Electron transport through silicon multiple quantum dot array devices

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Introduction

In recent years, silicon double quantum dot (Si DQD) structures have been attracting much attention as a building block for the quantum information devices (QIDs). To realize the QIDs, coherent manipulation of two qubits is required as well as that of one qubit. Hence, it is crucial to analyze the interaction between two DQDs [1]. In addition, the two DQDs system is applicable for the quantum cellular automaton [2]. So far, we have investigated the electrostatic coupling in Si DQDs [3]. In this paper, we study the electron transport through the Si multiple quantum dot array devices (Si MQDADs), and observe the strong correlation between two DQDs.

Structure and Fabrication of the Si MQDADs

Figure 1(a) shows the schematic image of the Si MQDADs. Since we need strong electrostatic couplings between two DQDs, DQD1 and DQD2 are physically connected each other. The MQDADs were defined on the silicon-on-insulator (SOI) of about 40 nm and the buried oxide of 200 nm in thickness. First, a 40-nm-thick SOI film, whose thickness was reduced via thermal oxidation, was doped heavily by ion implantation (n-type, phosphorous). The MQDADs were then patterned using the electron beam lithography. The electron cyclotron resonance reactive ion etching was used to transfer the resist pattern onto the SOI layer. Thermal oxidation was then done for 30 min at 1000 °C in order to passivate the surface states and reduce the dot size. Finally, Ohmic contacts were formed by evaporating about 300-nm-thick Al. Figure 1(b) shows the scanning electron micrograph (SEM) image of the MQDADs.

Measurement Results and Discussion

All measurements were performed for the MQDADs using the Hewlett Packard 4156A parameter analyzer at the temperature of 4.2 K in liquid helium. Figures 2(a)-2(d) show the currents I_{T1}, I_{T2}, I_{T3}, and I_{T4} measured at the terminals T1, T2, T3, and T4, respectively, as a function of the voltage of T1 (V_{T1}), where the terminals of T2, T3, and T4 are grounded. As shown in the insets of Fig. 2(a) and 2(c), the currents flow from the terminal T1 to the terminal T3 in the low bias region (-20 mV < V_{T1} < 10 mV). On the other hand, in the high bias region (10 mV < V_{T1}, -20 mV > V_{T1}), I_{T2} and I_{T4} begin to flow in the direction from DQD2 to DQD1, indicating Coulomb blockade between DQD1 and DQD2 is lifted. Note that I_{T3} is very low probably because of the weak coupling of the right part between two DQDs.

Figures 3(a)-3(d) show the contour plots of the I_{T1}-I_{T4}, respectively, as a function of the voltage of G1 and G4 (V_{G1}, V_{G4}), where V_{T1} is -6 mV and the other terminals are grounded. We observed the two current paths; one is in the direction from DQD2 to DQD1 (Path A) [see the white circle in Fig. 3(a)], the other is through the individual DQD (Path B) [see the white circle in Fig. 3(c)]. In addition, the current peaks through the path A appear at the top right corner, which are blown up in the inset of the Fig. 3(a), implying the periodic current oscillations.

To focus on the current through the path A, Figs. 4(a)-4(d) show the contour plots of the currents I_{T1}-I_{T4}, respectively, as a function of V_{G1} and V_{G4}, where the voltage of the terminals T1, T2, and T3 are -6 mV and the terminal of T4 is grounded. I_{T1} and I_{T3}, corresponding the currents through the path A, show the complicated behavior because of the electrostatic interaction in the two DQDs. On the other hand, I_{T2} and I_{T4} include the current through not only the path A but also the path B. The latter periodic current oscillations show the single dot property because of the strong coupling in DQD2. Note that while the maximal I_{T1} is about -1 pA, the local shift of the current I_{T2}, as shown in the white circle in Fig. 4(b), is one order of magnitude higher than that of I_{T1}. This result indicates the electron configuration in the DQD1 strongly influences on the current through DQD2, and vice versa.

Summary

We fabricated the Si MQDADs and measured their electron transport properties. The currents through the MQDADs were analyzed and the strong interaction between the two DQDs was observed. The MQDADs are promising candidates for the novel information devices.

Acknowledgment

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References

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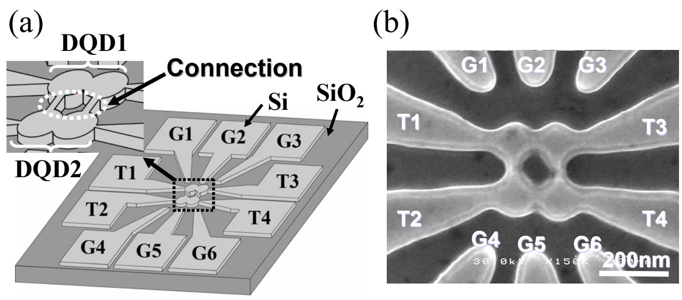

Fig. 1 (a) Schematic and (b) SEM images of the MQDADs

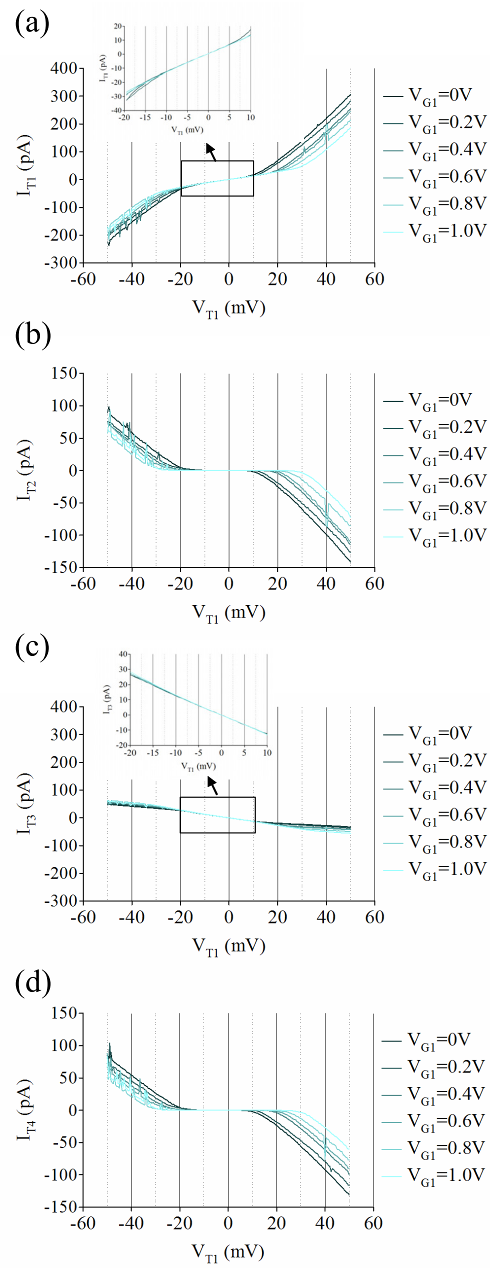

Fig. 2 (a)-(d) I_{T1}, I_{T2}, I_{T3}, and I_{T4} versus V_{T1} characteristics with different gate voltages V_{g1}.

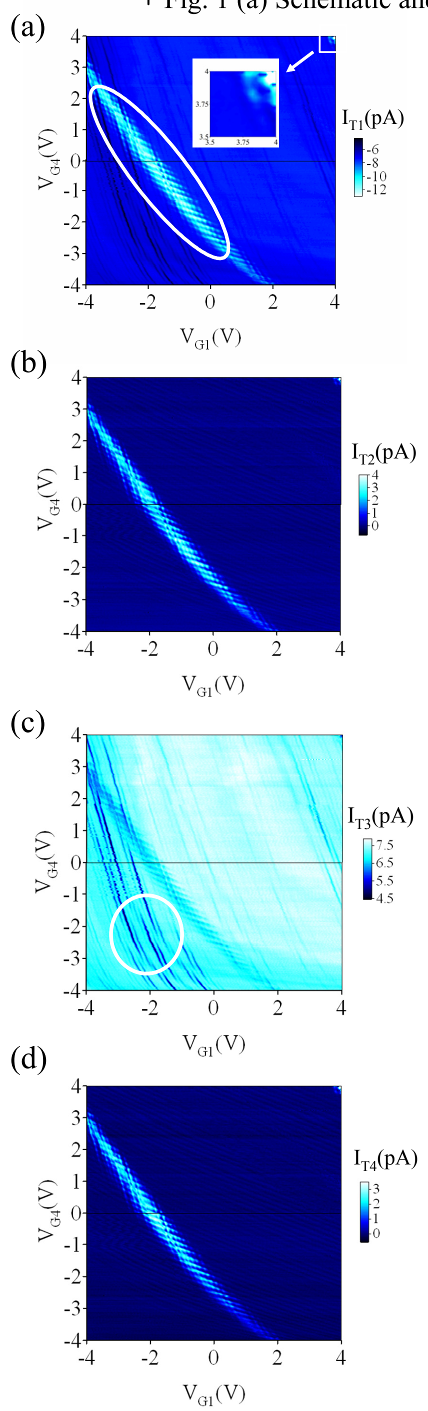

Fig. 3 (a)-(d) the contour plots of I_{T1}, I_{T2}, I_{T3}, and I_{T4} versus V_{G1}, V_{G4}, where V_{T1} = -6 mV and V_{T2}, V_{T3}, and V_{T4}, are grounded.

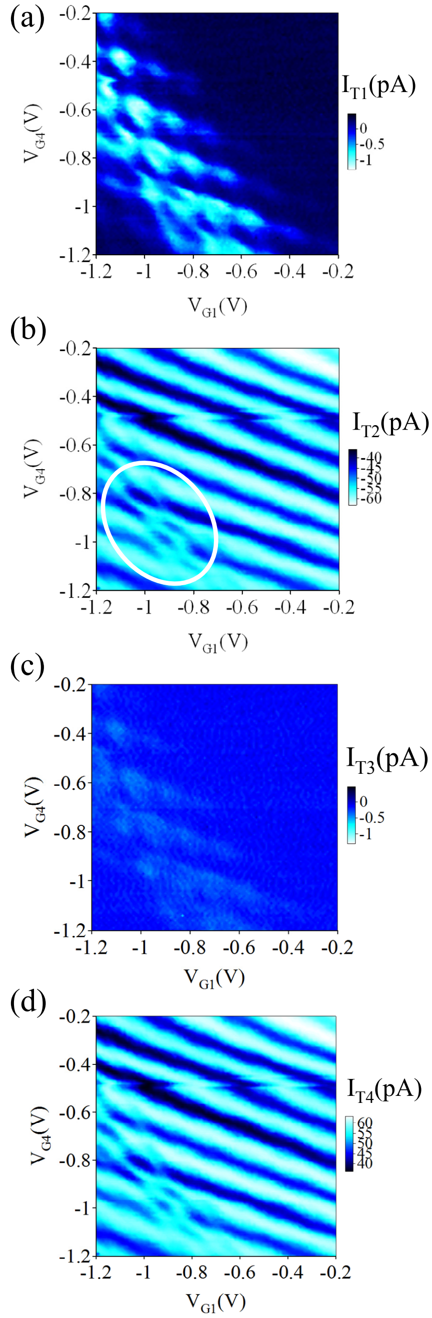

Fig. 4 (a)-(d) the contour plots of I_{T1}, I_{T2}, I_{T3}, and I_{T4} versus V_{G1}, V_{G4} where V_{T1}, V_{T2}, and V_{T3} are -6 mV and V_{T4} is grounded.