Spin dynamics and magneto-optical response in charge-neutral tunnel-coupled quantum wells

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The rapidly developing field of spintronics demands new types of high-quality feasible spin manipulation systems. This and the high level of the state of the art of the solid-state-based experimental techniques make the exploration of spin dynamics and spin coherence in semiconductors particularly interesting.

In this contribution, we provide a model of the electron and hole spin dynamics in a double quantum well structure [1], considering the carrier tunneling between quantum wells, which is enhanced by an electric field. Taking into account also the presence of an in-plane or tilted magnetic field, we provide the simulation of magneto-optical experiments, like the time resolved Kerr rotation measurement, which are performed currently on such structures to probe the temporal spin dynamics.

Probing exciton spin dynamics in neutral structures is limited by recombination much faster than the actual spin dynamics. In doped structures, in turn, the initialization of resident spins is subject to the intrinsic dephasing [2] affecting the results of experiments like the resonant spin amplification measurement [3]. The search for undoped systems with long-living spins brought a proposal and first realizations of double quantum wells, in which exciton is spatially separated due to the carrier tunneling between wells [4].

In our model of such system, spin precession in the magnetic field is treated exactly, while the dissipative dynamics of the system (spin relaxation, dephasing, carrier tunneling between quantum wells, and recombination) is described in the Markov limit by the universal Lindblad superoperator in the master equation for the density matrix evolution. Moreover, we include the spin-orbit coupling effects, which give rise to the mixing of states with different angular momenta and in cosequence to the probability of spin-flip tunneling of carriers. To obtain the direct correspondence with experimentally measured quantities we employ the numerical solution for the density matrix and construct substantial dynamical variables such as spin polarization and coherences for each of QWs.

We reproduce the experimentally observed effect of the extension of the spin polarization life time caused by the charge separation, which occurs in structures of this type. Moreover, we provide a number of qualitative predictions concerning the necessary conditions for observation of this effect as well as about possible channels of its suppression. We consider also the impact of the magnetic field tilting, which results in an interesting spin polarization dynamics. Finally, we discuss the relevance of the spin-flip tunneling caused by the spin-orbit interaction for typical systems.

We find that the effect of spin polarization life time extension depends essentially on the ratio of tunneling time to direct exciton recombination time. The comparison of simulated signals with experimental data will allow for extraction of dynamical parameters, such as carrier g-factors, spin lifetime and coherence time for investigated systems.

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