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Supersensitive Electrometer and Electrostatic Data Storage Using Single Electron Transistor

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Abstract

Since the beginning of human kind, the need for storing information has been very important. The age has bought us from storing them on papers to the magnetic storage which today are the major storage systems. This paper explains the objective in which discusses the functionality of the Single Electron Devices that assist in the improvement of the memory storage devices and the process of inception of information on them. The point that makes this device a part of VLSI family is the size of it and the function it provides in building of memory storage device.
When in the regular storage system let say a 100 Gbits/inch^2 is stored, the single electron device stores up to 1tbits/inch^2, this means storing more data yet not sacrificing on the resources. The technology used over here is Electrostatic Data Storage.[1] It involves the implementation of the single electron transistor (SET) to control the data storage. SET is the backbone of all the single electron devices and instruments that exist. This phenomenon to store such huge amounts of information (data) requires an equivalent read-write technology, so an electrometer with such efficiency was developed such that it can do this job without any hassle. An electrometer is an instrument which writes and reads data on a piece of storage element.

SET (Single Electron Transistor):

A SET is Solid state semiconductor ultra-small device, in which the addition or subtraction of a small number of electrons to/from an electrode can be controlled with one-electron precision. The characteristic of this electron in ON and OFF regions is observed.[2] These ON and OFF state represent 0’s and 1’s which are the binary numbers in machine level storage. These devices are based on the controllable transfer of single electrons between small conducting "islands". The island's electrostatic potential increases significantly with the introduction of just one electron. It has numerous purposes including signal modulation, amplification and voltage stabilization and is basically used to increase the battery life of the electronic device and requires minimal power than where high computing power is necessary.

Principle Involved:
The natural candidate for an alternative technology of storing data apart from magnetic storage is electrostatic data storage, where a digital bit (0, 1) is retained in the form of a minute (few-electron) charge of a small metallic grain or a group of grains[1]. There were problems during doing so,

One of them was lack of sensitivity of devices for reading such data
Another problem was speed of writing them.

But soon because of invention of so called SET, the condition has radically improved. The SET now has an improved version in which the barrier between junctions is transformed to a crested barrier. Figure(1) shows an electrostatic data storage system (ESTOR) which combines the unique charge sensitivity of single-electron transistors and speed of recharging through crested barriers .A crested barrier is a normal barrier which has some improvements that help the SET to perform better in performing reading and writing[1].

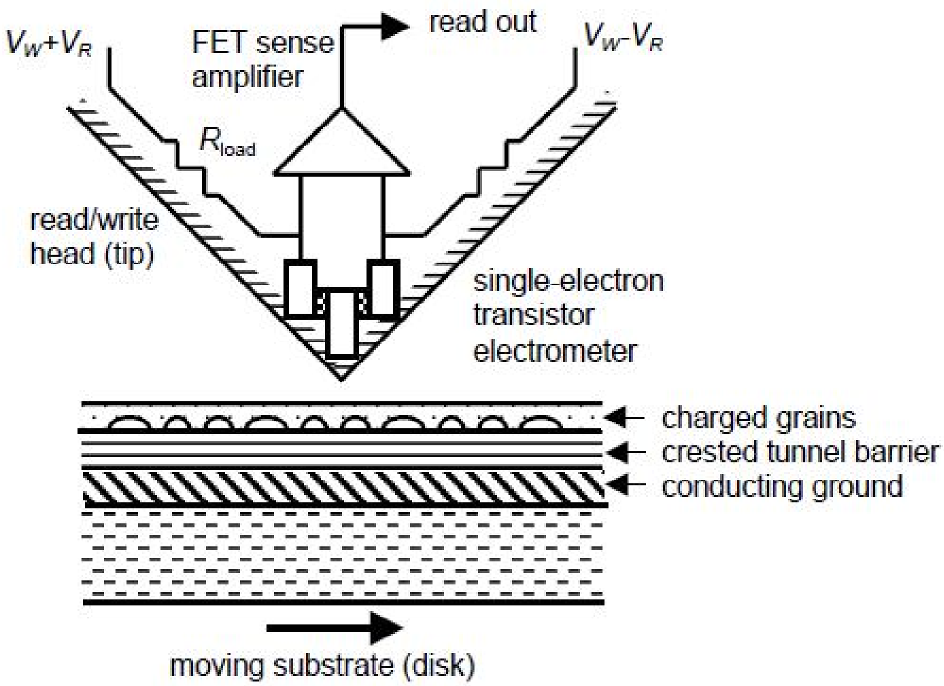

Figure1. Electrostatic data storage system

How memory operations are performed:

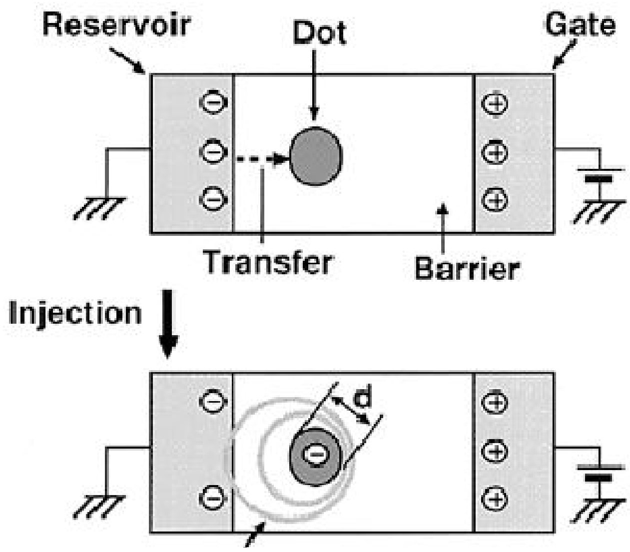

Figure 2.Coulomb repulsion blocks subsequent injection

There were few techniques involved in the Single electron storage, the most usual one is defined as follows the single electron box (figure(2))may be referred for this model, which shows non linear characteristic.[3] As the gate voltages increases, the voltage which is applied to the nonlinear resistance also increases. When reaches the threshold voltage, the nonlinear resistance becomes Conductive and an electron is transferred from the reservoir to the dot. Just after this transfer, decreases by — and again goes into a high resistance state (is the total capacitance of the storage node). This blocks the transfer of another electron. As the gate voltage increases, the number of electrons in the dot increases (there by increasing the memory) with every ─ gate voltage increase. The numbers of stored electrons are precisely controlled by the Coulomb blockade effect[3].

Supersensitive Electrometer:

A new type of electrometer is described that uses a single-electron transistor (SET) and that allows large operating speeds and extremely high charge sensitivity. The SET readout was achieved by measuring the damping of a 1.7-gigahertz resonant circuit in which the device is embedded, and in peculiar manner is the electrostatic "dual" of the well-known radio-frequency superconducting quantum interference device. The device is more than two orders of magnitude faster than its earlier single-electron devices, with a constant gain from dc to greater than 100 megahertz. For a still-unoptimized device, a charge sensitivity of $1.2 \times 10^{-5}\ e/\sqrt{\text{hertz}}$ was obtained at a frequency of 1.1 megahertz. This order of magnitude is better than a typical, 1/*f*-noise-limited SET, and corresponds to energy sensitivity (in joules per hertz) of about 41 $\hbar$.

This sensitive electrometer is based on a new type of SET—the radio-frequency SET or RF-SET, which was first proposed by Averin and Likharev. ($\hbar$=1.054 × 10^{-34}J/Hz).

Most of Coulomb blockade (SET) electrometers have a double-junction structure with a centralized metallic island that is capacitive coupled to the input. Under the suitable conditions, a device such as this has an onset of current that is controlled by the potential of the island. The onset is periodic in the gate charge, q_g, coupled onto the island via the gate capacitor, with a period equal to the charge of a single electron, *e*. The gate charge, q_g, can be simultaneously varied and is defined as $q_g = C_g V_g$, where C_g is the gate capacitance and V_g is the gate voltage. Usually, the SET is current-biased just above threshold, and the drain-to-source voltage is monitored with a high-impedance voltage amplifier at room temperature In order to display a strong Coulomb blockade and the desired sharp onset of current, each junction of the SET must be of the order of the resistance quantum, $R_K = h/e^2$ = 26 kilohms, leading to a typical device resistance of R = 100 kilohms or more. Given the capacitive load for the cabling (C_l = 0.1 to 1 nF) to the room-temperature amplifier, the bandwidth is limited to $f < 1/2\pi RC_l$, or less than a few kilohertz. Note, however, that the intrinsic limit on the speed of the SET should be determined by the RC time constant of the tunnel junctions themselves which can be greater than 10 GHz. [5].For improving the speed of SET electrometers has used a cryogenic voltage amplifier, integrated in close proximity to the SET, to minimize the capacitive load. The total capacitance, although it includes the capacitance of the GaAs high electron mobility transistor (HEMT) used as the amplifier, can be less than 1 pF; allowing a speeds as high as 700 kHz. The noise performance was also limited by the HEMT.

In the RF-SET, the readout of the charge state of the device is accomplished by monitoring the damping of a high-frequency resonant circuit to which the SET is connected, rather than by measuring either the current or the voltage. This readout scheme offers many advantages. By using a low-impedance (50 ohm) high-frequency amplifier, the capacitance of the cabling between SET and the amplifier becomes unimportant. Once it is physically and thermally separated from the SET, the amplifier can be optimized without the constraint of very low power dissipation required for operation at millikelvin temperatures. Finally, because the readout is performed at a high frequency, there is no amplifier contribution to the 1/*f* noise.

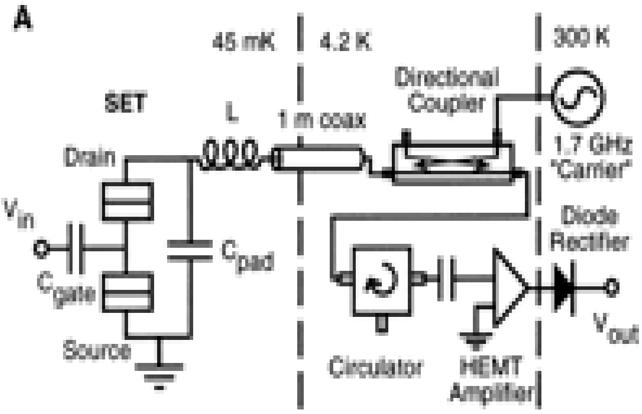

Figure 3a.Apparatus used for measurement

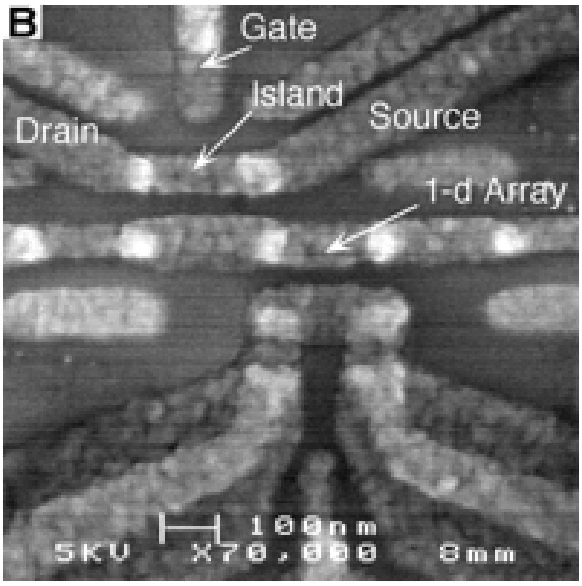

Figure 3b. Micrograph of one of the RF SET device of the high-frequency conductance

The aluminum leads for the gate, drain, and source are labeled, and the lighter regions are the tunnel junctions formed where the drain and source overlap the island. [5].

The main applications of the RF-SET electrometer will initially be in experiments on the physics of other single-electron and mesoscopic systems. SET electrometers have been used in this role, but because of their slow response, they have been limited to studying long-time or thermally averaged properties. For technological applications, more work will be required in optimizing the coupling to the electrometer and in finding devices and detectors for which the RF-SET is best suited.

The supersensitive electrometer measures voltages or chargewith a great accuracy when compared to electrometer.Amongst the properties of a Supersensitive electrometer we have some of the most evident as follows[4]:

- Low current measurements.
- Particle beam experiments, including precision mass spectrometry.
- RF-SET has the sensitivity and speed to count electrons at frequencies >10 MHz , with very good signal-to-noise (S/N) ratio
- Precise measurements of high resistances.
- Characterizing sub-threshold I-V curves.
- Characterizing prober performance.
- Up to 1200 readings/second
- <1fA noise
- >200TΩ input impedance on voltage measurements
- Built-in constant current source
- Active cancellation of voltage and current offsets

Figure 4. Electrometer

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