TFET I-V characteristics made of bi layer Armchair Grafene Nano Ribbon (AGNR)

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Abstract. The dispersion energy of bi layer arm chair grafene nano ribbon (AGNR) have been calculated using the Tight Binding method. This is used to analyze the characteristics of the device relating the voltage-current in the Tunnel Field Effect Transistor (TFET). The current's Landauer is used for the theoretical approach of the output properties of the generated device, and the use of the Gauss Quadrature method to calculate the current on the TFET device. The result show that the current of drain linear to the wide of ribbon.

Kata kunci: AGNR, TB, TFET

1. Introduction
Tunnel Field Effect Transistor (TFET) is a Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) for low-energy electronic devices. TFET has a low sub threshold and also has a low current leakage at off condition but performance when on condition still less when compared to MOSFET [1,2]. To improve performance at on condition, this TFET must be used with materials that have low effective electron mass [3].

AGNR bi layer is one of the suitable materials because the effective mass of the electron has a certain value with the density of the carrier charge and band gap energy can be controlled by the wide and gate-voltage. This two-dimensional material controls the gate for the better and with the relativistic nature of grapheme so TFET performance at on condition will increase.

To find the characteristic of its output is assumed to use quantum capacitance limit and its transmittance using Airy function method while its current using Landauer current with Gauss Quadrature numerical method.

2. Theoretical Approach
The TFET structure is the same as the MOSFET but for the source and drain is dopant or of different type, while the gate is intrinsic according to the material type. The work of the TFET transistor depends on the gate voltage used. When the gate voltage has not caused an overlap between the source valence band and the gate conduction band, the probability of electrons to tunnel through the potential barrier is still low or it can be said to be off condition. When the gate voltage causes an overlap in the
valence band at the source and the conduction band on the gate the probability of electrons to break through is so large that it can be said to be on condition.

In the research, the structure of the AGNR bi layer-based TFET device is modeled as Figure 1, in which the source, gate, and drain are dopant with p+, p, and n+ respectively.

![Figure 1. The AGNR TFET Structure](image)

The energy formed from the above scheme can be found by solving the Poisson Equation [4]

$$\frac{d^2 \phi_s(x)}{dx^2} = \frac{\phi_s(x) - \phi_{we} - \phi_G}{\varepsilon_{BAGNR}} - \frac{Q}{\varepsilon_{BAGNR}}.$$

With $\phi_s$ a surface potential, it describes the built-in potential that determines the location of the Fermi energy and depends on the amount of doping used [4] so that the magnitude can be determined from the difference between the energy in the conduction band and the Fermi energy and $\phi_G$ is the gate potential which can be searched by multiplying the electron charge (q) with gate voltage ($V_G$). The parameter describes the relevant length scale for potential variation with $\varepsilon_{BAGNR}$ and $\varepsilon_{ox}$ is the dielectric constant for the AGNR and oxide bilayers respectively. In addition, $t_{ox}$ is thick oxide and $t_{AGNR}$ is a thick bilayer of AGNR. The Solutions of differential equation is:

$$\phi_s(x) = Ae^x + Be^{-x} - (\phi_{hi} + \phi_{fc}) + \frac{\lambda^2 Q}{\varepsilon_{BAGNR}}.$$

Constants A and B can be determined by using boundary conditions. Boundary conditions are defined by assuming gate lengths from 0 to L. These boundary conditions include, firstly, an electric field equal to zero for very long distances. Second, potential and continuous electric fields in the source-gate area (x=0) and in the gate-drain (x=L) area. Third, the energy difference between the Fermi energy $E_{fs}$ and the valence energy in the source $E_{vs}$ is the charge multiplied by the thermal potential $qV_T$. This condition also applies to the difference between the Fermi energy $E_{fd}$ and the conduction energy $E_{cd}$ in the drain. Thermal energies $V_T$ are influenced by the magnitude of doping in source and drain [5]. Fourth is assumed that the conduction band energy on the gate $E_{cc}$ is equal to the valence band energy in source when no gate voltage $V_G$ is given. In every region is assumed $E_{fs} = 0$ and $L > l$. The quantum capacitance limit assumes that the oxide capacitance is so much greater than the quantum capacitance [6] that even if it is turned on, the band's energy profile changes, the carrier charge will not affect the gate or the charge can be considered zero and $\sigma = 2l$. The energy scheme is:

$$E_s(x) = \begin{cases} 
qV_s + E_G, & x \leq \sigma \\
-qV_G + \frac{E_{hi}}{2} + \frac{2qV_s}{2}, & -\sigma \leq x \leq \sigma \\
-qV_G + qV_f, & \sigma \leq L - \sigma \\
-qV_G + \frac{E_{hi}}{2} + qV_f, & L - \sigma \leq x \leq L + \sigma \\
-qV_{ds} + qV_f, & x \geq L + \sigma 
\end{cases}$$
The potential between the source and the gate is triangular as shown in Figure 2, the value \( x_1 \) and \( x_2 \) is:

\[
x_1 = \frac{2\sigma}{E_G - qV_G}\left(E - \frac{qV_T}{2}\right), \quad x_2 = \frac{2\sigma}{E_G - qV_G}\left(E - \frac{qV_T + 3E_c}{2}\right).
\]

To find the transmission it is used the Airy function approach, with wave function is

\[
\psi = \begin{cases} 
Ae^{ikx} + Be^{-ikx}, & x \leq x_1 \\
CAi(\xi(x)) + DBi(\xi(x)), & x_1 \leq x \leq \frac{x_2 - x_1}{2} \\
EAi(\xi(x)) + FBi(\xi(x)), & \frac{x_2 - x_1}{2} \leq x \leq x_2 \\
Ge^{ikx}, & x \geq x_2
\end{cases}
\]

A, B, C, D, E, F, G, and H is constants and Ai dan Bi is Airy functions with wave constant at I regions is \( k_1 = \sqrt{\frac{2m_1(qV_T - E)}{\hbar^2}} \), \( m_1 \) is effective mass of electrons at p⁺ area and E is breakthrough energy of electrons. Airy function for area II and III can be wrote as follows:

\[
\xi(x) = \left(\frac{2m_1 (E_G + qV_G)}{2\sigma}\right)^{\frac{1}{3}} \left(2\sigma \left(qV_T + E_G - E\right) \frac{E_G + qV_G}{E_G + qV_G} - \sigma - x\right),
\]

\[
\zeta(x) = \left(\frac{2m_2 (E_G + qV_G)}{2\sigma}\right)^{\frac{1}{3}} \left(2\sigma \left(qV_T + E_G - E\right) \frac{E_G + qV_G}{E_G + qV_G} - \sigma - x\right).
\]

\( m_2 \) is effective mass of electrons at p area, and \( k_2 = \sqrt{\frac{2m_2(qV_T - qV_G - E)}{\hbar^2}} \) is wave constants at gates with p doping. Furthermore, by entering the boundary conditions in each inter-region it will be obtained.
\[ \begin{bmatrix} 1 & 1 \\ ik & -ik \end{bmatrix} = \begin{bmatrix} A_i(\xi(x_1)) & B_i(\xi(x_1)) \\ w_iA_i'(\xi(x_1)) & w_iB_i'(\xi(x_1)) \end{bmatrix}, \quad x = X_1, \]
\[ \begin{bmatrix} A_i\left(\frac{x_2-x_1}{2}\right) & B_i\left(\frac{x_2-x_1}{2}\right) \\ w_iA_i'\left(\frac{x_2-x_1}{2}\right) & w_iB_i'\left(\frac{x_2-x_1}{2}\right) \end{bmatrix} = \begin{bmatrix} A_i\left(\frac{x_1-x_1}{2}\right) & B_i\left(\frac{x_1-x_1}{2}\right) \\ w_iA_i'\left(\frac{x_1-x_1}{2}\right) & w_iB_i'\left(\frac{x_1-x_1}{2}\right) \end{bmatrix}, \quad x = \frac{x_2-x_1}{2}, \]
\[ \begin{bmatrix} A_i\left(\xi(x_2)\right) & B_i\left(\xi(x_2)\right) \\ w_iA_i'\left(\xi(x_2)\right) & w_iB_i'\left(\xi(x_2)\right) \end{bmatrix} = e^{ikG}, \quad x = X_2. \]

\[ w_1 = \left( \frac{2m_i (E_G + qV_G)}{\hbar^2} \right)^{\frac{1}{2}}, \quad w_2 = \left( \frac{2m_i (E_G + qV_G)}{\hbar^2} \right)^{\frac{1}{3}}. \]

Transmittance can be found by finishing
\[ T = \frac{k_2}{k_1} \left( \frac{G}{A} \right) \]
And drains current with Landauer equations is
\[ I_D = \frac{e\sigma j}{h} \int T \left[ f_s(E) - f_D(E) \right] dE, \quad g_s \text{ describes the degeneration of materials valley.} \]

3. Result and Discussion
The dispersion energy of AGNR bi layer depends on the width of the AGNR as shown in Figure 3. [6].

![Figure 3](image-url)

**Figure 3.** a. The dispersion Energy  b. Density of state

The results of the AGNR dispersion energy calculation show that the width of the gap energy decreases by increasing the width of the AGNR. These results indicate that AGNR bi layer will lead to conductor properties if the width is enlarged.
Figure 4. Voltage current characteristics of TFET based on AGNR bi layers with variations of AGNR wide.

Figure 4 is a breakthrough current (current drain) relationship with gate voltage \( V_G \) based on variation of bi layer AGNR wide. The parameters used for this simulation are drain voltage \( V_D = 0.1 \) V, temperature \( T = 300 \) K, and thick oxide \( t_{OX} = 1 \) nm. The picture shows that the larger the bandwidth of the bi layer AGNR, the greater the drain current generated. This condition is achieved because the magnitude of the band width affects the potential magnitude between the source and gate portions of the device. If the big band width then the injection of electrons from the source to the gate is getting bigger. On the contrary when the width of the ribbon is small, the probability of electrons to break through becomes reduced.

The cut-off frequency produced by TFET AGNR bi layer (figure 5) shows that the greater the bandwidth, the greater the cut-off frequency at certain gate voltages. This is the opposite. Physically, this condition occurs because when the bandwidth increases, the electron current will be larger, while the relationship between frequency and current is proportional.

Figure 5. The cut-off frequency of TFET AGNR bi layer with variations in AGNR wide.
4. Conclusion
The changing of band gap is contributed to device characteristics like current-voltage relation and cut-off frequency in Tunnel Field Effect Transistor (TFET). Beside of that, the method which is applied to obtain those relation are used the Tight Binding method which has function to find band gap, Landauer current to approach theoretically the output characteristics from the device, and Gauss Quadrature to calculate current from TFET. The results show that decreasing of AGNR ribbon width the band gap energy will be more opened which causes current and frequency will be smaller in the small applied gate voltage.

5. Acknowledgments
This research was financially supported by “PTUPT DIKTI” Research grand in fiscal year of 2018

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