High-speed operation of Si single-electron transistor

Yasuho Takahashi, Hiroto Takenaka, Takafumi Uchida, Masashi Arita, Akira Fujiwara, and Hiroshi Inokawa††

Graduate School of Information Science and Technology, Hokkaido University, Sapporo 060-0814, Japan
†NTT Basic Research Laboratories, NTT Corporation, 3–1 Morinosato Wakamiya, Atsugi, 243-0198, Japan
††Research Institute of Electronics, Shizuoka Univ., 3–5–1, Johoku, Hamamatsu, 432-8011, Japan

High-speed and low-power devices are desired for future electronics. Single-electron transistor (SET) can be a candidate because electrons are transported by tunneling and its internal electrical capacitances can be made very small. On the contrary, many researchers believe that operation speed of SETs should be low due to the high tunneling resistance that is lower bounded by the resistance quantum. Moreover, high-frequency characteristics have not been measured, mainly because the voltage applied to the drain terminal was limited to be small so as to keep the Coulomb blockade condition.

Here, we propose a new method to measure the high-frequency characteristics by the use of special rectifying effect of SETs. It is well known that the rectification effect occurs, according as the gate voltage is swept through the peak of drain conductance, due to the asymmetry of Coulomb diamond when alternating current (AC) voltage is applied to the drain or source terminal [1]. Using this phenomenon, we evaluated the cut-off frequency of SETs. In addition, we obtained Si SETs with relatively large tunnel conductance, which is favorable for high-frequency operation.

The Si SETs were fabricated by pattern-dependent oxidation (PADOX) method [2] which converts a Si nanowire formed in a top Si layer of SOI to a small Si island together with tunnel barriers on both sides of the island. Fig. 1 shows typical source-drain conductance as a function of gate voltage measured at 8 K and drain voltage of 5 mV. Clear conductance oscillation can be observed, as shown in Fig. 1. Moreover, high-frequency characteristics as a function of gate voltage (Vg) is shown in Fig. 2. The peak conductance of the first peak is about 4x10^{-12} S, and the gate capacitance is about 0.6 aF, which enable us to attain the f_c of 1 MHz.

When AC voltage is applied to a drain of a SET, rectification effect occurs due to the asymmetry of the Coulomb diamond. We thought that the transport of electrons through the SET is inhibited when the AC frequency becomes higher than f_c. As a result, the rectification effect is also suppressed. Measured rectifying current is shown in Fig. 3. There is no reduction of rectifying current even in the frequency higher than f_c.

These results indicate that there is no cutoff frequency set by the capacitance and tunneling resistance in the Coulomb blockade of SETs, leading to the rectifying effect usable beyond the THz regime. It should be noted that tunneling event itself is limited by C/G time but the time does not put frequency limit on rectifying effect in the accumulative measurement as presented in this work.

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References


Fig. 1. Source-drain conductance as a function of gate voltage of a SET fabricated by the PADOX process, and measured at 8 K and drain voltage of 5 mV.

Fig. 2. Drain current I_d-V_g characteristics of a SET used for rectification measurements in a high frequency region.

Fig. 3. Rectifying I_d-V_g characteristics of a SET at several frequencies measured at V_{app} = ±12.5 mV.