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 or detectors in optoelectronics, other applications are only perspective so far. A particular example in this respect is their implementation in spin electronics or quantum information technology. For that purpose, the QDs are typically loaded with resident carriers whose spins are rather well protected from relaxation by the three-dimensional confinement. In this context, exciton complexes have been used up to now for manipulation of the spin of resident carriers, but are considered as less prospective as information carriers. This reservation is primarily related to their limited lifetime in the order of a nanosecond, which would most likely not allow enough coherent manipulations, either by microwave or optical techniques, to be of interest for quantum information. This situation may change if the exciton lifetime could be extended significantly.

Interesting, but technologically challenging in this respect is the placement of QDs in photonic crystals by which their radiative decay could be prevented. Another possibility is the realization of QDs with a band gap which is indirect in either real or momentum space or both. Here, we focus on self-assembled (In,Al)As/AlAs QDs, for which dependent on the dot size a crossover between the conduction-band ground states of the Γ-valley and X-valley occurs, as reflected by the lifetime of the lowest-energy exciton. This exciton is formed by a Γ-valley heavy-hole and a mixed electron contributed by the Γ- and X-valley, whereby both carriers are located within the QD. Besides the advantage of this indirect exciton to be optically addressable, its lifetime lasts hundreds of μs [1], which may be sufficient for a large number of coherent manipulations in this time range.

We report on spin properties of the indirect exciton in undoped (In,Al)As/AlAs quantum dots under influence of magnetic fields, studied by stationary and time-resolved photoluminescence. The application of high fields ($B \leq 10$ T) allows us to identify the dominant role of one-acoustic-phonon processes in the exciton spin relaxation [2]. The longitudinal spin relaxation time follows a B^{-5}-dependence from, e.g., 200 μs at 4 T to 1 μs at 10 T for a temperature of 1.8 K, and is rather robust against temperature changes. An approach for modeling the circular polarization of the photoluminescence induced by magnetic field is suggested for an ensemble of excitons with a considerable dispersion of lifetimes. At low fields in the mT-range, a high optical orientation degree for the indirect exciton is found under quasi-resonant excitation. It ranges around 80% at 50 mT depending strongly on the excitation and detection energies. Moreover, it sensitively responses to the optical excitation density as well as even weak variations in the magnetic field strength. Electron-nuclear hyperfine and exciton-exchange interactions are discussed for the low-field spin properties of the indirect exciton.

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