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Mohammad Javad Kiani, Mohammad Taghi Ahmadi, Meisam Rahmani, Mahmoud Zadehbagheri, Askar Bagherinasab and Fauzan Che Harun

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Resistance Analysis in Bilayer Graphene Based-FET Channel

Mohammad javad kiani[1,2], M.T Ahmadi[1], Meisam Rahmani[1], M.Zadehbagheri[2], A.Bagherinasab[1], F.K.Che harun[1*]
[1]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2]Dept. of electrical Engineering, Islamic Azad University, Yasooj branch, Yasooj, Iran.
Kianiph@gmail.com, taghi@fke.utm.my, fauzan@fke.utm.my
*Correspondence should be addressed to F.K. Che Harun: fauzan@fke.utm.my

Abstract-Recently, Graphene as two dimensional (2D) carbon based-material has been interesting because it has been greatly used to be scaled to smaller channel lengths and higher speeds. In this research, an analytical model for the resistance of tow dimensional bilayer graphene (BLG) is reported. Also, the conductance model of BG is improved by Landauer formula which includes the correction for a smaller size device . Furthermore, proposed model indicates that resistance model of BLG is a dependence of thermal energy near the neutrality point that thermal energy is a function of temperature. Finally, it is shown that with increasing of temperature, the resistance of BLG will be declined.

I. Introduction

As silicon was pushed to their theoretical limit, researcher change their interest non-silicon material, hoping that someday next generation electronic device will be based [1-2]. It turns out Carbon nano –material such as Graphene are the best candidate to replace silicon [1, 3-4]. Carbon base material with one dimensional behavior has been explored by many researchers for it has been widely used to accommodate nowadays technology [5-7]. Recent research on the stability of few-layer, multilayer and even single layer graphene has been a brilliant founding[8-9]. Graphene is a single layer of carbon atom that being arranged into a hexagonal lattice (honeycomb lattice) in two-dimensional (2D) forms as shown in *fig.1[10-11]*.

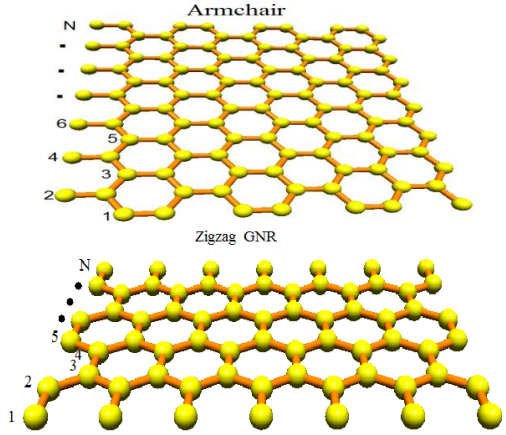

Fig. 1. Different structures if Graphene

Each carbon atom is tied to its three nearest neighbours via σ bonds[12-13]. Graphene demonstrates many unusual electronic and transport properties, such as the half-integer quantum Hall Effect [14], the weak localization phenomena. The possibility, in the case of the GNRFETs, to pattern the nanoscale strip of graphene (which has a definite orientation relative to the substrate) is a possible means of overcoming the CNT chirality control problems[13, 15]. Bilayer Graphene (BLG) with a gate-tunable band gap is the well-known material system to semiconductor application[16]. The AA-stacked of BLG (in figure1) shows metallic properties whereas BLG with AB-stacked has a gate-tunable band gap (0.02 EV) and role as a semiconductor material as shown in figure 2[17-18].

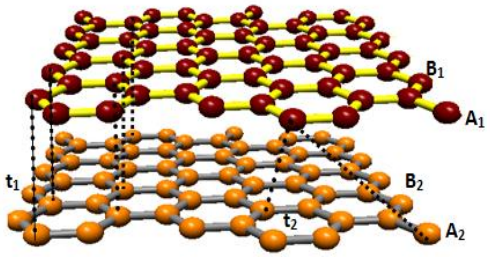

Fig.2. Bilayer graphene with AB stacked.

In this paper the resistance of BLG is modelled and also, its resistance as a function of gate voltage relevant to 2D structure is applied**.**

II. Model

Because of the suitable band gap of BLG between the conduction and valence bands as a result of applying an external voltage between layers of BLG it is accepted as a flexible material in the nanoscale applications.

The energy dispersion for V≠0 can be written as[19-20]

$$E(k)=\frac{V_1+V_2}{2}\pm \sqrt{|f(k)|^2+\frac{V^2}{4}+\frac{{t_\perp}^2}{2}\pm\frac{1}{2}\sqrt{4(V^2+{t_\perp}^2)|f(k)|^2+{t_\perp}^4}} \quad (1)$$

Where $t_\perp$ is the hopping energy parameter between equivalent carbon atoms inside the two layers. The form of Fermi surface for (V≠0) is unlike than (V = 0). For the smallest band gap wave vector of BLG which is in our focus is given by[21]

$$k_g=\frac{V}{2v_f\hbar}\sqrt{\frac{V^2+2{t_\perp}^2}{V^2+{t_\perp}^2}} \quad (2)$$

And also the energy dispersion of BLG near kg becomes[21]

$$E(k)=\frac{E_g}{2}+\frac{\hbar^2}{2m^*}\left(|k|-k_g\right)^2+\frac{V_1+V_2}{2} \quad (3)$$

Where m^* is the effective mass that it is a function of apply voltage to two layers and can be defined as

$$m^*=\frac{t_\perp(V^2+{t_\perp}^2)^{\frac{3}{2}}}{2V(V^2+2{t_\perp}^2)}\frac{1}{{v^2}_F} \quad (4)$$

The Density of states (DOS) in each state of energy defines the number of states that are available to be occupied by electrons in any energy interval so that can be written as

$$Dos=\frac{\Delta n}{A\Delta E}=\left(\frac{\hbar^2}{m^*}\frac{(k-k_g)}{k}2\pi\right)^{-1} \quad (5)$$

Where $k=k_x\hat{i}+k_x\hat{j}$. Also, number of Modes M (E) at an applied energy near the wave vector which is dependent on the sub band's position can be considered. By attractive the derivatives wave vector k over the energy E (dk/dE) The number of the mode M(E) as a summation over k space is written as

$$M(E)=\frac{\Delta E}{l\Delta k} \quad (6)$$

Where L is the length of the BLG channel, ΔK (wave vector variation) is obtained as $\Delta k=\frac{\Delta k_x\Delta k_y}{2\pi k}$ and also The directions of wave vectors in x and y are $\Delta k_x=\frac{2\pi}{l_x}$ and $\Delta k_y=\frac{2\pi}{l_y}$. Because of spin degeneracy in BLG, the number of BLG conducting channels is given as

$$M(E)=\frac{2\Delta E}{l\Delta k} \quad (7)$$

Constituting the energy dispersion in Eq (3) and the effective mass of Eq (4), we can write

$$\Delta E=\frac{\hbar}{m^*}(k-k_g)\Delta k \quad (8)$$

And

$$k=\left(\frac{2m^*(E-E_c)}{\hbar^2}\right)^{\frac{1}{2}}+k_g \quad (9)$$

Considering the wave vector in the equation (9) We have

$$M(E)=\frac{2\hbar}{l\times m^*}\left(\frac{2m^*(E-E_c)}{\hbar^2}\right)^{\frac{1}{2}} \quad (10)$$

A district of lowest G with regards to gate voltage as a basic constant proportional to the Planck's constant and electron charge in bulk graphene is defined and calculates for the minimum conductivity by the following formula

$$G_0=\frac{2q^2}{h} \quad (11)$$

Where h is Plank constant and q is the electron charge. Although the minimum conductance of BLG is two times bigger than this quantity (equation10) and is equal to $2G_0$ because the levels of up spin and down spin which are located in the small channels naturally have the same energy like a degenerate level. The conductance of large channel in graphene materials will be obtained in the ohmic scaling law by the Landauer formula however the conductance in nanoscale material can be written by two parameters, firstly conductance related to the width nonlinearly which depends on the number of modes that called quantizing parameter, Secondly interface resistance which independent of the length.

$$G = \frac{2q^2}{h}\int_{-\infty}^{+\infty} dEM(E)T(E)\left(-\frac{df}{dE}\right) \quad (12)$$

Where T (E) is the average probability of transmission electron in channel from one electrode to the other electrode, because of assumed ballistic channel this parameter is equal to one[22].

$$f(E) = \frac{1}{1+e^{\frac{E-E_F}{k_BT}}} \quad (13)$$

According to the number of sub bands (number of modes) in equation (10) And Fermi–Dirac distribution function conductance in equation (13) BLG conductance model of 2D graphene is presented in equation 14.

$$G_{BG} = \sqrt{\frac{32}{m^*}}\frac{q^2}{hl}\left(\frac{\sqrt{k_BT\pi}}{2}\Im_{-\frac{1}{2}}(\eta) - \frac{\sqrt{\eta\times k_BT}}{2}\right) \quad (14)$$

Where $\Im_{-\frac{1}{2}}(\eta)$ is the Fermi-Dirac integral of orders -0.5, $x = \frac{E-E_g}{k_BT}$ and normalized Fermi energy is $\eta = \frac{E_F - E_g}{k_BT}$. So, we can write the resistance of BLG as bellow.

$$R_{BLG} = 1/G_{BG} = \left(\sqrt{\frac{32}{m^*}}\frac{q^2}{hl}\left(\frac{\sqrt{k_BT\pi}}{2}\Im_{-\frac{1}{2}}(\eta) - \frac{\sqrt{\eta\times k_BT}}{2}\right)\right)^{-1} \quad (15)$$

As shown in figure 4, resistance increasing is obtained wit high values of gate voltage.

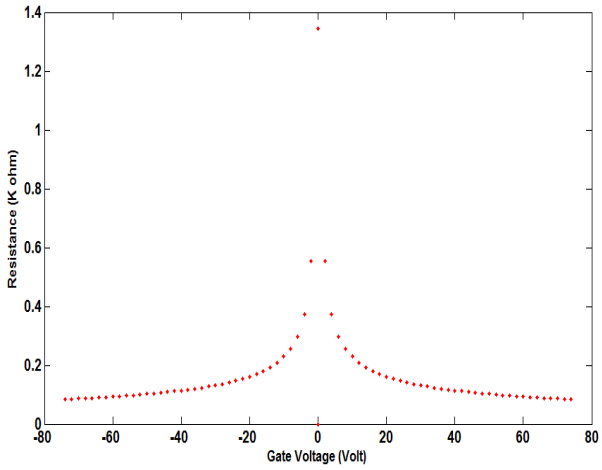

Fig.4. Resistance changing respect to gate voltage

In the other words, because of band gap increasing respect to gate voltage, conductance of BLG will be dramatically decreased.

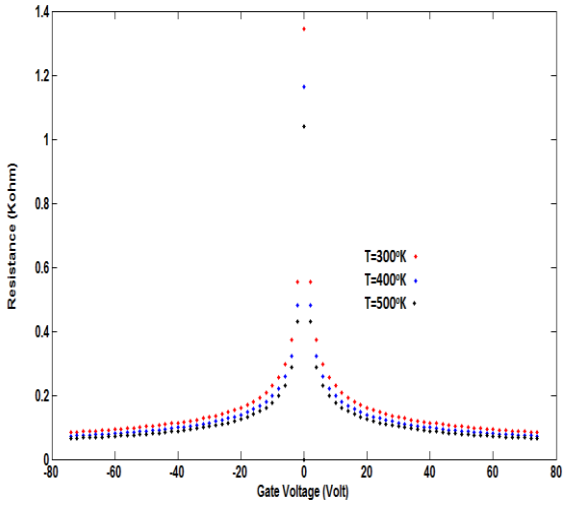

Fig.5. I-R Characteristic of BLG with different of temperature.

Finally, it is notable that the resistance will be decreased with increasing of temperature (is shown in figure 5) same as other metallic materials, because the perfect graphene role as e metallic but it's both conductance and resistance will be controlled by vertical external voltage.

III. Conclusion

Graphene become a promising new material in different of electronic application because of its unique electronic properties. In this paper the resistance of BLG respect to gate voltage is applied and it is seen that the declining of resistance is achieved for higher values of gate voltage. Also, in order to more study about electronic properties of BLG, the temperature effect on the resistance of the BLG is considered, and it is notable that decreasing of resistance can be obtained with the high values of temperature.

IV. ACKNOWLEDGMENTs

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