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Transport Properties of Resistively-Coupled Single-Electron Transistor

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1. Introduction

A single-electron transistor (SET) is one of the promising devices for future electronics, and has attracted researchers in recent years [1]. The field of single-electron transport was originated by K. K. Likharev [2, 3]. He proposed two types of SET; capacitively-coupled SET (C-SET) and resistively-coupled SET (R-SET) [2]. Figure 1 shows schematic diagrams of (a) C-SET and (b) R-SET with the Coulomb-blockade regions, i.e., Coulomb diamonds. As shown in this figure, the Coulomb diamond of C-SET appears periodically along the V_g axis and is surrounded by four tilted lines, while that of R-SET has only one Coulomb diamond surrounded by two horizontal and two tilted lines. The horizontal size of the Coulomb diamond is typically one- or two-orders larger than the vertical one in the C-SET case, while they are of the same order in the R-SET case.

After Likharev's proposal, C-SETs and C-SET-based devices have been intensively studied, while only a few reports [4, 5] on R-SET can be found. No experimental observation of the Coulomb diamond of the R-SET, which is schematically shown in Fig. 1, has been reported yet.

The purpose of this work is to observe the Coulomb diamond of R-SET.

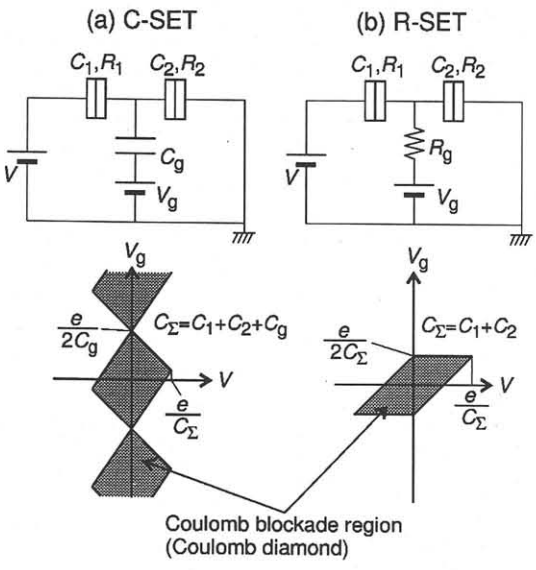

Fig. 1: Schematic diagram of (a) C-SET and (b) R-SET with the Coulomb-blockade regions.

2. Experiments

We fabricated an R-SET using a modulation-doped GaAs/AlGaAs heterostructure with the density and the mobility of the two-dimensional electron gas of 2.7×10^{11} cm^{-2} and 1.3×10^5 cm^2/V s, respectively, at $\simeq$ 30 mK. Conventional electron beam lithography and lift-off technique were used to define the metal Schottky gates. Figure 2(a) shows a secondary-electron-microscope (SEM) micrograph of the fabricated device. Although two quan-

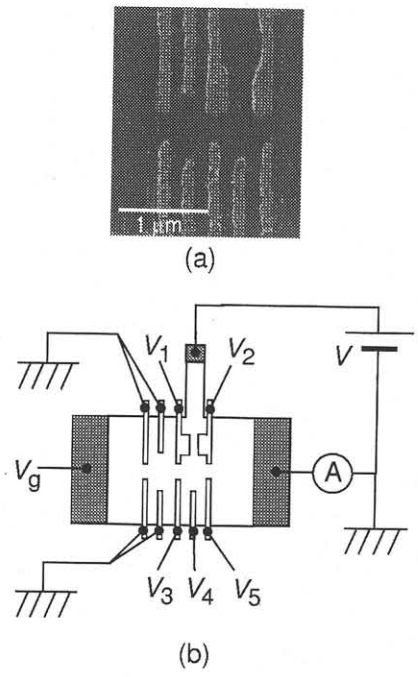

Fig. 2: (a)SEM micrograph of the fabricated device. (b)Measurement setup.

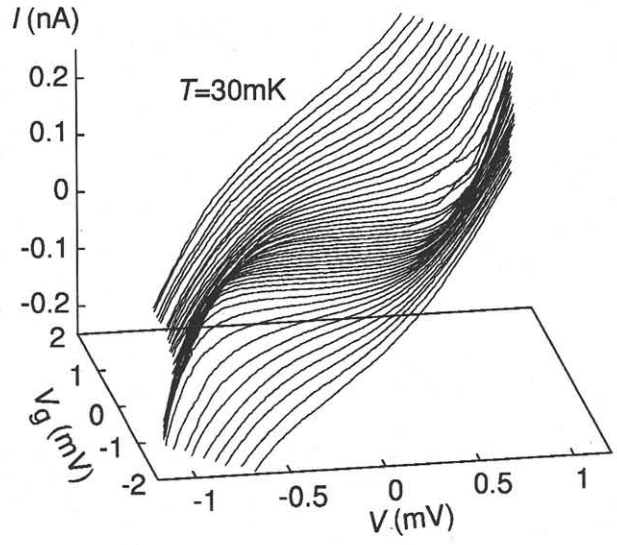

Fig. 3: I–V characteristics for various V_g. V_1, V_2, V_3, V_4 and V_5 were fixed to -0.398 V, -0.5135 V, -1.32 V, -0.795 V and -0.994 V, respectively.

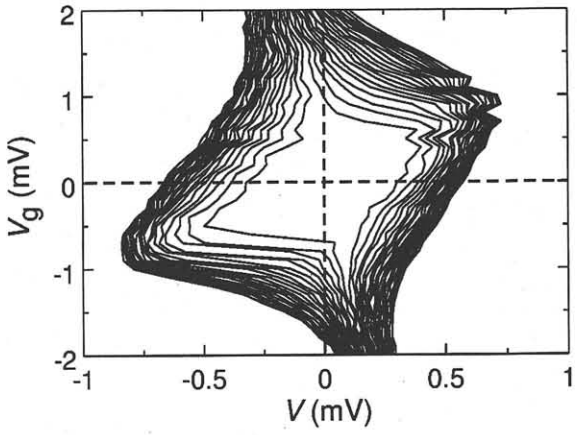

Fig. 4: The equi-current lines at $|I| = 2.5, 5.0, 7.5, \cdots, 50$ pA obtained from I–V curves shown in Fig. 3.

tum dots can be seen in Fig. 2(a), one of them was not used in the present work.

The measurement setup are shown in Fig. 2(b). One of the ohmic contacts was biased with the drain voltage V, while the source electrode was grounded through a current amplifier. The gate voltage V_g was applied on one of the ohmic contacts, and affected the transport properties through the tunnel barrier formed by the Schottky gates whose biases were V_1 and V_3. The current–voltage (I–V) characteristics were measured for various V_g at $\simeq 30$ mK using a dilution refrigerator.

3. Results and Discussion

Figure 3 shows the observed I–V curves for various V_g. The gate voltages V_1, V_2, V_3, V_4 and V_5 were fixed to -0.398 V, -0.5135 V, -1.32 V, -0.795 V and -0.994 V, respectively, during this measurement. The equi-current lines at $|I| = 2.5, 5.0, 7.5, \cdots, 50$ pA in V_g–V plane obtained from the I–V curves shown in Fig. 3 are shown in Fig. 4. Assuming that the Coulomb-blockade region is the region where the current is less than a few pA, the observed Coulomb diamond are surrounded by two almost horizontal lines and two tilted lines. The voltage ranges of the Coulomb diamond with respect to V and V_g are approximately the same ($\simeq 1$ mV). These features satisfy the predicted ones as shown in Fig. 1(b). However, the observed Coulomb diamond is not exactly the same as shown in Fig. 1(b) where the horizontal size is two times larger than the vertical one. The reason may be the smearing of I–V curves which is due to the finite temperature and the quantum fluctuation of the charge.

4. Summary

An R-SET was fabricated using a modulation-doped GaAs/AlGaAs heterostructure and metal Schottky gates. Current–Voltage characteristics were measured at $\simeq 30$ mK. The observed Coulomb diamond satisfies the features peculiar to R-SETs.

Acknowledgments

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