Gate-voltage dependence of inter dot coupling and Aharanov-Bohm oscillation in laterally coupled vertical double dot

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Artificial molecules, manifested in double quantum dot systems, are ideal for the investigation of controlled interaction and entanglement of electrons and, as a consequence, serve as a potential candidate for the implementation of quantum computing[1]. Unlike real molecules, double dots provide, in principal, for the independent manipulation of dot electron numbers and inter-dot coupling. We have devised a parallel double dot structure which combines the sensitive electron number control inherent in vertical quantum dots, with the metal gate modulation of the lateral coupling between the dots. This allows us to investigate two distinct quantum processes: (1) the tunnel barrier dependence of molecular bonding between the two "atoms," and (2) the Aharanov-Bohm oscillations produced by threading a magnetic field through the area enclosed between the two current paths which split into the left and the right dot[2-5].

Our device, Fig. 1(a), consists of two laterally coupled vertical dots with four split gates. Two of the gates (side gates) are used to independently tune the numbers of electrons in the two dots. The remaining two gates are used to tune the inter-dot tunnel coupling. Current flows from the source (substrate) to the drain (top metal contact) through the two dots, Fig. 1(b).

In Fig. 2 we show the current oscillation (Coulomb oscillations) as a function of the two side gate voltages at center gate voltages $V_{gcenter}$=-2.4 V, Fig. 2(a), and $V_{gcenter}$=-2.0 V, Fig. 2(b). The black dots denote the peaks of the Coulomb oscillations. Numerous anti-crossings are evident. The charging energies of the two dots, as determined by non-linear transport measurements, are 1 meV. Using this to establish the gate-dot capacitances, we find, in the weak coupling case, Fig. 2(a), that the anti-crossing energies range from 0.4 meV down to essentially 0 meV. This variation exhibits the eigenfunction dependence of the tunnel matrix elements. Compared to the weak tunnel coupling regime, the anti-crossings increase systematically when we increase the center gate voltage to –2.0 V, Fig. 2(b). The tunnel coupling is very sensitive to $V_{gcenter}$. It also shows a dependence on side gate voltage (note weakness of coupling when V_{gside1}>-1.3 V). In the strong coupling case (Fig. .2(b), for V_{gside1}<-1.3 V) the anti-crossings nearly vanish and the two dots appear to have merged. This is supplemented by the observation that the charging energy drops to 0.4 meV, about half that of the single dots in Fig. 2(a).

Fig. 3 exhibits the dependence on a magnetic field, applied parallel to the plane of the two dots, of the current at the crossing point of two Coulomb oscillations (for a different device) in the weak coupling regime. Oscillations with a period of about 0.6 T are observed. This value agrees with our estimate of the area enclosed by the paths which go through the two dots (1.2×10^{-14} m^2). We have not succeeded in observing a dependence of the AB oscillations on the singlet-triplet nature of the double dot ground state[3,4].

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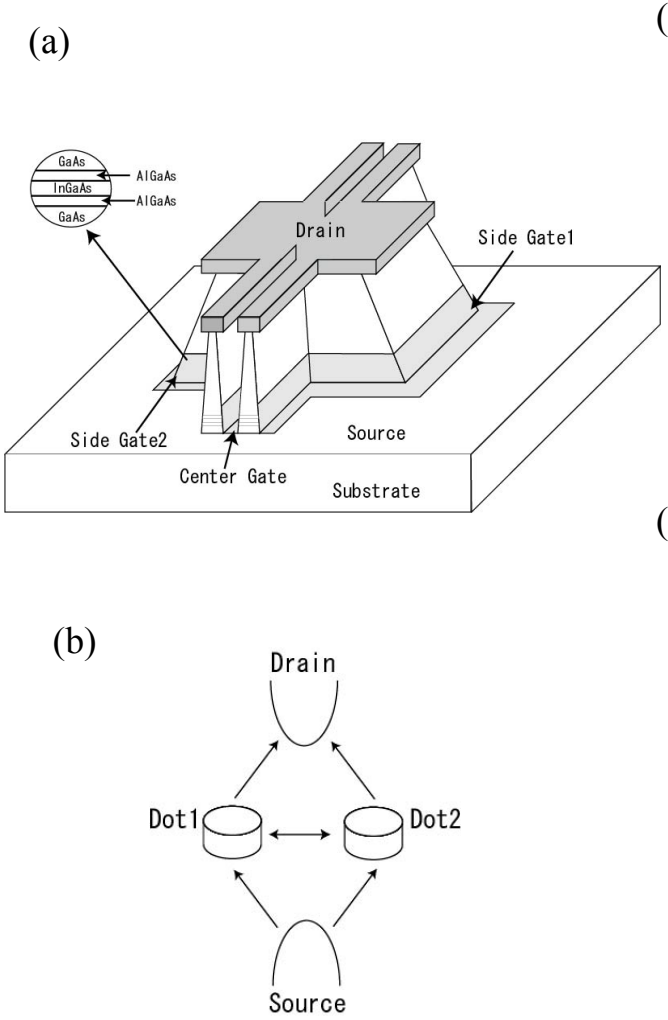

Fig. 1(a)Structure of our double quantum dot. The top and bottom contacts serve as source and drain electrodes. Current flows in the vertical direction through the two dots connected in parallel. Two side gates are used to tune the number of electrons in each dot, and two center gates are used to tune the tunnel coupling between the two dots. (b)Schematic representation of a double dot connected to source and drain. The current flows from the drain to source via the double dot.

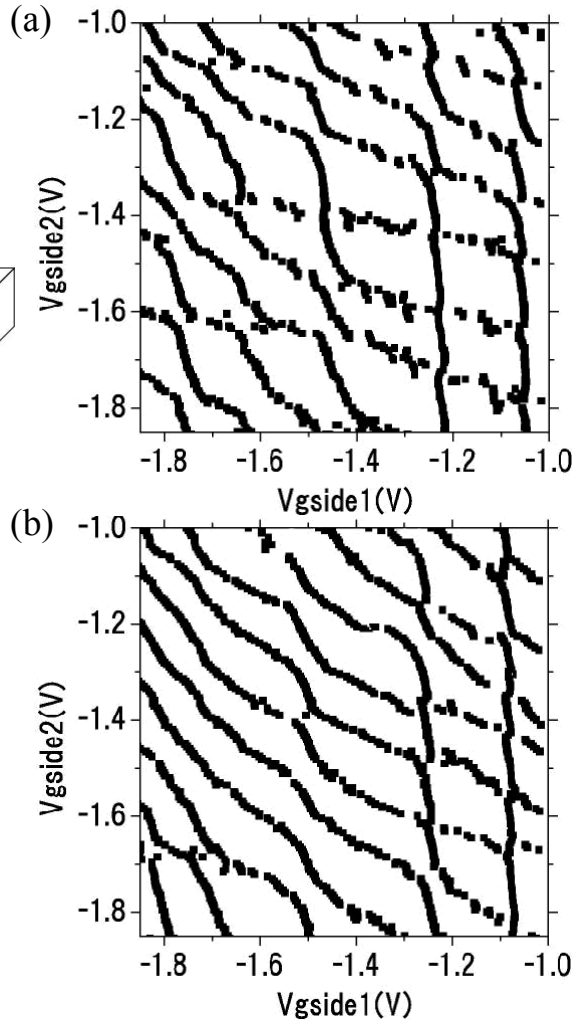

Fig. 2 Charging diagram in the plane of two side gate voltages (V_{gside1} and V_{gside2}) obtained for different center gate voltages (a) $V_{gcenter}$=-2.4V, (b) $V_{gcenter}$=-2.0V. Closed dots indicate the Coulomb peak positions.

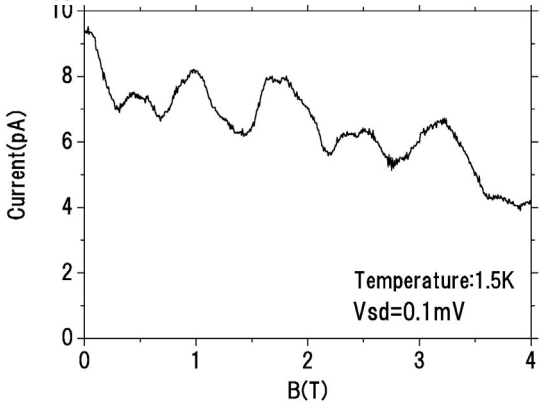

Fig. 3 Magnetic field dependence of current.