Single-electron charging in InAs quantum dot observed by NC-AFM

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The quantum dot (QD) is one of the most important entities in nanotechnology and a variety of applications such as information storage devices and quantum computation are being sought. Although access to individual QDs is considered to be a key technique for those applications, it still remains challenging especially for the QDs such as self-assembled semiconductor quantum dot or nanoparticles. In this paper, we present the first successful observation of the single-electron charging in an individual InAs QD in the spectroscopic measurement with NC-AFM. The main features of the experimental results agree with a simple theory based on the semi-classical theory of he Coulomb blockade effect.
The sample structure and experimental setup is shown in Fig. 1. A two dimensional electron gas (2DEG) layer was used as a back electrode and an InP spacer layer serves as a tunneling barrier. The Δf and the dissipation signal were recorded as a function of the tip-back electrode bias voltage, V_B while the average tip-QD distance was kept constant. The typical average tip-QD distance was 20 nm and the measurements were performed at 4.5 K in vacuum. The $\Delta f - V_B$ curves (Fig. 2) show several jumps on a parabolic background. The jumps can be interpreted by a series of single-electron charging of the QD and the parabolic background accounts for a capacitive interaction between the tip and the back-electrode. The corresponding peaks appear in the dissipation signal, indicating energy dissipation in the electron tunneling process. Comparison of the experimental spectra with the model calculation will be made and possible mechanisms of the energy dissipation will also be addressed. This NC-AFM based technique has the following advantages over the usual $I - V$ spectroscopy. It does not need to attach the lead to each QD. It is also much less invasive for the quantum states in the QD because no tunneling coupling between the tip and the QD is required. In light of qubit readout in quantum computation, it is of great importance to reduce such coupling because it introduces decoherence of the qubit. NC-AFM could be an important tool for such interesting application.

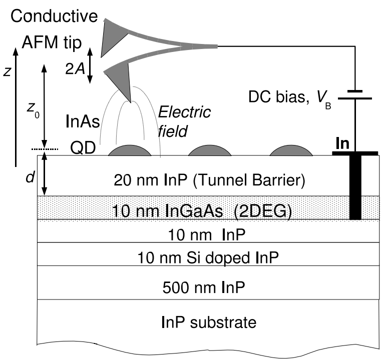

Fig. 1.

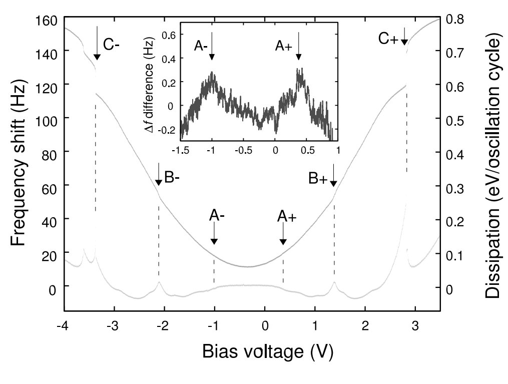

Fig. 2

[1] R. Stomp *et al.*, Phys. Rev. Lett. **94**, 056802 (2005).