Spin-orbit anisotropy and relaxation of GaAs single electron spin qubits

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In lateral quantum dots hosted in a semiconducture structure with lack of inversion symmetry the effect of Rashba (R) and Dresselhaus (D) spin-orbit (SO) interactions causes relaxation of the spin excited state, splitted in energy from the ground state due to the presence of an in plane static magnetic field. Considered together with a generic electric field fluctuation, that can come from external electrical noise or from phonons, the SO mediated spin mixture opens a spin decay channel [1]. The interplay of R and D spin-orbit coupling can result in a decay time with a striking anisotropy in the plane of the quantum well.

The study of the anisotropy in QDs has been realized looking at the hybridization between the ground and excited states with opposite spins [2]. When two different orbital states with opposite spin are tuned to a degeneracy the SO interaction causes an avoided crossing in the energy spectrum whose magnitude is twice the SO energy. This kind of experiment can be realized in quantum dots built in narrow gap semiconductors, where the SOI and the g-factor are quite high (hundreds of ueV). For GaAs-Qs, unfortunately, the SO energy will by barely visible from the anticrossing (being 10-20 ueV) and in the single electron regime, the magnetic field required to reach the hybridization region can be quite high due to its small g factor. A different approach to investigate the SO-anisotropy for single spin qubit in GaAs consists of measuring the spin excited state relaxation process as a function of the in-plane magnetic field orientation.

An experimental observation of such anisotropy in the relaxation time would be an unquestionable signature of the SO induced spin relaxation and could be used to extract information about the ratio R and D contibutions.

We measured the relaxation time (T1) for a single electron spin in a GaAs quantum dot with an all-electrical single shot readout technique [3] and found a clear 180 degree periodicity due to the interplay of R and D, as predicted by theory (see figure). Different from the theory for dots which are symmetrical in the plane, we find that the maxima in the T1 are not at a 45 degree angle respect to the [100] crystallografic direction. We speculate that this is related to the ellipticity and orientation of the single dot electrostatic confinement potential [4]. For the “magic” angle, the magnitude of the spin-orbit interaction is considerably quenched, allowing us to record an increase in T1 by one order of magnitude, reaching about 70 ms at 3 Tesla.

[1] PRL 93, 016601 (2004) ; **[2]** PRL 104, 246801 (2010), PRL 108, 166801 (2012) ;

[3] *Nature* 430, 431-435 (2004) ; **[4]** PRB 83, 245324 (2011) ;