Electric control of spin lifetimes in GaAs(111) quantum wells

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Dyakonov-Perel, Elliot-Yafet and Bir-Aronov-Pikus spin dephasing mechanisms are the main processes limiting electron spin lifetimes in III-V semiconductors. In GaAs quantum wells (QWs), the most relevant one is Dyakonov-Perel (DP): spin-orbit-interaction (SOI) induces an effective magnetic field, $\mathbf{B}_{\mathrm{SOI}}$, whose magnitude and orientation depend on the in-plane electronic wave vector, $\mathbf{k}$. Polarized spins moving with different $\mathbf{k}$'s will precess with different Larmor frequency vectors, losing the initial spin polarization of the ensemble within a few nanoseconds.

In high quality GaAs QWs, $\mathbf{B}_{\mathrm{SOI}}$ is dominated by two terms: $\mathbf{B}_{\mathrm{BIA}}$, due to the intrinsic bulk inversion asymmetry of the III-V lattice, and $\mathbf{B}_{\mathrm{SIA}}$ or Rashba term, related to a structural inversion asymmetry induced, for instance, by an electric field applied perpendicular to the QW plane, E_z. GaAs(111) QWs are specially interesting because both $\mathbf{B}_{\mathrm{BIA}}$ and $\mathbf{B}_{\mathrm{SIA}}$ are, to first order on k, always parallel to each other. As a consequence, an electric field, E_c, fulfilling the condition $\mathbf{B}_{\mathrm{BIA}} + \mathbf{B}_{\mathrm{SIA}} = 0$, will efficiently suppress spin dephasing mechanisms associated with the SOI, leading to very long spin lifetimes [1].

The high value usually required for E_c, however, is the main obstacle to reach the BIA/SIA compensation. The field reduces the spatial overlap of the electron and hole wave functions, diminishing considerably the radiative recombination rate and, consequently, the yield of the polarization-resolved photoluminescence (PL) technique normally used for probing the spin dynamics.

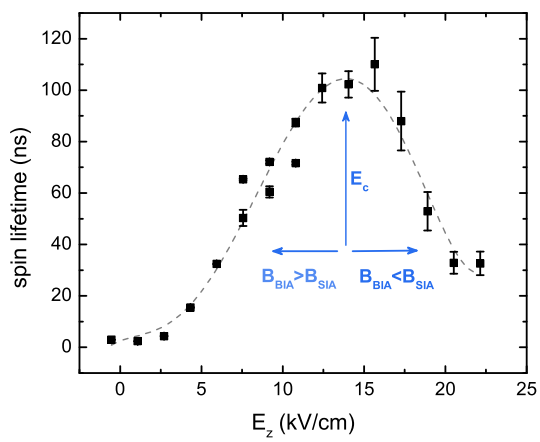

Fig. 1. Spin lifetime dependence on the electric field applied vertically to the quantum well plane.

In this contribution, we overcome this limitation by probing spins via a PL technique combining pulsed illumination and pulsed electric fields, enabling measurement of spin lifetimes in GaAs(111) QWs embedded in n-i-p diode structures over a wide range of electric fields across E_c. We show that the lifetime of optically injected, z-oriented spins initially increases with E_z, reaches a maximum, and then reduces for higher fields (cf. Fig. 1). This maximum is attributed to the transition between a BIA-dominated regime to another determined by the electrically induced SIA term: its observation provides a conclusive evidence of the SOI compensation mechanism. The long spin lifetimes around E_c, exceeding 100 ns [2], are among the highest reported for GaAs structures, making GaAs(111) QWs excellent candidates for spin-based quantum information processing.

[1] X. Cartoixà *et al.*, Phys. Rev. B. **71**, 045313 (2005).
[2] A. Hernández-Mínguez *et al.*, Phys. Rev. Lett. **109**, 266602 (2012).