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Carbon nanotubes based sensing device: A review

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ABSTRACT

Carbon Nanotubes based sensors are gaining its important day by day. Carbon nanotubes are unique tubular structures of nanometer diameter and large length/diameter ratio. The nanotubes may consist of one up to tens and hundreds of concentric shells of carbons with adjacent shells separation of ~0.34 nm. The nanotubes can be metallic or semiconducting depending on their structural parameters. The strength of the sp^2 carbon-carbon bonds gives carbon nanotubes amazing mechanical properties, which make them far lighter than steel, nanotubes are also between 10 and 100 times stronger. This report is intended to summarize some of the major achievements in the field of the carbon nanotube research both experimental and theoretical in the field of sensors and other applications connection with the possible industrial applications of the nanotubes. © 2013 Trade Science Inc. - INDIA

INTRODUCTION

Nanotechnology the manipulation of matter on a near-atomic scale to produce new structures, materials, and devices offers the promise of unprecedented scientific advancement for many sec-tors, such as medicine, consumer products, energy, materials, and manufacturing. Nanotechnology has the power not only to improve existing technologies, but to dramatically enhance the effective-ness of new applications.

Research on the potential applications of nanotechnology continues to expand rapidly worldwide. The desire to harness cutting edge science and technology for enabling development has prompted global interest in emerging technologies such as information technology, biotechnology and of late nanotechnologies. Nanotechnology aims to harness the unique properties of things at the nanometer scale (one billionth of a meter) that are not displayed by their larger counterparts. Nanoscience generally deals with understanding the “nano” phenomenon and includes the investigation of the properties of various nanomaterials, control and maneuvering of matter at the nano scale. On the other hand nanotechnology involves using tools and methods for the synthesis, analysis, manufacture and application of materials, products and systems that are at the nanometer scale or incorporate facets of the same dimensions[1]. However the term “nanotechnology” is by and large used as a reference for both nanoscience and nanotechnology especially in the public domain. Nanotechnology is based on the convergence of several disciplines ranging from chemistry, material science, physics, biology and engineering. Cutting across several disciplines nanoscience and technology lends itself quite naturally to being merged with other technologies facilitating enhanced scientific and technological prospects and applications. For that reason inter and transdisciplinary research is in most cases a characteristic feature of the R&D undertaken in this field. In fact several experts have called for the use of the term "nanotechnologies" instead of "nanotechnology" as the field does not pertain to a single kind of technology intervention but encompasses several diverse applications[2]. The potential of the convergence of emerging technologies such as nanotechnology, biotechnology and information technology have created a great deal of speculation and even conviction about the advantages it could bestow on mankind.

So one of the important nanomaterial, which gaining its applicational field day by day is Carbon Nanotube. Since their discovery by Iijima, carbon nanotubes (CNTs) have attracted the attention of researchers because of their unique structure and extraordinary physical properties (Iijima, 1991). Carbon-based nanomaterials have desirable electrical, mechanical, and thermal properties, useful in developing strong, lightweight building and packing materials, in computers, and in aerospace engineering. It has been confirmed theoretically and experimentally that nanotubes possess remarkably high stiffness and strength. Carbon nanotubes also have exceptionally high electrical and thermal conductivities. The unique mechanical and physical properties of nanotubes combined with their high aspect ratio and low density have brought about extensive research in creating composite material systems to exploit these properties. Considerable interest has focused on utilizing nanotubes as passive reinforcement to tailor mechanical, electrical and thermal properties[3-6].

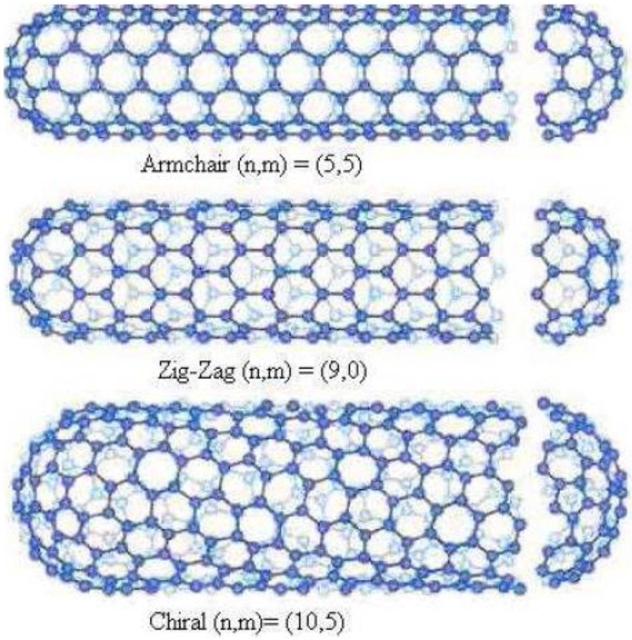
Recently, CNTs have been successfully applied as promising candidates for fabricating gas and chemical sensors, due to their high surface area, size and hollow geometry[7-9]. These authors demonstrated that small concentration of NO_2 are capable of producing large changes in the sensor conductance, shifting the Fermi level to the Valence band and generating hole enhanced conductance[10]. CNTs based sensors for detection of gases such as H_2, NH_3, CO or CH_4 have already been successfully demonstrated[11-13]. Their stability, high current capacity and low emission threshold, CNTs are expected to have application as field emission tips for flat panel displays, lamps, X-ray sources and microwave generators. The large surface, chemical stability, high electrical conductivity and high strength, CNTs are expected to be used in electrochemical devices including batteries, super capacitors, fuel cells and hydrogen storage cells[14]. In the past few years, worldwide industry has become a stronger supporter of nanotechnology and we are beginning to see its potential for broader societal impacts.

The new nanostructures are of substantial interest academically and technologically. Recently many CNT publications have discussed the preparation, characterization, functionalization, manipulation and application in fibers, fabrics and electronics and optical devices including sensors. Since sensing depends on a differential response, i.e, the difference in the response with and without analyze, we predict that applications in chemical and biochemical sensing will be realized sooner than applications such as transistors where exact control of the absolute properties of each CNT may be demanded. In the near future, the CNT will touch all manner of chemical and biochemical sensing. A brief introduction to CNT, describing its structures, properties and devices with special application. Then we discuss some of the fundamental electronics. Single Walled Nanotubes (SWNT) can be considered as long wrapped graphene sheets. As stated before, nanotubes generally have a length to diameter ratio of about 1000 so they can be considered as nearly one-dimensional structures. More detailed, a SWNT consists of two separate regions with different physical and chemical properties. The first is the sidewall of the tube and the second is the end cap of the tube. The end cap structure is similar to or derived from a smaller fullerene.

The chemical bonding of nanotubes is composed entirely of sp^2 bonds, similar to those of graphite. These bonds, which are stronger than the sp^3 bonds found in alkenes and diamond, provide nanotubes with their unique strength. The bonding in carbon nanotubes is sp^2, with each atom joined to three neighbours, as in graphite. The tubes can therefore be considered as rolled-up graphene sheets (graphene is an individual graphite layer). There are three distinct ways in which a graphene sheet can be rolled into a tube, as shown in the Figure 1. The carbon network of the shells is closely related to the honeycomb arrangement of the carbon atoms in the graphite sheets.

The first two of these, known as "armchair" (top left) and "zig-zag" (middle left) have a high degree of symmetry. The terms "armchair" and "zig-zag" refer to the arrangement of hexagons around the circumference.

The third class of tube, which in practice is the most common, is known as chiral, meaning that it can exist in two mirror-related forms. An example of a chiral nanotube is shown at the bottom.



Armchair (n,m) = (5,5)

Zig-Zag (n,m) = (9,0)

Chiral (n,m)= (10,5)

Figure 1 : Armchair, zigzag and chiral nanotubes.

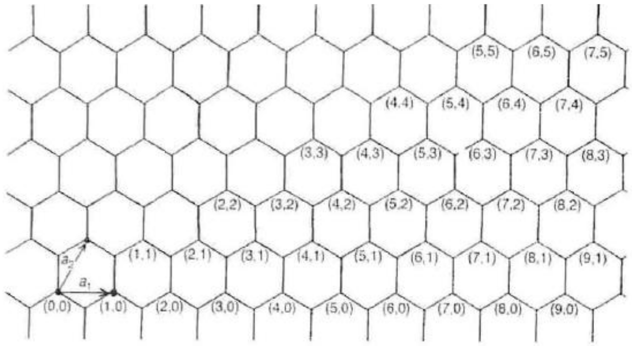


Figure 2 : Illustration of chiral classification of SWNT.

The structure of a nanotube can be specified by a vector, (n,m) as shown in Figure 2, which defines how the graphene sheet is rolled up. To produce a nanotube with the indices (6,3), say, the sheet is rolled up so that the atom labelled (0,0) is superimposed on the one labelled (6,3). It can be seen from the figure that m = 0 for all zig-zag tubes, while n = m for all armchair tubes.

SYNTHESIS OF CARBON NANOTUBES

CNTs are generally produced by three main techniques, arc discharge, laser ablation and chemical vapor deposition. Techniques have been developed to produce nanotubes in sizeable quantities and properties. The arc-evaporation method, which produces the best quality nanotubes, involves passing a current of about 50 amps between two graphite electrodes in an atmosphere of helium. This causes the graphite to vaporize, some of it condensing on the walls of the reaction vessel and some of it on the cathode. It is the deposit on the cathode which contains the carbon nanotubes. Single-walled nanotubes are produced when Co and Ni or some other metal is added to the anode. It has been known since the 1950s, if not earlier, that carbon nanotubes can also be made by passing a carbon-containing gas, such as a hydrocarbon, over a catalyst. The catalyst consists of nano-sized particles of metal, usually Fe, Co or Ni. These particles catalyze the breakdown of the gaseous molecules into carbon, and a tube then begins to grow with a metal particle at the tip. It was shown in 1996 that single-walled nanotubes can also be produced catalytically[3,4]. The perfection of carbon nanotubes produced in this way has generally been poorer than those made by arc-evaporation, but great improvements in the technique have been made in recent years. The big advantage of catalytic synthesis over arc-evaporation is that it can be scaled up for volume production. The third important method for making carbon nanotubes involves using a powerful laser to vaporize a metal-graphite target. This can be used to produce single-walled tubes with high yield.

Arc discharge

The carbon arc discharge method, initially used for producing C60 fullerenes, is the most common and perhaps easiest way to produce carbon nanotubes as it is rather simple to undertake. However, it is a technique that produces a mixture of components and requires separating nanotubes from the soot and the catalytic metals present in the crude product. This method creates nanotubes through arc-vaporization of two carbon rods placed end to end, separated by approximately 1mm, in an enclosure that is usually filled with inert gas (helium, argon) at low pressure (between 50 and 700 mbar) as shown in Figure 3. Recent investigations have shown that it is also possible to create nanotubes with the arc method in liquid nitrogen[15,16]. A direct current of 50 to 100 A driven by approximately 20 V creates a high temperature discharge between the two electrodes. The discharge vaporizes one of the carbon rods and forms a small rod shaped deposit on the other rod. Producing nanotubes in high yield depends on uniformity of the plasma arc and temperature of the deposit form on the carbon electrode.

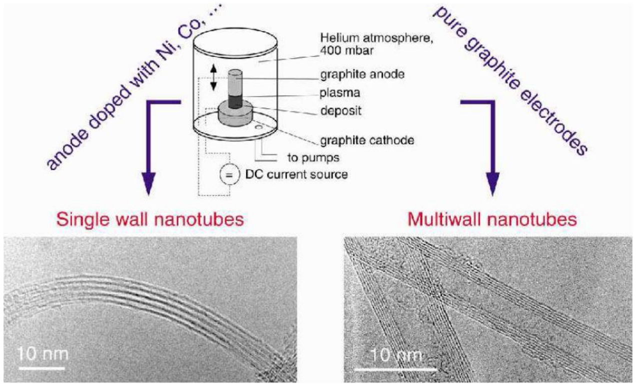


Figure 3 : Experimental set-up of an arc discharge apparatus.

Insight in the growth mechanism is increasing and measurements have shown that different diameter distributions have been found depending on the mixture of helium and argon. These mixtures have different diffusions coefficients and thermal conductivities. These properties affect the speed with which the carbon and catalyst molecules diffuse and cool, affecting nanotube diameter in the arc process. This implies that single-layer tubules nucleate and grow on metal particles in different sizes depending on the quenching rate in the plasma and it suggests that temperature and carbon and metal catalyst densities affect the diameter distribution of nanotubes[17].

If SWNTs are preferable, the anode has to be doped with metal catalyst, such as Fe, Co, Ni, Y or Mo. If both electrodes are graphite, the main product will be Multi Wall Nano Tubes (MWNTs). But next to MWNTs a lot of side products are formed such as fullerenes, amorphous carbon, and some graphite sheets. Purifying the MWNTs, means loss of structure and disorders the walls. However scientists are developing ways to gain pure MWNTs in a large-scale process without purification. The quantity and quality of the nanotubes obtained depend on various parameters such as the metal concentration, inert gas pressure, kind of gas, the current and system geometry.

Typical sizes for MWNTs are an inner diameter of 1-3 nm and an outer diameter of approximately 10 nm. Because no catalyst is involved in this process, there is no need for a heavy acidic purification step. This means, the MWNT, can be synthesised with a low amount of defects[15,16,18].

Laser ablation

In 1995, Smalley's group[19] at Rice University reported the synthesis of carbon nanotubes by laser vaporisation. The laser vaporisation apparatus used by Smalley's group is shown in Figure 4.

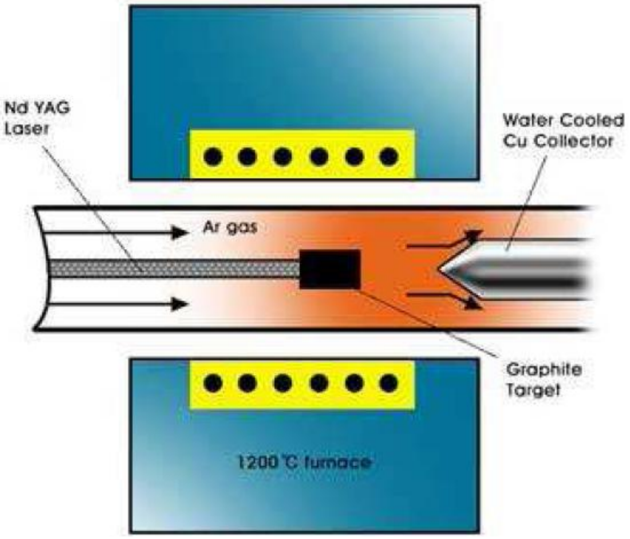


Figure 4 : Schematic drawings of a laser ablation apparatus.

A pulsed[20,21], or continuous laser[22,23] is used to vaporize 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/cm2 compared with 12 kW/cm2). 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[24]. 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 SWNTs formed in this case are bundled together by van der Waals forces.

There are some striking, but not exact similarities, in the comparison of the spectral emission of excited species in laser ablation of a composite graphite target with that of laser-irradiated C60 vapour. This suggests that fullerenes are also produced by laser ablation of catalyst-filled graphite, as is the case when no catalysts are included in the target. However, subsequent laser pulses excite fullerenes to emit C2 that adsorbs on catalyst particles and feeds SWNT growth. However, there is insufficient evidence to conclude this with certainty.

Laser ablation is almost similar to arc discharge, since the optimum background gas and catalyst mix is the same as in the arc discharge process. This might be due to very similar reaction conditions needed, and the reactions probably occur with the same mechanism.

The condensates obtained by laser ablation are contaminated with carbon nanotubes and carbon nanoparticles. In the case of pure graphite electrodes, MWNTs would be synthesized, but uniform SWNTs could be synthesized if a mixture of graphite with Co, Ni, Fe or Y was used instead of pure graphite. Laser vaporization results in a higher yield for SWNT synthesis and the nanotubes have better properties and a narrower size distribution than SWNTs produced by arc-discharge.

Nanotubes produced by laser ablation are purer (up to about 90 % purity) than those produced in the arc discharge process. The Ni/Y mixture catalyst (Ni/Y is 4.2/1) gave the best yield.

Chemical yapour deposition

Low-temperature chemical vapour deposition (CVD) apparatus has been set up in an effort to seek new processing routes for large-scale production of carbon nanotubes. Based on the early success of growing carbon fibers[25] using the pyrolytic decomposition of hydrocarbon gases, such as acetylene (C_2H_2), benzene (C_6H_6), carbon monoxide (CO), methane (CH_4) etc., the CVD technique has become one of the preferred methods for fabricating carbon nanotubes in much lower temperature regimes than is possible with the arc-discharge technique. CVD methods utilize the pyrolytic decomposition of hydrocarbon gases at elevated temperatures in the range 600–1200 °C. Several researchers have reported successful syntheses of carbon nanotubes using CVD techniques recently. For example, Endo et al[26] reported the observation of nanotubes in the pyrolytic product of benzene (C_6H_6) decomposition at about 1100 °C, Jose-Yacaman et al.[27] and Ivanov et al.[28] observed nanotubes and related nanostructures in the catalytic decomposition product of acetylene (C_2H_2) in the temperature range 1050–1350 °C, and Jaeger and Behrsing[29] found similar structures in a mixture of natural gas, methane and benzene decomposition products. In this letter we report the synthesis of carbon nanotubes at about 750 °C using a CVD technique. The reactant gases employed were high-purity methane (CH_4) and hydrogen (H_2) gases, and ferrocene ($C_{10}H_{10}Fe$) was used as catalyst. The reaction was carried out in an electrical tube furnance. A quartz tube, used as the substrate for CVD, was placed inside the ceramic furnace tube of inner diameter about 3 cm and length about 80 cm. The furnace was heated to 1150 °C in about 15 min and was kept at this temperature for about 5 min to allow the following reaction to occur with the addition of ferrocene vapours[30].:

$$\mathbf{CH_4(g) + H_2(g) \xrightarrow{600-1200\,^{\circ}C} C(s) + 3H_2}$$

PROPERTIES

The strength of the sp^2 carbon-carbon bonds gives carbon nanotubes amazing mechanical properties. The stiffness of a material is measured in terms of its Young's modulus, the rate of change of stress with applied strain. The Young's modulus of the best nanotubes can be as high as 1000 GPa which is approximately 5x higher than steel. The tensile strength, or breaking strain of nanotubes can be up to 63 GPa, around 50x higher than steel. These properties when coupled with the lightness of carbon nanotubes, gives them great potential in applications such as aerospace. It has even been suggested that nanotubes could be used in the "space elevator", an Earth-to-space cable first proposed. Far lighter than steel, nanotubes are also between 10 and 100 times stronger. They have been described as the strongest fibres known to man. Micro Newton's of force are required to break a single nanotube. No other known material possess a higher tensile strength. The practical application of the nanotubes requires the study of the elastic response, the inelastic behaviour and buckling, yield strength and fracture. Efforts have been applied to the experimental[31,32] and theoretical[33,34], investigation of these properties. Due to the sensitivity of the electronic properties of carbon nanotubes on their structure, they are suitable for preparation of metal–semiconductor, semiconductor–semiconductor and metal–metal junctions. It has been demonstrated that the nanotube junctions can be used successfully as building elements of nanoscale devices. Electrical transport through carbon nanotubes has attracted considerable interest due to the many possible applications of the nanotubes in nanoscale electronic devices.

The electronic properties of carbon nanotubes are also extraordinary. Especially notable is the fact that nanotubes can be metallic or semiconducting depending on their structure. Thus, some nanotubes have conductivities higher than that of copper, while others behave more like silicon. There is great interest in the possibility of constructing nanoscale electronic devices from nanotubes, and some progress is being made in this area. However, in order to construct a useful device we would need to arrange many thousands of nanotubes in a defined pattern, and we do not yet have the degree of control necessary to achieve this. There are several areas of technology where carbon nanotubes are already being used. These include flat-panel displays, scanning probe microscopes and sensing devices. The unique properties of carbon nanotubes will undoubtedly lead to many more applications. The image of the SEM image of the bundle of carbon nanotubes containing both SWCNT and MWCNT are shown in Figure 5.

The properties of nanotubes have caused researchers and companies to consider using them in several fields. For example, because carbon nanotubes have the highest strength to weight ratio of any known material, researchers at NASA are combining carbon nanotubes with other materials into composites that can be used to build lightweight spacecraft[34-39].

Another property of nanotubes is that they can easily penetrate membrances such as cell walls. In fact, nanotubes long, narrow shape make them look like miniature needles, so it makes sense that they can function like a needle at the cellular level. Medical researchers are using this property by attaching molecules that are attracted to cancer cells to nanotubes to deliver drugs directly to diseased cells[40].

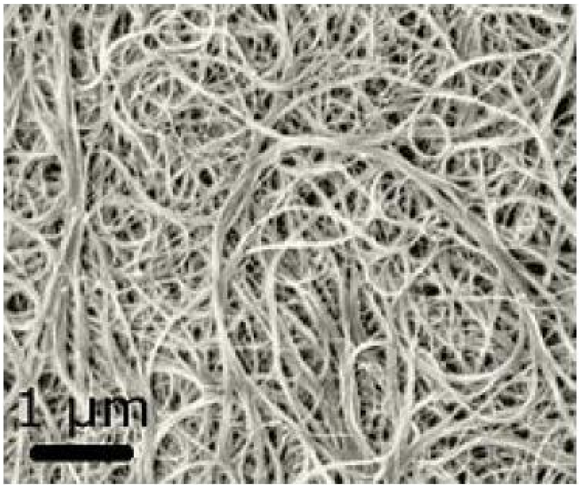


Figure 5 : A scanning electron microscopy image of carbon nanotubes bundles.

Another interesting property of carbon nanotubes is that their electrical resistance changes significantly when other molecules attach themselves to the carbon atoms. Companies are using this property to develop sensors that can detect chemical vapors such as carbon monoxide or biological molecules. Researchers and companies are working to use carbon nanotubes in various fields. The list below introduces many of these uses. Nanotubes bound to an antibody that is produced by chickens have been shown to be useful in lab tests to destroy breast cancer tumors. The antibody carrying nanotubes are attracted to proteins produced by a one type of breast cancer cell. Then the nanotubes absorb light from an infrared laser, incinerating the nanotubes and the tumor they are attached to. Lightweight windmill blades made with an epoxy containing carbon nanotubes. The strength and low weight provided by the use of nanotube filled epoxy allows longer windmill blades to be used. This increases the amount of electricity generated by each windmill. Nanotube electrodes in thermocells can generate electricity from waste heat. Inexpensive nanotube based sensor that detects bacteria in drinking water. Antibodies sensitive to the particular bacteria are bound to the nanotubes, which are then deposited onto a paper strip. When the bacteria is present it attaches to the antibodies, changing the spacing between the nanotubes and the resistance of the paper strip containing the nanotubes. A lightweight, low power anti-icing system using carbon nanotubes in a layer coated onto aircraft wing surfaces. Using gold tipped carbon nanotubes to trap oil drops polluting water[41-47].

CARBON NANOTUBE BASED SENSORS

Advantages of CNTs over other materials are due to their small size, high strength, high electrical and thermal conductivity, and high specific area. Therefore, several manuscripts have been published utilizing CNTs as the sensing material in pressure, flow, thermal, gas, optical, mass, position, stress, strain, chemical, and biological sensors. When uniform air pressure was applied on the membranes, a change in resistance in the SWNTs was observed. Moreover, the membrane was restored to its original condition when the gas was pumped out, indicating that the process is reversible. Dharap et al.[41] argued that the convenconventional sensors have disadvantage that they are discrete point, fixed directional, and are not embedded at the material level. To overcome these limitations, they developed a CNT film sensor for strain sensing on macro scale. The sensor was based on the principle that the electronic properties of CNTs change when subjected to strains. As randomly oriented bundles of SWNTs were used by them, the film was isotropic in nature. The isotropic nature of CNT films helps in measuring strains in multiple locations and in different directions. The experimental results revealed nearly linear relationship between the measured change in voltage and the strains in CNT films when they are subjected to tensile and compressive stresses. Wu et al.[42] demonstrated using first-principle quantum transport calculations, molecular-dynamics simulation and continuum mechanics analysis that hydrostatic pressure can induce radial deformation, and therefore, electrical transition of SWNTs. A pressure-induced metal-to-semiconductor transition in armchair SWNTs was observed, which provides a basis for designing nanoscale tunable pressure sensors. Sotiropoulou and Chaniotakis[43] developed an amperometric biosensor using CNTs as immobilization matrix. The study by Kong et al.[44] revealed that the electrical resistance of semiconducting SWNTs dramatically changes when exposed to gaseous molecules such as nitrogen dioxide (NO_2), ammonia (NH_3), and oxygen (O_2). It was found that the response times of nanotube sensors are at least an order of magnitude faster than those based on solidstate sensors. However, Modi et al.[7] argued that the carbon nanotube gas sensors based on electrical conductance changes have certain limitations, such as poor diffusion kinetics, inability to identify gases with low adsorption energies, and low capability to distinguish between gases or gas mixtures. They also noted that the conductance of CNTs is highly sensitive to changes in moisture, temperature and gas-flow velocity. To overcome these limitations, they proposed gas ionization sensors featuring the electrical breakdown of a range of gases and gas mixtures at the tips of CNTs. The cathode used for the purpose was aluminium and the anode was vertically aligned MWNT film (~25–30 nm in diameter, ~30 μm in length, and ~50 nm separation between nanotubes) grown on SiO_2 substrate. The electrodes were separated by a glass insulator. The sensors developed by them were found to have good selectivity and sensitivity, and were unaffected by various environmental conditions (moisture, temperature, and gas-flow). Snow et al.[45] demonstrated that the capacitance of SWNTs is highly sensitive to a wide range of vapors and, therefore, fast, low-power based chemical sensors can be formed using this mechanism. In another study, Jang et al.[46] proposed a chemical sensor employing laterally grown MWNTs as the active sensing element. It was found that the electrical resistance of MWNTs changes upon exposure to air or NH_3. They observed that an increase in measurement temperature and gas concentration resulted in fast response time and higher sensitivity.

Surface acoustic waves (SAWs) sensors coated by CNTs were fabricated by Penza et al.[47] for chemical detection of volatile organic compounds (such as ethanol, ethyl acetate, and toluene in nitrogen). CNT-coated SAW sensors were found to be highly sensitive during experiments. A gas sensor comprising of MWNT-silicon dioxide (SiO_2) composite was demonstrated by Ong et al.[48]. The sensor was built on the principle that the conductivity and permittivity of the composite changes with the absorption of different gases in the MWNT-SiO_2 layer. The humidity, temperature and concentrations of carbon dioxide, oxygen, and ammonia can be determined by tracking the frequency spectrum of the sensor with a loop antenna. It has the advantage of allowing remote monitoring conditions inside the opaque, sealed containers. Santhanam et al.[49] developed a chemical sensor using a nanocomposite of MWNTs and poly (3-methylthiophene). Upon exposure to different chloromethanes, the sensor showed a change in electrical resistance. The response time of the sensor was found to be 60 to 120 sec. Wong and Li[50] manipulated bulk MWNTs by AC electrophoresis to form resistive elements between Au microelectrodes and demonstrated that MWNTs can potentially serve as temperature sensors. Barone et al.[51] developed near-infrared optical sensors based on SWNTs making use of the fact that CNTs fluoresce in a region of the near infrared where human tissue and biological fluids are particularly transparent to their emission. Li and Chou[52] developed SWNT-based sensors to measure strainand pressure at nanoscale on the basis of the shift in resonant frequency of carbon nanotube resonator when subjected to a strain resulting from an external loading. Simulation studies by atomistic modeling revealed that the resonant frequency shifts are linearly dependent on the applied axial strain and the applied pressure. It was also found that the reduction in tube length and diameter enhances the sensitivities of sensors. A room temperature sensor based on carbon nanotubes and nanofibres was developed by Roy et al.[53]. Good sensing properties of films at room temperature were found. Chopra et al.[54] have reported the development of microwave resonant sensors coated with either SWNTs or MWNTs for detection of ammonia. The experiments revealed that SWNT sensors were more sensitive than the MWNT sensors. The sensor system designed by them is suitable for applications that prohibit the use of physical connections or require non-destructive testing. In their study, Someya et al.[55] reported alcohol vapour sensors based on SWNT field effect transistors (FETs). When the saturated ethanol vapour is delivered to the surface, a sharp spike is observed after a few seconds and then the current decreases and reaches a steady value. Recently, new chemical sensors based on single-stranded DNA (ss-DNA) as the chemical recognition site and SWNT field effect transistors as the electronic read-out component have been proposed by Staii et al.[56]. These sensors were able to detect variety of gases with rapid response and fast recovery times. These sensors are self-regenerating; samples maintain a constant response with no need for sensor refreshing for approximately 50 gas exposure cycles. These features make these sensors suitable for applications ranging from homeland security to disease diagnosis.

SUMMARY

Research activity in the areas related to CNTs has seen phenomenal growth in the last one and half decade. In this paper, an attempt has been made to provide the most contemporary overview possible of CNT and their potential applications. The exceptional properties, which allow CNTs to be used in sensors and other devices, have also been reviewed. The use of CNT will increase the sensitivity and dynamic range of sensors.

So due to great sensitivity against toxic fumes and other harmful gases of blasting they can be used in the development of significant gas sensors (i.e. for CO, CH_4, NOx and other) The developments of integrated circuits, which can detect, convert, process, and amplify minute signals, is required from the microelectronic community. We need an effective interface to the nano-material in order to extract the embedded signals. It is expected that many applications of CNT-based sensors will be explored in future as the interest of the nanotechnology research community in this field increases.

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