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Modeling of a Carbon Nanotube Sensing Device

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Abstract: A sensing device is modeled and discussed in this paper. The modeling is done by using carbon nanotubes. This carbon nanotube based sensing device makes it possible produce huge amount of nano chips as a disposable cartridge for diagnostic purposes. Modeling of nano-electrode, characterization and electrochemical detection of DNA hybridization is discussed here. The results shows that the importance of diagnostics with demonstrated characteristics of high sensitivity, reliability and inexpensive micro-fabrication for cost effectiveness.

Key words: CNT · Nano-electrode · NEMS

INTRODUCTION

Nano sensor production and marketing is very difficult in terms of the price and dimension of the device [1]. In engineering perspective, carbon electrodes have shown similar characteristics with the carbon nanotubes. Those characteristics contains faster transport, huge potential and compatible with biological substances. Very rare material contains these characteristics which is essential for amplifying the wave getting from the objects. Therefore, a metal electrode of platinum can be electrolyzed water before reaching the electro-potential required for the analysis of many biological substances. That's why huge amount of current produce to distort the real wave. By replacing electrode to carbon will overcome this limitation to get a better performance from the sensing device. A carbon nanotube (CNT) is shown in Fig. 1 to enable this research for modeling a sensing device.

The uses of CNT is increasing everyday for various field of implementation. CNTs are also contributed in medicine application industry [2]. To consider in advance technology in electronics, CNT has a great contribution towards the human society by creating a green technological concept. Where CNTs made devices are easy to recycle to prevent the environment from the pollution. Nano Electro Mechanical System is one of the major invention in this century where CNT play an important role for the massive production. This Nano Electro Mechanical System device will enable to carry-out the sensing experiment.

The smaller energy band-gap produce a semiconductor device using the CNT [3]. CNTs are direct-gap material and, as such, they directly absorb and emit light, thus possibly enabling a future optoelectronics technology based on SWCNTs. So it can be used as light emitters or a light detector depending on the biasing [4]. Biological medical field is very broad to conduct research on sensing devices. It will be in nano to micro scale for the sensing space for the development of this device. A CNT electrode named nano-electrode can be performed to build a sensing device in this NEMS field of research. A expected CNT sensing device operation is shown if Figure 2. CNT electrode is acting here as the end effecter of the device activated with the investigate substances.

Carbon Nanotubes: In terms significant electronics properties of CNTs, it becomes top position nano-material in the field of nano technology. Therefore, CNTs are recognized to fit for the nano-electronic FETs since they have their distinctive electromechanical and thermal properties. A single sheet of graphite is known as graphene which roll into a cylindrical shape with nanometer radius is called carbon nanotube is in Fig 3.

Single walled and multi walled CNTs are considered for the nanotechnology research. These two types of CNTs are useful for their different characteristics in device construction [5]. A complete study of CNT electronics structure was analyzed [6]. A CNT is a nano-scale substance with very small radius as 1.95nm [3]. Based on configuration of CNT, it is rolled up tube like graphene

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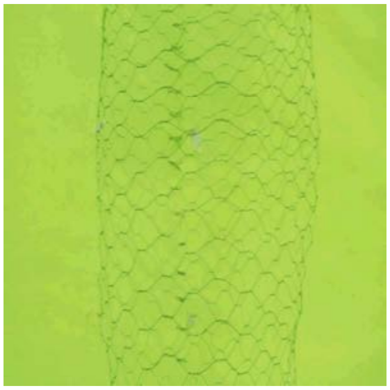

Fig. 1: The functional groups at the open end of a carbon nanotube. (Zigzag with 1.95nm)

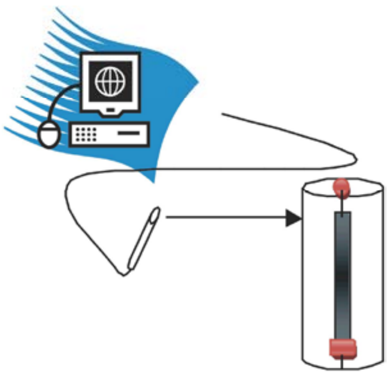

Fig. 2: Biomolecule sensing using carbon nanotubes (CNTs).

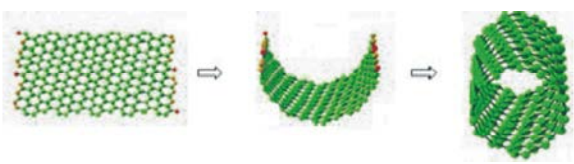

Fig. 3: Graphene sheet rolled up to form Carbon Nanotube.

sheet. By considering single walled CNT is identified by its chirality (n, m) where n and m are index numbers in the single graphite network. Metallic CNT is considered by (n-m)/3, on the other hand others are semiconducting CNT. In addition the single walled CNT has very strength mechanical properties is about 600 times more than steel. Compared with other materials, CNT perform highest strain is around 10%.

The development of numerous next generations' device applications using CNTs are becoming to the researchers more attractive day by day for its exclusive electronic properties. In present research, researchers are very curious about the development of like field effect transistors or sensing elements by using CNTs.

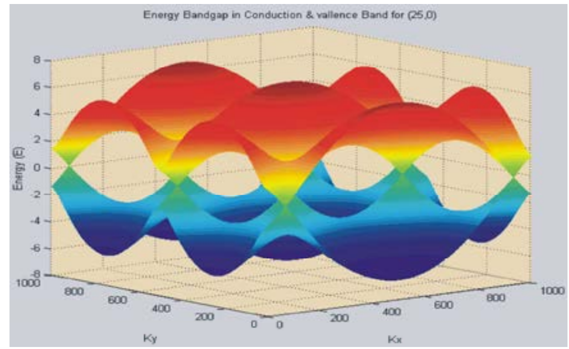

Fig. 4: Plot of the Energy dispersion relation between valence and conduction band for a CNT (25, 0)

The quantization of wave vectors is quantized in the circumferential direction for the sake of very small radius of carbon nanotubes. Furthermore, the fineness of the nanotube's cylindrical shell obviously acquiesce an even smaller length of confinement in the radial direction, thus making the material virtually one-dimensional as far as electron transport is concerned. Many published works to date have corroborated this claim with experimental evidence from device studies [3].

Reciprocal Lattice: The primal cell of a CNT is described from the unit vectors,

$$R_1 = \frac{a}{2}\left(\sqrt{3}\hat{x}+\hat{y}\right) \text{ and } R_2 = \frac{a}{2}\left(\sqrt{3}\hat{x}-\hat{y}\right) \tag{1}$$

where, R_1 and R_2 are the unit cell vectors of a CNT and a = 2.49 Å is the carbon to carbon atom distance between two carbon particles [4] and reciprocal lattice vectors are:

$$a_1 = \frac{2p}{a}\left(\frac{1}{\sqrt{3}}\hat{x}+\hat{y}\right) \text{ and } b_2 = \frac{2\pi}{2}\left(\frac{1}{\sqrt{3}}\hat{x}-\hat{y}\right)$$

Energy Dispersion Relation: Nanotubes' K relations need to derive due to examine the conductivity properties of the nanotube. The equivalent relation of a two dimensional graphene lattice may solve this requirement. Graphene electronic structure helps to calculate the energy dispersion for CNTs which is given by [4],

$$E_{2D}(K) = \pm V_{ppp}$$
$$\left\{3 + 2\mathrm{Cos}(KR_1) + 2\mathrm{Cos}(KR_2) + 2\mathrm{Cos}[K](R_1 - R_2)\right\}^{1/2}$$

where V_{pp}, is the adjacent shift integral. The 3D view of energy dispersion relation is shown Fig. 4.

Single-walled CNTs' 1D energy band calculation can be done as [3]:

$$E_{2D}(K) = \pm V_{ppp}$$
$$\left[1 + 4\mathrm{Cos}\left(\frac{\sqrt{3K_x}}{2}a\right)\mathrm{Cos}\left(\frac{K_y}{2}\right) + 4\mathrm{Cos}^2\left(\frac{K_y}{2}\right)\right]^{1/2} \quad (3)$$

Here K_x and K_y are the wave vectors. The potential application of CNT can be seen in the electronics market with CNT based field emitters for flat panel TV displays.

Carbon Nanotube Electrodes

Electrode Properties: Metals are in constructing electrode where carbon and other material can be used in constructing electrode for the various application. A perfect electrode should have the following properties for the better performances:

- Application required conduction.
- Appropriate dimensions.
- Prototyping Simplicity.
- Reliable characteristics.
- Environmental friendly and compatible.
- Performances of signal properties.
- Electromechanical properties.
- Functional integrated system

Nano-Electrode in Sensing Application: Signal to Noise Ratio (SNR) The sensitivity of an electrode is mainly determined to measure sensitivity. The flowing current create noise for the capacitive properties involvement at the electrode is shown as:

$$i_n \alpha C_d^o A \quad (4)$$

The capacitance is denoted by C_d^o. By reducing the electrode size to 20 nm from 20 ìm, the SNR would be modified in 1000 times.

Electrode dimension refer the function of the electrode's response time.

$$\tau = R_u C_d = r C_d^o / 4k \quad (5)$$

where electrolyte conductivity is denoted by k. the applied properties of this system would be more faster once the size reduced nanometers [7- 9]. Therefore, the sensitivity can be radically developed by decreasing the dimension of the electrodes to nano-size.

RESULTS

Modeling of Nano Device: CNTs are arranged in a forest configuration is shown in Fig. 5. 300°C are required to produce the CNT. Figure 5 shows an experimental image of CNT bundles which have been conducted in characterization laboratory. With a nominal diameter of 1.95nm, length of 5-15 μm of the single walled CNT forests are created smooth structure. The top and perspective view of the CNT bundles electrode is in Figure 6 by SEM.

For measuring each CNT current-voltage (I-V) characteristics, atomic force microscope (AFM) with Current-Sensing-Module (CS-AFM) is applied to show in Fig. 7.

Fig. 7 shows the I-V curve which cointains the resistance of a compact CNT forest with diameter 1.95 nm in 0.0056 Ω.

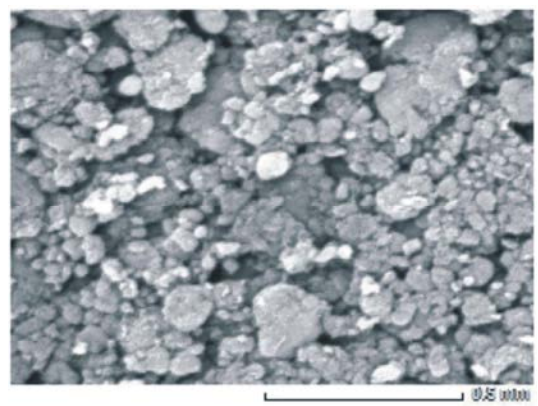

Fig. 5: Scanning electron microscopy (SEM) images of CNT.

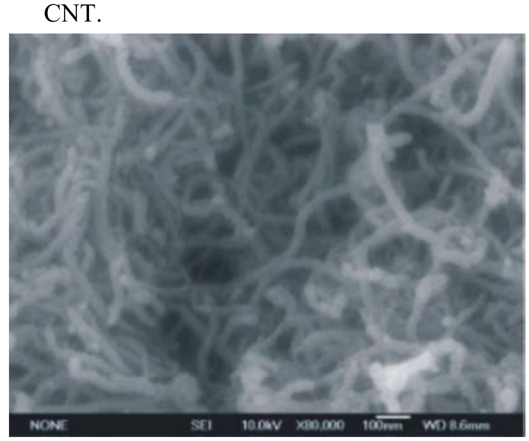

Fig. 6: SEM for CNT bundles.

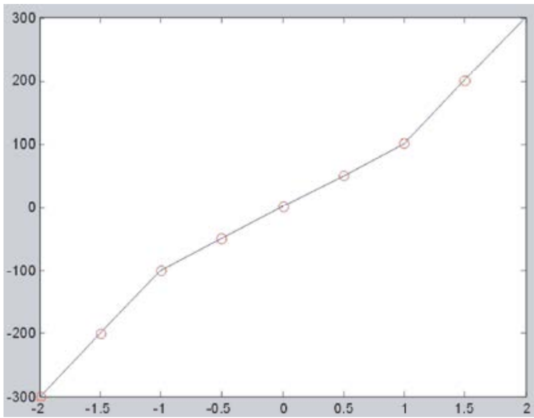

Fig. 7: I-V characteristics for CNTs.

CONCLUSION

An experiment is conducted to model a nano scale sensing device in this work. CNT used here for the modeling of the device. CNTs are successfully applied the transfer technology to setup electrode with a nominal diameter of 1.95 nm. This model will reduce the error rate of biosensor device measurement.

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