Inelastic Light Scattering on Few-Electron Quantum-Dot Atoms

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We investigate InAs self-assembled quantum dots (SAQD) by resonant inelastic light scattering. By applying a gate voltage between a metallic front gate and a back electrode, we can charge the quantum dots with single electrons (1 to 6). With resonant inelastic light scattering, we can directly observe the elementary electronic excitations of the few-electron quantum-dot atoms, which are formed by the SAQD. We observe excitations which we identify as transitions of electrons from the s- to the p-shell (s-p transitions) and from the p- to the d-shell (p-d transitions) of the quasiatoms. We find that the s-p transition energy *decreases* when the p-shell is filled with 1 to 4 electrons. This can be explained as an effect of Coulomb interaction, which is confirmed by calculations of the few-electron system, using exact numerical diagonalization.

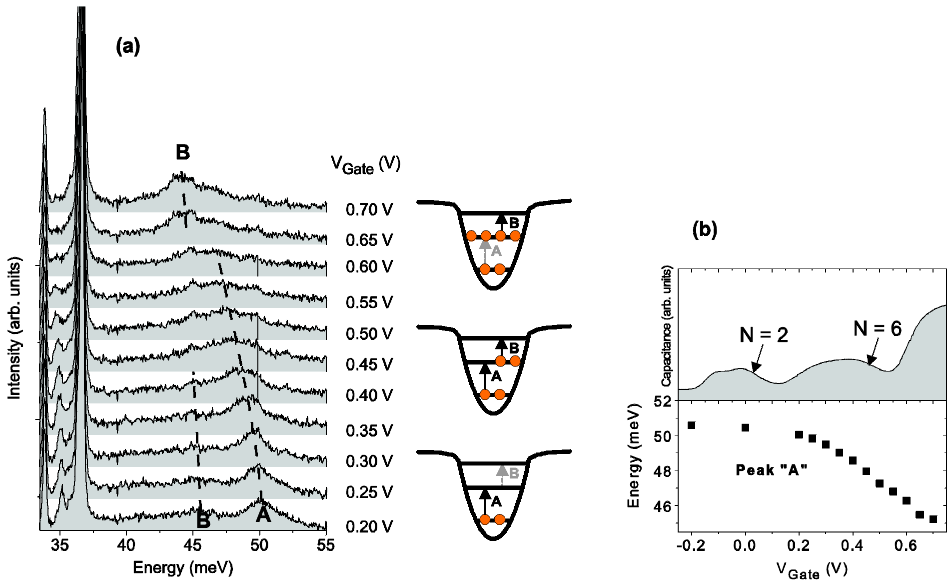

Fig. 1. (a) Polarized Raman spectra of InAs quantum dots for different gate voltages. Assignment to transitions was made by gate-voltage dependence of the excitations. (b) Capacitance spectrum of the same sample (upper curve) and experimentally determined positions of peak "A" (lower panel).

Figure 1 (a) shows, as an example, polarized Raman spectra for different gate voltages, applied between the frontgate and a back electrode. Two maxima (labeled A and B) can be observed. The schematic drawings in the center of Fig. 1 show some selected s-p and p-d transitions in a simplified single-particle picture. In the upper panel of Fig. 1 (b), a capacitance trace of the same sample is shown. One can see maxima which reflect the charging of the s- and p-shell with electrons (N is the number of electrons). In the lower panel, the experimentally determined mode positions of the peak "A" are displayed. This mode consists predominantly of s-p transitions. The mode energy decreases, when the p-shell is charged with electrons. For a quantitative analysis of the experimental findings, we have performed theoretical calculations of the exact many-body excitations of the few-electron system. The calculations were performed assuming a spherical quantum dot with finite potential height, and a two-dimensional quantum dot with parabolic external potential. For both cases, the charging of the p-shell with electrons leads to a decrease in energy of the lowest-energy excited states, when the total spin of the system is conserved, which is the case for polarized Raman spectra. This confirmes our experimental findings as an effect of electron-electron Coulomb interaction.