Spin properties of the indirect exciton in indirect band-gap (In,Al)As/AlAs quantum dot ensembles

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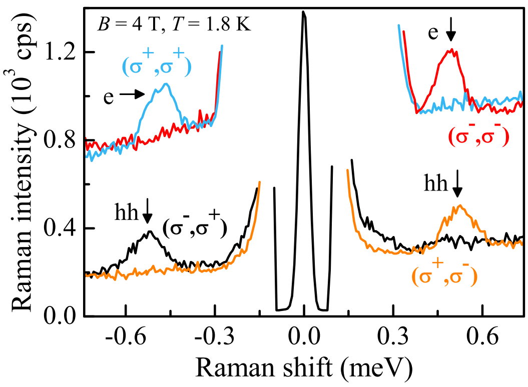
While semiconductor quantum dots (QDs) have been established as efficient light emitters and detectors in optoelectronics, other applications are only prospective so far. Particular examples are implementations in spin electronics and quantum information technologies. For these purposes, the QDs are typically loaded with resident carriers whose spins are well protected from relaxation by the three-dimensional confinement. In this context, exciton complexes are often used for spin manipulation, but are considered as less perspective as information carriers. This reservation is primarily related to the limited exciton lifetime of about a nanosecond, being too short to provide sufficient coherent manipulation for quantum information. This situation may change if the exciton lifetime could be extended significantly.

An appealing possibility is the realization of QDs with a band gap which is indirect in real or momentum space. We focus on self-assembled (In,Al)As/AlAs QDs, for which dependent on the dot size a crossover of the lowest conduction band states between the Γ- and X-valley occurs, reflected by the lifetime of the corresponding exciton: this exciton is formed by a Γ-valley heavy-hole and an electron contributed by the Γ- and X-valley, whereby both carriers are located within the QD. If the Γ- and X-electron states become admixed, the lifetime of that exciton can be as long as hundreds of μs [1], which may allow for sufficient manipulation within this time span.



We report on spin properties of the indirect exciton in undoped (In,Al)As/AlAs quantum dots studied by time-resolved photoluminescence and resonant spin-flip Raman scattering (SFRS). The SFRS is used to characterize the Γ-X-state mixing and, as shown in the figure, it allows for initializing as well as orienting the spins of the electron (e), heavy hole (hh), and, in particular, indirect exciton with coherent manipulation efficiencies of up to 20 % [2]. Besides a long and thermally robust spin relaxation time T_1 of up to 200 μs at an external magnetic field of $B = 4$ T [3], we have recently found a high optical orientation degree for the indirect exciton under quasi-resonant excitation at low fields in the mT-range. It ranges around 80 % at 50 mT depending strongly on the excitation and detection energies as well as optical excitation density. Furthermore, the temporal evolution of the circular polarization degree of the photoluminescence changes its sign in the μs-range thus hinting at dark and bright indirect excitons contributing by their different spin dynamics.

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[2] J. Debus, T. S. Shamirzaev, D. Dunker et al., *Phys. Rev. B* **90**, 125431 (2014).
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