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Graphene Nanoribbon Double Junction Device Modeling

S.N. Hedayat, M.T. Ahmadi, H. Sedghi, H. Goudarzi

***Abstract*- Low dimensional transmission coefficient as a main transport factor need to be explored in this work the transmission coefficient for multi potential barriers is investigated. All theoretical expressions such as height, width of potential barriers, distance between them and carrier property are included to have exact value of transmission coefficient. Additionally, as it is required in many electronic devices to specify conductance of component the exact determination of transmission coefficient especially for graphene based devices is analyzed. Non-isotropic character of transmission coefficient causes to have some extension on Land Auer formalism to derive more accurate expression on graphene based transistors. Finally based on the proposed model the temperature effect on device characteristics is discussed.**

In this paper transmission coefficient of the schottcky structure in the graphene based transistor is modeled based on the width of semiconducting channel and then its quantum properties due to the dependence on structural parameter are analyzed.

Index Terms : **Transmission Coefficient, Graphene Nanoribbon, Double barrier, Quantum current, Temperature.**

I. INTRODUCTION

quantum well structures as a result of confining in the direction of confinement due to quantization of carriers so a series of energy states and related sub-bands will be formed consequently. The numerical computation of Transmission coefficient established by Chandra [15], Christo moulids [16] and later by Scandals [17] but they were not considering the effect of material parameters after a while it was recognized by Chang [18] Read [19]. They One of the most unique concepts in the quantum field is Tunneling particle [1] which has been studied from its conception level to experimental achievements extensively [43].

This astounding properties of material and tunneling of charge carriers have been employed in scanning tunneling microscopy, tunneling of magnetic resistance, Josephson tunneling and so many other physical event. It is based upon transmission of charged particles through quantum barriers. It is so difficult to solve the Schrodinger equation exactly for any random and complicated potentials.

S.N. Hedayat, Department of physic, Faculty of science, Urmia University, Urmia, Iran

M.T. Ahmadi, Department of physic, Faculty of science, Urmia University, Urmia, Iran

H. Sedghi, Department of physic, Faculty of science, Urmia University, Urmia, Iran

H. Goudarzi, Department of physic, Faculty of science, Urmia University, Urmia, Iran

Tunneling of particles among all those forbidden regions can be considered as another consequence of quantum mechanics. It is obvious that utilization of this unique phenomena, electron tunneling, has been placed at the center scope of numerous Biological Molecular model [2, 3, 4] and also it is the key point of modern technology specially for electronic devices [5, 6, 7, 8, 9, 10]. Esaki and Tzu offered symmetric double barrier structure for semiconductor materials and has made pioneer work [11, 12, 13] in which the transportation of electrons proceed by means of resonant tunneling mechanism. After this step the super lattices [14] has been suggested in which it provides multiple started to study all those different material parameters separately to investigate resonant tunneling probability in semiconductor double barrier structure independently. In this path Wessel [20] calculated these problems for GaAs/AlxGa1-xAs composition for thin barrier.

For computation of electrical parameters of quantum well structures in which discontinuity of conduction band and envelope function approximation [21], it influences Eigen states, and consequently tunneling current have been effected with non-parabolic band structure so this should be considered as one of the most important feature. As tailoring transport properties is considered to obtain displacement of energy levels from band edge of 1-D confined structures thus first-order non-parabolic energy vs. K relationship plays a major role to calculate transmission coefficient and current density if the physical parameters of device would be included in order to get rid of these data it should be taken into account for each step of mathematical modeling and computation. The influence of conduction band non-parabolic on Eigen energies has been studied by Miller [22] by using Kane's two-band modeling and also Hiroshima [23] has considered non parabolic factor as a function of those models with ultrathin layers parameter. In this area one of the important items is NP effect on transmission probabilities which has been studied by Nelson [24] who considered energy-dependent effective mass and Dave [25] who used finite element method for more precise estimation [26]. By several numerical analysis techniques such as variation Method [27], airy's function approach [28,29], finite element method (FEM) [30], transfer matrix Technique (TMT) [31] and Weighted potential method(WPM) [28] the double barrier resonant tunneling structure can be computed. Among these mentioned techniques TMT can be considered one of the most effective and accurate methods and also most of the researchers rely on this typically. According to the estimation theory about tunneling resonance while applying field on these devices [30, 32] the transmission coefficient and tunneling current can be obtained.

As obtaining transmission coefficient is one important and necessary stage based on calculation of the intensity of electrical current or measuring conductance of various electronic devices [33] such as graphene super lattices [34] or some filters including with or without disorder [35]. As carrier transporting through these sorts of devices is anisotropic phenomenon so it provides ease of fabrication of electronic circuits for example ignoring any etching or cutting step. Computing transmission coefficient in an analytical expression for different potential barriers are in our scope of interest, however, it can be calculated by different methods such as S-matrix which is one of the most appropriate techniques for multiple barrier conditions.

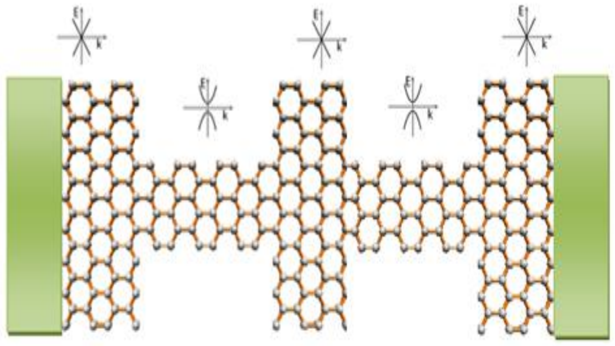

Figure (1): Schematic of three metallic graphene, connecting three pieces of GNR by two bridge semiconductors which each coupled make a schottcky Twin barrier

As shown in figure (1) in the proposed structure with two semiconducting channel is modulated and connected to drain and source terminal by three metallic graphene which make a schottcky twin barrier and through the source and drain at the graphene–metal interface in a transistor [36]. The proposed structure can be divided in to 5 regions as shown in figure 2.

II. Model

In regions 1, 2, 3, 4 and 5, the answer to Schrödinger's equation everywhere $E\langle V_0$ is of the same shape including traveling and reflecting wave. In region 1, 3and 5 the potential energy is zero, and in region 2 and 4 the potential energy is V_0 therefore,

$$k_1 = k_3 = k_5 = \sqrt{\frac{2mE}{\hbar^2}}, k_2 = k_4 = \sqrt{\frac{2m(E - V_0)}{\hbar^2}} \quad (1)$$

The transmission ratio is different in terms of the probability of currents according to T equation

$$T = \left| \frac{j_{transmitted}}{j_{incident}} \right| = \left| \frac{K}{A} \right|^2 \quad (2)$$

We determine the position of the display and the transmission ratios have to decide on restrictions on the use of the solution and the constants A, B, and K.

Perform our calculations; we need reflection and transmission amplitudes on junctions. Individual barrier does not depend on the amplitude of the reflection. Allow R be the reflection amplitude for a hydroplane gesture of component amplitude with energy $E\langle V_0$ interrupting on a barrier of length L as of the left at x = 0, perceive figure (2). T allows the transmission beam to be the same amplitude. Communication, which is recognized by the reflection and transmission facilities, as well as the reflection and transmission coefficients, is therefore $|R|^2$ and $|T|^2$ respectively.

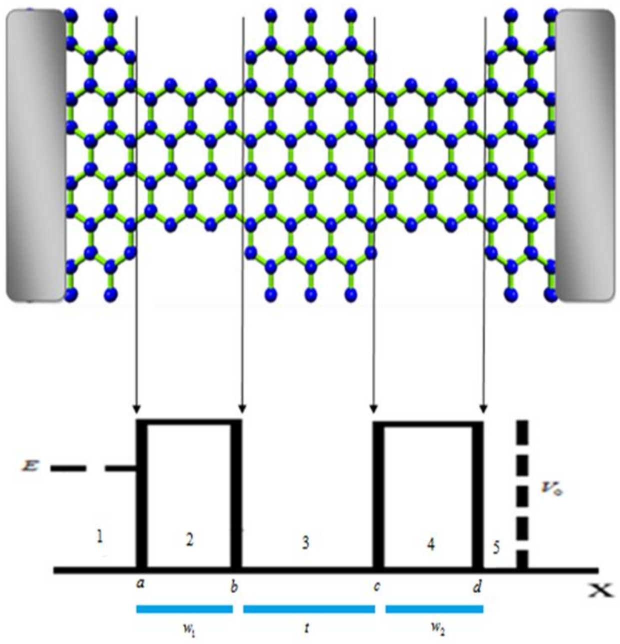

Figure (2): Multi barrier channel region in GNR transistor

Therefore, with the aspire of deducing the innovative T(E), believe the solutions to Schrodinger's equation through in every district for $E\langle V_0$:

$$\psi_1(x) = Ae^{ik_1x} + Be^{-ik_1x}, x\langle a$$
$$\psi_2(x) = Ce^{k_2x} + De^{-k_2x}, a\langle x\langle b$$
$$\psi_3(x) = Fe^{ik_3x} + Ge^{-ik_3x}, b\langle x\langle c$$
$$\psi_4(x) = He^{k_4x} + Je^{-k_4x}, c\langle x\langle d$$
$$\psi_5(x) = Ke^{ik_5x} + Le^{-ik_5x}, d\langle x \quad (3)$$

Someplace $(k_1 = k_3 = k_5 = k)$ and $(k_2 = k_4 = K)$ have their usual forms as certain in equation (1) and the locations of the interfaces have been labeled a, b, c and d, correspondingly. By means of the normal Ben Daniel-Duke [42] boundary conditions at every crossing point gives the following

$$\begin{cases}\psi_1(x)|_{x=0}=\psi_2(x)|_{x=0}\rightarrow A+B=C+D\\ \dfrac{d\psi_1(x)}{dx}|_{x=0}=\dfrac{d\psi_2(x)}{dx}|_{x=0}\rightarrow ik_1A-ik_1B=k_2C-k_2D\end{cases}$$

$$\begin{cases}\psi_2(x)|_{x=b}=\psi_3(x)|_{x=b}\rightarrow Ce^{k_2b}+De^{-k_2b}=Fe^{ik_3b}+Ge^{-ik_3b}\\ \dfrac{d\psi_2(x)}{dx}|_{x=b}=\dfrac{d\psi_3(x)}{dx}|_{x=b}\rightarrow Ck_2e^{k_2b}-Dk_2e^{-k_2b}=ik_3Fe^{ik_3b}-ik_3Ge^{-ik_3b}\end{cases}$$

$$\begin{cases}\psi_3(x)|_{x=c}=\psi_4(x)|_{x=c}\rightarrow Fe^{ik_3c}+Ge^{-ik_3c}=He^{k_2c}+Je^{-k_2c}\\ \dfrac{d\psi_3(x)}{dx}|_{x=c}=\dfrac{d\psi_4(x)}{dx}|_{x=c}\rightarrow ik_3Fe^{ik_3c}-ik_3Ge^{-ik_3c}=Hk_2e^{k_2c}-Jk_2e^{-k_2c}\end{cases}$$

$$\begin{cases}\psi_4(x)|_{x=d}=\psi_5(x)|_{x=d}\rightarrow He^{k_4d}+Je^{-k_4d}=Ke^{ik_5d}\\ \dfrac{d\psi_4(x)}{dx}|_{x=d}=\dfrac{d\psi_5(x)}{dx}|_{x=d}\rightarrow Hk_4e^{k_4d}-Jk_4e^{-k_4d}=ik_5Ke^{ik_5d}\end{cases} \quad (4)$$

The method of solution is the transport matrix technique as previous; the derived equation indicates the matrix form of the model.

$$\begin{pmatrix}1 & 1\\ ik_1 & -ik_1\end{pmatrix}\begin{pmatrix}A\\ B\end{pmatrix}=\begin{pmatrix}1 & 1\\ k_2 & -k_2\end{pmatrix}\begin{pmatrix}C\\ D\end{pmatrix}\rightarrow M_1\begin{pmatrix}A\\ B\end{pmatrix}=M_2\begin{pmatrix}C\\ D\end{pmatrix}$$

$$\begin{pmatrix}e^{k_2b} & e^{-k_2b}\\ k_2e^{k_2b} & -k_2e^{-k_2b}\end{pmatrix}\begin{pmatrix}C\\ D\end{pmatrix}=\begin{pmatrix}e^{ik_3b} & e^{-ik_3b}\\ ik_3e^{ik_3b} & -ik_3e^{-ik_3b}\end{pmatrix}\begin{pmatrix}F\\ G\end{pmatrix}\rightarrow M_3\begin{pmatrix}C\\ D\end{pmatrix}=M_4\begin{pmatrix}F\\ G\end{pmatrix}$$

$$\begin{pmatrix}e^{ik_3c} & e^{-ik_3c}\\ ik_3e^{ik_3c} & -ik_3e^{-ik_3c}\end{pmatrix}\begin{pmatrix}F\\ G\end{pmatrix}=\begin{pmatrix}e^{k_4c} & e^{-k_4c}\\ k_4e^{k_4c} & -k_4e^{k_4c}\end{pmatrix}\begin{pmatrix}H\\ J\end{pmatrix}\rightarrow M_5\begin{pmatrix}F\\ G\end{pmatrix}=M_6\begin{pmatrix}H\\ J\end{pmatrix}$$

$$\begin{pmatrix}e^{k_4d} & e^{-k_4d}\\ k_4e^{k_4d} & -k_4e^{-k_4d}\end{pmatrix}\begin{pmatrix}H\\ J\end{pmatrix}=\begin{pmatrix}e^{ik_5d} & 0\\ ik_5e^{ik_5d} & 0\end{pmatrix}\rightarrow M_7\begin{pmatrix}H\\ J\end{pmatrix}=M_8\begin{pmatrix}K\\ 0\end{pmatrix} \quad (5)$$

Then, as before, the coefficients of the outer regions can be linked by forming the transfer matrix,

$$\begin{pmatrix}A\\ B\end{pmatrix}=M_1^{-1}M_2M_3^{-1}M_4M_5^{-1}M_6M_7^{-1}M_8\begin{pmatrix}K\\ 0\end{pmatrix} \quad (6)$$

$$M_1^{-1}=\frac{1}{-2ik_1}\begin{pmatrix}-ik_1 & -1\\ -ik_1 & 1\end{pmatrix},M_3^{-1}=\frac{1}{-2k_2}\begin{pmatrix}-k_2e^{-k_2b} & -e^{-k_2b}\\ -k_2e^{k_2b} & e^{k_2b}\end{pmatrix}$$

$$M_5^{-1}=\frac{1}{-2ik_3}\begin{pmatrix}-ik_3e^{-ik_3c} & -e^{-ik_3c}\\ -ik_3e^{ik_3c} & e^{ik_3c}\end{pmatrix},M_7^{-1}=\frac{1}{-2k_4}\begin{pmatrix}-k_4e^{-k_4d} & -e^{-k_4d}\\ -k_4e^{k_4d} & e^{k_4d}\end{pmatrix} \quad (7)$$

$$\begin{pmatrix}A\\ B\end{pmatrix}=\frac{1}{-16k_1k_2k_3k_4}\begin{pmatrix}-ik_1 & -1\\ -ik_1 & 1\end{pmatrix}\begin{pmatrix}1 & 1\\ k_2 & -k_2\end{pmatrix}\begin{pmatrix}-k_2e^{-k_2b} & -e^{-k_2b}\\ -k_2e^{k_2b} & e^{k_2b}\end{pmatrix}\begin{pmatrix}e^{ik_3b} & e^{-ik_3b}\\ ik_3e^{ik_3b} & -ik_3e^{-ik_3b}\end{pmatrix}$$
$$*\begin{pmatrix}-ik_3e^{-ik_3c} & -e^{-ik_3c}\\ -ik_3e^{ik_3c} & e^{ik_3c}\end{pmatrix}\begin{pmatrix}e^{k_4c} & e^{-k_4c}\\ k_4e^{k_4c} & -k_4e^{k_4c}\end{pmatrix}\begin{pmatrix}-k_4e^{-k_4d} & -e^{-k_4d}\\ -k_4e^{k_4d} & e^{k_4d}\end{pmatrix}\begin{pmatrix}e^{ik_5d} & 0\\ ik_5e^{ik_5d} & 0\end{pmatrix}\begin{pmatrix}K\\ 0\end{pmatrix} \quad (8)$$

Obviously, this is a 2x2 matrix equation with four unknown parameters and cannot be resolved at this stage. Previously, the standard limits, that is $\psi_z \rightarrow 0$, as $z \rightarrow \pm\infty$ is used. Some states within the quantum wells is not suitable to find the wave form such as traveling waves in the barrier structures therefore the 2×2 matrix is written as M, then:

$$\begin{pmatrix}A\\ B\end{pmatrix}=M\begin{pmatrix}K\\ 0\end{pmatrix}\rightarrow A=M_{11}K \quad (9)$$

The transmission coefficient is merely:

$$t(E)=\frac{K^*K}{A^*A}=\frac{1}{M_{11}{}^*M_{11}} \quad (10)$$

We carry out a scaled-down version of the double-barrier position; the amplitude of the transfer income formula is written as:

$$t(E)=4\left[e^{ik_1(w_1+w_2)}\left(2\cosh(k_3w_2)-ik_{1-3}\sinh(k_3w_2)\right)\left(2\cosh(k_2w_1)\right)\right.$$
$$\left.-ik_{1-2}\sinh(k_2w_1)+e^{ik_1(g+b-w_1)}k_{1+3}k_{1+2}\sinh(k_2w_1)\sinh(k_3w_2)\right]^{-1} \quad (11)$$

Therefore $w_{1,2}$ are the widths of the two barriers and t is the distance between the barrier and the

Additional parameters are

$$g=w_1+w_2,b=w_1+w_2+t,k_{i\pm j}=\frac{k_i}{k_j}\pm\frac{k_j}{k_i},(i,j=1,2,3)$$

consequently:

$$t(E)=\frac{4ik_1^2k_2^2e^{-2iw_1k_1}}{\begin{pmatrix}\left(-ik_1^4-2ik_1^2k_2^2-ik_2^4\right)e^{2i(t-w_1)k_1}+ik_1^4-2ik_1^2k_2^2+ik_2^4+\left(ik_1^4+2ik_1^2k_2^2+ik_2^4\right)e^{2i(t-w_1)k_1}\cosh^2(w_1k_2)\\ \left(-ik_1^4+6ik_1^2k_2^2-ik_2^4\right)\cosh^2(w_1k_2)+4k_1k_2\left(k_1^2-k_2^2\right)\sinh(w_1k_2)\cosh(w_1k_2)\end{pmatrix}} \quad (12)$$

Therefore the transmission coefficient is a guess of how a large deal of an electromagnetic wave exceed throughout an outside or an optical constituent. Transmission coefficients are able to affects amplitude or the intensity of the wave as well is intended by gorgeous relation of the assessment subsequent to the outside or constituent to the worth .This complete square provides the transmission coefficient T. Therefore, the transmission coefficient is calculated as

$$T(E)=\frac{16k_1^2k_2^2}{\begin{pmatrix}\begin{pmatrix}\left(k_1^4+2k_1^2k_2^2+k_2^4\right)\sin\left(2k_1(t-w_1)\right)-\left(k_1^4+2k_1^2k_2^2+k_2^4\right)\sin\left(2k_1(t-w_1)\right)\cosh^2(w_1k_2)\\ +4\sinh(w_1k_2)k_1k_2\left(k_1^2-k_2^2\right)\cosh(w_1k_2)\end{pmatrix}^2\\ +\begin{pmatrix}-\cos\left(2k_1(t-w_1)\right)\left(k_1^4+2k_1^2k_2^2+k_2^4\right)+k_1^4-2k_1^2k_2^2+k_2^4\\ +\left(\cos\left(2k_1(t-w_1)\right)\right)\left(k_1^4+2k_1^2k_2^2+k_2^4\right)-k_1^4+6k_1^2k_2^2-k_2^4\right)\cosh^2(w_1k_2)\end{pmatrix}^2\end{pmatrix}} \quad (13)$$

In foregoing equation, the wave vector $(k_1=k)$ outside the barrier is a real quantity for all positive energies E of the electron. The minimum conduction band in the region outside barrier taken as zero energy. Since the minimum conduction band of barrier is above that of the region outside and hence as for certain energies of the electron ($E\langle V_0$) the wave vector $(k_2=K)$ will be imaginary and for energies above

V_0 ($E \rangle V_0$) is real. Thus the energy can be divided into two regions, ($E \langle V_0$) for non-classical transition through tunneling and ($E \rangle V_0$) where transition can occurs even under classical conditions.

The solutions and methods applied to evaluate the transmission coefficients in the two regions will be differed among many others. Since $(k_1 = k)$ and $(k_2 = K)$ are both effective mass and energy-dependent , hence for different material pairs the variation of the transmission coefficient for energy values is normalized with given barriers height [39, 40,41]. Where w_1, w_2 are the lengths of the barriers.

The transmission coefficient of electrons through a potential barrier is important for studying the leakage current in MOSFETs with nanometer dimensions. It is at the same time a crucial parameter to shed lights on behavior of multiple quantum well structures where the barriers are sandwiched between two coupled quantum wells. When the wells and barriers regions are in the nanometer range we expect further quantization of the energy levels. This is being considered in a further study of the multiple quantum well structure. the less barriers width, the more tunneling and transmission coefficient value with normalized electron energy will be more .For $\left(E_n = \frac{E}{V_0}\right)\langle 1$, the transmission coefficient increases from 0 to 1 in a non-linear manner as figure (3,4) illustrates it.

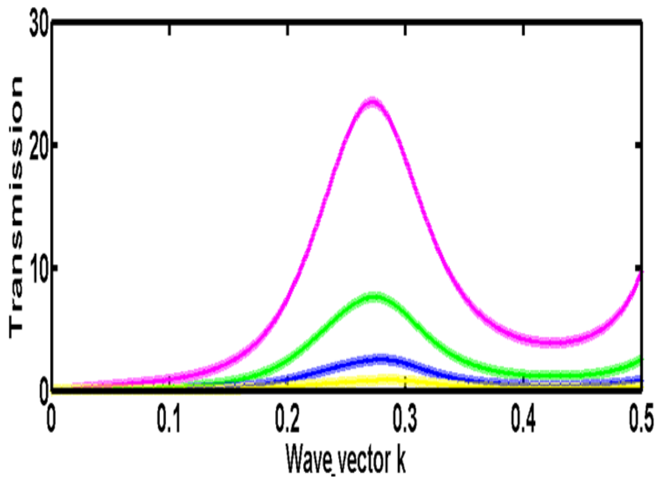

Figure (3): Transmission for different K values in the GNR at channel region

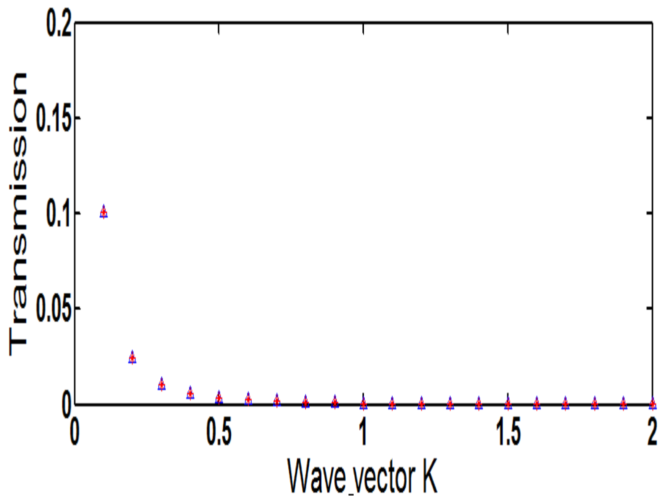

Figure (4): Transmission for different k values in the GNR at first, third and the fifth regions

As shown in figure (3) and figure (4) if the energy of electron in each region is changed within allowed values the transmission coefficient is varied accordingly.

In the presence of k^2 and K^2 the transmission can be modified as:

$$T(E) = \frac{16(\frac{V_0}{E}-1)}{\left(\begin{array}{l} \left(\left(1+2(\frac{V_0}{E}-1)+(\frac{V_0}{E}-1)^2\right)\sin\left(2\alpha\sqrt{E}(t-w_1)\right) - \left(1+2(\frac{V_0}{E}-1)+(\frac{V_0}{E}-1)^2\right)\sin\left(2\alpha\sqrt{E}(t-w_1)\right)\cosh^2\left(\alpha\sqrt{V_0-E}w_1\right) \right. \\ \left. +4(2-\frac{V_0}{E})\sqrt{\frac{V_0}{E}-1}\sinh\left(\alpha\sqrt{V_0-E}w_1\right)\cosh\left(\alpha\sqrt{V_0-E}w_1\right) \right)^2 \\ + \left(-\left(1+2(\frac{V_0}{E}-1)+(\frac{V_0}{E}-1)^2\right)\cos\left(2\alpha\sqrt{E}(t-w_1)\right) + \left(1-2(\frac{V_0}{E}-1)+(\frac{V_0}{E}-1)^2\right) \right. \\ \left. + \left(1+2(\frac{V_0}{E}-1)+(\frac{V_0}{E}-1)^2\right)\cos(2\alpha\sqrt{E}(t-w_1))\cosh^2\left(\alpha\sqrt{V_0-E}w_1\right) - \left(1-6(\frac{V_0}{E}-1)+(\frac{V_0}{E}-1)^2\right)\cosh^2\left(\alpha\sqrt{V_0-E}w_1\right) \right)^2 \end{array} \right)} \quad (14)$$

Where $k_1 = \alpha\sqrt{E}, k_2 = \alpha\sqrt{V_0 - E}, \alpha = \sqrt{\frac{2m}{\hbar^2}}$

Also Figure (5) gives an example of the Transmission coefficient for barriers of height as a function of the distance t between them.

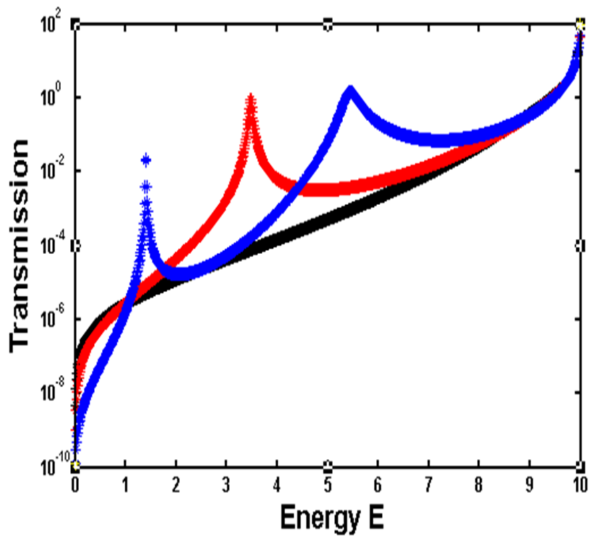

Figure (5): Transmission coefficient as a function of the energy through a double barrier of height, separated by a distance t

It is obvious that the results from the resonance increase the transmission T as expected which classically indicates a reduction on the transmission ratio that means it is more difficult for electrons to tunnel through the barriers. Increasing the resonance energy by applied voltage will increase the effect of confinement barrier height and appearance of the high-energy resonance is a reflection of the quasi-bound state existence [show me the reference]. In fact, the features, such as two-terminal electronic devices in general can be summarized with their current-voltage characteristics (I-V). As a result Quantum current based on the Land Auer formalism Written to the [37,38]:

$$I_q = \int_0^{\eta} T(E)F(E)dE \qquad (15)$$

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

$$f(E) = \frac{1}{\exp\left(\frac{E-E_F}{k_B T}\right)+1} \qquad (16)$$

Where K_B Boltzmann's constant and T is temperature.

Since the charge carrier barrier structure of the bulk of the group, then the integral of energy and Fermi-Dirac Distribution function and the density of states of the mass (3D) forms.

In the simplified form by considering the wave vector and quantum transmission coefficient the quantum current is modified as

$$I_q = \int_0^{\eta} \frac{16k_1^2k_2^2}{\left(\begin{array}{l}\left(k_1^4+2k_1^2k_2^2+k_2^4\right)\sin\left(2k_1\left(t-w_1\right)\right)-\left(k_1^4+2k_1^2k_2^2+k_2^4\right)\sin\left(2k_1\left(t-w_1\right)\right)\cosh^2\left(w_1k_2\right)\\ +4\sinh\left(w_1k_2\right)k_1k_2\left(k_1^2-k_2^2\right)\cosh\left(w_1k_2\right)\end{array}\right)^2 + \left(\begin{array}{l}-\cos\left(2k_1\left(t-w_1\right)\right)\left(k_1^4+2k_1^2k_2^2+k_2^4\right)+k_1^4-2k_1^2k_2^2+k_2^4\\ +\left(\cos\left(2k_1\left(t-w_1\right)\right)\right)\left(k_1^4+2k_1^2k_2^2+k_2^4\right)-k_1^4+6k_1^2k_2^2-k_2^4\right)\cosh^2\left(w_1k_2\right)\end{array}\right)^2} \frac{1}{\exp\left(\frac{E-E_F}{k_BT}\right)+1}\, di \qquad (17)$$

Consequently, quantum current can be simplified in the form of well-known Fermi integrals. Therefore, quantum current as a function of quantum transmission coefficients is modeled as bellow:

$$I_q = \int_0^{\eta} \frac{k_BT16k_1^2k_2^2}{\left(\begin{array}{l}\left(k_1^4+2k_1^2k_2^2+k_2^4\right)\sin\left(2k_1\left(t-w_1\right)\right)-\left(k_1^4+2k_1^2k_2^2+k_2^4\right)\sin\left(2k_1\left(t-w_1\right)\right)\cosh^2\left(w_1k_2\right)\\ +4\sinh\left(w_1k_2\right)k_1k_2\left(k_1^2-k_2^2\right)\cosh\left(w_1k_2\right)\end{array}\right)^2 + \left(\begin{array}{l}-\cos\left(2k_1\left(t-w_1\right)\right)\left(k_1^4+2k_1^2k_2^2+k_2^4\right)+k_1^4-2k_1^2k_2^2+k_2^4\\ +\left(\cos\left(2k_1\left(t-w_1\right)\right)\right)\left(k_1^4+2k_1^2k_2^2+k_2^4\right)-k_1^4+6k_1^2k_2^2-k_2^4\right)\cosh^2\left(w_1k_2\right)\end{array}\right)^2} * \frac{1}{1+\exp(x-\eta)}\, dx \qquad (18)$$

This equation might be numerically solved for different potential. Thus, the proposed quantum current model of graphene nanoribbon under nanostructured regime by the I-V characteristic is evaluated in Figure (6).

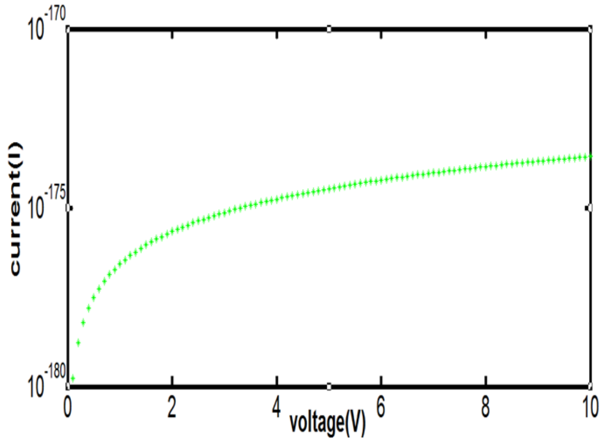

Figure (6): I-V model for the double barrier of grapheme nanoribbon

As number of carriers increases, device will operate in degenerate limit. Degenerate regime plays an important role on quantum current research in the Nano-scale devices. In the degenerate regime, $E - E_F < 3k_BT$, also, degeneracy of MGNS can be defined once Fermi probability function equals one $f(E)=1$. for the non-degenerate regime in the contrary, $E - E_F > 3k_BT$ then we can write $f(E) = \exp\left(\frac{E_F - E}{k_BT}\right)$.

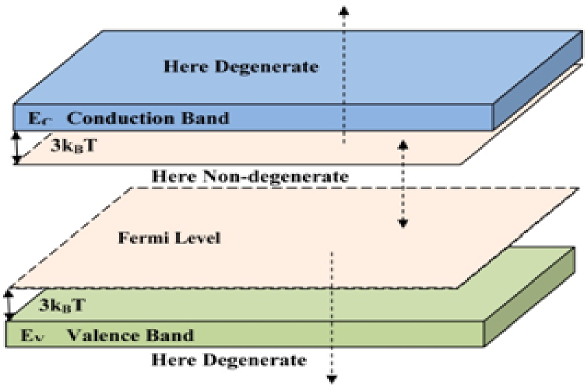

Figure (7): Compression of the degenerate regime and non-degenerate regime

As figure (7) illustrated in conduction band, where concentration of electrons pass the density states , the Fermi energy lies in the conduction band [18]. In the other words, given very small amount of x-η in this regime, expr(x-η) can be neglected. So quantum current in degenerate approximation is;

$$I_{qd} = \int_0^{\eta} \frac{k_BT16k_1^2k_2^2}{\left(\begin{array}{l}\left(k_1^4+2k_1^2k_2^2+k_2^4\right)\sin\left(2k_1\left(t-w_1\right)\right)-\left(k_1^4+2k_1^2k_2^2+k_2^4\right)\sin\left(2k_1\left(t-w_1\right)\right)\cosh^2\left(w_1k_2\right)\\ +4\sinh\left(w_1k_2\right)k_1k_2\left(k_1^2-k_2^2\right)\cosh\left(w_1k_2\right)\end{array}\right)^2 + \left(\begin{array}{l}-\cos\left(2k_1\left(t-w_1\right)\right)\left(k_1^4+2k_1^2k_2^2+k_2^4\right)+k_1^4-2k_1^2k_2^2+k_2^4\\ +\left(\cos\left(2k_1\left(t-w_1\right)\right)\right)\left(k_1^4+2k_1^2k_2^2+k_2^4\right)-k_1^4+6k_1^2k_2^2-k_2^4\right)\cosh^2\left(w_1k_2\right)\end{array}\right)^2}\, dx \qquad (19)$$

As shown in the Figure (8), quantum current in the range of more than zero leads to the degenerate approximation on graphene nanoribbon.

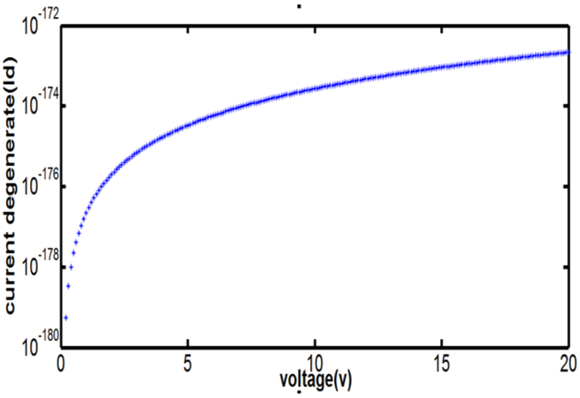

Figure (8): I-V model for the double barrier of graphene nanoribbon in degenerate approximation

Non-degenerate approximation as distance increases up to $3K_BT$ from either the conduction or valance band edge in the form of band gap near the Fermi level. In semiconductors, non-degenerate region is nestled in a band with distance less than $3K_BT$ beyond from the conductance and valence band. Hence, the current in non-degenerate regime can be modified by exponential function so that:

$$I_{qnd} = \int_0^{\eta} \frac{k_B T 16 k_1^2 k_2^2 \exp(\eta)}{\left(\begin{pmatrix} \left(k_1^4 + 2k_1^2k_2^2 + k_2^4\right)\sin\left(2k_1\left(t-w_1\right)\right) - \left(k_1^4 + 2k_1^2k_2^2 + k_2^4\right)\sin\left(2k_1\left(t-w_1\right)\right)\cosh^2\left(w_1k_2\right) \\ +4\sinh\left(w_1k_2\right)k_1k_2\left(k_1^2 - k_2^2\right)\cosh\left(w_1k_2\right) \end{pmatrix}^2 + \begin{pmatrix} -\cos\left(2k_1\left(t-w_1\right)\right)\left(k_1^4 + 2k_1^2k_2^2 + k_2^4\right) + k_1^4 - 2k_1^2k_2^2 + k_2^4 \\ +\left(\cos\left(2k_1\left(t-w_1\right)\right)\left(k_1^4 + 2k_1^2k_2^2 + k_2^4\right) - k_1^4 + 6k_1^2k_2^2 - k_2^4\right)\cosh^2\left(w_1k_2\right) \end{pmatrix}^2 \right)} dx \qquad (20)$$

Finally, the comparison of quantum current, degenerate regime and non-degenerate regime is shown in Figure (9). It shows the results obtained using the proposed model.

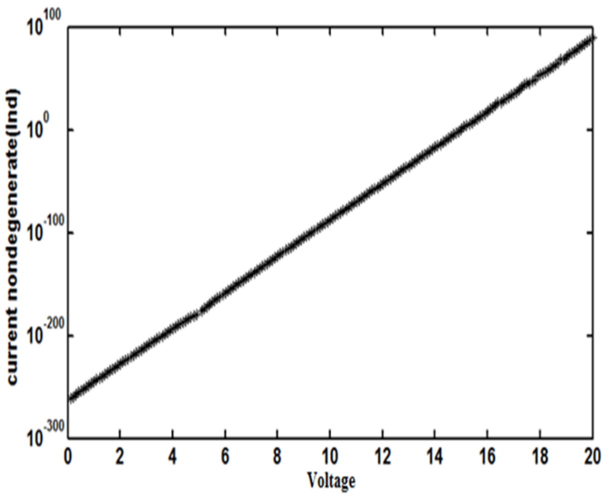

Figure (9): current-voltage curve for the double barrier of graphene nanoribbon in nondegenerate approximation

It shows that at low temperatures, a small part of the energy is in the space around band minima. Subsequently the voltage is increased, the current starts to fall only in the case of a narrow resonance line. When the temperature rises, the carrier distribution is expanded as the non-degenerate limit depends on the temperature in this limit the current is increased as well. It can be concluded that the peak occurs when the distribution corresponds to the peak of the resonance energy.

III. Conclusion

Additionally, structural parameter effect on quantum current of graphene based transistor is analyzed. Finally, At low temperatures, a small part of the energy carriers in the space around the band minima. Since the area has increased, the current starts flowing only when this narrow resonance line with the distribution of energy, and thus Current peak is narrow. When the temperature rises, the carrier distribution is expanding, so that it is more the range of applied voltage, which is a degree of alignment of the resonance energy carrier. The peak occurs when The distribution corresponds to the peak of the resonance energy. At voltages above this, the number of carriers available Reducing the tunnel and thus reduce the power.

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