Enhanced Spin Lifetime and Magnetococonductance in Wurtzite Semiconductor Nanowires

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Motivation

Experiments at UR: Au-catalyzed MBE grown GaAs/(Al_{0.36}Ga_{0.64}As) core/shell nanowires (NWs):
- pure wurtzite crystal phase
- undoped
- diameters: 20 - 500 nm
- length: 1 - 20 μm

Using time-resolved microphotoluminescence → spin relaxation τ_s of a spin state initially homogeneously polarized along the NW. Result: drastic increase of τ_s with decreasing nanowire diameter.

Theoretical approach:
- Assuming a diffusive system:
  - Investigation of D’yakonov-Perel’ spin relaxation:
    - long-lived spin states
    - time evolution of initial state prepared in the experiment
- Investigation of quasi-balistic case.
- For transport experiments: analysis of magnetococonductance → weak (anti-)localization.

The Model

The model Hamiltonian for conduction electrons in the bulk reads as

\[ H = H_0^{\text{ext}} + H_0^{\text{int}} + H_\text{D} \]

with the extrinsic (ext) and intrinsic (int) Rashba (R) and Dresselhaus (D) SOC contributions:

\[ H_0^{\text{ext}} = \alpha_R^{\text{ext}} (k_x \sigma_y - k_y \sigma_x), \]
\[ H_0^{\text{int}} = \gamma_D^{\text{int}} (k_x^2 - k_y^2), \]
\[ k_x^2 + k_y^2 \]

Without loss of generality, we assume a gate-induced homogeneous electric field along the y-axis, i.e., \( \mathbf{E} = E_y \mathbf{e}_y \).

Quantum Conductivity Correction

3D diffusive system → quantum interference between self-crossing paths leading order correction to the conductivity is given by the Cooperon:

\[ \Delta \sigma \propto \Re \left( \sum_{n,m} \chi_n \langle \sigma_i | \mathbf{Q} | \sigma_f \rangle \chi_m \right) \]

\[ \chi_0 = 1, \chi_1 = -1, \]
\[ x_i \in \{0,1\}, m_i \in \{0, \pm 1\} \]

With \( Q = k - k' \): sum of the wave vector of an electron with spin \( \sigma \) and the wave vector of an electron with spin \( \sigma' \).

Cooperon Hamiltonian is defined as \( \tilde{H}_C = (\mathbf{Q}, \mathbf{Q})^{-1} \). The triplet (T) eigenvalues determine the D’yakonov-Perel’ spin relaxation rates of the system via the relation \( \Delta \tau_s = 1 / \tau_s \).

Lateral gate: Magnetoconductivity G(B)

\[ \Delta G(B) = \frac{\sigma_0^{(1)}}{k_B} \left( \frac{1}{\sqrt{Q_s^{(1)}} + \frac{\mathbf{B}}{k_B}} \right) \]

with \( \sigma_0^{(1)} = \frac{2}{k_B} \sum_{n, \text{dominant} \sigma} \frac{\sigma_0^{(1)}}{Q_s^{(1)}} \), minimum at \( Q_s = 0 \).

References