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Behavior analysis of single electron transistor (SET) in physics and various Nanoscience applications

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Abstract

To gain the practical approach for low dimension designing of electronic chips, SET is being used widely to provide nanoscience applications. SET (Single Electron Transistor) is a new kind of switching device that uses proscribed electron tunneling to amplify current. SET is to be considered as elements for future low power, high density integrated circuits reason for this of their the potential to involving only few electrons for ultra low power. In this paper, the author has studied about the single electron transistor being used in physics and various nanoscience applications. The operation as single electron transistor with its past is mentioned included with advantages, disadvantage and various applications of SET.

Keywords: SET, physics, nano, applications, transistor

1. Introduction

The simplest device in which the effect of Coulomb blockade can be observed is the so-called single-electron transistor. It consists of two electrodes known as the drain and the source, connected through tunnel junctions to one common electrode with a low self-capacitance, known as the island. The electrical potential of the island can be tuned by a third electrode, known as the gate, which is capacitively coupled to the island.

In the blocking state no accessible energy levels are within tunneling range of an electron on the source contact. All energy levels on the island electrode with lower energies are occupied.

When a positive voltage is applied to the gate electrode the energy levels of the island electrode are lowered. The electron can tunnel onto the island occupying a previously vacant energy level. From there it can tunnel onto the drain electrode where it inelastically scatters and reaches the drain electrode Fermi level.

The energy levels of the island electrode are evenly spaced with a separation of Delta E. This gives rise to a self-capacitance C of the island, defined as,

$$C = \frac{e^2}{\Delta E}$$

According to the various studies, the transistor's central component is an island of only 1.5 nanometers in diameters and is being operated with only a or two electron it's state is assumed to sensitivity at small pressure changes at nanoscale, to make such a device potentially useful for nanoscale charge and force sensor. A computer memory which is basically based on this property would be ability to retain information in case if processor itself powered off. SET is to be considered as elements for future low power, high density integrated circuits reason for this of their the potential to involving only few electrons for ultra low power. To make practically it useful however, the Single Electron Transistor must be operate at room temperature. Thermal fluctuation limitation and capacitance requires that the size of island of SET not to exceed over 10 nm, a conventional size out of the range to present conventional process of micro fabrication for the operation of single electron on room temperature memory is being realized to use of self organized, small size over thin poly silicon films.

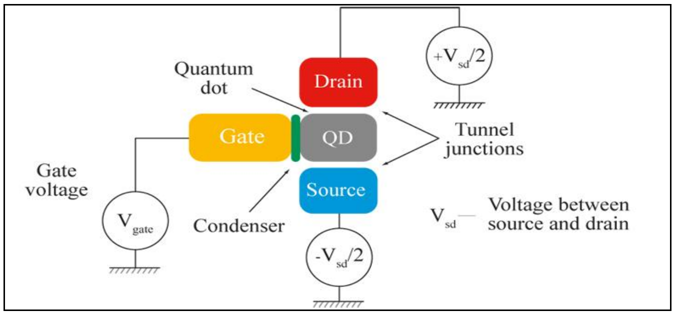

Fig 1: Single Electron Transistor (SET)

2. Working of Single Electron Transistor (Set)

Continuing with our discussion on the working of SET, this lecture shall give further insights to its operation. The basic operation of the single-electron transistor is shown in Fig.1, where the tunneling junctions are presented as barriers. The island is represented as a valley or well between the two barriers.

A mathematical understanding shall make the behavior of SET more authentic.

The energy required to move one electron from the full top energy level to the bottom empty level in the island can be derived as follows. If we observe the working of SET, the entire discussion was focused on moving a single electron from Source to Drain. The Fermi energy levels of the island (dot), the drain, and the source are shown in the Fig. 1 as $E_F{}^D$, $E_F{}^{dot}$, and $E_F{}^S$, respectively.

The Fermi energy level is the potential energy possessed by the electron, when it is in different regions When a drain-source bias voltage is applied, these Fermi energy levels are no longer aligned, as shown in the Fig. 1, as opposed to the case of absolute zero. At zero temperature (zero thermal energy), the current is zero as the gap between the bottom empty state and the top full state is aligned with $E_F{}^D$ and $E_F{}^S$.

This is called Coulomb blockade. From basics of semiconductor Physics, we know that the minimum energy required to add an electron to the dot is $E_F = E_N - E_{N-1}$ where N is the total number of electrons in the dot (island).

$$E_F^{dot}(N) = E_N + q^2 \frac{\left(N - N_o - \frac{1}{2}\right)}{C} - \frac{qC_g}{C} V_g \qquad \text{(I)}$$

Where, N_o = Number of electrons in island $V_G = 0$'
N = Number of electrons at dot with gate voltage V_G
$C = C_s + C_g + C_d$

3. Set Applications in Physics Ansd Nanoscience

Supersensitive Electrometer

The high sensitivity of single-electron transistors has enabled them as electrometers in unique physical experiments. For example, they have made possible unambiguous observations of the parity effects in superconductors. The transistors have also been used in the first measurements of single-electron effects in single-electron box- es and traps. A modified version of the transistor has been used for the first proof of the existence of fractional-charge excitations in the fractional quantum hall effect.

Single-Electron Spectroscopy

One of the most important application of single-electron electrometry is the possibility of measuring the electron addition energies (and hence the energy level distribution) in quantum dots and other nano-scale objects.

DC Current Standards

One of the possible applications of single-electron tunneling is fundamental standards of dc current. For such a standard, a phase lock SET oscillations or Bloch oscillations in a simple oscillator with an external RF source of a well characterized frequency f, the phase locking would provide the transfer of a certain number m of electrons per period of external RF signal and thus generate dc current which is fundamentally related to frequency as I=mef. This arrangement have limitation of coherent oscillation that are later overcome by the use of such a stable RF source to drive devices such as single-electron turnstiles and pumps, which do not exhibit coherent oscillations in the autonomous mode.

Detection of Infrared Radiation

Single dimension multi-junction array with their low co-tunneling rate, may be used for ultra- sensitive video- and heterodyne detection of high frequency electromagnetic radiation, similar to the superconductor- insulator-superconductor (SIS) junctions and arrays. The Single electron array have advantages over their SIS counterparts: Firstly lower shot noise and secondly convenient adjustment of the threshold voltage. This opportunity is especially promising for detection in the few-terahertz frequency region, where no background-radiation-limited detectors are yet available.

Voltage State Logics

The single-electron transistors have single-electron charging effects which are confined to the interior of the transistor, while externally it looks like the usual electronic device switching multi-electron currents, with binary unity/zero presented with high/low dc voltage levels (physically not quantized). This concept simplifies the circuit design which may ignore all the single-electron physics particulars. One substantial disadvantage of voltage state circuits is that neither of the transistors in each complementary pair is closed too well, so that the static leakage cur- rent in these circuits is fairly substantial, of the order of 10-4 e/RC. The corresponding static power consumption is negligible for relatively large devices operating at helium temperatures.

Charge State Logics

The problem of leakage current is solved by the use of another logic device, named charge state logic in which single bits of information are presented by the presence/absence of single electrons at certain conducting islands throughout the whole circuit. In these circuits the static currents and power vanish, since there is no dc current in any static state.

Programmable Single Electron Transistor Logic

An SET having non volatile memory function is a key for the programmable SET logic. The half period phase shift makes the function of SET complimentary to the conventional SETs. As a result, SETs having non-volatile memory function have the functionality of both the conventional (n-MOS like) SETs and the complementary (p-MOS like) SETs. By utilising this fact the function of SET circuit can be programmed, on the basis of function stored by the memory function. The charge around the QD of the SET namely an SET island shifts the phase of coulomb oscillation, the writing/erasing operation of memory function which inject/eject charge to/from the memory node near the SET Island, making it possible to tune the phase of coulomb oscillation. If the injected charge is adequate the phase shift is half period of the coulomb oscillation.

4. Disadvantages of Set

The main problem with all the known types of single-electron logic is devices in the requirement which in practice means sub nanometer island size for room temperature operation. To handle SETS at room temperature, very large quantities of monodispersed Nan parts which is less than 10nm in diameter should be synthesized. It is not easy to construct v large quantities of SETs by traditional semiconducting process and optical lithography. It is difficult to link SETs which is practically difficult to construct and fabricate Single electron transistors (SETs).

Some disadvantages

- Integration of SETs in a large scale: To operate SETS at room temperature, large quantities of monodispersed Nano particles less than 10nm in diameter must be synthesized. But, it is very hard to fabricate large quantities of SETs by traditional optical lithography and semiconducting process.
- It is difficult to link SETs with the outside environment.
- Practically difficult to fabricate Single electron transistors (SETs).

5. Conclusion

Single electron devices have effectively demonstrated their value as tools in scientific research. There are strong efforts around the world to make the artificial atoms in SETs smaller, in order to raise the temperature at which charge quantization can be observed. These involve self assembly techniques and novel lithographic and oxidation methods whereby artificial atoms can be made nearly as small as natural ones. This is, of course, driven by an interest in pragmatic applications. Be that as it may, as SETs get littler, the greater part of their vitality scales can be extensive.

Single Electron Transistors are highly used in one bit memory applications. Thus the application of SET we reached to approach for the various use of single electron transistor in memory, physics, neural network and nanosciences.

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