I-V Characteristics of Single Electron Transistor using MATLAB

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ECE1006- Introduction to
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I.Abstract -
Single Electron Transistor(SET) is a key element of current research area of Nano Technology which can offer low power consumption and high operating speed. We are planning to get the IV characteristics of the single electron transistor using the help of MatLab.Our goal is to review in brief the basic physics of 'Single Electron Transistor's well as to simulate numerically the Current Voltage characteristics in the SET based on the Master equation**.**

II.INTRODUCTION[2]

Single Electron Transistor (SET) is a key element of current research area of Nano Technology , which can offer low power consumption and high operating speed. SETs are often discussed as Nano-scaled switching devices because it retains its scalability on an atomic scale and can detect and control the motion of individual electron.The goal of this project is to review in brief the basic physics of Single Electron Transistor as well as to simulate numerically the Current-Voltage characteristics in the SET based on the Master equation for the probability distribution of SET dot obtained from stochastic process using MATLAB.

III-Methodology[1] *–A SET is similar to a normal MOS transistor* except the channel is replaced by a nano dot. The dot is separated from source and drain by thin insulators (SiO_2). An electron tunnels in two steps:The underlying philosophy of our simulation methodology consists in combining the accuracy of the results at device level with the effectiveness of the functional model as a circuit-level simulation technique.The methodology for simulating hybrid circuits is graphically described in the flow diagram shown below. Hereafter, a step-by-step explanation of the blocks of the methodology is given.

IV-TUNNELING PHENOMENA [1]-

Tunneling is a quantum mechanical effect. A tunneling current occurs when electrons move through a barrier that they classically shouldn't be able to move throughfect. A tunneling current occurs when electrons move through a barrier that they classically shouldn't be able to move through.In classical terms, if you don't have enough energy to move "over" a barrier, you won't.However, in the quantum mechanical world,electrons have wavelike properties.

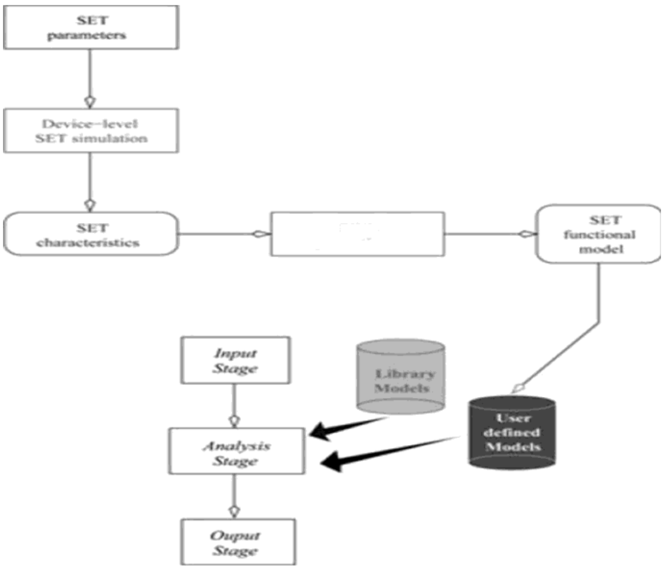

Figure 1: Methodology of SET[1]

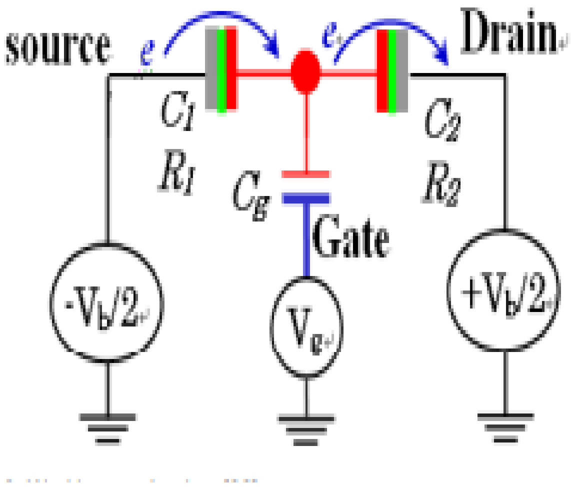

Fig-2: Structure of the SET [1]

These waves don’t end abruptly at a wall or barrier, but taper off quickly. If the barrier is thin enough, the probability function may extend into the next region, through the barrier. Because of the small probability of an electron being on the other side of electrons, some will indeed move through and appear on the other side.When an electron moves through the barrier inthis fashion, it is called tunneling.

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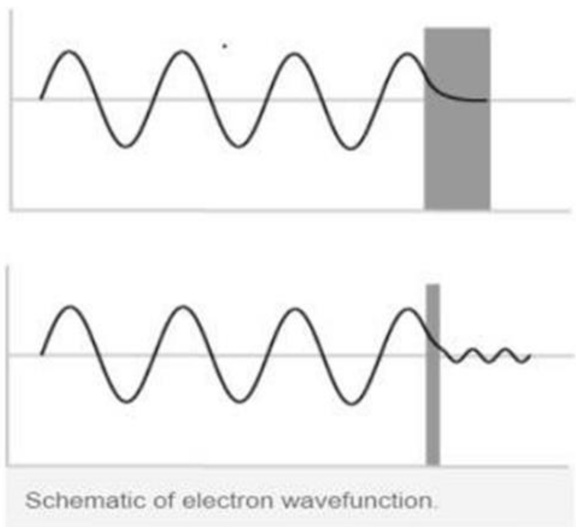

Figure 4: Tunneling Wave function [3]

<u>V-**FUTURE PROSPECT OF SINGLE ELECTRON TRANSISTORS**</u>:[3]

The scope of the SET future is immense and its market analysis and the growth in the market is shown below.

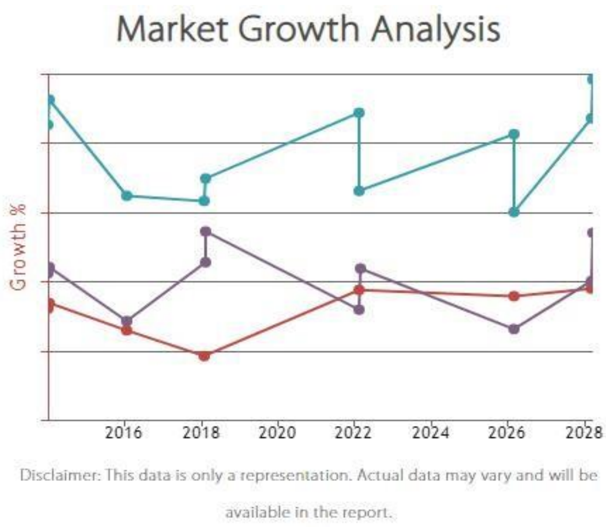

Figure 4: Market Growth of SET [1]

Single electron transistor is progressing towards logic application to improve performance of ultra-logic scale integrated circuits (ULSI) and metal oxide semiconductor field effect transistors.The major factor dividing the adoption of SET is the rising need of energy saving single transistor for internet of things. The internet is witnessing the rapid growth as multi-computers are linking with electronic objects such as the mobile phone. Improved power gain for SET for achieving better operational performance is another factor driving the market of SET in a positive manner.

<u>Coulomb blockade</u>: Coulomb blockade can be defined by three factors: Coulomb energy. , Tunnel resistance., Excess electrons. Coulomb energy: A typical tunnel junction is actually a fine insulating strip acting as a barrier between the electrodes which are conductive in nature. In accordance to principle of electrodynamics, insulating barriers restricts the flow of charge thereby preventing the current flow due to tunnel of electron from source electrode to island; there will be increase of the electrostatic energy of island which is given by, Ec = e2 / 2C where C is the effective capacitance of the island. Electrostatic energy denoted by Ec is also termed as coulomb blockade energy. This coulombing charge energy is amount of energy required to repel the upcoming electron by previous electron present within the island.In case of a tiny system,

the capacitance C of the island is very small. Thus, according to equation above, EC will be very high and due to this reason, electrons are unable to move simultaneously, but pass one-by-one. This phenomenon is known as "Coulomb blockade"

Schematic Circuit of Set Similar to conventional FET the SET is also a three terminal device having a metallic island situated in between the 2 tunneling junctions; which joined to drain, source and gate electrode . These junctions are primarily fine oxide layers . A small conducting island [Quantum Dot] coupled to source and drain leads by tunnel junctions and capacitively coupled to one or more gate, which is used to control the transfer of single electron from source to drain The conducting island is placed in between 2-tunnel junction having stored charge capacitance values as Cd and Cs. SET can electrostatically be steered by the gate capacitance CG.

Function of Coulomb Island (quantum dot)

Quantum dot (QD) having diameter of the order smaller than 100nm is a type of microscopic system [12] (Figure 2). Here the alteration in electrostatic energy or coulomb energy is obtained by either removing or adding an electron with energy greater than heat energy and monitors the electron transport into and out of quantum dot. In other words, Quantum dot is a small conducting island that contains a tunable number of electrons occupying discrete orbitals

VI- I-V Characteristics of Set [4]

From the IV- characteristics of the SET for |V| < e/C∑ , the current is zero. This state is called Coulomb blockade (Figure 17&18). Hence, if the bias is low, the tunneling of electron will not take place. Now, if the applied bias junction voltage Vbias is increased above the threshold voltage Vt by charging energy, the effect of Coulomb blockade can be removed and the current flows. In this condition, the junction behaves like a resistor. Figure 19 represent the IVCharacteristics for a highly asymmetric junction circuit for RS << RD. In this case, there is a rapid movement of excess electrons from one junction to another which increases the total charge of the island. If the bias voltage is increased, the population of electrons in the island also increases. In this case the IV-Curve represents Stair-like characteristics, which are commonly referred to as the "Coulomb Staircase"

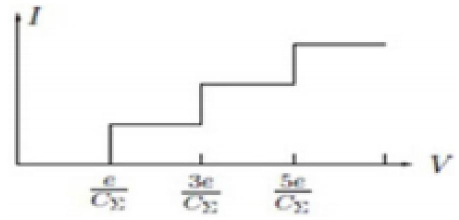

Figure 5: I-V Characteristics of SET[2]

VII-Advantages[1]

Compact size , Low energy consumption , High sensitivity , High operating speed , Simplified circuit , Feature of reproducibility , Simple principle of operation , Straight forward co-integration with traditional CMOS.

VIII-Applications Single electron memory[3]

SET can be used as memory cell because of the state of Coulomb Island can be changed by the existence of one electron. In this way, SET enhances the capacity of memory devices that stores the information as the presence or absence of single electron on the island of SET. SETs also surpass the functionality of CMOS with such application. However, it is very difficult to fabricate such device. Although scientists are still working for it and if the fabrication becomes possible then it will be a revolutionized change in area of quantum computing High sensitivity electrometer SET based electrometer is said to be operating by capacitively coupling external charge source to be computed to the gate node and then alteration of source-drain current is calculated. Due to enormous value of amplification coefficient, this device is used for calculating small change of current. Experiments showed that if there is a charge change of e/2 on the gate, the current through the Coulomb Island is 109 e/sec. This sensitivity is many orders of magnitude better than common electrometers made by MOSFIT. SETs have already been used in metrological applications as well as a tool for imaging localized individual changes in semiconductors. Microwave detection If black body radiation is incident on SET, the photon-aided tunneling will affect the charge transfer of the system. Even a small amount of radiation will affect the SET system. The sensitivity of this equipment is about 100 times higher than the current best thermal radiation detector [7,11]. Single-electron spectroscopy One of the most important application of single-electron electrometric is the possibility of measuring the electron addition energies (and hence the energy level distribution) in quantum dots circuits.

IX-DISADVANTAGES [1]

Integration of SETs in a large scale To use SET at room temperature, the necessary condition is that the size of island must be less than 10nm which is very difficult to fabricate. ,Linking SETs with the outside environment , Practical difficulty in fabrication , Most SETs works at extremely low temperatures around 100mK , Background charge problem , Low voltage gain , The voltage increases until the charging energy is of order kb T, then it drops.

IX-Problems Gain In SETs[1]

voltage gain decreases as the size of device decrease.because of the low gate capacitance. It is difficult to achieve a large gate capacitance when the island of a SET consists of a single electron. For the single electron devices, the gate capacitance can be as small as a few zepto Farads. And for this the required bias voltage is tens of volts so that the output can be modulated by tens of millivolts which results in voltage gain of the order of 0.001 i.e., the transistor attenuates the signal by a factor of about 1000. The voltage gain in SET is the ratio of the gate capacitance to the junction capacitance. As the gate, capacitance is increased for fixed junction capacitance and fixed temperature, the voltage gain first increases and then it decreases. The voltage gain increases with increasing gate capacitance until the charging energy is on the order of kBT and then the voltage gain drops sharply. However, in transistor voltage gain is not a very useful factor. For SETs, it is more relevant to consider the charge gain. The charge gain is the modulation of the charge that passes through the SET divided by the change in charge on the gate. This is a frequency dependent quantity. It is also become possible to transport more charge through the SET than was added to the gate. Charge gain can easily be achieved at room temperature. The charge gain is maximum at low bias voltages and low temperatures.

X-OUTPUT

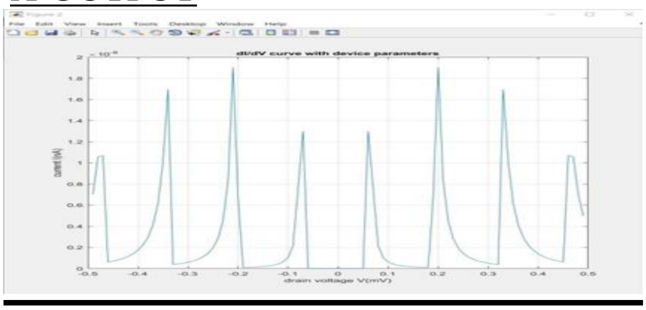

Figure 6: I-V Characteristics of SET (MATLAB)

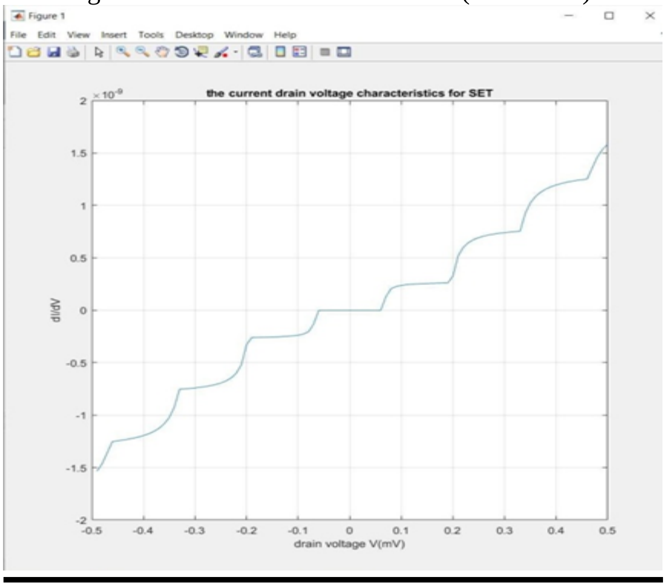

Figure 7: drain voltage vs dV/dv

XI-References

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