Direct measurement of the valley splitting in a few-electron silicon quantum dot using charge sensor source-drain bias spectroscopy

Kosuke Horibe [1], **Tetsuo Kodera** [1,2,3] **and Shunri Oda** [1]

[1] *Quantum Nanoelectronics Research Center, Tokyo Institute of Technology*
[2] *Institute for Nano Quantum Information Electronics, the University of Tokyo*
[3] *PRESTO, Japan Science and Technology Agency (JST)*

One of the important topics for silicon based qubits is the investigation of the valley degeneracy [1], such as the valley splitting and physics of electron transition between the different valleys. In this work, we measured directly the valley splitting in a few-electron silicon QD using charge sensor source-drain bias spectroscopy at 300 mK.

We fabricated a double QD (DQD) and a charge sensor (CS) QD in a metal-oxide-semiconductor structure on a non-doped silicon-on-insulator substrate (Figure 1(a)). Few-electron occupancy states in the DQD are detected by measuring the transconductance dI_{CS}/dV_{SG2} of the CS (Figure 1(b)). Figure 1(d) shows the plot of dI_{CS}/dV_{SG2} as functions of the side gate voltage V_{SG2} and the source-drain bias voltage V_{DCS} on the CS. We observed two transition lines between the (0, 1) region and the (0, 2) region; the left and right lines in the Fig. 1(d) correspond to the lower and higher energy Γ valley on the conduction band in the right QD of the DQD in Fig. 1(a), respectively. When V_{DCS} is higher than 3.5 mV, the right side line appears because of the increase in the excitation rate Γ_3 of electrons from the lower energy valley to the higher energy valley (Figure 1(c)). This excitation is ascribed to the dissipated energy generated by the electrons which transport through the CS. We obtained the valley splitting $E_{VS} \approx 0.33$ meV.

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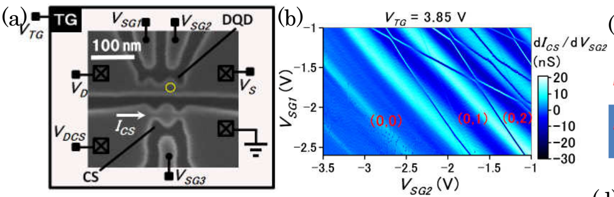
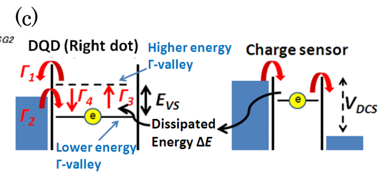
[1] M. A. Eriksson *et al.*, Quantum Inf. Process. **3**, 133 (2004).





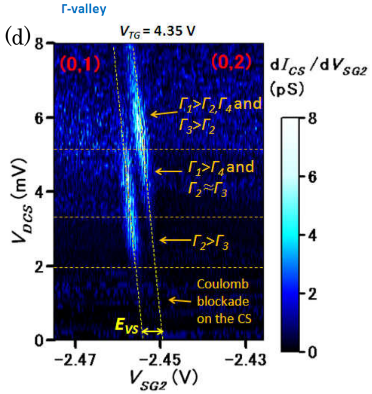


Figure 1: (a) Scanning electron microscope image of the device and schematic measurement setups.
(b) Transconductance dI_{CS}/dV_{SG2} of a CS as functions of V_{SG1} and V_{SG2}. *n* and *m* in (*n*, *m*) indicate the number of electrons confined in the left and right QD. V_{TG} = 3.85 V, V_D = 602 mV, V_S = 600 mV, V_{DCS} = 13 mV, and V_{SG3} = 0 V.
(c) Schematic electrochemical potential diagrams for the right dot and the CS. Γ_1 and Γ_2 are unloading and loading rate of the electrons between the right dot and the right lead, and Γ_3 and Γ_4 are the excitation and relaxation rate of electrons between two lowest valleys on the conduction band in the right QD, respectively. (d) Transconductance dI_{CS}/dV_{SG2} of a CS as functions of V_{SG2} and V_{DCS}. V_{TG} = 4.35 V, $V_D = V_S$ = 600 mV, V_{SG1} = -2.49 V, and V_{SG3} = -155 mV.