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ANALYSIS OF TEMPERATURE LIMITATION OF GRAPHENE SINGLE ELECTRON TRANSISTOR

Vahideh Khadem Hosseini[1], Ahmed K. Jameil [2], Mohammad Taghi Ahmadi[3*]
[1]PhD Electrical Engineering student, Department of Electrical Engineering, Pardis of Urmia University, Urmia, Iran
[2]Department of computer and software engineering, university of diyala, Iraq
[3]Assistant Professor ,Nanotechnology Research Center, Nano electronic Research Group, Physics Department, Urmia University, Urmia, Iran
v.khademhoseini@urmia.ac.ir[1], Ahmedkhudaer@yahoo.com[2], mt.Ahmadi@urmia.ac.ir[3]

ABSTRACT: - The single-electron transistors are a key element of nano-technology and they are good alternative to field-effect transistors due to high operating speed and power. Function properly transistors is need to Coulomb energy 100k_BT so they should be integrated below nano dimensions. Decreasing transistor size causes to temperature limitation and unpredictable changing in the spectrum of energy levels and its variation threshold voltage. In this paper, we have investigated this problem using graphene**.**

Keywords: Graphene, Island Size, Temperature Limitation, Single-electron transistor

1. INTRODUCTION

A recent nanotechnology system is Single-electron transistor (SET) which it can control electron tunneling to amplify current by the quantum mechanical effects[(1).] It can use lower power and it works faster and it has smaller size because it is according to coulomb blockade and quantum size. [(2)] SET will work at room temperature when quantum dot size is smaller than 10nm therefore every small change in island size cause to un predictable and considerably changing in the range of energy levels and so in the threshold voltage of system and this is an important limitation of SET and big challenge for nanofabrication technology.[(3)]

2- SINGLE-ELECTRON TRANSISTOR PRINCIPLES AND STRACTURE

The single electron transistor consists of drain and source electrodes and they contact by tunnel junctions to island. Dot coupled to gate electrode with capacitor C_g that its electrical potential can be tuned by a gate and also it controlled the current flow.
Structure of single electron transistor is shown in figure (1). [(4)] The electrons must be tunnel for transferring current but the coulomb barrier prevents from electrons tunneling and it does not allow electrons to tunnel through source and drain junctions. Thus the coulomb barrier should be removed for tunneling electrons and the bias voltage must be greater than coulomb gap and it must be transferred to the place that it dependent to the highest slope on the coulomb staircase and thermal energy system is less than coulomb energy .The coulomb energy is calculated by

$$E_c = e^2 / 2C \quad \ldots\ldots\ldots \quad (1)$$

In above equation "e" is the electron charge and sum of system capacitance is shown by "C". Coulomb barrier disappear then electron tunnel freely in all over junctions, thereupon gate has identically minus half an electron charge and current is conducted in transistor. Other minus half an electron charge is added to gate then it driven flow stop [(5, 6, 7)].To operate transistor at room temperature the following values should be chosen kT lower than $e^2/2C$

and capacitor is less than $e^2/2KT$ .So $d \prec 10nm$ that "C" is sum of capacitors and "d" is diameter of the island. Capacitance, electron mobility, crystalline structure, the ease of fabrication and ease of growing oxide layers of any material are different and according to these properties ,material of SET is selected and it can be "metallic SET " and "semiconducting SET".[8,9]

All kind of single electron transistors have a lot of advantages such as, using lower energy, small dimension , faster operation and simple circuit. [10]

SETs have many applications, including: charge sensor, detection of infrared radiation, ultra-sensitive microwave detector, super sensitive electrometer, single-electron Spectroscopy and DC current standards. [11]

3- SELECT OF ISLAND MATERIAL

For operation transistor at room temperature should be reduced island size less than nano scale therefore island to be small and every small variation in shape of island is caused to significant and unforeseen changes in the energy levels and its threshold voltage. [3] The island material should have a temperature coefficient higher than silicon transistors so different properties of materials are compared together and suitable material is selected to island. The important factor of material is temperature coefficient and it describes the relation variation of physical characteristics by changing temperature and it is shown by "α" that it is given by $\frac{dR}{R} = \alpha dT$, "dT" is changing temperature and "dR" is changing resistance.

In table (1) characteristic of silicon and graphene are written that these properties are resistivity, conductivity and temperature coefficient . [12, 13] The temperature coefficient of many material are negative, it means that their physical characteristic decrease in higher temperature. [14]Another property is electrical resistivity that it is a natural property and it is shown value of opposition to the flow of current. The electrical resistivity of many materials will decrease with increasing temperature. Electric charge is moved easily in material with low resistivity. [15,16 ,17] The opposite of electrical resistivity is electrical conductivity or specific conductance that it is value of conductance of electric current.

Graphene temperature coefficient is 375 times smaller than silicon thus its physical properties are redacted with changing temperature .conductivity of graphene is greater than silicon and its resistivity is lower therefore it have more electrical conductivity in island so according to reasons mentioned graphene is suitable material for transistor island.

4- STRACTURE OF GRAPHENE

Graphene is kind of carbon when its atoms is regular in hexagonal networks and its form is two-dimensional.[18] Andre Geim and Konstantin Novoselov discovered Graphene in 2004.[19]It can have different dimensions such as fullerene with zero dimensional and nanotubes in one dimensional and graphite with three dimensional and their structures are shown in figure (2) .[20]

Transistor will work in room temperature when size of island is in nano scale so shape of graphene should be stable in nano scale and its size is controllable in fabrication process. Molecule c_{60} (fullerene) is the most stable form of graphene and it has spherical shape and high stability against high temperature and pressure.[21]

Thermal stability of nanotube is less than fullerene and its size is larger than fullerene.[22]Therefore fullerene with more stability and smaller size is chosen for transistor.

5- BASIC EQUATIONS SINGLE - ELECTRON TRANSISTOR

The single electron transistor includes two electrodes and an island coupled by tunneling junctions. Tunnel capacitors C_1 and C_2 have tunnel resistances. Gate capacitance is connected to dot and it controls the current flow. Applied voltages of drain and source are V and V_G , respectively and schematic of single electron transistor is in figure (3). [23]

The current as voltage characteristic of single electron transistor is calculated in the following. The free (electrostatic) energy change ΔF is given by equation (2) and (3)

$$\Delta F^{\pm}(n_1,n_2)=\frac{e}{c\sum}\{\frac{e}{2}\pm(Ne-Q_0)\mp(C_G+C_2)V\pm C_GV_G\} \quad (2)$$

$$\Delta F^{\pm}(n_1,n_2)=\frac{e}{C\sum}\{\frac{e}{2}\pm(Ne-Q_0)\mp C_1V\mp C_GV_G\} \quad (3)$$

In equation (2) and (3) "n_1, n_2" are all transmission electrons via the capacitor c_1 and c_2 , respectively. "K_B" and "e" and, "N" and "T" are elemental charge and Boltzmann constant and total electrons in the dot and the temperature, as mentioned. Electron tunneling between c_1 and c_2 from left to the right is "+" and otherwise is "- ". Tunneling probability/rate is expressed in equation (4) and (5)

$$\Gamma_1^{\pm}=\frac{1}{R_1e^2}[\frac{-\Delta F_1^{\pm}}{1-\exp[\Delta F_1^{\pm}/K_BT]} \quad (4)$$

$$\Gamma_2^{\pm}=\frac{1}{Rje^2}[\frac{-\Delta F_2^{\pm}}{1-\exp[\Delta F_2^{\pm}/K_BT]} \quad (5)$$

Steady state master equation is given by

$$\rho(N)[\Gamma_2^{-}(N)+\Gamma_1^{+}(N)]=\rho(N+1)[\Gamma_2^{+}(N+1)+\Gamma_1^{-}(N+1)] \quad (6)$$

Current calculation is written in equation (7). [23]

$$I(V)=e\sum_{N=-\infty}^{\infty}\rho(N)[\Gamma_1^{+}(N)-\Gamma_1^{-}(N)]=e\sum_{N=-\infty}^{\infty}\rho(N)[\Gamma_2^{+}(N)-\Gamma_2^{-}(N)] \quad (7)$$

We simulated current-voltage curves of single-electron transistor with Fullerene Island according to the theory and experimental work by using MATLAB software and it is shown in figure (4) and also the results have been evaluated.

Three diagrams of theoretical and experimental and simulation are compared together and they match together in low bias. This adaptation express proper functioning of transistor and lower energy consumption. Curves in high voltages are different and it seems that the island material and difference of the electrons number for any material are ignored.

The number of island electrons is stable in the simulation diagram but it is changed in experimental curve because island electrons tunnel and density will be varied.

6- CONCLOUSION

Single electron transistors due to faster performance and higher power are good alternative to field-effect transistors but their integration is faced to temperature limitation. In this research to solve this problem is used graphene.

Its theory model and experimental model are simulated and their matching is suggested they have a good performance in lower voltage indicator that lower energy consumption in this device. Difference in high voltages is because of the island material and sum of electrons on dot is not considered, therefor the size and type of the island are important factors in the operation of single electron transistor and its voltage and current levels, so by selecting a suitable material such as graphene for transistor island material, its operation can be independent of temperature.

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Table (1): the resistivity, conductivity and temperature coefficient of silicon and graphene at 20 C (68 °F, 293 K)

Material	**resistivity** **ρ (Ω·m)**	**conductivity σ** **(S/m)**	**temperature coefficient** **(K^{-1})**
graphene	1.00×10^{-8}	1.00×10^{8}	-0.0002
Silicon	6.40×10^{2}	1.56×10^{-3}	−0.075

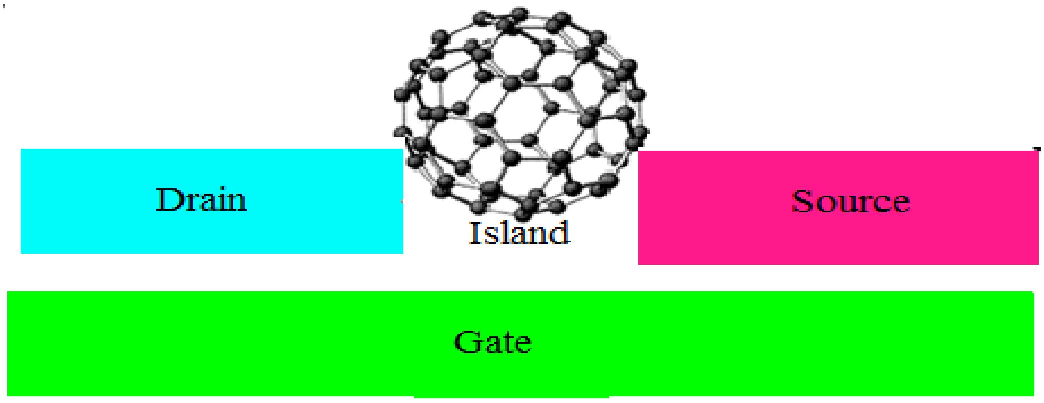


Figure (1): Single Electron Transistor.

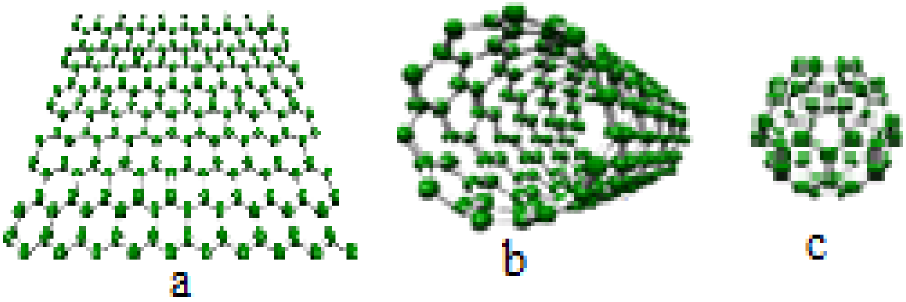


Figure (2): different allotropes of grapheme: a- graphite, b- nanotube, c- fullerene

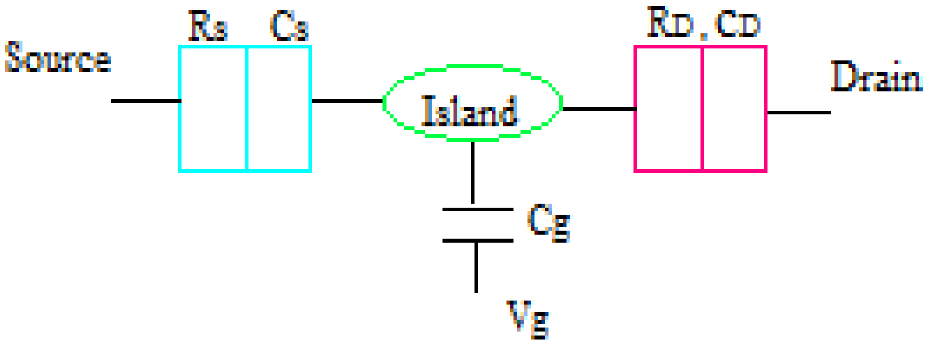
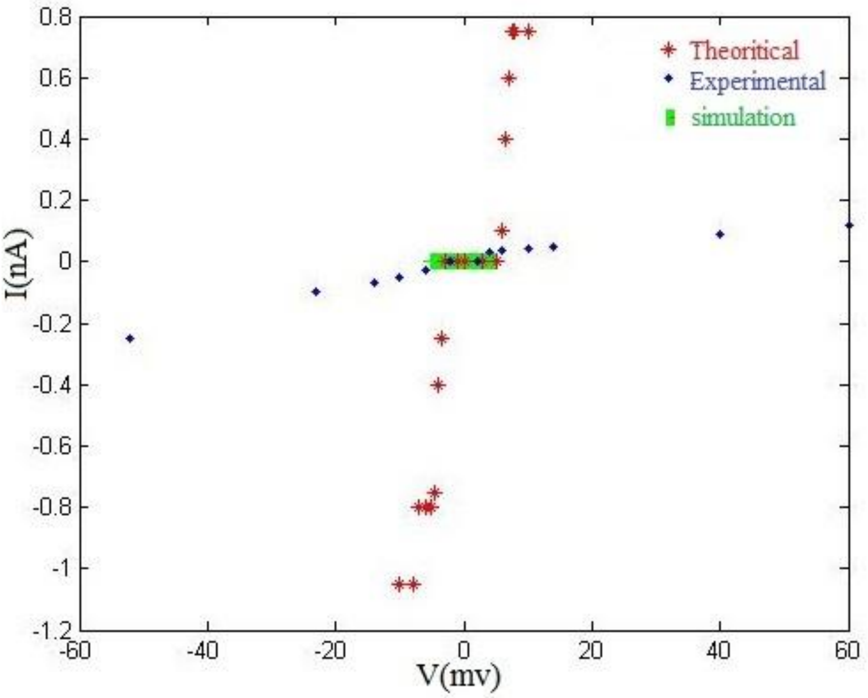


Figure (3): schematic of Single Electron Transistor



Figurer (4): current-voltage curves of single-electron transistor with Fullerene Island for theory and experimental work.