

Abstract

Title of doctoral thesis:

Magneto-optical studies of anisotropy of CdTe quantum dots with single cobalt ion

This work is devoted to the magneto-optical studies over the anisotropy of the system in which single magnetic ion (Co^{2+}) is embedded in a semiconductor quantum dot. In our investigation we consider two sources of the anisotropy: first, electron-hole exchange interaction within the exciton, and second, strain induced modification of magnetic ion spin structure.

Using molecular beam epitaxy we have grown two novel systems of quantum dots with single magnetic impurities: CdTe/ZnTe (telluride) quantum dots with an individual cobalt ion and CdSe/ZnSe (selenide) quantum dots with an individual manganese ion. In both cases energies of intra-ionic transitions are lower than excitonic emission energy of quantum dot. Therefore, there was serious doubt that similarly to bulk materials the observation of the excitonic luminescence from our structures will not be possible due to the efficient energy transfer from excitonic energy levels to excited levels of the ion. However, our time-resolved experiments of excitonic lifetimes proved that in case of a quantum dot with exactly one transition metal ion inside the photoluminescence quenching, caused by nonradiative recombination channel, is negligible or does not exist at all.

The work addresses also systematic comparison of optical properties of two popular quantum dots systems that do not contain magnetic impurities – telluride and selenide quantum dots. Those investigations are kind of the base and an introduction to the main part of this thesis related to much more complex phenomena occurring during spectroscopic studies of quantum dots containing a single cobalt ion.

In low-temperature measurements of the emission from telluride quantum dots with single Co^{2+} ions we observed characteristic four-fold splitting of the neutral

exciton line. Each line corresponds to the one of the possible cobalt spin projection ($\pm 3/2$ and $\pm 1/2$) onto the quantization axis of the dot. However, in contrast to previously studied CdTe quantum dots with a single Mn^{2+} ion, the intensities of the lines related to Co^{2+} spin projections $\pm 3/2$ can be significantly different from those related to the spin projections $\pm 1/2$. This is due to the fact that even in zero magnetic field the initial four-times degeneracy of the spin states of the Co^{2+} ion is removed through the spin-orbit interaction in the presence of axial strain. Crystal field with symmetry T_d induces splitting of free ion 4F state (orbital momentum $L = 3$ and spin $J = 3/2$) and as a result 4A_2 state become the ground state. Due to the orbital part of the wavefunction, such state is sensitive to further lowering of local symmetry, which is manifested by splitting of spin states.

Analysis of experimental data and corresponding theoretical simulations of the four main emission lines of the neutral exciton, in particular their evolution in an external magnetic field, allow us to determine the anisotropy axis of the Co^{2+} ion. In turn, the temperature and the excitation power dependences of the photoluminescence confirmed that the typical splitting of cobalt spin state is of the order of single meV.

Finally, through the magneto-optical studies of very weak optical transitions partially allowed by mixing of the Co^{2+} ion spin states, we have precisely and, what is important, directly determined cobalt spin states splitting. Additionally, thanks to the theoretical calculations we have obtained analytical formulas on cobalt Landé factor g_{Co} and Hamiltonian parameters D and E describing the impact of local strain in a quantum dot (the parallel and the in-plane components respectively) on the energy structure of Co^{2+} ion.