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A Systematic Study of a Transistor Fabricated by a Bent Carbon Nanotube, based on Nanotechnology

Dr. Ali Ahmad Ansari

Asst. Professes, Deptt. of Physics, MKCET,
Veriadangi, Kishanganj, Bihar, India
E-mail: aliahmadansari456@gmail.com

Abstract—*The present paper reports, a systematic study of a transistor fabricated by a bent carbon nanotube, based on nanotechnology. Carbon nanotubes can be considered by as a graphitics one atom thick can be rolled into a cylindrical tube whose radius be less than 1nm and diameter be 1.4nm. Carbon nanotube is discovered in 1991. The remarkable electronic properties of these structures have attracted much attention. The bending phenomena in carbon nanotubes have been study experimentally and had indicated that under sever bending the buckling is usual way for nanotubes to reduce its strain. The use of individual molecules was first proposed in 1970[1]. After that molecular electronics has attracted much interest because it was related with electronic and computer industry [2].It was the challenged for realization for single molecular devices. Recent advantages in nanotechnology for the measurement of molecular level electrical measurement on single molecule[3]. Here we report the fabrication of a field effect transistor that is a three terminal device consists of one semi conducting single walled carbon nanotube connected to two metal electrodes. The present device in contrast operates at room temperature with an important potential application. The fabrication of three terminals device at level of a single molecular represent an important steps towards molecular electronics [4]. We will study the electrical measurement on the nanotube transistor that indicates that its operation characteristics can be qualitatively described by the semi classical bands [5]. The theoretical obtained results will be compared with previous obtained theoretical and experimental results.*

Keywords*: Single walled carbonnanotubes, Nanotechnology, Transistor.*

1. INTRODUCTION

Nanotechnology-Nanotechnology is a field of applied science and technology covering a broad range of topics. The main unifying theme is the control of matter on a scale smaller than micrometer, as well as the fabrication of device on this same length from field, drawing from field such that as colloidal science, device physics and super molecular chemistry much speculation exists as to what new science and technology might result from these lines of research [6].

Nanotechnology and nanoscience got started in the early 1980s with two major developments: The birth of cluster science and the inversion of scanning tunneling microscope (STM) The development led to the discovery of fullerenes in 1985 and carbon nanotubes a few years later. Carbon nanotubes have recently received extensive attention due to their nanoscale dimensioning and outstanding material properties such as ballistic electronic conduction, immunity from electro migration effect at high current densities and transparent conduction [7]

When a graphiitic sheet of one atom thick can be rolled into a tube then obtained helical tube is called carbon nanotube, This is demonstrated in fig. 1. A single walled carbon nanotube is demonstrated in fig. 2**.**

Steps involved in research work:

1. Fabricate a field effect transistor using single walled carbon nanotube (SWCNT)
2. Connect the device with metal electrodes
3. Apply voltages to gate electrodes
4. The resultant device acts as a transistor and amplifies the electrical signal and current.

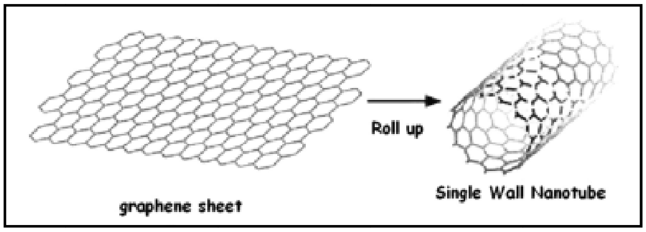

Fig. No. 1: Fabrication of nanotube

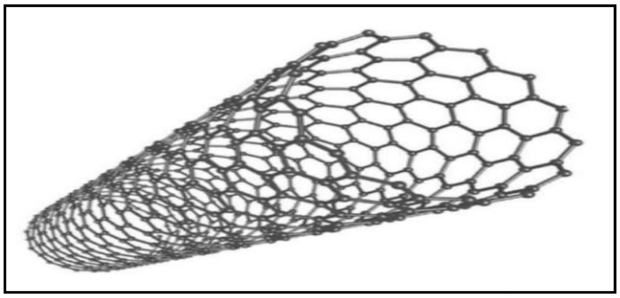

Fig. No. 2: Single walled carbon nanotube.

2. RESULT AND DISCUSSION

Atomic Force Microscope (AFM): The samples introduced in my study are fabricated as described elsewhere [8]. Fig.3 shows an atomic force microscopy (AFM) image of a single walled nanotube with Pt electrodes (1,2and3) The semiconducting Si substrate, covered with 300nm layer of thermally grown Sio_2 was used as a back gate (Fig. 4). In our electrical transport study on a single walled nanotubes, we have measured many individual tube as more than 20 tubes and having find two types of behaviour at room temperature. The metallic variety of tubes those reported previously have liner I-Vbias curve and show no dependence on the gate voltage (Vgate). Here we discuss two probe and three probe measurements on the second kind of sample.

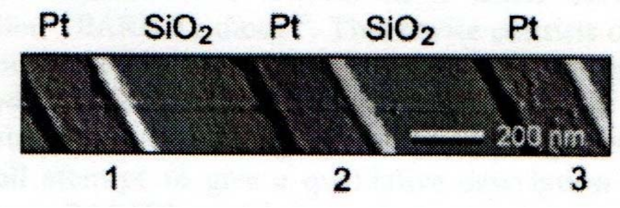

Fig. No.-3: ATM image of of single walled carbon nanotubes

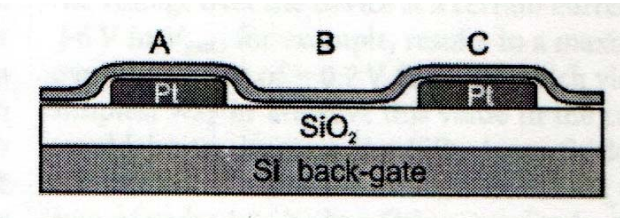

Fig. No.-4.Schematic side view of tube device

Fig. 7 show I-Vbias curve for the sample in Fig. 3. At Vgate =0, a small nonlinearity seems to be present in the I-Vbias curve a when Vgate is increased to positive values, a pronounced gap like nonlinearity develops around Vbias =0, the curve seen to be exhibit a power law behaviour (solid stateliness), that is I is proportional to alphath power of (Vbias) with aipha between I and 2. Upon application of a negative Vgate, the I-Vbias curve becomes linear with a resistance that saturates around 1MΩ. This is the same resistance that we find for the metallic tubes in a similar layout. For the major part this resistance is due to the contact resistance between the tube and electrodes [9]. Thus we obtain a controllable semiconductor to metal transition in a one dimensional system. The nonlinearity at room temperature and asymmetric dependence of the gate voltage polarity indicate that the nanotube of this sample is semiconducting. In the inset of Fig. 7. The conductance of the device at Vbias=0 is plotted against Vgate. This shows that the conductance can be strongly moduled by about six orders of magnitude on a change of 10 V in Vgate. Measurement of the electrode pair 2-3 gave similar results. This example (Fig. 3) is one of the samples that showed a similar behaviour. In the other samples, noise due to two level fluctuators was often larger, especially at large applied voltages. For some samples the I-Vbias curves were asymmetric around Vbias=0. Although same drift occurred along the Vgate axis, the transport characteristics of the sample presented here were reproducible over a period of months.

In the energy diagram of Fig. 5, and 6 we attempt to model the electric structure and function of device.The charge careers flow through the part of the tube that is on top of the tube source(A) on the $Si0_2$ surface (B) and on the drain electrode (C) (in Fig.4) .Samiconducting tube with 1.4 nm diameter having a band gap of ~ 0.6eV [10]. As for a traditional semiconductor, metal interface a difference in work function will result in bending of the bands of the semiconductor [11]. The work function of Pt is 5.7eV, where as the work function of carbon nanotubes are 4.5Ev. Owing to difference a local polarizations layer will develop on the electrode nanotube interface until the nanotube valence band adge aligns with the Fermi level of the metal electrodes. Such pinning of the Valence band edge to the Fermi level of the electrode was observe in scanning tunneling microcopy experimental of semiconducting nanotubes on Au (111) [12]. A way from the electrodes, the band bend to lower energy as demonstrated in fig 5, segment B. A Vgate will not have a strong effect on the nanotube at position A and C owing to the screening of the nearby metallic leads and the capacitive coupling between the tube and the leads. Electric field of the gate electrodes will couple of the tube in the segment B. For negative Vgate this will lead to an accumulation of holes and an increasing conductance where as for positive Vgate the holes are depleted, yielding a lower conductance as shown in Fig. 5. Cooling the sample to160K the metallic saturation resistance increases from 1to 4MΩ. For a metallic tube we find the same room temperature resistance in order of 1MΩ and similar dependence on temperature. This results support the band diagram proposed above (in Fig.5), because our model predicts that in segments A and C the tube should be metal like owing to pinning of the valence band edge. If an on alternative model there were an induced shottky barrier will be inside the tube at A and C, the device would exhibit much stronger temperature dependence [13].

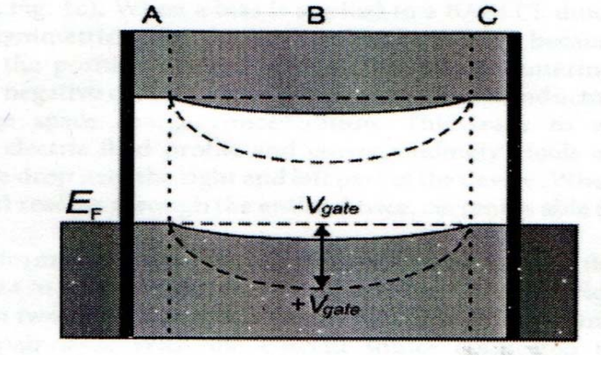

Fig. No.-5: Energy diagram of positive and negative V_{gate}

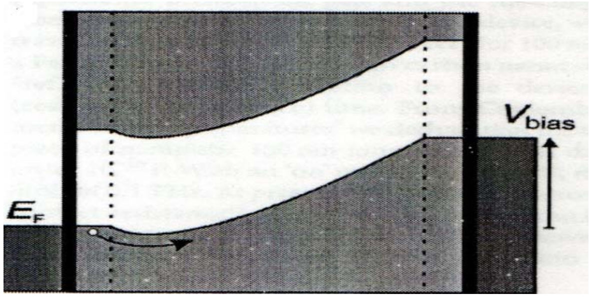

Fig. No.-6: Energy diagram of relation between E_f & V_{bias}

The suggested band structure of this device (in fig.5) is similar to that of a traditional semi conductor device that so called, barrier injection transit time diode [13]. This device consists of a semiconductor connected to two mental contacts that is two schottky type diodes connected back to back. Althougt we do not yet have a detailed understanding of the function of device, we shall attemt to give a qualitative description by using the well known barrier injection transit time model.In device holes have to be transported over the barrier produced by band between(in fig.5,segment B). when a bias is applied to a barrier injection transit time model diode (Fig. 6) an **asymmetric** space charge distribution results, because the barrier at the positive contact presents holes exit from the semiconductor leaving a large space charge concentration. This leads to an asymmetry in electric field profile and correspondingly yields an unequal voltage drop over the right and left part of the device. When the electric field reaches through the entire device, current is able to low.

Current bias transport measurement : We have performed current bias transport measurement on the sample of Fig.3, in a three point of configuration we divide the sample into two segments: One between electrode pair 1-2 and other between pair 2-3 with the current source connected to electrode 3 and 1 grounded we can measure separately the voltage drop over these two tube segments.The total voltage over pair 1-3 is also measured with electrode 2 left floating.The result for Vgate=2V is demonstrated in Fig. 8(a). Again we observe gap like features in the I-V curves. The voltage over the two segments indeed add upto the total voltage drop over the device. However the voltage drop seems to be different for both segments with most of voltage dropping over segments 2-3 at negative bias. This is in agreement with the above described mechanism for barrier injection transit time model like diode because at negative bias potentil of electrode-3 is lower than that of electrode 1, resulting in more space charge and thus a larger voltage drop near contact 3. For positive bias electrode 1 has the lowest potential, yielding a large voltage drop at the electrode 1.This is indeed observed in the measurement. A different voltage division is observed when the same measurement is performed at the larger positive Vgate [Fig.8(b)]. The space charge profile is rather symmetric, as can be concluded from the almost equal voltage drop over segments 1-2 & 2-3. At large positive Vgate more holes are depleted from the tubes, leaving less room for an asymmetric space charge profile. With fewer free charges in the tube,it behaves more like an insulator and the dominant charge build up is in the electrodes, resulting in equal voltage drop over the two segments. This condition is indicated in the inset of fig. 8(a), where the voltage over the two segments at -4nA and +4nA is plotted as percentage of the total voltage (1-3) against Vgate.

3. SCREENING OF DEVICES

Screening in truly one dimensional conductor is expected to be different form that in the 3- dimensional system. It is therefore of interest to deduce the typical length over which the bands are bent along the nanotube axis. From our data we can make a rough estimate of this value. Fig.7, shows that Vgate =0, the tube is almost in metallic state and that the Fermi energy must therefore be close to the valence band edge throughout the device. If the band bending length were short, the Fermi level in the nanotube segment away from the electrodes would be located in the middle of the gap between conduction and valence band, and the hole transport would be very hard because of appreciate (~0.3eV) barrier. If the band bending length were very large (≥400nm),now no significant band bending would occur and the tube would respond similarly to a metallic tube. A negative gate voltage would thus have no effect. Now what we conclude that without applied electric fields, the band bending length is roughly of the order of the distance between the electrodes, which is 400nm.

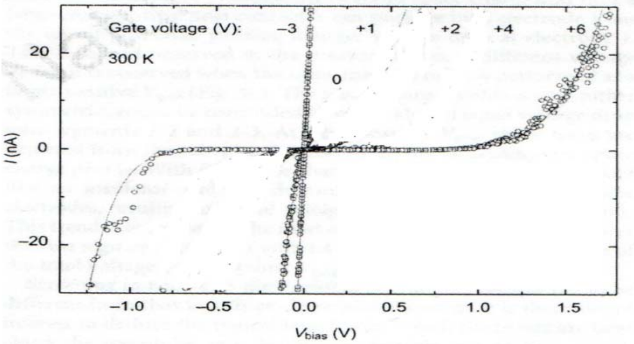

Fig. No.-7. Two probe I-V_{bias} curves

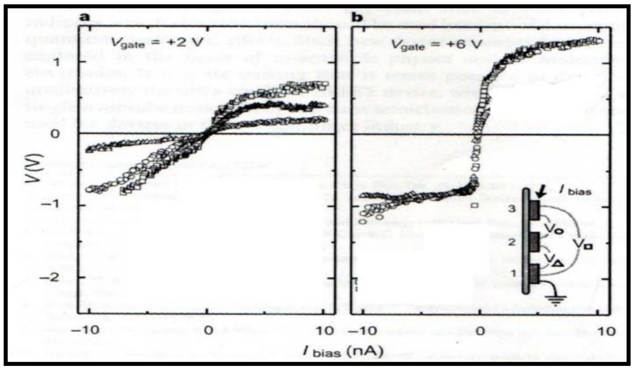

Fig. No.-8: Three probe I_{bias}-V curves for Two gate voltage.

4. GAIN OF THE DEVICE

The gain of the device can be estimated by considering the voltage over the device at a certain current. Now we going from 4V to 6V in Vgate. We consider an example, result in a maximum change in voltage over the device of ~0.7V (Fig. 7) which yields a gain of 0.35. The simplest way to improve the value in current device geometry would be to decrease the $SI0_2$ layer thickness. Currently this is 300 nm but it could be reduce to ~5nm [14], resulting in a gain of order 1 or higher. Other geometries that further increase the capacitance between gate and tube might also the capacitance between gate and the tube might also be possible. Consider the ultimate speed of device for we calculate the ballistic traversal time of orders of $10.^{-13}$ sec or 10 THZ for 100 nm length of the tube and a Fermi velocity of electrons in carbon nanotubes of $8x10^5$ meter per second[10]. Another limitation to the device speed is the RC (resistance-Capacitance) time. From Coulomb block measurements at low temperatures we deduce that the total capacitance of a piece of nanotubes 100nm long in a similar device geometry of order of 10-^{18} F[8]. With an on resistance of 1MΩ, this gives a frequency limit of 0.1Hz. At present the device resistance is dominated by the contact resistance [15]. If low ohmic contacts can be realized, the two probe resistance is expected to reach the lower quantum limit of about 6kilo Ohm which would allow a maximum frequency of order of 10 THz.

5. FUTURE DIRECTION

As it stands now the majority of commercial nanoparticle applications in devices fabrications are geared towards revolution in small nanoscale device production industries. There are some developments in the direction and remotely controlling the function of nanoprobe and other kind of strang nano particles.The major trend in future development of nonmaterial is to make them multifunctional and controlled by external signals or by local environment.Thus essentially turning them into nanodevices. If nano technology produces some difficulties then we have to work on other new technology that is called pico technology that may be provide a great advantages on nanotechnology in our future.

6. CONCLUSION

The non linearity at room temperature and the asymmetric dependence of the conductance on the gate voltage polarity indicate that the nanotube of this sample is semiconducting. The conductance can be strongly modulated.

The fabrication of three terminal switching device describe here is relatively straight forward and integration of multiple devices into a circuit may eventually be possible by using molecular self assembly techniques. Potential application may be possible, particularly as the device operate at room temperature and high switching speeds and improved voltage gains seem possible.

In discussion of the fundamental limits of integrated circuits dimensions, warnings are often expressed that at some point radically new devices structure should be used because of dominant quantum mechanical effects.

In this environment sure a new device concepts have been explored in the field of mesoscopic physics and molecular electronics. It is quite striking that it seems possible to describe qualitatively the ultra small transistor device based on single nanotubes molecule, by the same semi classical models are used for devices in today computer and in other industries.

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