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Recent Advances in Carbon Nanotube Flow-Sensor: A Review

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ABSTRACT: The flow of a liquid on single walled carbon (SWNTs) or multi-walled Nanotube (MWNTs) bundles induces a voltage in the sample along the direction of the flow. The magnitude of the voltage depends on the sensitivity on the ionic conductivity and on the polar nature of the liquid. This makes nanotubes as highly sensitive flow sensors and energy conversion devices. Carbon nanotubes have been among the most studied materials during the last two decades. They have many remarkable properties, such as high tensile strength, electrical conductivity however, one of the unique property is its viscoelastic behaviour in a wide range of temperature that is not shown even by any solid so far. The present article reviews the recent advances in carbon and its allotropes, the allotropes that are used to develop nanotubes, the wonderful properties of nanotubes and their applications in science and technology with special emphasis on the carbon Nanotube flow sensors.

KEYWORDS:Allotropes, Carbon nanotube, flow sensors, electrical conductivity, viscoelasticity.

I. INTRODUCTION

Carbon has maximum allotropes [1] as it is capable for creating the most diverse variety of compounds [2]. Fullerenes and nanotubes are the latest addition to this list [3]. The most studied allotrope of carbon is Graphite which has a two dimensional structure due to sp^2 hybridization. Diamond is another important allotrope of carbon with sp^3 hybridization. The two-dimensional sheets made of sp^2 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 result in a closed cage structure [4]. 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. Tube can be open or closed and length can be several hundred times the width. The structure of a cylinder is described in terms of a tubular diameter *d* and a chiral angle theta, . The chiral vector $C=na_1+ma_2$ along with two parameters d and define the tube. The unit vectors a_1 and a_2 define the graphene sheet (a single sheet of graphite is called graphene [5], a carbon nanotube is produced by curling a graphene sheet) [6]. The properties of the tube get modified depending on the chiral angle and the diameter *d*.

Carbon nanotubes were first noticed in the graphite soot deposited on the negatively charged electrodes used in the arc-discharge synthesis of Fullerenes [7]. Due to its unparalleled properties it finds use in wide range of applications [8, 9, 10, 11].

II. RELATED WORK

Several authors have studied preparation properties and applications of carbon and its allotropes[1, 2, 3, 5] such as fullerenes, carbon nanotubes, nanowires, nanorods, nanocomposites, nanocrystals. All these nano materials have been studied in detail and many reviews have also been written[4, 5, 7]. They have wonderful properties [8, 9, 10, 11] which have drawn attention of scientists and technologists to research and develop new techniques using these materials. The challenges such as creating efficient heat sinks, super conduction in electronics, cancer therapy in medical science, etc., can all be overcome by exploiting the potential of these allotropes. A lot of work has been reported so far on the nanomaterials, however, the wonderful applicationof carbon nanotubes in flow sensor[27] seems greatly neglected. The author has made an effort to emphasize on this important application which has a

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great future especially in the science of gas spectrometry and analysis as it offers a cheap and highly efficient device for the same. Thus, the properties of carbon nanotubes specifically pertinent to the application of flow sensor have been compiled and described here.

III.PROPERTIES OF CNTS

Carbon Nanotubes (CNTs) shows excellent physio-chemical properties [12].

1) Electronic properties: It depends on the chirality. There are three structures such as zigzag, chiral and armchair. The first two can be semi-conducting or metallic, but armchair is always metallic. This means that nanotubes can be treated as quantum wires at least at very low temperatures.

2) Mechanical properties: The strength of C-C bond is among the highest, as a result any structure with this bond will have ultimate strength. Nanotubes therefore are highly strong carbon fibers [13].

3) Physical properties: Nanotubes have a high strength to weight ratio (1.8g/cm^2 for MWNTs and 0.8g/cm^2 SWNTs) [14]. This property is very useful for lightweight applications. This value is 100 times that of steel and over twice that of conventional carbon fibers. Nanotubes are also highly resistant to chemical attack [15]. It is difficult to oxidize them [16]. Temperature is also not a limitation in practical applications of nanotubes [17]. Nanotubes have a high thermal conductivity [18] and the conductivity increases with the decrease in diameter.

IV. APPLICATIONS OF NANOTUBES

Use of Nanotubes as electrical conductors is an exciting possibility [19]. Nanotube based single molecule field effect transistor [20] is already been built and its performance is comparable to that of semiconductor based devices, but its integration into circuits still require a lot of effort [21]. It has been found that it is not possible to fabricate nanotube based connectors. This developed a need to make devices that can adopt newer kind of approaches for making contacts. Such interconnectors between structures patterned on substrates have also now been made. One of the areas of immediate commercial application of nanotubes is CNT based emission-displays [22]. Here CNTs act as electron emitters at lower turn-on voltages and high emissivity.

Nanotubes tips can also be used as nanoprobes [23]. The functionalization of tips can also be used in chemical force microscopy. Research has also shown that nanotubes have the ability to store hydrogen [24].

A flow sensor using nanotubes has also been demonstrated. The flow generates an electrical potential of the order of few millivolts. The potential is sensitive both to flow velocity as well as the dipole moment of the analyte. Gas flow sensors have been developed along similar lines. Nanotube based gas sensors have also been developed [25]. Nanotube-based filters have also been demonstrated as a wonderful application.

V. INTRODUCTION TO FLOW SENSORS

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. Applications where coating can occur poses potential problems in devices such as magnetic and ultrasonic units. If the coating is insulating and electrodes get insulated then the operation of magnetic flow meters is ultimately impaired. Similarly with ultrasonic flow meters, refraction angles may change and the sonic energy absorbed by the coating cause the meter to become inoperative.

VI.MECHANISM OF CNT FLOW SENSOR

Several studies have been made to understand the novel behavior of Carbon nanotubes such as their structural, electronic and mechanical properties and to explore their immense potential for its applications in nano electronics as

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actuators [26] and sensors [27]. Scientists have shown theoretically the generation of electric current in a metallic carbon nanotube immersed in a flowing liquid. Two mechanisms are discussed here :

1. One mechanism they have suggested for the generation of electric current and voltage is the transfer of momentum from the flowing liquid molecules to the acoustic phonons in the nanotube as the phonon quasi-momentum which in turn drags free charge carriers in the nanotube [28].
2. Another mechanism suggested by these authors involves a direct scattering of the free carriers from the fluctuating coulombic fields of the ions or polar molecules in the flowing liquid.

The latter mechanism suggests that a current that is five times in magnitude smaller than the current that results from the phonon-induced electron drag.

This led them to propose a mechanism for the observed flow induced voltage based on a pulsating asymmetrical thermal rachet model [29]. This mechanism involves the fluctuating coulombic potentials that result from the ionic liquid in flow, where the symmetry is provided by velocity gradient (sheer) at the liquid-solid interface. Finally, a flow sensor that is based on SWNT [30] directly produces an electrical signal in response to a fluid flow. It is believed that this sensor can be scaled down to length dimensions on the order of micrometers, i.e., the length of the individual nanotube making it usable even in very small liquid volumes. The sensor also has high sensitivity at low velocities and fast response time (better than 1ms). The nanotubes also could be used to make a voltage and current source in a flowing liquid environment which have numerous interesting engineering and biomedical applications [9, 31, 32].

VII. CONCLUSION

Carbon nanotubes have been among the most studied materials for the past two decades, as explained above they display remarkable properties [12] which has become an attraction point for various applications especially as sensors in the field of science and technology [33]. Researchers in this field are leaving no stones unturned to make use of these properties in the implementation and improvement of technology that may further lead to the improvement of lifestyle. In other words the core novelty in science and technology on the scale of nanometer is that the scientists and technologists do not invent the word *ex novo* as in the past but *de novo* since the new artifacts are made of components that have no natural analogs. The term “nano” refers to measurement, the nanometer as it indicates the size of the matter and does not refer to any object. This explains the unlimited spectrum of nano since all physical matter irrespective of its nature can be measured. Nanoscience is not limited to traditional boundaries of disciplines, but is trans-disciplinary [34] in nature. It controls building blocks of all objects of the living and non-living world, thus influencing each and every area of life. Its knowledge and implementation will take science and technology to another level that is most desired now.

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REFERENCES

[1] Pierson, Hugh O. “Handbook of carbon, graphite, diamonds and fullerenes: processing, properties and applications ” William Andrew, 1994.
[2] Sederberg, D. “Allotropes of carbon: It’s all in the way you’re put together”. http://www.physics.purdue.edu/psas/, 2009.
[3] Hirsch, A. (ed) “Frontmatter, in The Chemistry of the Fullerenes”, Wiley-VCH Verlag GmbH, Weinheim, Germany. doi: 10.1002/9783527619214.fmatter, 1994.
[4] Ugarte, D., et al. "Filling carbon nanotubes." *Applied Physics A: Materials Science& Processing* 67.1: 101-105,1998.
[5] Geim, Andre K., and Konstantin S. Novoselov. "The rise of graphene." *Nature materials* 6.3: 183-191,2007.
[6] Ebbensen T. W. & Ajayan P. M., “Large-scale synthesis of carbon nanotubes”; Nature 358, 220 - 222 doi:10.1038/358220a0, 1992.
[7] Iijima, Sumio"Helical microtubules of graphitic carbon". *Nature* 354 (6348): 56-58.Bibcode:1991Natur.354...56I. doi:10.1038/354056a0, 1991.
[8] Endo, Morinobu, et al. "Applications of carbon nanotubes in the twenty–first century." *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences* 362.1823: 2223-2238,2004.

[9] Baughman, Ray H., Anvar A. Zakhidov, and Walt A. de Heer. "Carbon nanotubes--the route toward applications." *Science* 297.5582: 787-792,2002.
[10] Král, Petr, and H. R. Sadeghpour. "Laser spinning of nanotubes: A path to fast-rotating microdevices." *Physical Review B* 65.16: 161401,2002.
[11] Yoshino, Katsumi, et al. "Electrical and optical properties of conducting polymer-fullerene and conducting polymer-carbon nanotube composites."*Fullerene science and technology* 7.4: 695-711,1999.
[12] Zhang, Shunli, et al. "Morphological structure and physicochemical properties of nanotube TiO2." *Chinese Science Bulletin* 45.16: 1533-1536,2000.
[13] Berhan, L., et al. "Mechanical properties of nanotube sheets: Alterations in joint morphology and achievable moduli in manufacturable materials." *Journal of Applied Physics* 95.8: 4335-4345,2004.
[14] Barber, Asa H., et al. "On the tensile strength distribution of multiwalled carbon nanotubes." *Applied Physics Letters* 87.20: 203106,2005.
[15] Ryu, Jungki, and Chan Beum Park. "High stability of self-assembled peptide nanowires against thermal, chemical, and proteolytic attacks." *Biotechnology and bioengineering* 105.2: 221-230, 2010.
[16] Shao, Yuyan, et al. "Comparative investigation of the resistance to electrochemical oxidation of carbon black and carbon nanotubes in aqueous sulfuric acid solution." *ElectrochimicaActa* 51.26 : 5853-5857, 2006.
[17] Gogotsi, Yury. "High-temperature rubber made from carbon nanotubes."*Science* 330.6009 : 1332-1333, 2010.
[18] Che, Jianwei, TahirCagin, and William A. Goddard III. "Thermal conductivity of carbon nanotubes." *Nanotechnology* 11.2: 65, 2000.
[19] Ebbesen, T. W., et al. "Electrical conductivity of individual carbon nanotubes.": 54-56, 1996.
[20] Martel, Richard, et al. "Single-and multi-wall carbon nanotube field-effect transistors." *Applied Physics Letters* 73.17: 2447-2449, 1998.
[21] Collins, Philip G., Michael S. Arnold, and PhaedonAvouris. "Engineering carbon nanotubes and nanotube circuits using electrical breakdown." *Science*292.5517 : 706-709, 2001.
[22] Lee, N. S., et al. "Application of carbon nanotubes to field emission displays."*Diamond and related materials* 10.2 : 265-270, 2001.
[23] Dai, Hongjie, et al. "Nanotubes as nanoprobes in scanning probe microscopy."*Nature* 384.6605 : 147-150, 1996.
[24] Schlapbach, Louis, and Andreas Züttel. "Hydrogen-storage materials for mobile applications." *Nature* 414.6861 : 353-358, 2001.
[25] Wang, Yun, and John TW Yeow. "A review of carbon nanotubes-based gas sensors." *Journal of Sensors*, 2009.
[26] Baughman, Ray H., et al. "Carbon nanotube actuators." *Science* 284.5418 : 1340-1344, 1999.
[27] Ghosh, Shankar, A. K. Sood, and N. Kumar. "Carbon nanotube flow sensors."*Science* 299.5609 : 1042-1044, 2003.
[28] Park, Ji-Yong, et al. "Electron-phonon scattering in metallic single-walled carbon nanotubes." *Nano Letters* 4.3 : 517-520, 2004.
[29] Xu, Zhiping, Quan-ShuiZheng, and Guanhua Chen. "Thermally driven large-amplitude fluctuations in carbon-nanotube-based devices: molecular dynamics simulations." *Physical Review B* 75.19 : 195445, 2007.
[30] Chen, Yuan, et al. "Low-defect, purified, narrowly (n, m)-dispersed single-walled carbon nanotubes grown from cobalt-incorporated MCM-41." *ACS nano* 1.4 : 327-336, 2007.
[31] Zhang, Xueji, HuangxianJu, and Joseph Wang, eds. "Electrochemical sensors, biosensors and their biomedical applications." Academic Press, 2011.
[32] Sinha, Niraj, and John T-W. Yeow. "Carbon nanotubes for biomedical applications." *IEEE Transactions on NanoBioscience*4.2: 180-195, 2005.
[33] Rao, C. N. R., et al. "Nanotubes and nanowires." *Chemical engineering science*59.22: 4665-4671, 2004.
[34] Blau, Werner J., and Alexander J. Fleming. "Designer nanotubes by molecular self-assembly." *Science* 304.5676: 1457-1458, 2004.

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