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Study of Coulomb Blockade, Background Charge and Quantum Tunnelling using Single Electron Transistor

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***Abstract*—Single electron transistor is crucial elements in contemporary nanotechnology research that can enable low power consumption and high operating speeds. The Coulomb blockade may be modified by regulating the gate charge of the device. The SET can also be used in DC ad RF mode as an ultrasensitive electrometer. Increasing the performance of extremely large integrated circuits has been identified as a basic approach for improving performance by shrinking the size of electronic devices (ULSIs).**

Keywords— SET, MOSFET, MOS, FET, Quantum Tunnelling, Coulomb Blockade

I. INTRODUCTION

A completely new era in electrical technology began in 1948 with the creation of the transistor by John Bardeen and William Shockley, which marked the beginning of a new phase in the field's history. Scientists realized that this solid-state technology, originally designed to just imitate the vacuum tube, may give a lot more. As well-regulated materials like pure single-crystal silicone were available; the transistor's immense potential to achieve speed, compactness and reliability has been extensively utilized. According to the newest 'road map' for the micro-electronics sector, a few years into the new millennium microchips with a one-billionth transistor cycle and a one-billionth-second clock cycle. Whenever the size of transistors is reduced, there is always the risk that quantum mechanics will become more significant in the manner that devices are constructed as the transistors grow smaller. To put it another way, what happens if the size and performance of a transistor are reduced to a few atoms or perhaps a single molecule and then reassembled is an interesting question [1, 2].

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A. Theoretical Concept of SET (Single-Electron Transistor)

Researchers in the field of electronics are speculating about what may happen if transistors were to shrink to such a small size that quantum effects become dominant, while also inventing new transistors that actively use the intrinsic quantum features of electrons. After first developing solid state technology to imitate the vacuum tube, scientists rapidly realized that it had the potential to give much more functionality.

Given the extensive exploration of well-controlled materials such as pure single crystal silicone and other similar materials, the transistor has enormous potential in terms of speed, compactness, and reliability. It is predicted that, within a few years following the United States' entry into the twenty-first century, microchips having a billion transistors and functioning with a clock cycle of one billionth of a second would be available for purchase on the open market [2].

B. At the beginning transistor

The field-effect transistor (FET) is the metal oxide semiconductor transistor that is most often used in today's microchips (MOSFET). It is remarkably simple to operate just a few quantum mechanics students are required to grasp how it works, despite the fact that a typical gadget today is only a few thousand atoms in size. It is claimed that the channel is isolated if there are no electrons present in it at any point in time when the voltage across the gate is equal to zero. With an increase in voltage, on the other hand, the electrical region at the gate absorbs electrons from both the source and the drain, propelling the channel ahead. A field effect transistor's current changes in response to the tension that exists between its source and its drain when there is a field effect in play. In both positive and negative gate tension circumstances, the current is switched on to a predefined bias tension, and the current is turned off to the same bias tension.

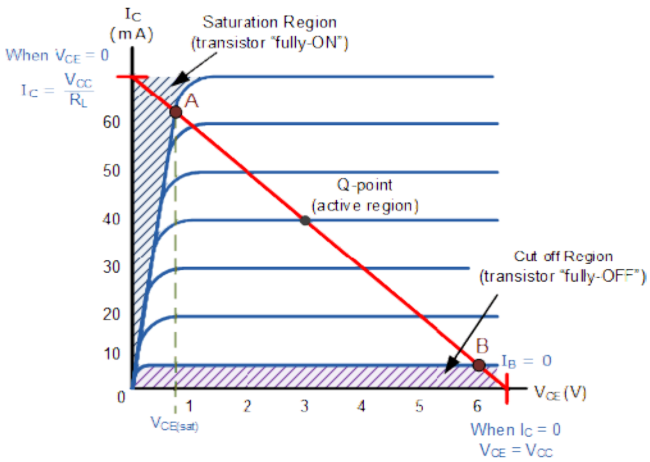

Fig. 1. Amplification in a field-effect transistor

The current flowing through the source drain is determined by the channel conductance, which is determined by two factors: density and electron mobility, respectively. In most cases, the mobility of electrons is determined by how often electrons hit with crystal defects, and it is not affected by gate voltage. The gate voltage, on the other hand, has a direct effect on the density of electrons in the system. Water is regulated between two tanks by means of a transistor acting as a faucet, with the tap in a third tank being opened by the pressure of the water in the previous two tanks. The electrons within the channel, on the other hand, behave as if they were a compressible fluid with a local density that is greatly influenced by the amount of power applied to the channel. As an alternative to a solid wall, the electrical field produced by the door generates a continuously changing potential for electrons in the channel. Neither the wavelike characteristics of electrons nor the fact that the channel is made up of individual atoms were discussed in any detail. The Pauli Exclusion Principle is the single quantum property in play, and it states that only one electron may be in any possible channel state at any one time. Because only specific electrons may collect in the channel, the current flow is constrained as a result of this restriction [3].

However, as the number of transistors in use decreases, the quantum characteristics of electrons and atoms will become more significant. For example, the wavelike character of electrons will alter the manner in which they move along the passageway. When the canal width is comparable to the wavelength of the electron (about 100 nm), the propagation of electrons in the device produced during the manufacturing process is more susceptible to atomic disorder than when the canal width is more than the wavelength of the electron. Unless the decrease in size is accompanied by an improvement in the atomic structure of the devices developed, this becomes a serious problem. We may be forced to adopt a new physical paradigm for transistor functioning as a consequence of the technical constraints of going to the atomic scale as a result of the limits of existing technology. Alternatively, a new concept might be created that would allow for the implementation of functions that are not currently possible with existing technology [4].

II. PRINCIPLES OF THE SINGLE ELECTRON TRANSISTOR

Although the electronics industry is asking what happens if transistors get so thin that they have considerable quantum effects, the researchers are developing new transistors which actively use the quantum characteristics of electrons. The single electron transistor is primarily obtained via the addition of an electrode door linked to the island by a twin tunnel connection.

A single transistor consists of an island containing a three-dimensional electron. The island is linked by two tunnel connections and isolation barriers to a source electrode and a drainage electrode. Then the gate terminal is linked to the island via a condenser. There may be more than one gate electrode. Coulomb Blockade The single-electron transistors are a metal island linked to a drain and a source by two tunnel connections with a door electrode, like a conventional field-effect transistor. The tunnel connections between the island and the electrodes are just a thin layer of oxide (<10 mm). Quantum points were also used as SET islands. The SET systems are shown in the picture. Each tunneling crossing in the SET has inherent tunnel and

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capacity resistance (parallel to each other). However, we must first grasp the Coulomb blockade idea before we fully understand the functioning of the SET.

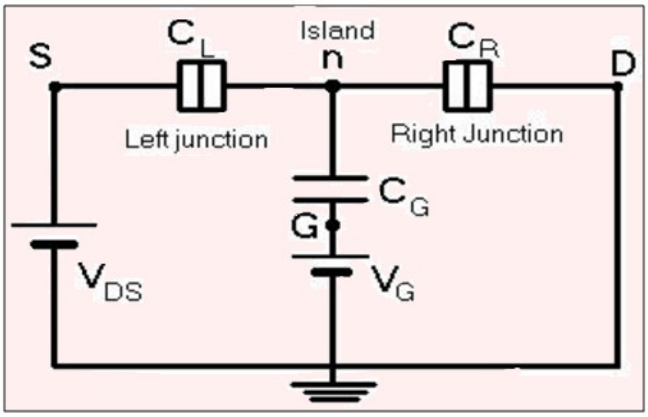

Fig. 2. Single-electron transistor schematic circuit diagram

Even if the transistor is incredibly small (on the nanometric scale), the island still contains a substantial number of electrons despite its small size. Tunneling, on the other hand, allows one to either add or remove electrons from the island in a negative or positive manner. Surplus and n are the terms used to describe the extra electrons that load the island. Negative electron counts indicate that the island has lost electrons, leaving a positive charge in its place (one could talk of excess holes in this case). When there are too many electrons in a system, the electrostatic energy balance shifts [5, 6].

A. Quantum Tunnelling

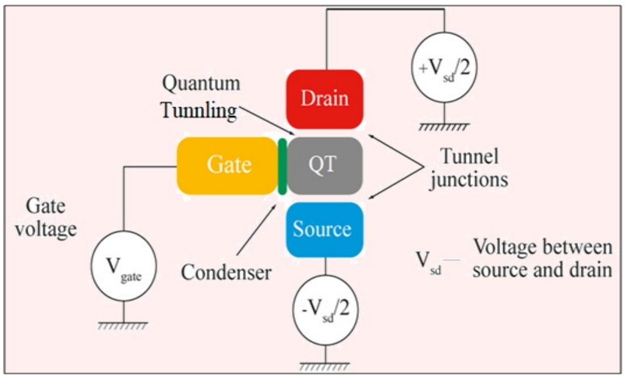

Fig.3. Quantum tunneling schematic representation for a SET

The concept of quantum tunneling is based on a single transistor electron. When the potential of an electron is in classical physics, it cannot travel where its potential is higher than that of an electron. The single-electron transistor describes by a quantum point a single transit of electrons. A quantum point implies a semiconducting nanoparticle containing electrons in all three spatial dimensions. The structure of the transistor varies greatly.

B. Coulomb Blockade

Due to the repulsion of the Coulomb electron field electrons which crossed the final junction, the Coulombe blockade ends up in a tunnel to halt the electron tunnel (or a tunnel system). This effect is defined by the area size at the beginning of the current voltage intersection, with a zero tunneling line. This region is termed the Coulomb blocking tension, critical tension, coulomb blockage, and a threshold tension. As previously mentioned, SET consists of a metal island connected to two metal pipes via tunnel barriers. No low voltage current may flow through the island at temperatures below 1 K. As a consequence of the repellent interactions between electrons in the island, the Coulomb barrier has come to be identified as such. When an electron arrives on the island, the Coulomb blockade is created by the repellent energy of the island's preceding electron towards the incoming electron. At low temperatures and low voltages, coulomb blocking is a tunnelling process that is blocked across an island. Coulomb blocking is also known as coulomb blocking. This is because electrostatic charging energy is required when this system is supplemented by a single electron. The crossings of the tunnel may be recognized as two thin obstacles to insulation. There is no current passing across the barrier in conventional thermodynamics. However, electrons are always likely to be transmitted on one side according to quantum physics [7]. This leads to an increase in the supply of electrostatic energy:

$$E_c = e^2 /2C.$$

Where: C is the island's capacitance
This is also called coulomb energy blockage.

C. Coulomb Oscillations in a Semiconductor SET

The important thing is that the load is monitored across the island. In order to sail on

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the island, an energy must be the energy of Coulomb. If the door and distortion voltages are zero, there is not enough energy for electrons to travel to the island. The energy in the system may migrate about the island near the coulomb energy when the tension between source and drain rises. This phenomenon is known as Coulomb blocking and is known as Coulomb gap voltage, equal to e/C, the crucial tension needed to transfer the electro to the island. Now assume the trend voltage is below the gap voltage of Coulomb [8]. The voltage of the door rises continuously (without electrons), whereas the energy of the system progressively falls on the island with a supplementary electron. The two configurations at the door voltage of the Coulomb staircase are the lowest energy level of the system and the largest route. This removes the barrier to Coulomb, which allows electrons to enter and exit the island. When the door capacity of little about half an electron is charged, the Coulomb barrier is removed. The island is very sensitive to contaminants or stray charges. It is circled by insulators to avoid blockade of coulomb by road charges or ions; thus, the charge must be measured in electron units even when the door is a metallic electrode linked to many electrons. The charge on the condenser is just a movement of electrons on the positive ion backdrop [9, 10].

D. Background Charge

Fluctuations in backlog volumes continue to be the most significant technical barrier. Unless substantial improvements in the control of background costs can be made, it is doubtful that SET circuits will be incorporated in a broad variety of applications. It is necessary to develop techniques for controlling device sensitivity to various noises, even if widespread integration is possible (such as temperature changes and electrostatic interactions between devices). The device is likely to operate within acceptable limits at temperatures that are lower or higher than normal. Now, according to current thinking, SET devices are most beneficial for applications in memory, electrometers, and metrology.

III APPLICATIONS, CHARACTERISTICS OF SET

A. Applications

(i) Supersensitive Electrometer

Single-electron transistor's exceptional sensitivity was utilized for single physical exams such as electrometers. For example, clear findings of parity effects in superconductors have been shown to be feasible. Absolute measurements have been shown with extremely low dc currents (~10-20 A). The transistors were also utilized in single electron boxes and traps. The earliest sign of fractional load excitation in the fractional quantum Hall Effect was a modified version of the transistor.

(ii) Single-Electron Spectroscopy

One of the most significant uses of single electron electrometric in quantum points and other nano-meter structures is the ability to detect electron addition energies (and therefore energy level distribution), which is one of the most important applications of single electron electrometric.

(iii) DC Current Standards

A phase-locking SET oscillations and Bloch oscillations are one of the potential applications for a single electron tunnelling system with a well-defined external RF source f. The phase lock would allow the transmission of a number of electrons per external RF signal period, producing dc current, mostly related to frequency I = mef. This design limits coherent oscillations, which afterwards are handled by a steady RF source for control devices, e.g., single-electron torque pipes that are not always autonomous.

(iv) Temperature Standards

The 1D single electron arrays may offer a new path to a new absolute standard of temperature. The N>>1 island arrays exhibit typical I-V DC curves at low voltages at low temperatures with various Coulomb tunnel blockages (|V|Vt). When Ec/kB is raised, thermal fluctuations remove coulomb lockage and almost linear I-V of all tensions: G/dIüdV/Gn/NR. The only remaining object of the blockage of Coulomb is a little reduction in differential conduct at V =0.

(v) Charge State Logics

The Charging Status Logic Device is yet another logical device. In order to deal with the issue of leakage current, logic is used to transmit single bits of information across a circuit by detecting the presence or absence of individual electrons in the circuit. Because there is no static current in these circuits, static currents and power are not present in them [11, 12].

B. Advantages and Disadvantages of Set

The advantages and disadvantages of single-electron transistors are as follows:

(i) Advantages

•_Compact size
•High sensitivity
•Low energy consumption
•Feature of reproducibility
•Simplified circuit
•High operating speed
•Co-integration with CMOS circuits
•Simple principle of operation

(ii). Disadvantage

•Integration of large-scale SETs: To run SETS at normal temperature, vast amounts of mono-dispersed Nan particles with a diameter of less than 10 nm must be summed up. However, it is exceedingly difficult for conventional lithography and semiconducting processes to produce significant numbers of SETs.

• It is very hard to link SETs with the outside environment.

•Basically, complex to fabricate Single electron transistors (SETs).

III. CONCLUSION

Because of advances in acoustic nanotechnology and the continuous downsizing of circuit components, single electron devices have been developed that are smaller in size and use less power than their predecessors in the industry. When changing devices from conducting to nonconducting, these devices are based on the idea of mechanical tunnelling of amount, and one or a few electrons are utilized to accomplish the conversion. It is the goal of this research to provide a theoretical explanation of the fundamental principles of SET, as well as the significance of SET in the manufacturing of various electronic instruments in the realm of nanotechnology to achieve low energy consumption and high operating speed in the design of VLSI. SET has shown to be a valuable instrument in scientific research throughout the years. One of the most challenging challenges in the nanometre age is the development of nano scaling equipment that can be enabled by SET. In recent years, researchers have been investigating the possibility of using digital electronic SET transistors in digital electronic systems (DES). Even the most recent SET transistors are susceptible to "offset charges," which means that the gate tension required to generate the maximum power varies from device to device and from unit to unit. The presence of such oscillations makes it impossible to construct complicated circuits.

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