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Revealing Energy Level Structure of Individual Quantum Dots by Single-Electron Sensitive Electrostatic Force Spectroscopy[1]

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The ground and excited electronic level structure of quantum systems is of fundamental importance for their optical, electric and chemical properties. Single-electron sensitive electrostatic force measurement with AFM has been demonstrated to be capable of quantitative energy level spectroscopy of individual and coupled semiconductor quantum dots (QD). In our experiments the oscillation of a dc biased AFM tip modulates the charge state of a QD. The QD is separated from a back gate via a tunnelling barrier. The resulting charge dynamics leads to measurable changes in cantilever resonance frequency and dissipation. The tip of our AFM can thus be described as a movable gate to address a QD of choice and is at the same time a charge detector with single electron sensitivity. Key to the experimental implementation is that the QD-back electrode tunnelling barrier is engineered to have a QD-back electrode tunnelling rate similar to the AFM cantilever mechanical resonance frequency. Furthermore, one needs to correct for the frequency dependent phase transfer function to obtain 'true' dissipation values. The changes in dissipation and frequency measured by AFM are quantitatively described by the back-action of the single electron on the capacitive coupled AFM tip. In particular, we find that the ratio of the measured frequency shift to dissipation directly yields the QD-back electrode tunnelling rate. This allows an experimental determination of the energy dependence of single electron tunnelling rates, yielding quantitative information on the continuous DOS of gold nanoparticles, the discrete degenerate energy levels in single and coupled InAs QDs or possibly even homo- and lumo orbitals of single molecules coupled to an electrode.

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