Optical spin control of a single Mn atom in a single quantum dot via the light hole exciton

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When a single Mn atom is doped into a semiconductor quantum dot (QD), new possibilities for spin control emerge. The strong exchange interaction between the exciton and the Mn spin leads to prominent features in the photolumescence spectrum, where instead of a single exciton line a set of six equidistant lines appears for a CdTe QD [1]. Due to valence band mixing previously dark excitons can become also visible in the spectrum [2]. In these QDs the uppermost valence band is considered as mostly heavy hole (HH) type. However, it is also possible to fabricate QDs where the uppermost valence band is of light hole (LH) type [3]. If a CdTe QD with a LH exciton doped with a single Mn atom is considered, the spectrum changes qualitatively and a set of twelve lines is expected [4].

In this contribution we discuss the possibility of spin control of the Mn atom via optical manipulation of the LH exciton and the signatures of the Mn spin dynamics in the signals of time-resolved optical measurements. We model a CdTe QD doped with a single Mn atom. For the exciton system we take into account the ground state without exciton, four single exciton states and one biexciton state. For circularly polarized light propagating along the growth axis, the two exciton states with spin ± 1 are bright, while the two exciton states with spin 0 are dark. In principle, when the LH exciton with an angular momentum of 1 interacts with the Mn spin, the Mn spin can flip by two, once by transferring the spin to the electron and once by spin transfer to the LH. However, because these states are off-resonant, no complete spin transfer is achieved. In the dynamical picture the spin transfer is reflected by exchange-induced Rabi oscillations of the occupations. A complete spin transfer of the Mn spin by two can be achieved by the usage of 2π pulses, which do not change the occupations of the states, but influence the coherences. For linearly polarized light propagating perpendicular to the growth axis, the exciton states with spin 0 become bright, while the other two exciton states become dark. Then by interaction of the LH exciton and the Mn spin a spin of 1 can be transferred. Using a sequence of pulses consisting of π pulses, which excite and de-excite the LH exciton, and 2π pulses, the Mn spin can be switched from a given initial state into all other eigenstates on a ps timescale [4]. When we compare this switching scheme to a previous switching scheme which includes also HH excitons [5], we find that the switching is much faster and a change of the Mn spin by one can be achieved, while the exciton system is returned to its ground state.

In a time resolved spectroscopy measurement the dynamics of the Mn spin can be followed. Because every Mn spin has its own spectral fingerprint, each switch of the Mn spin changes the position and strength of the lines appearing in the spectrum, which allows for an optical detection of the time-dependent Mn spin state.

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