Carbon Nano Tubes Transport Peroperties as a Channel of FET

Safiullah Muheeby[1,2], Ahad Khan Pyawarai[3,4,*]

1- Electrical power Engineering Department ,Polytechnics University,Karte-Mamorin, Kabul,Afghanistan

2- Electrical power Engineering Department, Kabul, Afghanistan

3- Polytechnics University,Karte-Mamorin, Kabul,Afghanistan

4- Physics Department, Electromechancs Faculty, Kabul, Afghanistan

ABSTRACT

In this paper we have simulated electron transport in a CNTFET by solving Boltezman equation to obtain distribution function. Our results show that system takes a stationary state after passing a time around 10^{-13}s.

Keyword: *CNT, CNTFET, Electron Phonon Scattering*

1 Introduction

Any logical circuits in computer processors use some elements to simulate 0 or 1 states. This can be simulated by an electronic device like as a lamp. When the lamp is on it is equal to 1 or true and when it is off the state is equal to 0 or false. One of the most popular electronic device that be used in logical circuits is transistors. Transistors could simulate 0-1 states by on-off situation of electrical current. Modern CPU and RAM (the basic elements of computers) consist of many transistors. To make better and faster CPUs and logical device we need to use more transistors and this cause many problems in designing. As we know a MOSFET (Metal-Oxide-Semiconductor-Field- Effect- Transistor) is made of 5 basic components: 1-Gate, 2-Source, 3-Drain, 4-Gate Oxide, 5-Channel[1]. When a transistor is shrunk, all of its parts must be shrunk. When gate oxide is very slim, the current tunneling to gate increases exponentially. Some scientists were shown Silicon Nitride is a good material instead of silicon oxide because of its high dielectric constant and its amorphous structure [2, 3, 4]. Another problem is the length of channel. Making a channel of Si in nano scale is very difficult, because it is very difficult to control the impurity density in nano scale designing. One of solution for this problem is using of CNT's as a channel of FET (Field Effect Transistor). We can product pure CNT's in room condition, therefore this material attract many of scientist mind to design future race of CNT's. The time that recent transistors must spend to switch on to off is equal around 0.1 - 1 ns (recent CPU speed is around GHz). But we have shown in this paper that in CNTFET (Carbon Nano Tube Field Effect Transistors) this time is smaller around 10000 times than recent FETs. So future race of memory device which use CNTs have a magic speed and have more little size. The high speed is referred to one dimension structure of CNT's band energy.

2 Calculation

Electronic band structure of CNTs is provided from those graphen one (Zone Folding)[5]. Electronic band structure of graphen can be calculated by tight binding theory[6, 7] Phonon dispersion relations of CNTs can be calculated using tight-binding methods[8, 9,10, 11], density functional theory [12, 13], and symmetry-adapted models [14, 15]. The phonon dispersion relations of SWCNTs can be understood by zone folding of the phonon dispersion branches of graphen. In this work we have calculated phonon dispersion of a graphen sheet by force constant model[16, 17]. In this model we have applied the effect of 4 nearest neighbors. Since there are two carbon atoms, in the unit cell of graphen, one must consider 6 coordinates. The secular equation to be solved is thus a dynamical matrix of rank 6, such that 6 phonon branches are achieved. Fig.1 show phonon dispersion relation of graphen along high

symmetry lines. We have assumed CNT is perfect and doesn't have any crystal defects so transport can be described by two different processes.

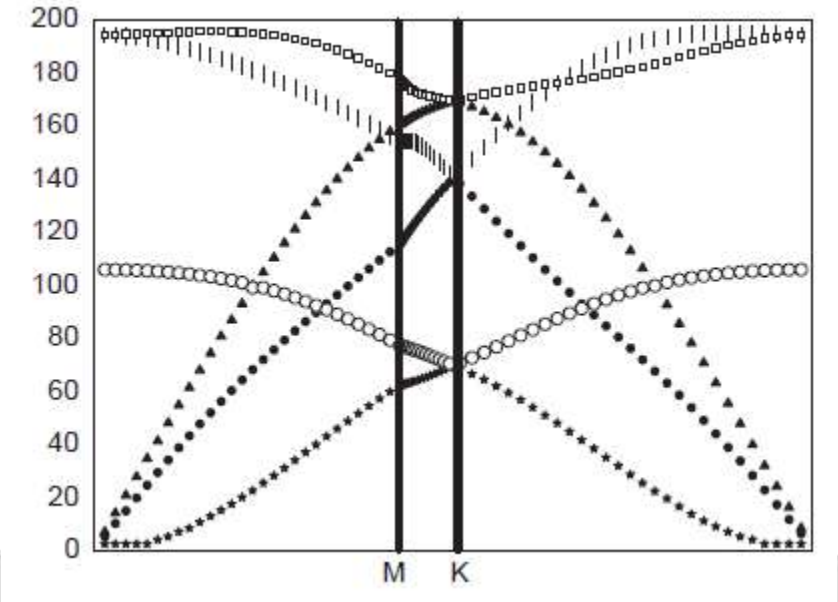

Figure 1: Phonon dispersion of graphen along high symmetry points.

One blastic transport and the other is diffusion transport[18, 19]. Blastic transport take place in metallic CNT but our calculations show that in semiconducting CNT electron is scattered from phonos. We can calculate scattering rate for electron - phonon scattering by use of fermi golden rule[20, 21]. Energy and momentum conversation define allowed transition. Electron can be scattered by optical phonon or acoustic phonon. The scattering rate for this scattering process is given by.

$$W_{\vec{k},\vec{k'}} = \frac{D^2 DOS(\vec{k'})}{\rho d \omega_p}\left(N_p + \frac{1}{2} \pm \frac{1}{2}\right) \quad (1)$$

Where Np is Bose - Einstein occupation number and ρ is mass density of graphen sheet and D is deformation potential, d is CNT diameter, q is phonon wave vector [20,21]. For determine electron-phonon scattering rates, electron band structure and phonon dispersion is divided into 2000 grid points covering first BZ . The requirements of energy and momentum conservation lead to following selection rules for final electron state.

$$E_f = E_i + E_{ph} \quad (2)$$

$$\vec{k}_f = \vec{k}_i \pm \vec{q} \quad (3)$$

Where k refer to electron and q refer to phonon wave vector. Distribution function of electron or hole can be varied by applied electric or magnetic fields and scattering phenomena. We have investigated carrier transport in single-walled semiconducting carbon nanotubes by solving the Boltzmann equation [22, 23] .

$$\frac{\partial g_n(\vec{r},\vec{k},t)}{\partial t} + \vec{v}.\vec{\nabla}_r g_n(\vec{r},\vec{k},t) + \vec{F}.\vec{\nabla}_k g_n(\vec{r},\vec{k},t) =$$

$$\sum_{k'} \left[W_{\vec{k},\vec{k'}} g_n(\vec{r},\vec{k},t)(1 - g_n(\vec{r},\vec{k'},t)) - W_{\vec{k'},\vec{k}} g_n(\vec{r},\vec{k'},t)(1 - g_n(\vec{r},\vec{k},t))\right] \quad (4)$$

One can simplified the Eq. 5 by using relaxation time approximation.

$$\frac{\partial g_n(\vec{r},\vec{k},t)}{\partial t} + \vec{v}.\vec{\nabla}_r g_n(\vec{r},\vec{k},t) + \vec{F}.\vec{\nabla}_k g_n(\vec{r},\vec{k},t) = -\frac{g_n(\vec{r},\vec{k},t) - g_n^0(\vec{r},\vec{k},t)}{\tau} \quad (5)$$

In the Eq.5 g^0 is equilibreum electron distribution function which is described by Fermi-Dirack distribution. The velocity of electron is defined by:

$$V_n(\vec{k}(t)) = \frac{1}{\hbar}\vec{\nabla}_k E_n(\vec{k},t) \quad (6)$$

As we mentioned before distribution function is deviated from its primary Fermi – Dirac shape. Another most important that must be considered in CNTs is the amount of energy level which be cut by fermi level. As you know Fermi - Dirac distribution is a sharped function around fermi level so it's differential treat as a delta function around fermi level. So in carrier transition those levels which cut fermi level have the major role in conduction. For CNTs with little radios only first conduction band cut fermi level and other was omitted. From t=0 to 10−13s There is unstable condition so we have finally obtained the scattering phenomena randomly depending on the position of electrons/hole.The average of velocity is obtained as below.

$$\bar{V} = (\sum_i V_i g_n(k_i,t_i)) \times (\sum_i g_n(k_i,t_i))^{-1} \quad (6)$$

$$and \quad t_i = it_d$$

And average of current is calculate by

$$n(t) = \sum_v \int_{-\frac{\pi}{T}}^{\frac{\pi}{T}} g_v(k,t)dk \quad (7)$$

$$\bar{n} = \frac{1}{t}\int_0^t n(t')dt' \quad (8)$$

$$I_{DS} = |\bar{n}e\bar{v}| \quad (9)$$

But after this time system goes to a stationary state and electric current can easily obtain as below:

$$\mathrm{I} = \frac{1}{t}\int_0^t n(t')dt' \quad (8)$$

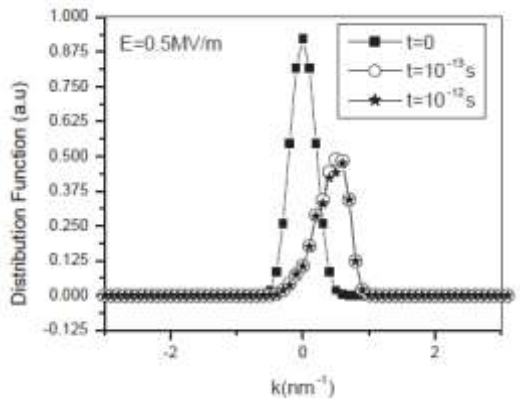

Figure 2: Distribution function takes a uniform shape.

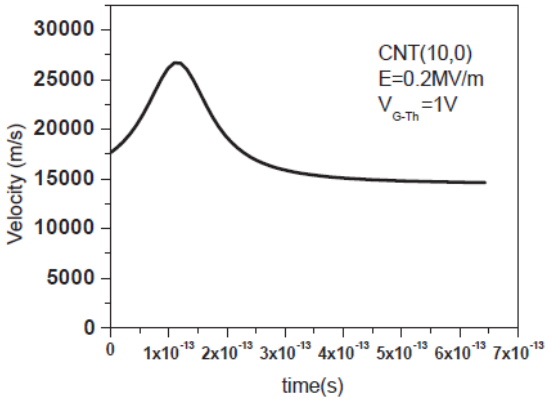

Figure 3: Time dependent velocity curvature.

2 Result and discussion

Fig.2 Show time dependent of distribution function. As you see at origin of time (t=0) distribution function is coincided with Fermi - Dirac function. After separating 10^{-13}s everything reach stable shape because distribution function after this time has not any change. Fig.3 Show time dependent velocity of electron in CNT(10,0). As you see electron velocity take a uniform value after 2×10^{-13}s. Fig .4 show stable and instable velocity of electron which be accelerated from source to drain. We calculate unstable velocity by using MC (Monte Carlo) simulation for an ensemble consisting of 1000 electron. Another important result we have obtained is shown in Fig.5. By increasing CNT diameter the current which carried from source and drain increase. That region which is notified by a circle has a rather violent slope this region of voltage is the best region of CNTFET performance.

Future race of CNTFETs have a magic speed and have more little size. As you see in Fig.2 the time that a CNT receive stable condition is littler than 10–12s which is more faster than recent silicon device.

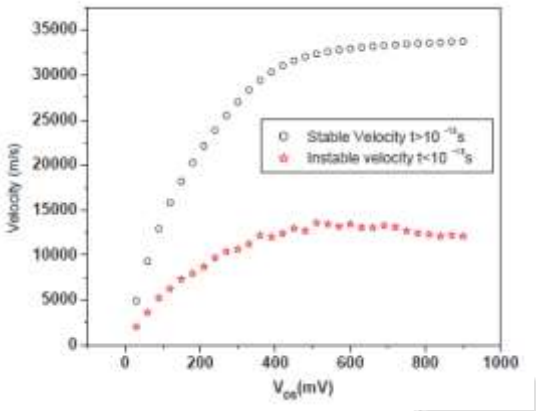

Figure 4: This figure compare stable velocity via as instable one.

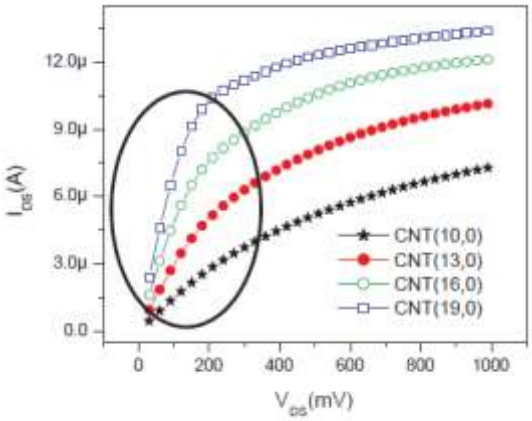

Figure 5: This figure compare current between various CNTs .

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