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NEWS RELEASE

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Manipulation and detection of single electrons in a silicon charge-coupled device

NTT Basic Research Laboratories (BRLs) have devised a new type of single-electron device, a charge-coupled device (CCD) that can manipulate a single electron. The test device was fabricated on a silicon wafer and was found to operate successfully. The operation principle of the device is similar to that of the conventional CCD* that is widely used in image sensors. The distinct feature is that the new CCD can transfer a single electron and also detect its position with the sensitivity of the elementary charge. NTT BRLs have taken the world lead in developing silicon single-electron transistors. With the new type of single-electron device, we have developed another candidate for the ultralow-power application. This is a big step for the future application of single-electron devices. The present work was published in the British scientific magazine Nature (vol 410, 29 March 2001) as "Manipulation of elementary charge in a silicon charge-coupled device" by Akira Fujiwara and Yasuo Takahashi (NTT Basic Research Laboratories).

* The CCD consists of an array of gates on a silicon wafer. A large number of electrons trapped under the gate are transferred from one gate to another.

< Background and details>

NTT is aiming for an environmentally gentle and continuously growing multimedia society by promoting energy savings in communication terminals (including cellar phones). However, the energy consumption accompanying communication as well as the amount of information in communication has increased drastically year by year. Modification of conventional technology alone can reduce energy consumption to only a tenth. Single-electron transistors, on the other hand, can reduce the energy consumption to one ten-thousandth.

Manipulation of a single electron becomes possible in single-electron tunneling devices such as single-electron transistors. Single-electron transistors include some complex structures consisting of conductive islands and tunnel barriers (thin insulating layers). As a result, some special techniques are needed to fabricate them with good controllability. NTT BRLs have developed a technique named "Pattern-dependent oxidation" by which Si islands and tunnel barriers are automatically formed with high reproducibility. Single-electron transistors, single-electron inverters, and single-electron pass-transistor logic circuits have been successfully fabricated by this method. However, simpler and easier methods are favorable from the viewpoint of large-scale integration of devices on a silicon wafer.

NTT BRLs have succeeded in fabricating a new device manipulating a single electron, which is different from the single-electron tunneling devices. The device, which is in effect an ultrasmall version of the CCD, is easy to fabricate because it does not include tunnel barriers and is therefore more suitable for large-scale integration.

The fabricated test device consists of a T-shaped Si wire with the two overlapping gates (Fig.1). Firstly, in the Si-wire channel under either gate, a single hole (positive elementary charge) is generated and stored. Next the single hole is transferred back and forth between the two gates. The position of the hole can be sensed by the electron current that flows through each Si-wire channel from the ground electrode to each output electrode (Fig. 2). This new sensing scheme has single-electron-level sensitivity. The sensing method is based on the separation of the Si-wire channel into a region that store charges (hole) and a region where the sensing electron current flows. The separation is done by introducing a voltage slope within the Si wire along the direction perpendicular to the wafer.
In the single-electron transfer device featuring the conventional tunneling devices, single electrons were transferred a million times per second and the resultant current (sum of the transferred electrons) was measured. The real-time monitoring of the transferred single charge has been demonstrated for the first time. The reason the manipulation of a single hole was demonstrated is simply because of the carrier-type of the current electrode of the fabricated device. We can fabricate a device that manipulates a single electron on the same principle.

<Future Prospect>

Because the structure of the device is simple without tunnel barriers, we can transfer the single charge in either direction just by arranging the gate electrodes on a silicon wafer. This feature is suitable for large-scale integration. However, so far we have just tested the basic operation at 25 K. The evaluation of device performance (transfer error rate, possibility of room-temperature operation, and transfer speed) in comparison to that of the single-electron tunneling devices will be necessary. In order to raise the operating temperature from 25 K to room temperature, further scaling down of the device size will be needed.
Since the device is brand new, the target applications should be widely considered. We will investigate the possibility of application to logic devices based on single-electron transfer, single-electron memory, and current standards based on the exact transfer of electrons.

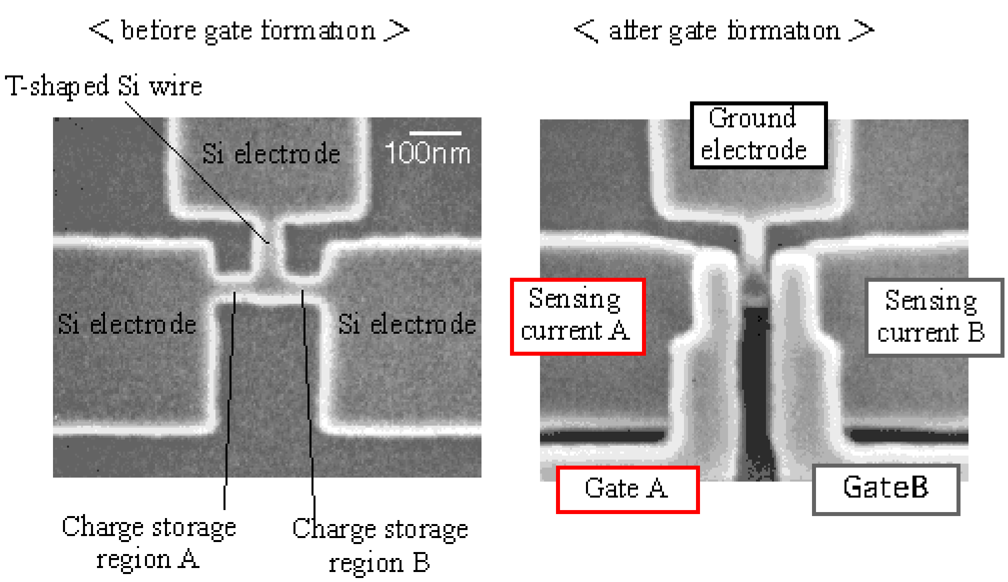

Fig. 1 Scanning electron microscope (SEM) image of the single-electron CCD.

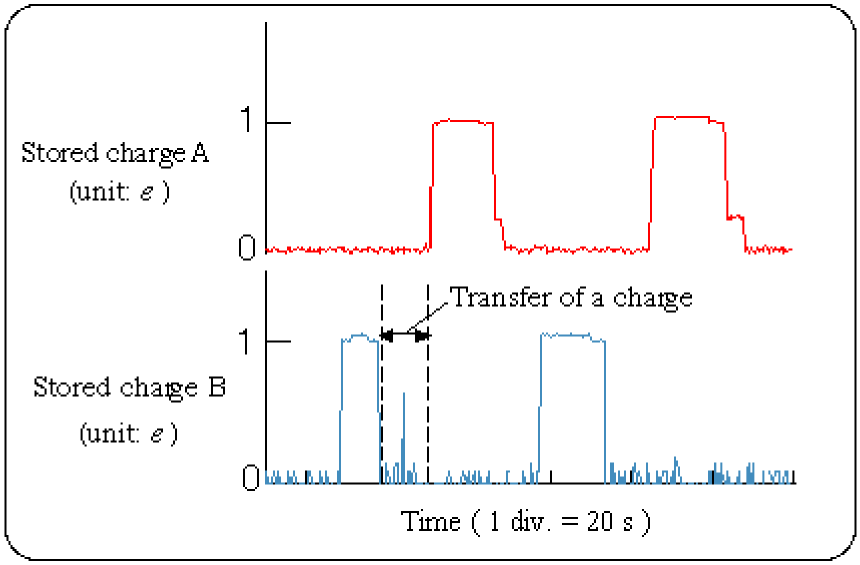

Fig. 2 Transfer and detection of the single electron (hole).

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