Hole Spin Decoherence in Coupled Quantum Dots

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In this contribution, we analyze hole spin relaxation and pure dephasing in a coupled quantum dots (QD) system during phonon-assisted tunneling of the hole between the dots. We conjecture two distinct mechanisms contributing to spin decoherence in the external magnetic field. The first one is a "which-way" type of dephasing, studied already in the case of electron spin [1] as well as hole spin [2] in a simplified model. This effect is due the mismatch of Zeeman splittings between states localized in the QDs, leading to the emission of spin-dependent phonon wave packets and resultant loss of information by and effective "measurement" of the spin state by the phonon bath. The second one is Dyakonov-Perel-like effect due partly misaligned hole spin quantization axes in the two QDs, arising from strong g-tensor anisotropy combined with its dependence on the geometry and composition of QDs. Due to this, one can control both effects by varying orientation of the external magnetic field.

Our model consists of a hole localized in a self-assembled vertically-stacked GaInAs double QD system. Moreover, the hole is coupled to the acoustic-phonon bath via deformation potential (DP) and piezoelectric (PE) couplings as well as to electric field and an arbitrarily oriented magnetic field. In our simulation, we tune hole energies and g-tensors by varying indium concentration and geometry of QDs according to available morphological details of real coupled QDs structures. This includes variable misalignment of the QDs and deformation of the upper dot. We calculate hole wave functions and energies using the 8-band $\boldsymbol{k} \cdot \boldsymbol{p}$ theory in the envelope function approximation [3]. The dynamics of the system are then studied using a Markovian master equation in the Redfield form with hole-environment couplings evaluated from the multiband wave functions, accounting for DP and PE couplings. Numerical solution is then compared with the analytical considerations based on Weisskopf-Wigner theory of spontaneous emission adapted for the phonon bath.

In this work we analyze the effect of the two considered decoherence mechanisms. Extending our previous work on electron spin, we propose a new way of control the dephasing in case of hole spin: in-plane and out-of-plane tilt of the external magnetic field. We show that in certain systems one can, due to mismatch of the highly anisotropic g-tensors, cancel out or minimize the Zeeman splittings difference by tilting the magnetic field. Moreover, we test the Dyakonov-Perel-like effect and show that in the case of quantization axes mismatch it leads to spin relaxation even in if the "which-way" dephasing channel is eliminated.

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