Spin-flip Raman scattering in type-I quantum dots with direct and indirect band structure

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The spin structure of neutral and negatively charged excitons and fundamental spin interactions of carriers confined in InAs-based quantum dots (QDs) are characterized by means of the resonant spin-flip Raman scattering (SFRS). The SFRS spectroscopy is a suitable optical technique to probe the characteristics of spin structures as it provides the direct measurement of the *g* factor. Hereby, both direct band-gap (In,Ga)As/GaAs and the novel indirect band-gap (In,Al)As/AlAs QDs with type-I band alignment are studied.

The spin-flip scattering processes of the electron, heavy-hole and exciton depend on the symmetry of the crystal lattice, QD potential and magnetic field confinement as well as the type and excitation state of the carrier complex. The spin-flip scattering in InAs-based QDs is shown to be frequently based on the mixing between light-hole and heavy-hole states, induced by strain and dot shape anisotropies, as well as the level mixing resulting from the coupling of a tilted magnetic field to a nonzero in-plane magnetic moment of the electron and/or heavy-hole. In singly charged (In,Ga)As/GaAs QDs a novel optical resonance excitation is observed where an incident photon excites an electron-hole pair and simultaneously the resident electron to an excited Fock-Darwin state; in this excited carrier complex the electrons mutually change their spin states thus yielding an electron-SFRS. Since strong magnetic fields, close-to-Faraday geometries, and large-diameter QDs are necessary to initiate that process, it can be compared to the quantum well phenomenon of an exciton-cyclotron resonance.
The undoped (In,Al)As/AlAs quantum dots with indirect band gap provide an indirect exciton which is formed by a Γ-point hole and an electron at the X-point, whereby both are located within the QD. These excitons have remarkable dynamical properties: their radiative recombination time and spin lifetime exceed hundreds of microseconds. By tailoring the composition profile and size of the QDs not only the exciton recombination dynamics can be controlled, but also a mixing between electron levels from direct and indirect valleys can be obtained. Due to the level mixing the indirect exciton is optically addressable, thus, its spin properties are specified by the resonant SFRS. The *g* factor tensor components of the electron, hole, and exciton indicate a high QD symmetry, where spin-orbit interaction and valence band mixing are negligible. The experimental results of the spin structure characteristics are compared to theoretical predictions.