Non-Invasive Detection of the Ionic and Covalent Charge States of an Isolated Double Dot System.

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Semiconductor quantum dots have been proposed as potential candidates for qubits in quantum computation. In particular, double quantum dots could act as spin or charge qubits. In the former case the system represents two entangled qubits. In the latter case, the position of charge on the double dot system determines the state of the qubit [1]. By isolating such a system from the surrounding 2deg leads decoherence due to electron-electron scattering can be reduced. For a quantum computer to be based on such qubits it will, therefore be important to measure the state of such an isolated system. Here we use the change in the conductance of a quantum point contact (QPC) [2] to measure the charge state of two quantum dots coupled via a controllable tunnel barrier. The double dot system is produced by applying voltages to gates fabricated on a GaAs/AlGaAs heterostructure using electron-beam lithography (figure 1). Gates 1-4 define the double dot and gates 4 and 5 define a QPC detector. Gate 2 allows the tunnel barrier between the dots to be tuned independently. When biased in the tunneling regime, the conductance of the detector shows steps each time an electron enters or leaves the double dot or moves between the dots. Figure 2 shows the positions of these steps as a function of the voltages applied to gates 1 and 3. We can identify 4 distinct regimes, labelled A-D that show the evolution of the system from being open to the surrounding 2deg leads to being isolated from them. In the region labelled A we observe the characteristic honeycomb lattice, the boundaries of which correspond to the electron number on the left or right dot changing by 1 due to the exchange of an electron with the surrounding 2deg reservoirs. In region B the barrier between the left hand dot and the left lead is so high that electrons can only enter or leave the dots via the right hand dot. This gives rise to a series of lines with the same period as region A, but a gradient pointing in the opposite direction. These lines represent an electron leaving the left hand dot via the right hand dot. In region C the period between the lines has doubled and the gradient is now 45 degrees to the axes. In this region the dots are totally isolated from the reservoirs and each line represents the transfer of a single electron between the dots. Figure 3 depicts schematically the situation in regions A-C. We suggest that the region labelled D corresponds to the transfer of an electron between the left dot and a charge trap in the vicinity of the dots, which may be due to an impurity in the GaAs/AlGaAs wafer. Indeed, in other regions (not shown) we see evidence of electron transfer between the right hand dot and a charge trap.

Closer inspection of the detector signal, when an electron moves between the two dots in region C, reveals the presence of a double step as the gate voltage is swept across the line (inset to figure 4). Such a feature is not observed in region D. We speculate that this feature is due to tunneling via symmetric and antisymmetric states of the molecular wavefunction which forms when the dots are strongly coupled. Previous conductance measurements through coupled dots have also revealed evidence of a molecular state [3]. Our measurements represent the first observation of a molecular state in an isolated double dot. The separation of these steps in a perpendicular B-field (figure 4) shows behaviour consistent with the reduced overlap of the wavefunctions as the electrons become more localised in the dots.

[1] D Loss and DP Vincenzo, Phys. Rev. A 57, 120 (1998).
[2] M Field et al. Phys. Rev. Lett. 70, 1311 (1993).
[3] AW Holleitner, CR Decker, H Qin, K Eberl and RH Blick, Phys. Rev. Lett. 87, 256802 (2001).

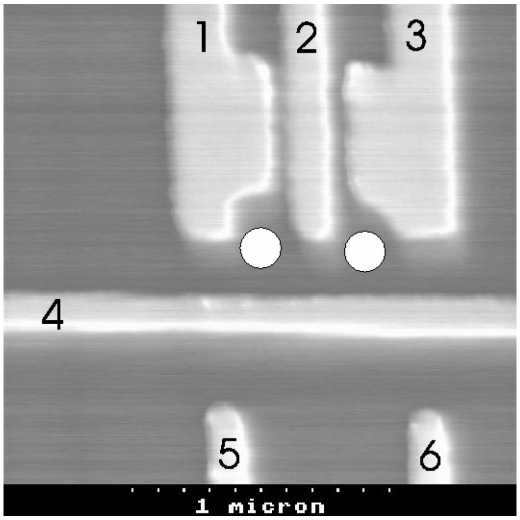

Figure 1. SEM image of the device. White circles represent the positions of the dots.

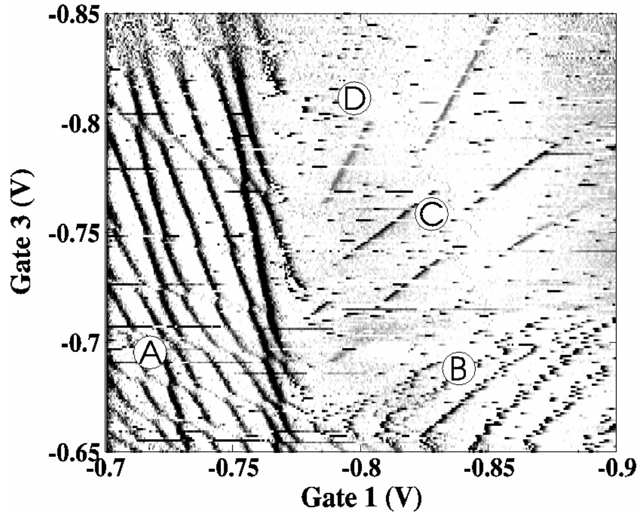

Figure 2. Plot showing the conductance steps (black lines) as a function of gate voltage.

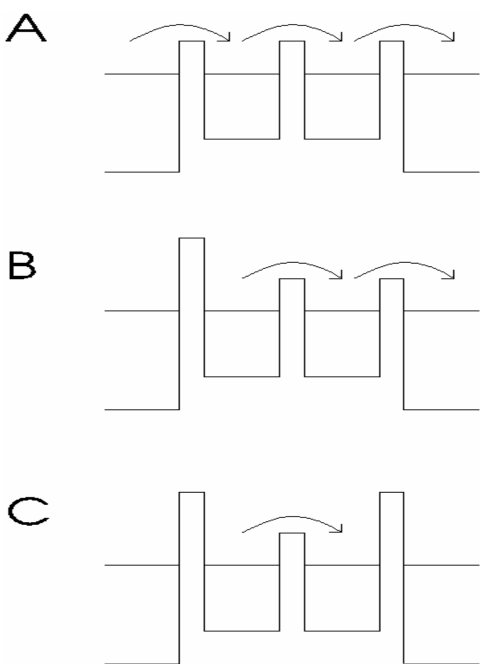

Figure 3. Schematic diagram of the double dot system showing the transitions available to the electrons.

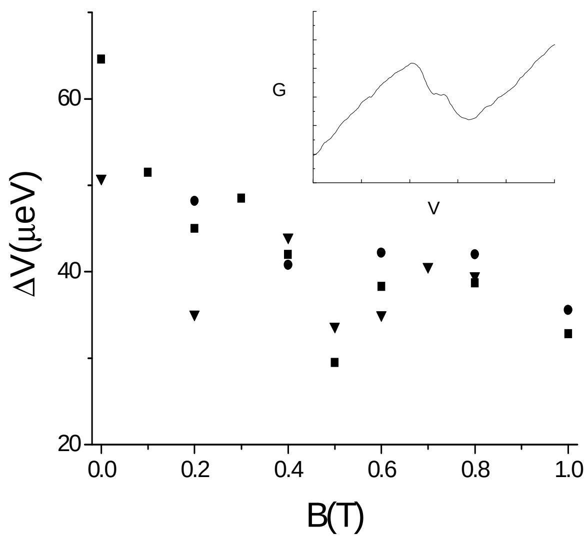

Figure 4. Spacing between double steps as a function of B-field. Different symbols represent measurements at different positions in region C. Inset shows the double step in the detector conductance.