Abstract

This thesis describes the study of spin relaxation times of magnetic ions embedded in semiconductor nanostructures. The use of semiconductor nanostructures produced from materials with different crystal lattice constants allowed to obtain samples differing in strain. The purpose of this study was to investigate the effect of the strain present in the immediate vicinity of the magnetic ion on the spin relaxation time of the manganese ion Mn^{2+} and the cobalt ion Co^{2+}. The main feature that differentiates the two ions is the value of the orbital angular momentum, which for the manganese ion Mn^{2+} is equal to zero ($L = 0$), while for the cobalt ion Co^{2+} is greater than zero ($L = 3$). For this reason, the spin-orbit interaction is much stronger for the cobalt ion, and thus the expected effect of crystal lattice strain on the spin relaxation time is stronger.

Two nanostructure systems were used in the study: (Cd, Mn)Te/(Cd, Mg)Te quantum wells, for which the level of manganese doping was about 0.25%, and single CdTe/ZnTe quantum dots with single cobalt Co^{2+} ions.

In the case of quantum wells, optically detected paramagnetic resonance (ODMR) measurements were carried out in a rotating magnetic field in a specially designed holder (antenna), providing a strong coupling with microwave radiation. The results of the measurements combined with numerical simulations allowed the determination of the value of D: the strain-induced parameter of the axial component of the crystal field of the spin Hamiltonian. The parameter D is directly related to the deformation of the quantum well through the parameter G_{11} describing the coupling strength between the spin and crystalline network. The studies were performed for a series of samples differing in

the magnesium content of the buffer layer. This way of designing the samples resulted in obtaining a specified deformation value in the quantum well's layer. Obtaining specific deformation values was indirectly confirmed based on magnetospectroscopic results and directly (for selected samples) based on X-ray diffraction results. The identification of exciton transitions associated with light and heavy holes in white light reflection spectra allowed the determination of deformation potential values in CdTe: $b = (-0.94 \pm 0.08)$ eV.

Based on the measured data, the value of the spin-lattice coupling parameter for the Mn^{2+} ion in CdTe was determined: $G_{11} = (72.2 \pm 1.9)$ neV. The obtained value of G_{11} is larger than the only one so far reported (57 ± 1.3 neV). The difference can be attributed to the different growth techniques of the samples – in this work, molecular-beam epitaxy (MBE) was used, while the studies presented in the literature used bulk samples, which were produced by the modified Bridgman method. In addition, time-resolved ODMR was used to determine spin relaxation times. The results show that in the strain range studied, the spin relaxation time of the manganese ion Mn^{2+} shortens with increasing deformation. In addition, the dependence of the spin relaxation rate on the magnetic field and temperature was determined. The obtained results are well-reproduced in a model based on kinetic equations describing a six-level system given by the spin Hamiltonian. The dominant relaxation mechanism is the one-phonon direct mechanism.

It was not possible to carry out analogous studies for cobalt Co^{2+} ions due to the photoluminescence quenching by intra-center transitions. This problem was solved by lowering the dimensionality of nanostructures. For this reason, studies of the cobalt ion were performed for self-organized CdTe/ZnTe dots. Based on the analysis of the photoluminescence spectra in a magnetic field, the values of the D parameter and the polarization transfer efficiency between the exciton and the cobalt ion were estimated. A value close to unity was obtained, which means that an average of one exciton is needed to change the value of the spin projection of the cobalt ion on the quantization axis. In addition, spin relaxation times were measured, which showed that the relaxation rate of the Co^{2+} cobalt ion is more than an order of magnitude higher than that

of the Mn^{2+} ion. Interestingly, the obtained relaxation times did not depend on the value of the parameter D. The dependence of the relaxation time on the magnetic field measured for the Co^{2+} is similar to that obtained for the manganese ion, again suggesting a direct relaxation mechanism.

In addition, the experimental challenges of measuring the spin relaxation times of magnetic ions in single quantum dots led, as part of the study, to the development of elliptical polymer microlenses made by 3D printing. These lenses allow for a degree of improvement in the extraction of light from the semiconductor structures under study and an increase of more than an order of magnitude in the distance separating the sample from the optical elements of the measurement system.