Optical probing of the carrier-mediated coupling of the spin of two Co atoms in a quantum dot

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Semiconductor heterostructures offer the possibility of controlling the interaction between distant magnetic dopants by varying the carrier density of the host. In the case of a quantum dot (QD) containing a few magnetic atoms, the spins are only coupled via a short-range exchange that could be only relevant for the first or second neighbors. The injection of a single hole spin can couple ferromagnetically the magnetic atoms.

We report here on the optical spectroscopy of the spin of two Co atoms (Co^{2+}: $3d^7$, S=3/2, L=3, I=7/2) in a QD and interacting with a single exciton [1]. Spectra of QDs containing two Co atoms are controlled by the carrier-Co exchange interaction and by the strain at the location of the magnetic atoms. A wide range of spectra can be obtained depending on the relative coupling of each atom to the confined exciton. In most of the dots, the emission is dominated by four main lines resulting from the contribution of the ground states of the two Co spins with $M_z = \pm 3$ or $M_z=0$ (Fig. 1). We obtained a comprehensive interpretation of the experimental data with a spin Hamiltonian model. We show that the two Co atoms spins can be orientated at zero magnetic field by the injection of spin polarized carriers. This induces a correlation between the two spins that is observed in the intensity distribution of the emission spectra.

The optical absorption in the phonon sideband of QDs doped with two Co reveals resonant absorptions which strongly depend on a transverse magnetic field. We show that these characteristic absorptions result from an interplay between the mixing of Co spin states induced by the presence of in-plane strain anisotropy at the magnetic atoms location and the transverse field.

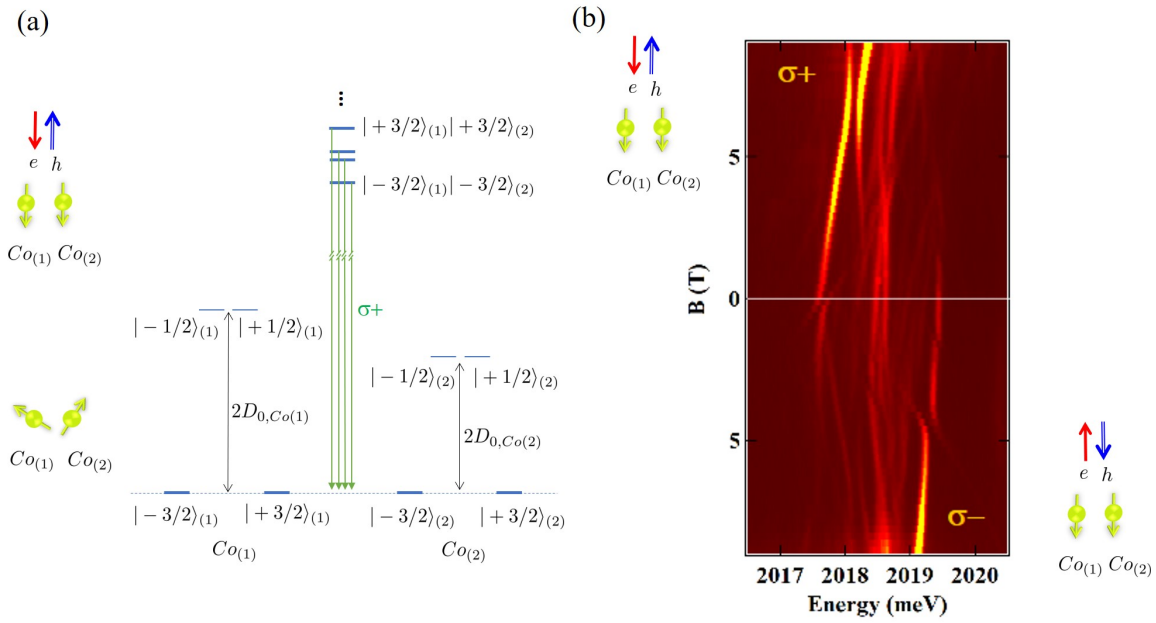

Figure 1: (a) Scheme of the energy levels at zero magnetic field of a QD containing, in the ground state, two Co atoms with $D_{0,Co(1)} > D_{0,Co(2)}$ and, in the excited state, a σ+ exciton with $I_{hCo(1)} > I_{hCo(2)}$. Only the PL transitions from the four lowest energy states with the largest occupation probability are presented. (b) Intensity map of the longitudinal magnetic field dependence of the PL of a neutral QD containing two Co atoms.

References

[1] L. Besombes, J. Kobak, W. Pacuski, Physical Review B 109, 235302 (2024).

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