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Conduction coefficient modeling in bilayer graphene based on schottky transistors

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ABSTRACT: Nowadays carbon nanoparticles are applied on the island of single electron transistor and Nano-transistors. The basis of single electron devices (SEDs) is controllable single electron transfer between small conducting islands. Based on the important points in quantum mechanics, when a wave passes through several spatial regions with different boundaries, the wave function of the first region differs from the second and third wave functions. But the boundary conditions are similar in neighboring areas. The single-electron transistor as a nano-switch can control the current. In the single electron transistor, the velocity of current is influenced by the characteristics of materials such as conductivity. Therefore, the choice of two-dimensional graphene as a material with high conductivity can be increase speed in single-electron transistor. In this research, proposed a model of conductivity for single electron transistor with island as bilayer graphene. Also, the diagram of G-Vg is plotted and the number of key factors is checked.

Keywords: *Bilayer graphene, Conductivity, Island, Single electron transistor.*

INTRODUCTION

The growing interest in two dimensional graphene has attracted much attention attributed because of its unique properties such as high mobility, its large surface–to–volume ratio, high conductivity and strong mechanical and elasticity properties (Mehrdel, *et al.*, 2015). Carbon base material with low dimensional behavior has been explored by many researchers for it has been widely used to accommodate nowadays technology. Recent research on the stability of few-layer, multilayer and even bilayer graphene (Morsin, *et al.*, 2017) has been a brilliant founding. Also, for bilayer graphene nanoribbons (BGNs) two various stacking structures (AA and AB) have been reported, which have armchair edge (Barbier, *et al.*, 2009). This study has focused on the AB-stacked configuration whose band gap is 0.02 eV and is considered as smeiconductor material, while the AA-stacked configuration is metallic (Mousavi, *et al.*, 2011). The atoms A_2 and B_2 existing in the AB structure of bilayer graphene were on the upmost layer of BGNs having hezgonal carbon lattice (See Fig. 1.), but atoms A_1 and B_1 exist on the lowest layer of them

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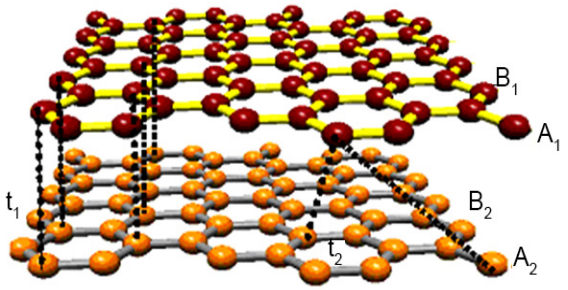

Fig. 1. Schematic of AB bilayer graphene lattice configuration

(Mousavi, *et al.*, 2011).

If the precise electric field is utilized on BGNs, a gap will be created on its band energy. By using voltage, it is possible to manage the value of band gap energy (Sadeghi, *et al.*, 2011). On the other hand, applied electric field effect can be observed in the form of carrier velocity in the channel region of a FET. However, theoretical studies on the carrier velocity of BGNs needs to be done, and velocity characteristic based on the BGN band structure is unexplored. Many researches and examinations have been lately conducted on GNR based FET. Fabricating too narrow nanowire, which has an appropriate energy band in such temperature is the most important challenge related to this issue. These theoretical researches revealed that there is a negative relationship between width and the energy band gap of graphene nanoribbon. They also proved that for operating the transistor at room temperature while creating the smallest band gap, it is crucial to have width down to sub-10 nm. However, in defining the function of the materials, the significant influence of edge effect and width must not be ignored (Huang, *et al.*, 2008). The studies illustrate that different layers of the graphene as a unique material system have an exceptional potential for FETs device applications. In this regard, recent studies have shown that BLG with a gate-tunable band gap is the well-known material system for semiconductor application (Shioya, *et al.*, 2012). Theoretically, band gap can be induced in grapheme with two methods. The first method is narrowing the graphene to nano-ribbon in which the band gap has a reverse relation with the width of nanoribbon (Son, *et al.*, 2006). The second one is applying a perpendicular electric field on BLG that provides a potential difference between layers which opens the band gap in BLG (Zhang, *et al.*, 2011). This property makes it possible for BLG to be used in the future generation nano-electronic devices such as FETs (Ando, *et al.*, 2009).

MATERIAL AND METHODS

In quantum mechanics, the values of the bands with potential barriers one dimensional are scattered. Based on the important points in quantum mechanics, when a wave passes through several spatial regions with different boundaries, the wave function of the first region differs from the second and third wave functions. But the boundary conditions are similar in neighboring areas. So the single electron transistor is divided into three sections, Source, Drain, and Island, that in Fig. 2. Single-electron transistor with a bilayer graphene island is plotted. Nowadays carbon nanoparticles are applied on the island of single electron transistor and Nano-transistors. The basis of Single electron devices (SEDs) is controllable single electron transfer between small conducting islands. A single electron transistor can control the electron tunneling with the effects of quantum mechanics for the desired current.

For the biased BLG, the energy dispersion relation is given by:

$$E(k) = \pm\left(\frac{v_g}{2} + 142.16\frac{t^2 a_{c-c}{}^2 v_g}{\hbar^2}k^2 + 33.28\frac{t^4 a_{c-c}{}^4}{\hbar^4 v_g}k^4\right) \quad (1)$$

where $k = \left(\frac{t_\perp (V^2 + t_\perp{}^2)^{\frac{3}{2}}(E - E_c)}{\hbar^2 V (V^2 + 2t_\perp{}^2) v_F^2}\right)^{1/2} + k_g$ and $m^* = \frac{t_\perp (V^2 + t_\perp{}^2)^{\frac{3}{2}}}{2V(V^2 + 2t_\perp{}^2)}\frac{1}{v_F^2}$

is the effective mass which is a function of applied voltage between the two layers. The effective mass of the free electron in the crystal lattice is different from

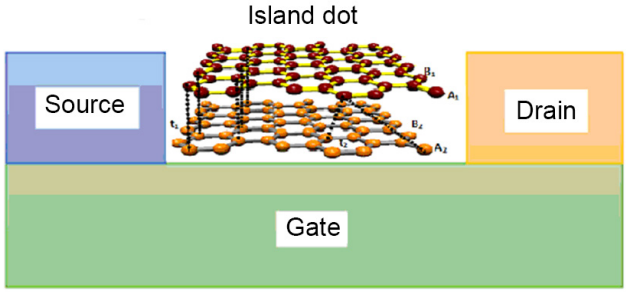

Fig. 2. Single electron transistor with bilayer graphene Island

m_0. Based on the perpendicular electric voltage; the effective mass of the free electron in the crystal lattice is either higher or lower than m_0 for the carriers in BLG lattice. It is notable that in a solid structure, electrons move around randomly without any applied electric field. On the other hand, each electron can be controlled and accelerated using an applied electric field. Due to the high electron transport, the BLG FET channel is assumed to be completely ballistic. Thus, the electrons would be accelerated to achieve faster velocity. For the smallest band gap, wave vector of BLG as the focus of this study is adopted as (Nilsson, *et al.*, 2006):

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

Where $v_F = (\sqrt{2}/3)at/\hbar \approx 1\times10^6 m.s^{-1}$ is the Fermi velocity and ħ is the reduced Planck's constant. So, the energy dispersion of BLG near k_g becomes:

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

In the conductance calculation, we need to find the number of sub-bands instead of DOS. The number of sub-bands, M (E), at applied energy can be considered near the wave vector, which is dependent on the sub band's position. Therefore;

$$M(E) = \frac{\Delta E}{l\Delta k} \tag{4}$$

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

$$M(E) = \frac{\Delta E}{L.\Delta k} = \frac{-284.32k + 133.12k^3}{L} \tag{5}$$

RESULT AND DISCUSSION

The conductance of large channel in graphene materials will be obtained based on the ohmic scaling law by the Landauer formula; however, the conductance in nanoscale devices can be written by two parameters; firstly, conductance related to the width nonlinearly which depends on the number of sub-bands called quantizing parameter and secondly, interface resistance which is independent of the length.

$$G = \frac{2q^2}{h}\int_{-\infty}^{+\infty} M(E)T(E)\left(-\frac{df(E)}{dE}\right)dE \tag{6}$$

Where f (E) is Fermi Dirac distribution function which illustrates the probability of occupied levels at energy E and that can write as;

$$f(E) = \frac{1}{1+e^{\left(\frac{E-E_f}{k_BT}\right)}} \tag{7}$$

We define K_B is Boltzmann's constant and T is temperature. According to the number of sub-bands and Fermi–Dirac distribution function, the conductance of 2D BLG can be obtained by;

In the equation (8), $a_{c-c} = 1.42A^0$ is carbon-carbon band length, ħ is plank constant, t is the distance between the islands, L is island length and V_g is gate voltage, $\eta = \frac{E_F - E_g}{k_BT}$ normalized Fermi energy and $x = \frac{E - E_g}{k_BT}$. This equation might be numerically solved for different potential. It is also evident that the resistance of BLG for higher values of V increases. In addition, resistance shows a similar action regarding the gate voltage (V_g) for various values of perpendicular

$$G = \frac{4q^2}{hL}\int_{-v_g}^{+v_g} \frac{0.75\sqrt{\frac{142.15t^2a_{c-c}{}^2v_g{}^2\hbar^2 + \frac{t^2a_{c-c}{}^2}{\hbar^2v_g{}^{0.5}}\sqrt{20209.1v_g{}^3 + 133.12xk_BT}\hbar^4v_g}{66.56}} - 0.534v_g{}^2}{\sqrt{\frac{142.15t^2a_{c-c}{}^2v_g{}^2\hbar^2 + \frac{t^2a_{c-c}{}^2}{\hbar^2v_g{}^{0.5}}\sqrt{20209.1v_g{}^3 + 133.12xk_BT}\hbar^4v_g}{66.56}} * \frac{t^2a_{c-c}{}^2}{\hbar^2v_g{}^{0.5}}\sqrt{20209.1v_g{}^3 + 133.12xk_BT}} \cdot \frac{1}{1+e^{x-\eta}}dx \tag{8}$$

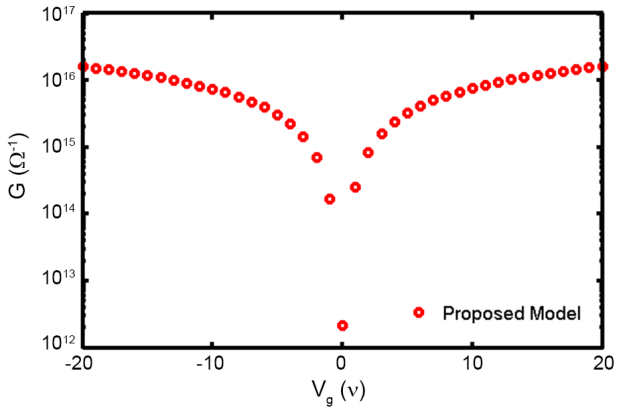

Fig. 3. Conduction coefficient curve is based on the gate voltage for the proposed model.

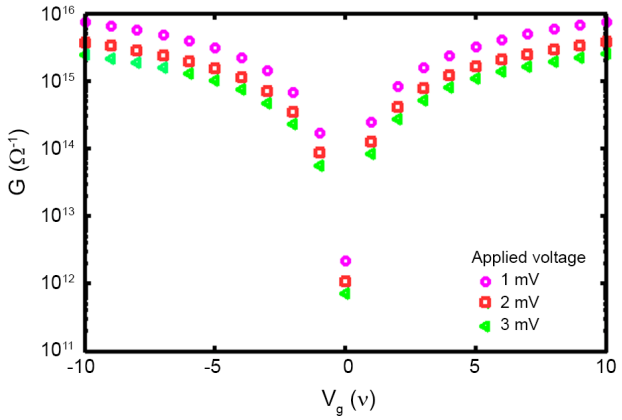

Fig. 5. G-V_g model for different gate voltage (V_g= 1.0, 2.0 and 3.0 mV) with island length

applied voltage. Based on the simulation results, it is concluded that the BLG band gap and resistance can be controlled by applying an external perpendicular electric field. Moreover, the conductance decreases when the band gap is induced. The conductance of FET channel is dependent on the graphene structure and the environment conditions especially temperature and the conductance-changing ratio as a result of temperature altering is different for various gate voltages as well. By focusing on proposed model, it is evident that temperature can effect on the conductance of BLG. In the conductance model the declining of BLG conductance when temperature increases. In addition, the conductance curve is almost symmetric near V_{CNP}, while at the large carrier concentration a saturation behavior is depicted. The conduction coefficient curve is based on the gate voltage for the proposed model is plotted in Fig. 3.

In the Fig. 4 and Fig. 5, the conduction coefficient

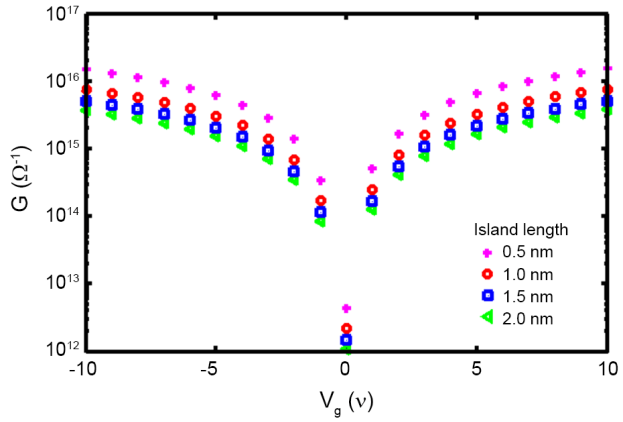

Fig. 4. G-V_g model for different island lengths (a= 0.5, 1, 1.5 and 2 nm) with gate voltage (V_g=0.1mv).

diagram is plotted with different island lengths and different gate voltage.

Examining Fig. 4 and Fig. 5 shows that island length and applied voltage to the gate are two important factors for controlling current in the low bias and Nano range. Graphs show, the decrease in island length leads to an increase in the conduction coefficient. Also, increasing the bias voltage reduces the conductivity of the single-electron transistor with bilayer graphene Island. (a = 1nm).

CONCLUSIONS

The single-electron transistor as a nano-switch can control the current. The velocity of current is influenced by the characteristics of materials such as conductivity. Therefore, the choice of two-dimensional graphene as a material with high conductivity can be increase speed in single-electron transistor. In this research, proposed a model of conductivity for single electron transistor with island as bilayer graphene. Also, the diagram of G-Vg is plotted and the number of key factors is checked. As a result, the conductivity can be controlled by the island length and the applied voltage to the gate.

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