Growth by MBE and magneto-photoluminescence of single quantum dots $In_{0.4}Al_{0.45}Ga_{0.15}As$:Mn / $Al_{0.75}Ga_{0.25}As$ doped with single Mn impurity

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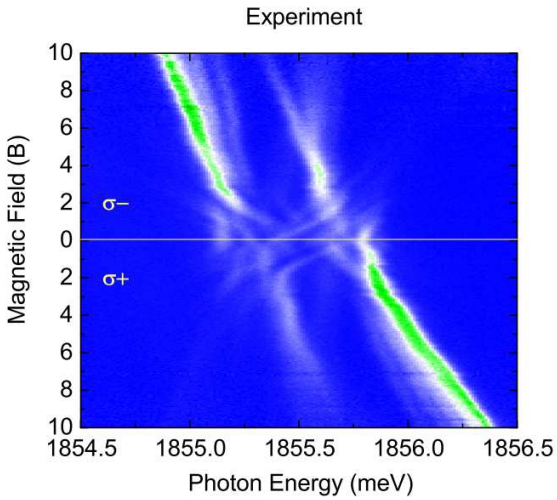
Doping of single quantum dots (QD) with single magnetic impurity atom, as InAlGaAs:Mn/AlGaAs QDs reported here, offers a sensitive probe of our understanding of QDs formation, excitons radiative recombination and exchange interactions in QDs. Here we report on magnetospectroscopic measurements of Mn-doped quaternary $In_{0.4}Al_{0.45}Ga_{0.15}As/Al_{0.75}Ga_{0.25}As$ QDs which revealed exciton interaction with magnetic moment of single Mn impurity in QD. The emission wavelength of QDs studied is around 700 nm, which is close to the shortest wavelengths possible in III-As material system.

Introducing single Mn impurity atom into QDs emitting strong narrow spectral lines of single QD is technologically a demanding task. It required two stages of careful optimization of samples growth by MBE. First, to receive strong single QD emission from self-arranged Stranski-Krastanov (S-K) 3D islands, a careful geometrical conditions of 3D islands lateral arrangement had to be fulfilled, which allowed for an enhanced emission from some 3D S-K islands, appeared as single QD. The conditions of transfer of excitation (photo-carriers) to some QDs had to be optimized. Second step of optimization was a careful Mn molecular flux doping, which assured that an experimentally significant fraction of single QDs were doped with single Mn atom. The optimized probability of finding single Mn atom doped single QD was nevertheless rather low, at about 0.1-1% of single QD emission lines observed in micro-photoluminescence, which was similar to the effectiveness of Mn doping reported by Kudelski [1] or Krebs [2] in InAs:Mn/GaAs QDs. The range of Mn composition which allowed for optically effective Mn doping spanned over a factor of 1-2 only. Too high Mn doping resulted in a decrease of radiative recombination, while lower doping was not enough to find single QD doped with Mn.

The presence of single Mn atom in single QD was recognized from magneto--spectroscopic studies as a splitting of exciton lines to several components, which showed a characteristic dependence on magnetic field - Figure. This dependence could be calculated within Kudelski *et al*. model [1] including a ferromagnetic p-d exchange coupling between Mn+hole complex and heavy hole in InAlGaAs QD. Parameters of model calculations were adjusted for a case of higher bandgap InAlGaAs material of QD and lower hydrostatic stress in low lattice mismatch (~3%) QD system studied comparing to InAs/GaAs (misfit ~7%) [1,2]. The anisotropy of the Mn+hole complex in quaternary InAlGaAs system is comparable to that in previously studied InAs/GaAs QDs [1,2], so it seems to be not much influenced by lowered stress in InAlGaAs QDs.



[1] A. Kudelski, A. Lemaître, A. Miard, P. Voisin, T. C. M. Graham, R. J. Warburton, and O. Krebs, *Phys. Rev. Lett.* **99**, 247209 (2007)
[2] O. Krebs, E. Benjamin, and A. Lemaître, *Phys. Rev. B* **80**, 165315 (2009)