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Carbon Nanotubes-Based Gas Sensor

Vahid Behtaji Siahkal Mahalleh[1],Elnaz Karimpour[2],Farshad Davoudifar[3],Ali Hosseingholipourasl[4]
[1,2,3,4] *(Department of Electrical Engineering, UTM Skudai)*

ABSTRACT : forsome past decades, the studies on carbon nanotubes-based sensor has become increasingly and tremendously popular. This paper presents the discussion about carbon nanotubes based as gas sensor. Nowadays,following the changes in the world, research about this type of sensor is a crucial issue. Many methods have been proposed to make this type of gas sensors response better and enhance their performances. The basic materials 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. The basic knowledge about the properties of carbon nanotubes is crucial in order to develop multi-functional material systems. The fundamental characteristics of electromechanical carbon nanotubes (CNT) and their application in development of nano-scale based gas sensor that has been discussed before will be reviewed in the current study. In future, the progression and development of the CNT as gas detection and sensors will be more

INDEX : Carbon Nanotubes, gas sensor, Single wall carbon nanotubes.

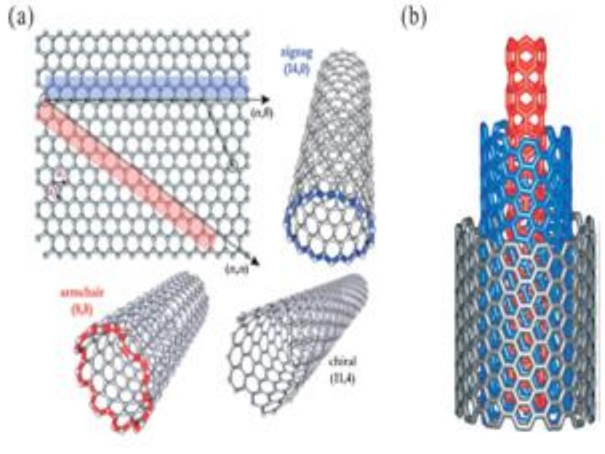

Figure 1(a): Schematic drawing of the roll-up vectors (n,m) of a CNT showing armchair (n=m), chiral (n¼6 m) and zigzag (n,0) SWNTs
Figure 1(b): Conceptualized depiction of a multiwalled carbon nanotube (MWNT) with concentrically nestled walls.

I. INTRODUCTION

The industry in sensory devices, nowadays, has becomes overflowed with the development of carbon nanotubes based sensor.The basic properties of the carbon nanotubes make them a better choice of micro-electro-mechanical material in sensory devices.Thiscarbon nanotubes characteristic depends on wall thickness, the number of concentric cylinders, cylinder radius, and cylinder length. The carbon nanotubes have a unique property called chirality, an emergence of the vertically twisting. The 3 main types of chiral are zigzag, armchair and chiral shown in Figure 1(a). Carbon nanotubes types are categorized into 2 types: a single cylinder known as Single Wall Carbon Nanotubes (SWCNTs) revealed in Figure 1(a); and two or more concentric cylinders known as Multi Wall Carbon Nanotubes (MWCNTs)depicted in Figure 1(b).[1-3] The materials usually used in gassensors are semiconductor metal oxides,vapor-sensitive polymers and other porous designed materials consideredas porous silicon. The desorption and the adsorption of gas molecules on sensing materials is the common gas sensors' principle. It is easy to understand that the sensitivity can increase significantly by enhancing the contact interfaces between sensing materials and the analyses.

Single walled carbon nanotubes are formed by creating a cylindrical shape of graphene, with the diameter of 0.4 to 2.0 nm. Multi walled carbon nanotubes is a combination of several layers of SWCNTs that are eccentric together. The diameter for both SWCNTs and MWCNTs is between a fraction of one of nanometer to tens of nanometers. The length of both can be up to several centimeters[2].The action of nanotube based field-effect Transistor (NTFET) processes are affected by different ranges of metallic and semiconducting CNTs. Based on research by Martel et al, and according to Figure2 NTFETprocesses are created through distinction of CNTs among drain(D) and source (S) electrodes by a Si back gate split via a Si divided layer. As figure 3 illustrates, an AFM copy of an NTFET process is made of a combination of a separate semiconducting SWNT. Based on Allen et al.,a potential barrier is advanced at the interface via a metal and a semiconductor which are transported into an interface of potential barrier naturally related to a Schottky barrier (SB) as mentioned by Zangwill on his study.

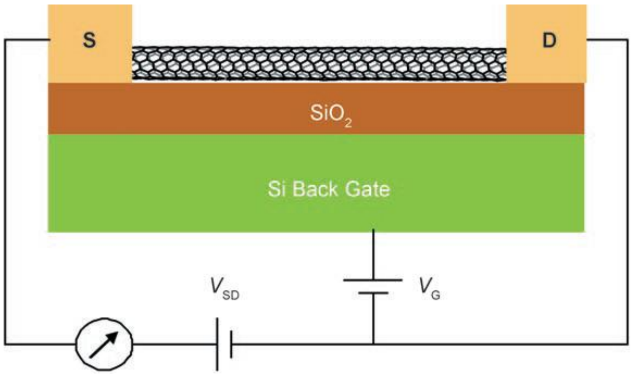

Figure 2: Nanotubes field-effect Transistor (NFET) with semiconducting SWNTs

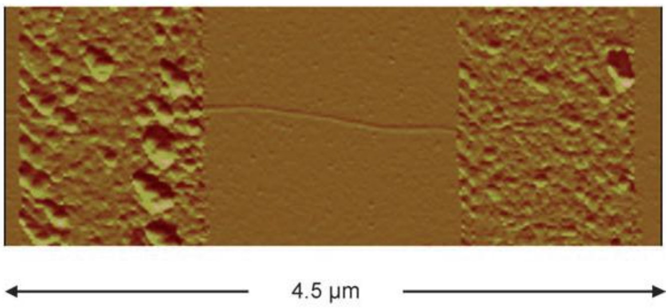

Figure 3: Image of AFM of typical NTFET

Figure 4 demonstrates NTFETprocesses, the level of the SB relying upon the function of the metal [2]to apply a potential toward the gate electrode that influences the conduction of semiconducting CNTs marked as VG.The functional VG aids to adapt the SB. Thus, the Prospect of holes (h+) itinerantssince the metal connection inside the CNT valence band. Transfer characteristic I-VG can be produced by sweeping VG among negative and positive voltages less than a constant bias [Figure 4]. The metal work function of the process contact is related to the CNT conductance that is shown in figure 4.

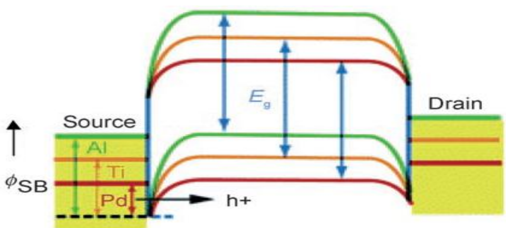

Figure 4: Schottky Barrier (SB) on the SWCNTs-metal-contact interface.

The whole surface of atoms composes the CNT condition channel that expert at monitoring molecular environments of NTFETs. Finally, NTFETs act like SBTs the work function of the process contact can be affected in order to make them extremely sensitive [4]. modifying of the SB at the CNT metal interface can be served as chemical interaction with the process contact[5]. The lack of clarity over the signal transduction mechanism of NTFET process can made via SB adjustment.

II. LITERATURE REVIEW

Some gas sensors were designed by this principle 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 for the gas sensors. To solve of these problems, high voltage and insecurity of gas sensors has been limited and replace by using CNTs based gas sensor.[6]

The development and research about enhancement of carbon nanotubes properties have been carried out due to some issues. The high cost for production is the main issue because there are not many companies produce CNTs for commercial purposes[7]. The knowledge about the growth mechanism is also play major issues due to difficulty level to produce continuous perfectly nanotubes in such microscopic length. To produce such big scale of nanotubes structures requires a continuous control of growth the nanotubes on surface.

Based on several journals, many developments on fabrication of carbon nanotubes (CNTs) have been made due to demands on better performance including response time and higher sensitivity. The enhancements of both SWCNT and MWCNT have been studied and various methods have been proposed. According to Teerapanich, P., et al.[8], using interdigitated silver electrode (IDE), it was shown that the sensitivity of the sensor can be enhancedthrough this simple and inexpensive technic including dispersion and shaking the sensor into specified solution. The result shows that the performance gives maximum response to 500 ppm and NI about 27.3 % in room temperature.

The other method proposed for sensitivity enhancement is by fabricating the SWCNTs using electrophoresis (DEP)[7]. The spin column and dextran-based gel technic is applied to capture the CNTs onto micro electrode. The trapped DEP is able to detect ppm gas level at room temperature.

III. CARBON NANOTUBES BASED GAS SENSOR

Nowadays, carbon nanotubes havebeenillustrated as sensitivitynoticed to be used by gas sensor; for example, NH3, NO2, CO, O2 and H2. Later, a lot of works have been done and continuously being done to manipulate the sensitivity of carbon nanotubes on the subject of new development of micro sensor technology.

A. CNTs for Nitrogen Dioxide and Ammonia

NH3 and NO2 are very useful to make avariety 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 surrounding. To avoid such malicious outcomes, proper detection of these gases is a lot in demand. Development of highly sensitive devices for monitoring and controlling purposescontinued intensively around the world. The major issues of this sensor are the selectivity and performance including response time and recovering time of the sensor. CNTs based sensor has been experimented as better choice to overcome the mentioned issue [3].

B. CNTs for Hydrogen Gas (H2) and Methane Gas (CH4) Sensor

The accuracy of measurement of the concentration of H2 and CH4 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 H2 well but after discussion about its functionalization, the level of sensitivity is reported increased[2], it means that

- The sensitivity of Pd has amajor effect on H2 gas ppm level in SWCNTs[9]. When the thin layer of Pd on H2 is ceased into hydrogen atoms on the surface of Pd (at room temperature), the Pd work function will be lost and the electron will prompt into the SWCNTs
- After H2 gas is disappeared from the process, the molecule of O2 will retaliate with H2 gas in the process and turns into H2O
- The process is finished when the SWCNTs' state returns into the conductance.

- The response time for the process is about a few seconds at 40 to 400 ppm sensing level

The recovery time is about 400 seconds. SWCNTsuse electron evaporation, which change the form of the particle of Pd to the SWCNTs. The basic principle of CNTs for H2 was first detected and recovered.

C. CNTs for Hydrogen Sulfide (H2S) and Sulfur Dioxide (SO2)Sensors

Precise and early detection of H2S and SO2 is vital for security defense and ecological purposes. The reaction of gases such as SO2 is a major principle of petroleum refining activities and is environmentally dangerous due to the ability to form acid rains; moreover, it can encourage health nuisance such as respiratory problems. Dangerous and unsafe gases like H2S are prone to explode and be toxic because of 4% of lower-explosive-limit (LEL). The growth of H2S is a critically distressed in petroleum refineries activities. SO2 has been revealed to adsorb onto nude CNT with a result alike to NO2.In spite of this, informationof CNT sensors for this gas is limited. The sensitivityof CNT in the presence of SO2 gas resulted in regularapparatus manners with electron donating class. The need todetailed reports about the progress of CNTs sensors for the detection of SO2 and H2S suggests additional research on the relations between CNTs and SO2 and H2S [10].

D. CNTs for Carbon Dioxide

The proficiency to observe CO2 is significant for medical reasons and personal safety.CO2 is one of the most dangerous gases if its level is more than 5% thus it can be toxic. Capnography is the volume of CO2 in human breath that no dispersive infrared (NDIR) sensors is use for measuring it [2]. According to Fowler and Berengo, NDIR can consume lower power, that has odd long term stability and accuracy. So they are advantageous to utilize NDIR CO2 sensors. Moreover, this kind of sensors can gauge the lowest range of CO2, and the volume of an intense CO2 taking in wavelength decreases interference. Technology of the structure of these types of sensors has been combined with portable techniques for pre-hospital care but the high cost of this technology might stop general use[5].

According to the investigation of Zhao et al.,it was proved that net transferal of nearly 0.015 electrons into the CNT for each adsorbing molecule causes to adsorb CO2. Yet, it has been shown experimentally. Actuators studied by Varghese et al.showed a lower detection restrict of nearly 10% CO2 by cross sensitivity to CO2 via their impedance based CNT gas sensors. Ong et al. demonstrated sensitivity to CO2 via the expansion of a wireless CNT based gas sensor. Changing a slight layer of a CNT-SiO2 compound on a level capacitor-inductor resonant circuit can detect changing absorptions of CO2 via observing the permittivity of the CNT compound. Their structure permitted a quantity of CO2 absorptions of 0-100% which is different proportion of temperature and humidity with a response time of nearly 45s. Moreover, according to Zibo's theory, 0-15% CO2 can be gaugedemploying a CNT- founded resonator-frequency sensor that permitted a minor detection bound of nearly 1% CO2(10 000 ppm)[11, 12].

Research by McCaldin et al indicated that NTFETs functionalized via a starch and a polymer matrix comprising of PEI that showed good sensitivity to CO2[13]. The CO2 concentration was scaled linearly by device conductance. According to Douglas R. Kauffman and Alexander Star's theory there are two mechanisms for response originated as a probable combination: 1) the overall electron-donating nature of the PEI was reduced using CO2 response with the polymer compound; 2) charge-scattering sites on the SWNT was presented by physical variations in the starch complex. Although the range of 500ppm and 10%CO2 in air was the reaction shown by this device. Acidic gases such as NO2 and SO2 would be certainly demonstrated cross-sensitivity by PEI

E. CNTs for Nitric Oxide

One of the most important cases revealed in medical patients is the finding of NO because of variations in NO quantities can indicate specific illnesses as Alzheimer's. Based on the study by Gill et al., the skill to observe NO quantities in patient's breath are useful aimed at medical professionals attempting to identify diagnostic assessments[14]. Now, chemiluminescence is generally utilized for the finding of NO gas according to Robinson et al. This method is extremely sensitive. It needs enormous instrumentation, expensive and different supporting supplementary part as an ozone generator and vacuum pumps.Based on reports of Long and Yang that detected CNTs that adsorbed oxides of nitrogen, it was shown NO in the exposed to O_2 can be one opportunity for the making a medical sensor. Also, the little response to NO gas was shown by bare SWNT networks provided that they are ornamented with metal nanoparticles. They demonstrated matchless electronic features below a NO atmosphere[15].In their investigation, Liang et al stated cross sensitivity to NO with their CNT-SnO_2-based sensor that it is shown in figure 11A. A ceramic tube with an internal heating part was applied for the CNT-SnO_2. NO absorptions in rang 2 and 50 ppm were identified by this device at 300$^{\circ}C$ that is shown in figure 11B. Finally, a NO sensor established on PEI functionalized SWNT networks for sensing NO gas have been developed to simulate breath condition asthma diagnosis[16]. Douglas R. Kauffman and Alexander Star reported that NO was oxidized into NO_2 with a CrO_3 converter, and the PEI layer on the SWNT network responded to the converted NO_2 that is shown in figure 11C. 5-ppb absorption of change NO in pureN2can be detected as it is demonstrated in figure 11D.

IV. IMPLICATION AND VIEWPOINT

A.Outcome usage of CNTs

Carbon nanotubes are dynamic fundamentals in detecting a large range of gases with prominent response since 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. CNTs gas sensors have verified to perform acceptably at room temperature that will lower the powerful utilization of the device and permit the safer detection of harmful and toxic gases.Nevertheless, a lot of attempts have to be done before the realistic function of CNTs gas sensors occurs. Initially, CNTs with defined structure and property is required to be manufactured in large number at minimalrates. Then, the detecting possessions, especially the recovery and selectivity, have to be enhanced. For viable application, gas sensors are vital to be with eminent selectivity, low operating temperature, fast reaction and recovery. One familiar flaw of CNTs gas sensors is the likely interference from relative moisture at room temperature. Extra attempts are required on research paper about the long-term strength and dependability of the CNTs sensors, that have been less considered.Nonetheless, the innovation of carbon nanotubes, a group of excellent nano-materials, provides exceptional choice for gas sensors, particularly for nano sensors which possibly will be essential to their definite applications.

B. Final Viewpoints of CNTs

Following the research and studiesconducted by others, 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 a fundamental sensory devices. For future works, the enhancement of carbon nanotubes can be progressed. Carbon nanotubes as the basic or fundamental material in sensory device, provides many benefits to humankind and also to the environment because of its characteristics and size that is not harmful. Carbon nanotubes is also useful in crucial area such as in medical fields to sense or detect malicious gases.

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