Fine structure of hole states in a self-assembled quantum dot

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In this contribution we present a theoretical study of the fine structure of hole states in a single InGaAs quantum dot. We investigate the role of subband mixing in the magnetic field dependence of the hole states. We show that the Fock-Darwin model with Zeeman splitting fails to describe the hole p-shell, giving incorrect state ordering with respect to the spin (see figure 1), while the correct structure can be reproduced by an effective Hamiltonian that accounts for an interplay of Zeeman and spin-orbit couplings. We calculate the influence of axial symmetry breaking on the magnetic field dependence of the carrier states. Finally, we compare the magnitude of spin-splitting obtained from various $\boldsymbol{k}\cdot\boldsymbol{p}$ approaches and we show that the 8 and 14 band $\boldsymbol{k}\cdot\boldsymbol{p}$ models give very similar results.

Our modeling is based on the compilation of several methods: electron and hole states are calculated using 8-band and 14-band $\boldsymbol{k}\cdot\boldsymbol{p}$. The strain field is accounted for in terms of the continuous elasticity method. We include piezoelectric field up to the 2nd order in strain tensor elements [1]. We take into account non-uniform InGaAs distribution in the dots according to the trumpet-shape composition [2]. Magnetic field is incorporated via gauge invariance theory [3]. Recently, the spectrum of excited hole states was shown to be reflected in the structure of resonances in a double QD system [4], which was successfully modeled using the k.p theory. The present results constitute an essential step towards extending that analysis to QD systems in magnetic fields.

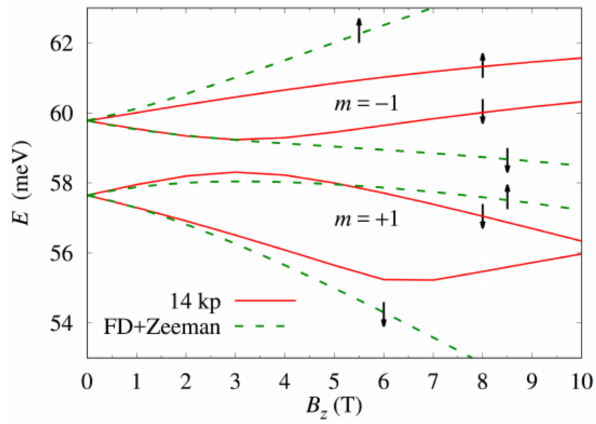

Figure 1: Spectrum of the hole p-shell states in a QD from 14-band kp calculations (red lines), compared to the simple model of Zeeman-split Fock-Darwin-like states modified by anisotropy (green dashed line), arrows show the spin orientation.

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