Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.406-407

G-3-4

Real-time observation of charge state transitions in a double quantum dot

T. Hayashi[1], T. Fujisawa[1, 2], R. Tomita[2] and Y. Hirayama[1,3]

[1]*NTT Basic Research Laboratories, 3-1, NTT Corporation, 3-1 Monrinosato-Wakamiya, Atsugi 243-0198, Japan*
[2]*Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan*
[3]*SORST-JST, Kawaguchi-shi, Saitama 331-0012, Japan*
E-mail: toshiaki@nttbrl.jp, TEL: 046-240-3447, FAX: 046-240-4723

1. Introduction

The electronic charge is a fundamental quantum which could be useful for quantum information processing because modern electronics allows us to control and measure charge at the level of single electrons. In the effort toward building up semiconductor charge qubits, coherent manipulation of a single electron in a double quantum dot (QD) has been recently demonstrated, in which the charge states were determined from ensemble measurements of electric current I_{QD} passing through the double QD [1]. For further development, single shot readout of individual charge qubits is desired. Therefore, as a first step, we have studied time-resolved single charge detection in a double QD by monitoring the time evolution of the electric current I_{QPC} through a quantum point contact (QPC).

2. Experiment

The device is fabricated from a AlGaAs/GaAs single heterostructure as shown in Fig. 1(a). A current path is defined by the etched trenches and divided into two channels by applying gate voltage V_{ISO}, both of which have independent Ohmic contacts. A lateral double QD was formed in the upper channel by applying negative gate voltages V_L, P_L, V_C, P_R and V_R, and the lower channel was used for a QPC. The QPC is coupled to the two QDs via the Coulomb interaction, where the coupling to the left QD is stronger than to the right QD because of the difference in distance (see Fig. 2(a)). Therefore the current through the QPC I_{QPC} depends on the charge state of the double QD. In this experiment, the source-drain bias voltage V_{QPC} for the QPC was set at 1 mV, and I_{QPC} was measured with a conventional current meter. To obtain the maximum sensitivity, the gate voltage V_l for the QPC was tuned so that the conductance of the QPC is about a half of $2e^2/h$. As shown in Fig. 1(b), the derivative of the time-averaged current $d\langle I_{QPC}\rangle/dV_R$ clearly shows a honeycomb structure which is a domain structure of the charge states of the double QD [2, 3]. It suggests that the noninvasive measurements with the QPC make it possible to determine the charge states of the double QD even if I_{QD} was negligibly small.

Next, we performed time-resolved charge detection for the double QD with an oscilloscope. Fig. 2(b) shows a schematic viewgraph of the stability diagram. Although the double QD we used for this work does not reach to the few-electrons regime, we can define (m, n) = (0, 0), (1, 0), (0, 1) and (1, 1) states, considering only m and n excess electrons in the left and right QD respectively. For example, the triple point E represents a condition where three charge states (0, 0), (1, 0) and (0, 1) are degenerate. The charge detection can clearly resolve those three charge states. In Fig. 2(d), the spectrum of I_{QPC} shows step-like features, and the histogram of I_{QPC} verifies that there are three levels. The highest current level corresponds to the (0, 0) state since there is no excess Coulomb interaction to reduce the current. The transitions between (0, 0) and (1, 0) and the transitions between (1, 0) and (0, 1) are clearly observed. By performing statistical analysis [4], we estimated the transition rates to be of the order of milliseconds. Direct transition between (0, 0) and (0, 1) are almost absent from the graph, reflecting the right tunnel barrier being much thicker than the other tunnel barriers in this measurement. Similarly, other related transitions are seen in Fig. 2(c) and 2(e).

In order to demonstrate single-shot readout of a charge qubit, the measurement time τ_{meas} has to be made shorter than the charge relaxation time τ_{relax}. According to the previous study [1], electron phonon coupling determines τ_{relax} ~10 ns when the tunneling coupling is strong enough to induce coherent oscillations. This is much shorter than the present result of τ_{meas} ~200 μs, which is determined from the rise time of I_{QPC} (see Fig. 2(f)). This large gap can be overcome by improving current measurement electronics and by dynamically controlling the relaxation time with gate voltages.

3. Summary

We performed real-time observation of single charge transitions in a double quantum dot by monitoring the electric current passing through the quantum point contact. This charge detection is a great advance toward single-shot readout of charge qubits.

Acknowledgements
This work was partly supported by a Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science.

References

[1] T. Hayashi *et al.*, PRL**91**, 226804 (2003).
[2] A.C. Johnson *et al.*, cond-mat/0410679.
[3] J. M. Elzerman *et al.*, PRB**67,** 161308(R) (2005).
[4] T. Fujisawa *et a*l., APL**77**, 543 (2000).

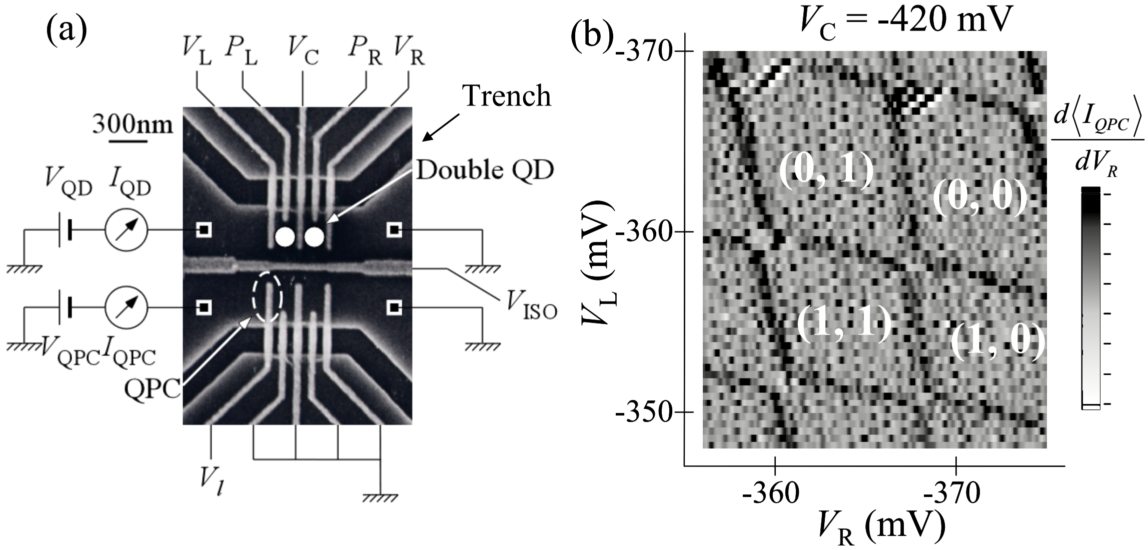

Fig. 1: (a) SEM image of the device and schematic measurement set-up. (b) Differential current passing through the quantum point contact d<I_{QPC}>/dV_R as a function of the left and right gate voltages. It corresponds to a charge stability diagram of the double quantum dot.

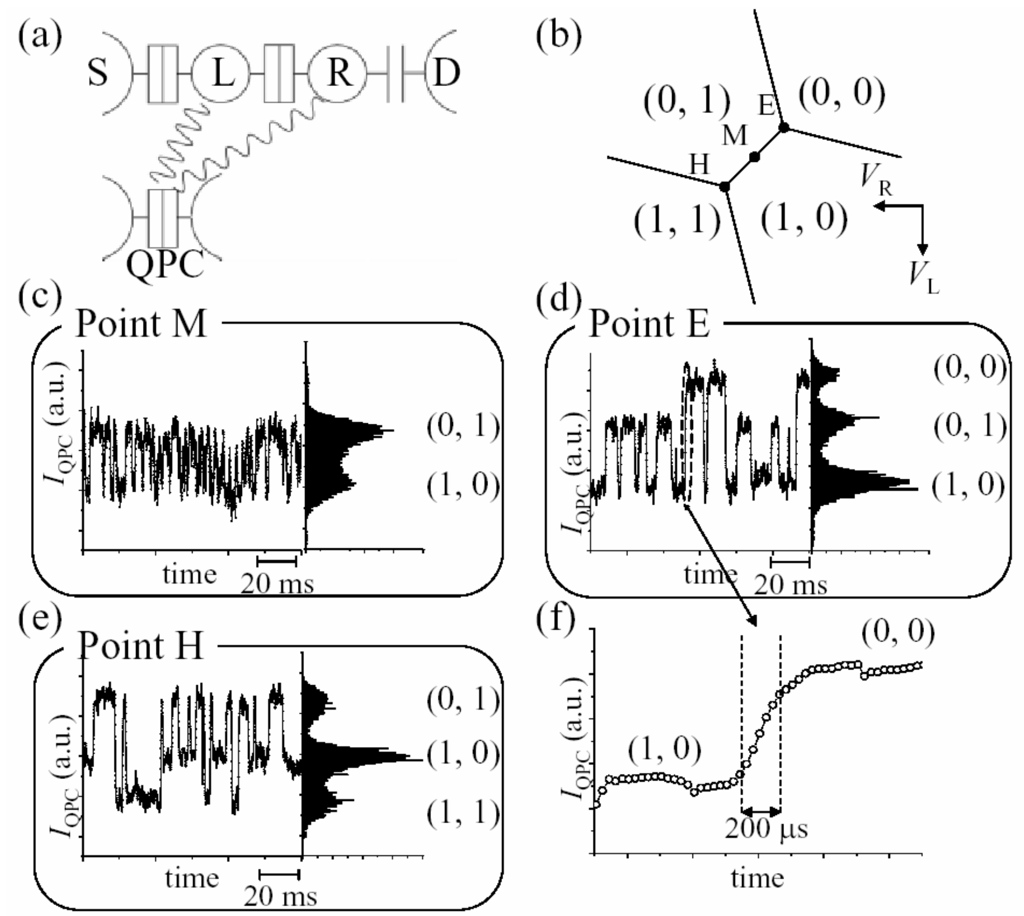

Fig. 2: (a) Schematic electric circuit, (b) Schematic charge stability diagram, (c)-(e) Currents through the quantum point contact as a function of time and their histograms at Point M, E and H, (f) Magnified graph of (d).