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A Review Study of Advances in the Science and Technology of Carbon Nanotubes

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Abstract
In this paper, we are presenting a brief literature review of present and future carbon nano tubes applications in different fields. Carbon nanotubes are the allotropes of carbon present as wires of pure carbon with nanometer diameters and lengths of many microns. There are several carbon nanotubes applications, which take full advantage of CNTs unique properties of mechanical strength, electrical and thermal conductivity. Many developments on fabrication of carbon nanotubes (CNTs) have been made to fulfill the demands on better performance including response time and higher sensitivity. In the very near future, carbon nanotubes will play a significant role in a wide range of commercial applications.

Keywords: *Carbon nanotube, electronics, current, graphene*

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INTRODUCTION
Carbon Nanotubes
Carbon nanotubes (CNTs) are the recently discovered allotrope of carbon, which take the form of cylindrical carbon molecules and have novel properties that make them potentially useful in a wide variety of applications in nanotechnology, electronics, optics, and other fields of material science. They exhibit extraordinary strength and unique electrical properties and are efficient conductors of heat [1]. Carbon nanotubes are wires of pure carbon with nanometer diameters and lengths of many microns. The carbon nanotubes have a unique property called chirality, an emergence of the vertically twisting (Figure 1).

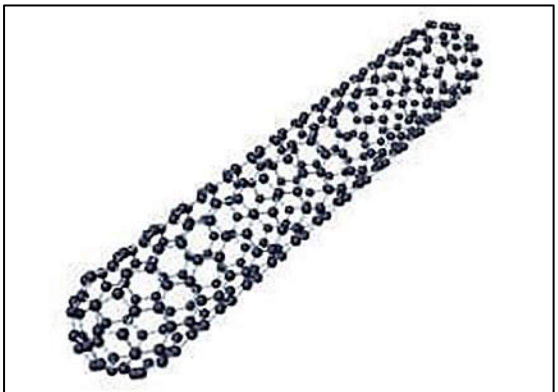

Fig. 1: *Carbon Nanotubes View.*

Carbon nanotubes types are categorized into two types: single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). A single-walled carbon nanotube (SWNT) may be thought of as a single atomic layer thick sheet of graphite (called graphene) rolled into a seamless cylinder. Multi-walled carbon nanotubes (MWNT) consist of several concentric nanotube shells. Graphene is a zero-gap semiconductor; for most directions in the graphene sheet, there is a bandgap, and electrons are not free to flow along those directions unless extra energy is given.

However, in certain special directions, graphene is metallic, and electrons flow easily along those directions. This property is not obvious in bulk graphite, since there is always a conducting metallic path, which can connect any two points, and the graphite conducts electricity. When graphene is rolled up to make the nanotube, a special direction is selected, the direction along the axis of the nanotube. Single-walled carbon nanotubes can be formed in three different designs: armchair, chiral, and zigzag. The design depends on the way the graphene is wrapped into a cylinder. For example, imagine rolling a sheet of paper from its corner, which can be considered one design, and a different design can be formed by rolling the paper from its edge. There are two structural models of multi-walled nanotubes Russian doll model and parchment model. In the Russian doll model, a carbon nanotube contains another nanotube inside it (the inner nanotube has a smaller diameter than the outer nanotube). In the parchment model, a single graphene sheet is rolled around itself multiple times, resembling a rolled up scroll of paper. Multi-walled carbon nanotubes have similar properties to single-walled nanotubes, but the outer walls on multi-walled nanotubes can protect the inner carbon nanotubes from chemical interactions with outside materials. Multi-walled nanotubes also have a higher tensile strength than single-walled nanotubes.

RELATED WORKS

The potential of carbon nanotubes (CNTs) as the basis for a new nanoelectronic technology was evaluated by Avouris in 2003 [1]. The electronic structure and transport properties of CNTs make possible the fabrication of CNT field-effect transistors (CNTFETs) which are formed from individual single-walled nanotubes (SWCNTs), SWCNT bundles, or multi-walled (MWCNTs). CNTFETs are very competitive with state-of-the-art conventional devices. The switching mechanism can account for the observed subthreshold and vertical scaling behavior of CNTFETs, as well as their sensitivity to atmospheric oxygen. The potential for integration of CNT devices is demonstrated by fabricating a logic gate along a single nanotube molecule. CNTs are very strong, resulting in an extremely high mechanical stability (Young's modulus about ten times higher than that of steel) and chemical inertness. The strong covalent bonding also leads to near perfect side-wall structures with very few defects.

CNTs are currently considered as promising building blocks of a future nanoelectronic technology. This is not simply due to their small size but rather to their overall properties. In fact, many of the problems that silicon technology is or will be facing are not present in CNTs. CNTs are new materials with outstanding electrical properties. The high conductivity and exceptional stability of metallic nanotubes make them excellent for future use as interconnects in nanodevices and circuits.

FETs using semiconducting CNTs have operating characteristics that are as good as or better than state-of-the-art silicon devices, and significant improvements should be expected in the near future. However, while CNTs are one of the most promising materials for molecular electronics, many challenges remain before they can become a successful technology. Most challenging are the materials issues. Another possible solution involves the development of efficient separation techniques, and work is pursued in this direction with encouraging initial results. The sensitivity of the electrical properties of CNTs and CNT devices to the nature of the CNT-metal contacts and the ambient environment problems is absolutely essential to control. CNTs are ideal model systems for the study and understanding of transport in 1-D systems and for the development of molecular fabrication technologies (Figure 2).

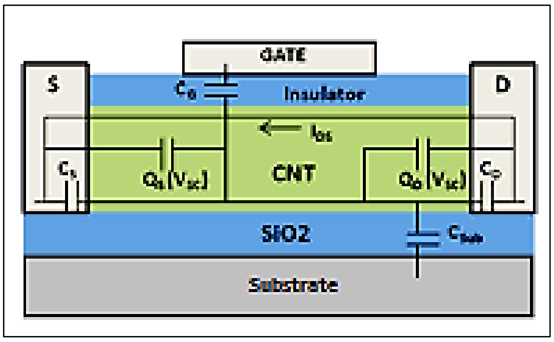

Fig. 2: *CNTFET Schematic Cross Section.*

Electrical properties and applications of carbon nanotube structures have been experimentally verified by Bandaruin [2]. The properties such as thermoelectricity, superconductivity, electro-luminescence, and photoconductivity have been analyzed. The possibility of using naturally formed complex nanotube morphologies, such as Y-junctions, for new device architectures are then considered. Technological applications of the electrical properties of nanotube derived structures in transistor applications, high frequency nanoelectronics, field emission, and biological sensing are then outlined. Electrical properties have been measured on nanotubes synthesized through a variety of methods. SWNTs and MWNTs have been synthesized by various methods, e.g., by arc discharge and laser ablation methods, which seem to have a higher degree of structural perfection, due to the high temperatures (>3000°C) involved in the synthesis. Ten nanotubes are also grown through chemical vapor deposition (CVD) at a lower temperature (<1000°C) with a higher defect density, which in turn adversely affects the electrical and thermal characteristics along with the structural properties. The electrical properties of a few applications of chemical sensing in an aqueous environment include the specific detection of protein binding; exploiting the well-known biotin-streptavidin interactions on to a polymer (a mixture of polyethyleneimine-PEI for n-doping the nanotube and polyethylene glycol-PEG for inducing a hydrophilic surface) coated nanotube arranged in a FET configuration (Figure 3).

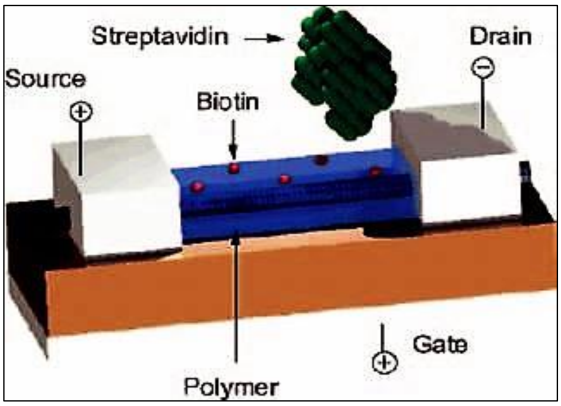

Fig. 3: *A Schematic of a Nanotube FET Configuration that can be used to Detect Protein Binding.*

On immobilizing biotin on the polymer surface, the covalent binding reduces the overall electron concentration and the device characteristics revert to p-type. On streptavidin attachment, the conductance is reduced considerably, which indicates the onset of detection. While the current detection level is around ten streptavidin molecules, higher sensitivity can be achieved through a better control of the surface charges. In another interesting application, the fast electron transfer rate and the high electro catalytic effect, intrinsic to CNTs, was used for the fabrication of glucose sensors of several nanotubes. The outstanding message is that the reduced dimensionality, inherent to nanotubes, gives rise to new physical effects in which quantum mechanical considerations are important. This marks a departure from classical electromagnetic phenomena and devices, and also represents a large opportunity for future technological advancement. As CNTs can be synthesized both, as metallic and semiconducting forms, this feature can be used to make heterogeneous metal-semiconductor junctions or homogeneous metal-metal/semiconductor-semiconductor junctions, and this can be extensively exploited in devices.

Highly sensitive carbon nanotubes flow-rate sensors and their performance improvement by coating was analyzed by Yang in 2010 [3]. On the basis of experimental results it is show that due to the large surface-volume ratio and thin coated Al_2O_3 layer, the CNT flow-rate sensor has higher sensitivity and faster response than a conventional platinum (Pt) HWFS. It is also demonstrated that the covered CNT flow-rate sensor has better repeatability than its bare counterpart due to insulation from the surrounding environment. The proposed CNT flow-rate sensor shows application potential for high-sensitivity measurement of flow rate. A new type of hot-wire flow-rate sensor (HWFS) with a sensing element is made of a macro-sized carbon nanotube (CNT). An effective way to improve repeatability of the CNT flow-rate sensor by coating a layer of Al_2O_3 on the CNT surface is proposed.

Hot-wire (or hot-film) flow-rate sensors, with their wide application in fluid mechanical measurements, are predominantly used for measurement in low-velocity flow or low turbulence flow. HWFS is characterized by high spatial and time resolution, high frequency band, low background noise, simple apparatus, and low cost. With the recent developments of micro-fluid, microelectromechanical systems (MEMS), and the lab-on-a-chip, a HWFS is now required to accommodate higher sensitivity for fluid mechanics measurement in small scale. According to the principles (convective heat transfer), HWFS should have a large surface-to-volume (S/V) ratio, large temperature coefficient of resistance (TCR), and large slenderness ratio to improve their sensitivity. MSCNTS-HWFS shows the application potential for high-sensitivity measurement of air velocity or flow rate, which can be also used for high-sensitivity measurement of fluid due to the covered insulating layer.

Carbon nanotubes-based gas sensor was presented by Mahalleh *et al*. [4]. Carbon nanotubes-based sensor has become increasingly and tremendously popular. Many methods have been proposed to make this type of gas sensors response better and enhance their performances. The basic material of carbon nanotubes that has two major properties such as electrical properties and mechanical deformation coupling, are good choices for future multi-functional material system that is capable of adaptive and sensory combination. Some gas sensors were designed by this principle such that various gases should be identified by their discharge currents and unique breakdown voltages. This way has some weaknesses such as large cost and short usage time, longer desorption time and adsorption time, and the environment can affect easily to the gas sensors.

Carbon nanotubes have been illustrated as sensitivity to be used by gas sensor; for example, NH_3, NO_2, CO, O_2 and H_2. Later, a lot of work has been done and continuously being done to manipulate the sensitivity of carbon nanotubes on the subject of new development of micro sensor technology. NH_3 and NO_2 are very useful to make variety of industries such agricultural sectors. Despite of the fact that, exposure to these gases not only totally affects the health of human being but also is harmful to the surroundings. The accuracy of measurement of the concentration of H_2 and CH_4 is crucial due to the risk level of explosion if it is exposed to air as low as 4%. If CNTs alone do not respond to H_2 well but after discussion about its functionalization, the level of sensitivity is increased.

Carbon nanotubes are dynamic fundamentals in detecting a large range of gases with prominent response because of their rare arrangements and good electronic properties Amendments of carbon nanotubes with functional groups and metal nano particles or integration of carbon nanotubes with metal oxides and polymers will significantly boost the selectivity of the CNTs sensors. Carbon nanotubes provide significant effects on various fields of micro scale sensory devices. They include from environmental to industrial area consisting of oil and gas to medical usage. The size and magnificent properties allow them to be major components of fundamental sensory devices. For future works, the enhancement of carbon nanotubes can be progressed. In future, the progression and development of the CNT as gas detection and sensors will be more.

'Recent advances in carbon nanotube flow-sensors' was presented by Upadhyay in 2014 [5]. The flow of a liquid on single-walled carbon nanotubes (SWNTs) or multi-walled nanotubes (MWNTs) bundles induces a voltage in the sample along the direction of the flow. The magnitude of the voltage depends on the sensitivity and the ionic conductivity and on the polar nature of the liquid. This makes nanotubes highly sensitive flow sensors and energy conversion devices. Carbon has maximum allotropes as it is capable for creating the most diverse variety of compounds. Fullerenes and nanotubes are the latest addition. The most studied allotrope of carbon is graphite, which has a two-dimensional structure due to sp2 hybridization. Diamond is another important allotrope of carbon with sp3 hybridization. The two-dimensional sheets made of sp2 hybridized carbon can curl, like a piece of paper and can make cylinders.

Hexagons alone cannot produce closed three-dimensional structures. The inclusion of pentagons results in a closed cage structure. Minimum six pentagons are needed on each side of the cylinder, thereby making a closed pipe. This is called a nanotube as the diameter of such a tube is in the nanometer range. Flow sensors are used in number of monitoring and control applications to measure both, air and liquid flows. Flow meters that have no movable parts usually need less attention than units with moving parts but all flow meters eventually require some type of maintenance.

Carbon nanotubes' present and future application was presented by De Volder in 2013 [6]. Advances in CNT synthesis, purification, and chemical modification are enabling integration of CNTs in thin-film electronics and large-area coatings. Widespread development continues on CNT based transparent conducting films as an alternative to indium tin oxide (ITO). A concern is that ITO is becoming more expensive because of the scarcity of indium, compounded by growing demand for displays, touch-screen devices, and photovoltaics.

Besides cost, the flexibility of CNT transparent conductors is a major advantage over brittle ITO coatings for flexible displays [7]. Further, transparent CNT conductors can be deposited from solution (e.g., slot-die coating, ultrasonic spraying) and patterned by cost-effective non litho-graphic methods (e.g., screen printing, microplotting). Recent commercial development effort has resulted in SWNT films with 90% transparency and a sheet resistivity of 100 ohm per square. This surface resistivity is adequate for some applications but still substantially higher than for equally transparent, optimally doped ITO coatings. Related applications that have less stringent requirements include CNT thin-film heaters, such as for defrosting windows or sidewalks [7, 8]. Microelectronics high-quality SWNTs are attractive for transistors because of their low electron scattering and their bandgap, which depends on diameter and chiral angle. Despite the promising performance of individual SWNT devices, control of CNT diameter, chirality, density, and placement remains insufficient for microelectronics production, especially over large areas.

Therefore, devices such as transistors comprising patterned films of tens to thousands of SWNTs are more immediately practical. These CNTs also give better results in the field of biomedical, which are somewhat better to optical fibre sensors [9]. The use of CNT arrays increases output current and compensates for defects and chirality differences, improving device uniformity and reproducibility (Figure 4).

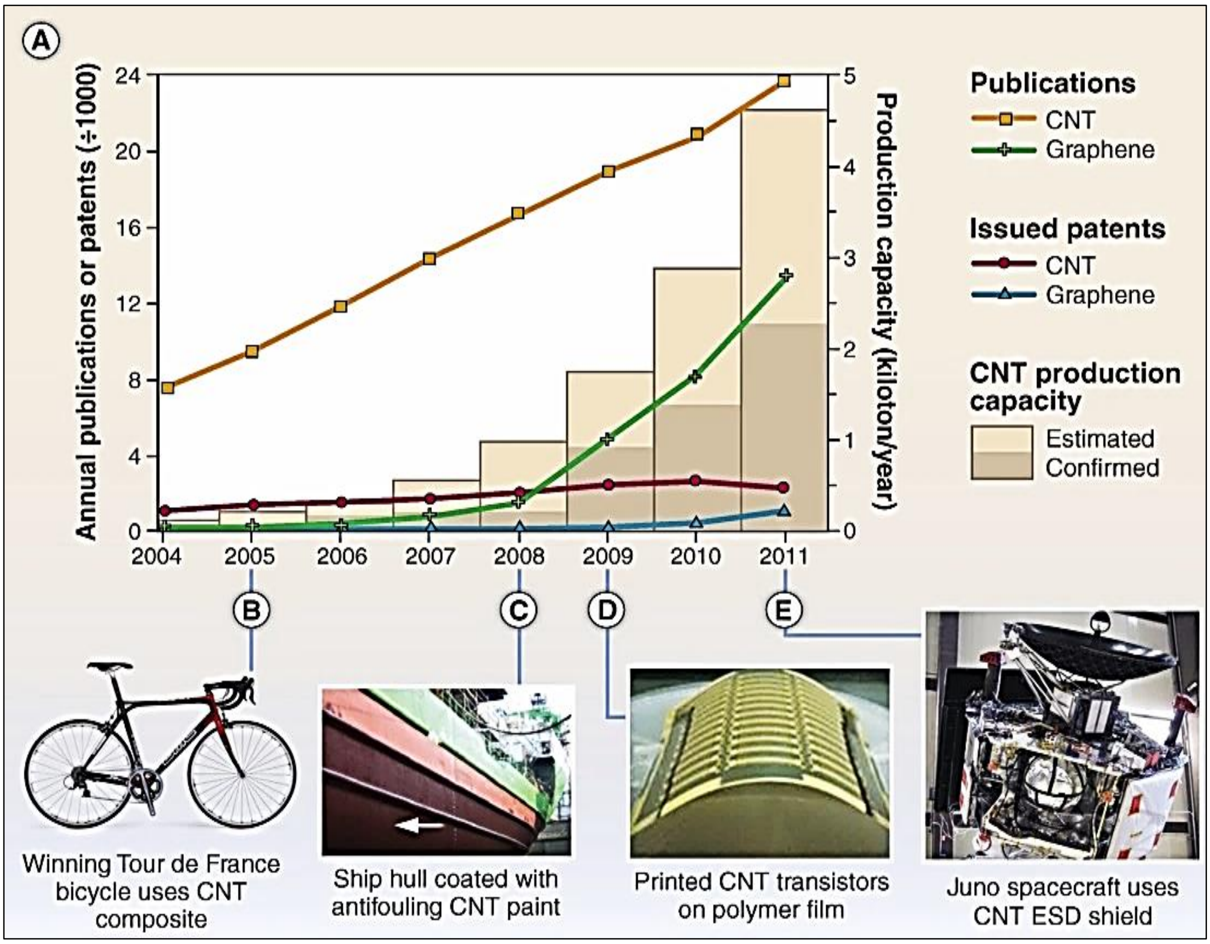

Fig. 4: *Trends in CNT Research and Commercialization.*

As larger quantities of CNT materials reach the consumer market, it will also be necessary to establish disposal and/or reuse procedures. CNTs may enter municipal waste streams, where, unless they are incinerated, cross-contamination during recycling is possible. Broader partnerships among industry, academia, and government are needed to investigate the environmental and social impact of CNTs throughout their life cycle.

CONCLUSION

Carbon nanotubes have been among the most studied materials for the past two decades, as explained above. They display remarkable properties, which has become an attraction point for various applications, especially as sensors in the field of science and technology. The science and applications of CNTs, ranging from surface chemistry to large-scale manufacturing will contribute to the frontier of nanotechnology and related commercial products for many years to come. Apart from their technological importance, CNTs are ideal model systems for the study and understanding of transport in 1-D systems and for the development of molecular fabrication technologies.

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