Single CdSe quantum dot containing a single copper ion

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In this work, we report photoluminescence (PL) measurements performed on CdSe quantum dots (QDs) doped with copper. The PL behavior in magnetic field is consistent with the one expected for a QD with a single Cu ion in a d^9 configuration. Our results underline the possibility of employing Cu as magnetic dopants in II-VI semiconductors.

Self-assembled CdSe/ZnSe QDs were grown by molecular beam epitaxy. First, a ZnSe barrier layer is grown on 100-GaAs substrate and is followed by 3 monolayers of CdSe grown by alternating opening of Cd and Se effusion cells for 5 seconds at 280C. Simultaneously to the Cd flux the copper effusion cell has been opened for 5 seconds. Its flux is characterized by the beam equivalent pressure being of the order of 10^{-9} – 10^{-8} torr depending on the sample. The quantum dots formation process is induced by the Se-covering at low temperature and its subsequent thermal desorption. The QDs are finally capped with 50nm ZnSe barrier layer.

The PL was measured at 5 K in magnetic fields up to 10 T in Faraday configuration in two circular polarizations. The measurements were carried out in the system with a spatial resolution of the order of 1 micrometre allowing for investigations of individual QD.

In order to distinguish the CdSe dots with no copper ions from those containing the dopants we searched for appearance of the line splitting in the absence of the magnetic field, the splitting being the result of copper–exciton exchange sp-d interaction combined with the anisotropic electron-hole exchange interaction. The PL dependence on the magnetic field is then compared to calculations within a model based on the following Hamiltonian:

$$\hat{H} = \hat{H}_{Cu-e} + \hat{H}_{Cu-h} + \hat{H}_{e-h} + \hat{H}_{Zeeman} + \gamma B^2 \quad (1)$$

where the first two terms describe the s-d and p-d exchange interaction between the Cu^{2+} ion and the carriers, while the third term describes the electron-hole exchange interaction (both the isotropic and anisotropic one, the latter causing a mixing of the two spin states of the bright exciton. The last two terms describe the interaction of carriers and the ion with the field. Comparison between the measured and calculated PL dependence on magnetic field allows to conclude that the investigated QD indeed contains a single Cu ion with a spin ½ resulting from the 9 electrons occupying the ion d shell. The anticrossings observed at ~5 T are due to a compensation of the exchange field by the external one, whereupon the anisotropic exchange splitting is resolved.

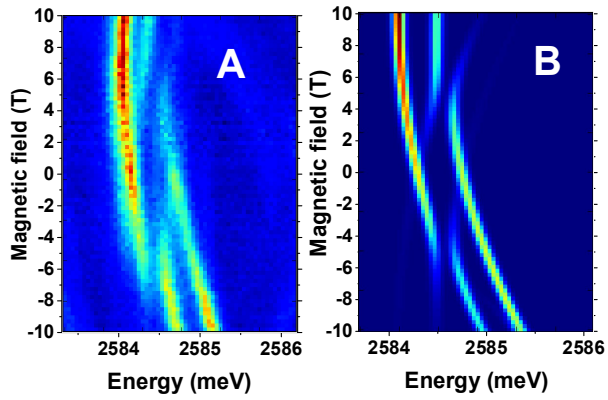

Figure 1. Magnetic field dependence of the μ-PL spectra of a CdSe QD doped with a single Cu ion (A - experiment, B - calculation). Positive/negative fields correspond to $\sigma_+/\sigma-$ PL detection polarizations.

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