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Study on Single-Electron Transistors Based on Artificial Intelligence

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ABSTRACT

Nanotechnology is ushering in the era of self-replicating machinery and self-assembling consumer goods made from raw atoms. Using the surely knew properties of iotas and atoms, nanotechnology proposes the development of novel sub-atomic gadgets having phenomenal properties. The single electron semiconductor or SET is another sort of exchanging gadget that utilizations controlled electron burrowing to intensify current. It is a critical component of ebb and flow research area of nanotechnology which can offer low power utilization and high working rate. Single electron semiconductor [SET] is a new nano scaled exchanging gadget since single-electron semiconductor holds its versatility even on a nuclear scale what's more this; it have some control over the motion of a solitary electron. Here, versatility implies that the presentation of electronic gadgets increments with a diminishing of the gadget aspects. By utilizing the "Electron shaft lithography" and "Electro relocation", the exploration prompts the planning of a solitary particle semiconductor with the assistance of the carefully orchestrated semiconductor precious stones called "quantum specks", which encapsulates the electrons bound in a direct and looks like same in its properties as a genuine molecule. Though we can comprehend traditional semiconductors utilizing old style ideas, the SET is quantum mechanical in a fundamental manner. Truth be told, there is a nearby relationship between the bound electrons inside a SET and a molecule. In this paper, the physics hidden the activity of SETs is made sense of, a concise history of its creation is introduced, and issues of current interest are examined.

Keywords: Nano electronics, single-electron box, Quantum tunnelling, Coulomb blockade, Quantum Dot, Single-electron transistor

INTRODUCTION

The discovery of the transistor has clearly had enormous impact, both intellectually and commercially, upon our lives and work. It prompted the microminiaturization of gadgets, which has allowed us to have strong PCs on our work areas that discuss effectively with one another by means of the Internet. Throughout the course of recent years, silicon innovation has been overwhelmed by Moore's regulation: the quantity of semiconductors on a silicon coordinated circuit pairs about like clockwork. To proceed with the rising degrees of mix past the cutoff points referenced above, new methodologies and models are required. In the present computerized coordinated circuit structures, semiconductors act as circuit changes to charge and release capacitors to the expected rationale voltage levels. It is additionally conceivable to encode rationale states by the places of individual electrons (in quantum speck single-electron semiconductors, for instance) as opposed to by voltages. Such designs are versatile to sub-atomic levels, and the exhibition of the gadget works on as the size diminishes. Falsely organized single electron semiconductors concentrated to date work just at low temperature, however sub-atomic or nuclear measured single electron semiconductors could work at room temperature.

Single-electron semiconductor (SET) is extremely famous in the field of nano gadgets since 10 years. Single electron semiconductor (SET) is the most essential three-terminal single electron gadget (SED) which is fit for offering low power utilization and high working velocity. Since the innovation comes to nano size, the way of behaving of a nano electronic single electron semiconductor (SET) is constrained by the quantum mechanical impacts.

END OF MOORE'S LAW

Moore's law is named after the Intel cofounder Gordon Moore in 1965, who stated that, "the number of transistors on a chip will double approximately every two years". The term is not an actual law in any scientific rule, similarly to "the rule of thumb"; however, Intel's development from Moore's law has fulfilled the many breakthrough achievements and has made the law widely acceptable.

But physicists predict that in about ten years or so, we will see the collapse of Moore's Law. In fact, already, we see a slowing down of Moore's Law. Computer power simply cannot maintain its rapid exponential rise using standard silicon technology. Intel Corporation has admitted this. In fact, Intel Corporation is now working towards three-dimensional chips, chips that compute not just flatly in two dimensions but in the third dimension. But there are problems with that. The two basic problems are heat and leakage. That's the reason why the age of silicon will eventually come to a close. No one knows when, but we now can see the slowing down of Moore's Law, and in ten years it could flatten out completely. The problem is that a Pentium chip today has a layer almost down to 20 atoms across. When that layer gets down to about 5 atoms across, it's all over. You have two effects. Heat--the heat generated will be so intense that the chip will melt and disintegrate, and second of all, leakage--you don't know where the electron is anymore. The quantum theory takes over. The Heisenberg Uncertainty Principle says you don't know where that electron is anymore, meaning it could be outside the wire, outside the Pentium chip, or inside the Pentium chip. So there is an ultimate limit set by the laws of thermal dynamics and set by the laws of quantum mechanics as to how much computing power you can do with silicon.

Moore's law could "flatten out completely" in the next few decades because sooner or later the silicon transistors will not get any smaller and no more could be squeezed onto a chip, and there needs to be a post-silicon era. Going beyond silicon, there have been a number of proposals. SET is one such proposed candidate.

BASIC PHYSICS OF SET OPERATION

Single Electron Transistor [SET] have been made with critical dimensions of just a few nanometer using metal, semiconductor, carbon nano tubes or individual molecules. A SET consist of a small conducting island [Quantum Dot] coupled to source and drain leads by tunnel junctions and capacitive coupled to one or more gate. Unlike Field Effect transistor, Single electron device based on an intrinsically quantum phenomenon, the tunnel effect. The electrical behavior of the tunnel junction depends on how effectively barrier transmit the electron wave, which decrease exponentially with the thickness and on the number of electron waves modes that impinge on the barrier, which is given by the area of tunnel junction divided by the square of wave length.

Quantum dot [QD] is a mesoscopic system in which the addition or removal of a single electron can cause a change in the electrostatic energy or Coulomb energy that is greater than the thermal energy and can control the electron transport into and out of the QD. This sensitivity to individual electrons has led to electronics based on single electrons. For QD, the discrete energy level of the electrons in the QD becomes pronounced, like those in atoms and molecules, so one can talk about "artificial atoms and molecules". When the wave functions between two quantum dots overlap, the coupled quantum dots exhibit the properties of a molecule. To understand the electron transport properties in QD. Let us consider a metal nano particle sandwiched between two metal electrodes. The nano particle is separated from the electrodes by vacuum or insulation layer such as oxide or organic molecules so that only tunneling is allowed between them. So we can model each of the nano particles-electrode junctions with a resistor in parallel with a capacitor. The resistance is determined by the electron tunneling and the capacitance depends on the size of the particle. We denote the resistors and capacitors by R1, R2, C1 and C2, and the applied voltage between the electrodes by V. We will discuss how the current, I depends on V. When we start to increase V from zero, no current can flow between the electrodes because movement of an electron onto (charging) or off (discharging) from an initially neutral nano particle cost energy by an amount given by equation 1.

APPLICATIONS

1. 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. Absolute measurements of extremely low dc currents (~10-20A) have been demonstrated. The transistors have also been used in the first Measurements of single-electron effects in single-electron boxes 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..

2. 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.

3. 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.

4. Detection of Infrared Radiation

The calculations of the photo response of single-electron systems to electromagnetic radiation with frequency ~EC / h have shown that the response generally differs from that the well-known Tien-Gordon theory of photon-assisted tunneling. In fact, this is based on the assumption of independent (uncorrelated) tunneling events, while in single-electron systems the electron transfer is typically correlated. This fact implies that single-electron devices, especially 1D multi-junction array with their low co-tunneling rate, may be used for ultrasensitive 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.

5. Voltage State Logics

The single-electron transistors can be used in the "voltage state" mode. In this mode, the input gate voltage V controls the source-drain current of the transistor which is used in digital logic circuits, similarly to the usual field-effect transistors (FETs). This means that the single-electron charging effects 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 current in these circuits is fairly substantial, of the order of 10-4e/RC. The corresponding static power consumption is negligible for relatively large devices operating at helium temperatures. However, at the prospective room-temperature operation this power becomes on the order of 10-7 Watt per transistor.

Though apparently low, this number gives an unacceptable static power dissipation density (>10 kW/cm2) for the hypothetical circuits which would be dense enough (>1011 transistors per cm2) to present a real challenge for the prospective CMOS technology.

6. 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.

7. 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.

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PROBLEMS IN SET IMPLEMENTATIONS

1. Lithography Techniques

The first biggest problem with all single-electron logic devices is the requirement Ec~100kBT, which in practice means sub-nanometer island size for room temperature operation. In VLSI circuits, this fabrication technology level is very difficult. Moreover, even if these islands are fabricated by any sort of nanolithography, their shape will hardly be absolutely regular. Since in such small conductors the quantum kinetic energy gives a dominant contribution to the electron addition energy (Ek >> Ec,), even small variations in island shape will lead to unpredictable and rather substantial variations in the spectrum of energy levels and hence in the device switching thresholds.

2. Background Charge

The second major problem with single-electron logic circuits is the infamous randomness of the background charge. A single charged impurity trapped in the insulating environment polarizes the island, creating on its surface an image charge Q0 of the order of e. This charge is effectively subtracted from the external charge Qe

3. Cotunneling

The essence of the effect is that the tunneling of several (N>1) electrons through different barriers at the same time is possible as a single coherent quantum-mechanical process. The rate of this process is crudely (RQ/R)N-1 times less than that for the single-electron tunneling described by Equation of the orthodox theory

$$\Gamma(\Delta W) = (1/e)\ I(\Delta W/e)\ [1 - \exp\{-\Delta W/kBT\}]-1 \quad (4)$$

If the condition expressed by equation is satisfied this ratio is rather small; cotunneling can nevertheless be clearly observed within the Coulomb blockade range where orthodox tunneling is suppressed.

4. Room Temperature Operation

The first big problem with all the known types of single-electron logic devices is the requirement Ec ~ 100 kBT, which in practice means sub-nanometer island size for room temperature operation. in such small conductors the quantum kinetic energy gives a dominant contribution to the electron addition energy even small variations in island shape will lead to unpredictable and rather substantial variations in the spectrum of energy levels and hence in the device switching thresholds.

5. Linking SETs with the Outside Environment

The individual structures patterns which function as logic circuits must be arranged into larger 2D patterns. There

are two ideas. The first is to integrating SET as well as related equipments with the existed MOSFET, this is attractive because it can increase the integrating density. The second option is to give up linking by wire, instead utilizing the static electronic force between the basic clusters to form a circuit linked by clusters, which is called quantum cellular automata (QCA). The advantage of QCA is its fast information transfer velocity between cells (almost near optic velocity) via electrostatic interactions only, no wire is needed between arrays and the size of each cell can be as small as 2.5nm, this made them very suitable for high density memory and the next generation quantum computer.

ADVANTAGES

Following are the advantages of Single-electron transistors (SETs):

- Low energy consumption
- High sensitivity
- Compact size
- High operating speed
- Simplified circuit
- Feature of reproducibility
- Simple principle of operation
- Straight forward co-integration with traditional CMOS circuits.
- Performance is better than (FETs) because of their compact size.

Single electron transistors (SETs) have high input impedances and low voltage gain. Besides this, these are also very sensitive to random background charges. Due to this, SETs have replaced the FETs in many applications where low output impedances and large voltage gain is necessary.

DISADVANTAGES

Following are the disadvantage of Single-electron transistors (SETs):

- 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).

CONCLUSIONS

Single Electronic Transistor (SET) has proved their value as tool in scientific research. Resistance of SET is determined by the electron tunneling and the capacitance depends on the size of the nanoparticle. The current starts to flow through the junction when applied voltage is just sufficient to raise the energy of electron above the coulomb blocked, this is called threshold voltage Vth and the flat zero current persist for 2Vth. Several applications of nanoscale devices in metrology, including the fundamental standards of current, resistance and temperature also seem quite promising. Another potential application is terahertz radiation detection. The situation is much more complex with digital single electronics. The concept of single electron logic suggested so far face sturdy challenges: either removing background charge or providing continuous charge transfer in nanoscale. The main problem in nanometer era is the fabrication of nanoscale devices. SET provide the potential for low-power, intelligent LSI chips, appropriate for ubiquitous application.

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