Characteristics of Single Electron Transistor: A comparison of Carbon Nanotube with Slicon based quantum dot

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***Abstract*—Single Electron Transistor is a promising for future nano electronic devices with low-power consumption, fast speed, and ultrahigh density integration [2]. The work is to compare the characteristics of silicon based Single Electron Transistor , Single-walled-carbon-nanotube -based single-electron devices . Single walled carbon-nanotube - based single electron devices are fabricated with long SWNT channel surrounded by several short SWNTs on the electrodes [16]. Silicon based Single Electron Transistor has the quantum dot which is made up of Silicon. Based on the material of the dot characteristics of the SET will vary. The Coulomb blockade effect is the key mechanisms for such devices to work properly. Since the first demonstration of SWNT single electron transistors at room temperature is carried out [1]. The Silicon Based Single Electron Transistor is demonstrated by L. Zhuang et al.[3]. Previously, the silicon single electron transistor operating at 170 K was reported[4]. These results are discussed in terms of different tunnelling rates and V-I characteristics.**

Keywords—Single Walled NanoTube , tunneling rate, , quantum dot, coulomb blockade ,Single Electron Transistor

1. Introduction

The MOS transistor cannot shrink beyond certain limits due to short channel effect, drain induced barrier lowering effect etc.,. The above problem is overcome by Single Electron Device technology that meets the demand for increasing the density, performance &decrease in power dissipation in the trend of VLSI technology . Single Electron Transistor (SET) has attracted attention due to three features:. Nanoscale feature size, unique coulomb blockade character oscillation characteristics and low power dissipation [7].Single Electron tunneling effect is one of the most exciting challenges in semi conductor industry in which Single Electron Transistor (SET) utilizes instansic quantum phenomenon and tunnel effect.

SETs are attractive because of their sensitivity and unique current-voltage characteristics. Applications include the readout of quantum computers, measurement of nanometer-scale movement and coulomb blockade thermometers. Many techniques have been developed to process and analyze the SET. Recently a reliable process of SET with an Si dot of diameter smaller than 5nm [4]. The current calculation in SETs has been derived based on the Poisson and Schrodinger equation including quantization corrections .Very currently a nanocrystal- based SET is simulated using a 3-D simulator sub regions with different degrees of quantum confinement are simultaneously considered and analyzed conductance of tunnel constrictions [5]. In order to operate the Single Electron Transistor at room temperature, the size of the island should be less than 5nm [13] and silicon quantum dot with a size of 1nm [14].

In this paper , we analyzed the characteristics of Single electron Transistor based on Silicon based

Single Electron transistor and Carbon Nanotube Single Electron Transistor. This paper is organized as follows: Section II explained the principle of SET, it includes structure , operating principle and characteristics of SET. In section III illustrates Experiments and Methods, we present the experimental and study result of Silicon based Single Electron transistor and Carbon Nanotube Single Electron Transistor. Conclusions are drawn in section IV.

2. PRINCIPLE OF SET

A. *Structure of SET*

The SET transistor can be viewed as an electron box that has two separate junctions for the entrance and exit of single electrons shown in fig.1. It is similar to a field-effect transistor in which two tunnel junctions forming a metallic island instead of the channel. The voltage given to the gate electrode affects the amount of energy needed to change the number of electrons on the island.

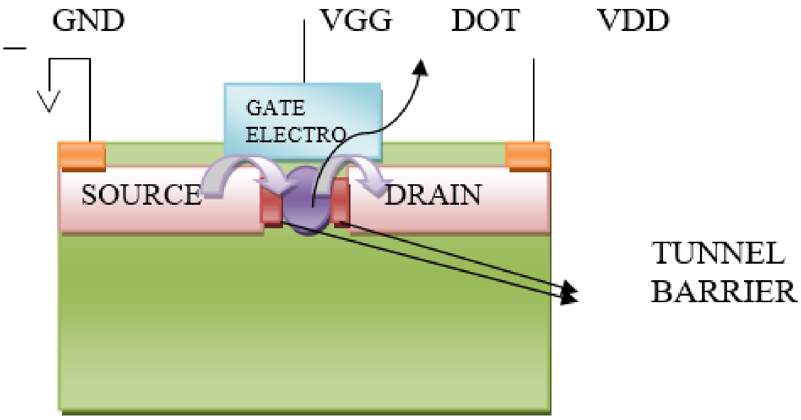

Fig.1 Structure of Silicon based SET

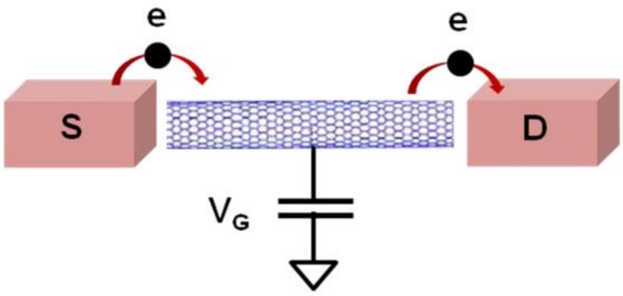

Fig.2 Structure of Carbon Nanotube SET

The carbon nanotube single electron transistor is fabricated by creating quantum dot in the nanotube. In a nanotube quantum dot can be created by creating tunnel barrier along the nanotube. The defects in the nanotube will create the tunneling barrier.

B. *Operating principle of SET*

The CMOS technology should overcome its limitations in terms of size. One of the most promising technologies is the single electron tunneling phenomenon. If a metallic or semiconducting island is placed between the electrodes separated by the tunnel junctions with very small capacitance, the single electron phenomenon can be observed. When an electron tunnels into the island it raises the electrostatic potential of island stopping the tunneling of the following electrons until external potential is applied [14]. This phenomenon is known as Coulomb blockade. Due to quantization of electronic charge, there is increase in current in staircase form is called coulomb staircase. This is due to the phenomenon of coulomb blockade.[15] The conductance of the SET oscillates between the multiples of e and the maxima of half multiples of e[6].

C. Characteristics of SET

Consider the double junction system shown in Figure 2. The values shown are the characterizing values of both junctions shown in the circuit. Assume initially that C1 <<C2 and R1 <<R2 so that the tunneling rate through the first junction is higher than that through the second junction. Make the external source to drain bias voltage V , so that the charge flow to right from left is preferred, and increase the bias voltage above the coulomb gap voltage.

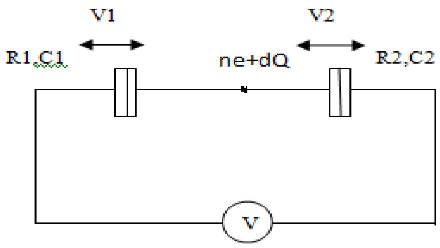

Fig. 3. Double junction system

The governing circuit equations are:

$$V1 = \frac{C2}{C1 + C2} . V - \frac{ne + \delta Q}{C1 + C2} \qquad (1)$$

And

$$\mathrm{V2} = \frac{\mathrm{C1}}{\mathrm{C1 + C2}} . \mathrm{V} - \frac{\mathrm{ne} + \delta\mathrm{Q}}{\mathrm{C1 + C2}} \qquad (2)$$

where ne+δQ is the charge on the central electrode. This is the result of n electrons on the electrode due to tunneling events, and an initial charge δQ due to external voltages coupled to the electrode via the gate capacitance.

For given external voltage V, electrons will tunnel onto the central electrode until V1<< e, at which point the junction becomes coulomb blockaded. Because of the tunneling rate assumptions above, the blockade condition is always reached before we need to consider charge tunneling out through C2. Since tunneling rate through C2 limits and governs the current through the device and since V2 is pinned by the blockaded condition of junction1, current through the device remains constant for a range of external V [6].

The ΔV can be written as,

$$\Delta V = \frac{e}{C_2} \qquad (3)$$

Which increases the current

$$\Delta I = \frac{\Delta V}{R_2} = \frac{e}{R_2(C_1 + C_2)} \qquad (4)$$

Thus, the I-V curve of such a device shows distinct steps of width ΔV and height ΔI. As the junction parameters are brought nearer, C1 ≈C2 and R1≈ R2, the tunneling rates through the two junctions become comparable, blockade conditions are less likely to build up and the I-V curve tends to be linear as shown in Figure 3.

3. EXPERIMENTS AND METHODS

A. Carbon nanotube Single Electron Transistor

The familiar coulomb peaks are available in the conductance of an SET as a function of gate voltage. In the fig. the peaks are now equally spaced . The grey area represents some defect in the vicinity of the SET electro statically and the voltage from the gates and thus the SET current also changes.

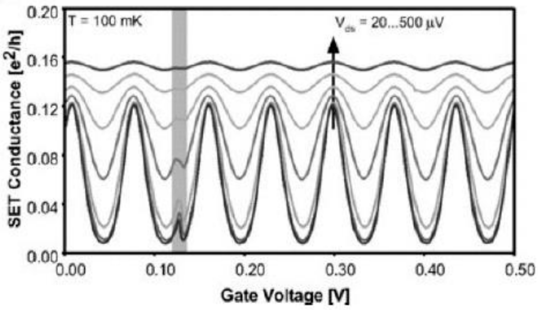

Fig.4. Conductance of SET

Large period oscillations correspond to charging of the SET island . SET conductance measured as a function of one of the side gate voltages of a double dot configuration is shown in fig. 4 The conductance changes the most halfway up the coloumb peak .

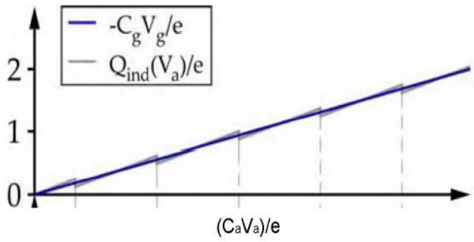

Fig.5.Induced charge of SET

The SET voltage consists of two contributions. The first is a linear characteristics since the linear increase of voltage of the Carbon Nanotube side gates that is required to induce tunneling events. The second is the sawtooth characteristics due to sudden change of the dot potential when tunneling events takes place. The linear increase in the voltage sensed by the SET due to the dot side gates is effectively canceled out and only the sawtooth from tunneling events remains. The induced charge on the SET island by sweeping the nano tube side gate is shown in fig.5.

B. Silicon based Single Electron Transistor

The classical tunneling points for the electrode also position dependent. After 0 radius i.e. both Close to each other so the probability density reduces. After reach 0.5 or nearer value again it starts increasing. Then the probability density reduces after 1.5. It is shown in fig.6.

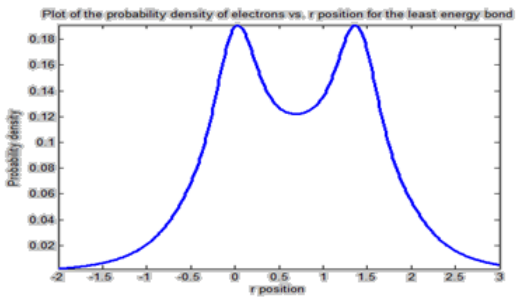

Fig.6 The classical turning points for Silicon based Single Electron transistor.

The potential energy curves behaves properly when bonds are broken. Tunneling probability decreases exponentially with the square root of barrier height. 1In this simulation, The final total energy (including nuclear-nuclear repulsion) after convergence for this bond is -1.0327. The least energy bond length (A) is 0.7408.

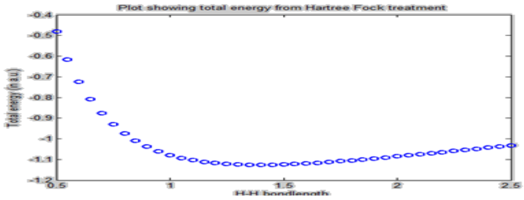

Fig.7. plot between total energy vs bondlength.

The energy (Hartree) of this bond is The graph shows in fig. 7 is about the relationship between total energy and r radius i.e. bondlength. Here too the bondlength increases the total energy reduces. -1.1265.

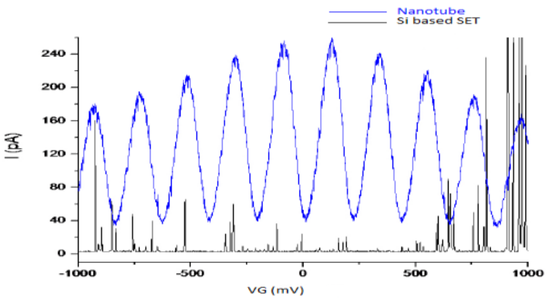

Fig.8.V-I charecteristics of Nano tube and Silicon based SET

Fig.8. Explains the gate voltage and drain current characteristics of carbon-nanotube -based single electron transistor and Silicon based single electron transistor. The black sharp peak represents the Si based SET while the blue curve represents the Carbon nanotube SET.

4. CONCLUSION AND FUTURE SCOPE

We have presented experimental results for the operating characteristics of Single Electron Transistor based on Silicon based dot and nano tube structure. When we consider these experiments the nanotube structure characteristic is more stable and balanced one. Still the tunnelling rate is better in the case of silicon based SET , based on the application and need we can choose the Single Electron transistor type .

The good agreement found in our study is an expectation that the Carbon Nanotube double quantum dot allows for an accurate description of the minimum conductance over the whole range of experimentally accessible parameters.

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