problematic. Therefore, a controlled synthesis of different kinds of CNTs based nano-fiber nano-tubes, their purification and the property modification has become a very important aspect of materials research investigations.

Although, the nano-tube-polymer composites showed improved properties, there have not been many industrial successes yet. In order to realize the potential applications of these composite materials some work must be done on cost-effective developing mass production techniques for CNTs. Current production rate is only enough for doing research and to build a knowledge base on the CNT polymer composite properties. The most critical factor is the production cost. Until this is reduced to a competitive level with the existing materials used in composite production, large scale use of...
CNTs is unlikely\(^{45}\). Purified / modified CNTs have a high potential of finding unique applications in wide areas of medicine. Also, the encapsulation of other materials in the CNTs would open up a possibility for their applications in medicine. The problems in the commercialization of CNTs are the cost of mass production and optimization\(^{46}\).

**REFERENCES:**