Control of Spin Helix Symmetry in Semiconductor Quantum Wells by Crystal Orientation

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Motivation

We investigate the possibility of spin-preserving symmetries due to the interplay of Rashba (R) and Dresselhaus (D) spin-orbit coupling in n-doped zinc-blende semiconductor quantum wells. There are special cases known in 2DEGs where the effective quantum wells.

System

The analyzed system is a 2DEG confined by an electric field \( \mathbf{E} \) with the normal \( n = (n_x, n_y, n_z) \). The model for the lowest subband is given by

\[
\mathcal{H} = \frac{k^2}{2m} + \mathbf{\Omega} \cdot \mathbf{\sigma}
\]

with the SO field due to Rashba

\[
\mathbf{\Omega}_R = \alpha (k \times n)
\]

and Dresselhaus SOC

\[
\mathbf{\Omega}_D = \gamma_{D} \mathbf{\sigma} \times \mathbf{r} + \gamma_{R} \mathbf{\sigma} \times \mathbf{k}
\]

and the boundary condition \( k \cdot n = 0 \).

Spin Diffusion

Assumptions:

1. Uncorrelated disorder: \( \langle \mathbf{v} \rangle = 0 \), \( \langle \mathbf{v}(x)\mathbf{v}(y) \rangle \propto (x-y) \times \mathbf{v} \)
2. Weak disorder: \( k_l P_l \gg 1 \)

The dominant mechanism for spin relaxation in systems (III-V compounds) is D'yakonov Perel' spin relaxation

\[
\mathbf{\Delta} = \text{minimum in magnetic field}
\]

Assumptions:

1. Calculation of \( \lambda_{\alpha}(q) \) for arbitrary growth direction.
2. Finding eigenvalues \( \lambda_{\alpha}(q) \)
3. Identifying longest spin lifetimes.

For \( q_{\text{min}} \neq 0 \Rightarrow \) persistent spin HELIX.

Measurement: Weak (Anti)Localization

Magnetoeconductivity (MC) measurements allow for extracting SOC parameters. One characteristic quantity:

Minimum in the magnetic field \( B \) of the correction to static conductivity

\[
\Delta \sigma = \frac{2}{r} \frac{1}{\pi^2} \int \frac{d^2 q}{(2\pi)^2} \left( \frac{1}{\gamma_{D}^2 q_{D}^2 + \gamma_{R}^2 q_{R}^2} \right)
\]

If the MC is measured near the SU(2) symmetry => parabolas of the form \( \frac{\Delta \sigma}{\sigma} \propto \omega^{2} \) approximate the spectrum of the triplet sector of the Cooperon by three parabolas of the form

\[
\lambda_{j}/q_{j} = q_j^2 + (Q - j/2) + \Delta_{j}, \quad j \in \{0, \pm 1\}
\]

We used the equivalence of the Cooperon spectrum and \( \Delta \sigma \).

The minima of \( \Delta_{j} \) are shifted to finite in-plane wave vectors

\[
\mathbf{Q} = \mathbf{Q}_{j} = \epsilon \mathbf{Q}_{j0}(\epsilon = 0.1, 0.2, 0.3)
\]

where \( \mathbf{Q}_{j0} \) are oriented along \( \mathbf{Q} \). The spectrum can be rewritten

\[
\mathcal{H} = \frac{k^2}{2m} + (k \cdot \mathbf{Q}) \sum_{\alpha}
\]

Conserved Spin Quantity

The Hamiltonian can be rewritten

\[
\mathcal{H} = \frac{k^2}{2m} + (k \cdot \mathbf{Q}) \sum_{\alpha}
\]

with

\[
\sum_{\alpha} = \left( \sigma_x + \sigma_y + \frac{3\sqrt{2} \mathbf{Q} \cdot \mathbf{Q}_{j0}}{2m} \sigma_z \right) / N \quad \text{and} \quad \mathbf{Q} = \frac{\mathbf{Q}_{j0}}{2}(1, 1, 0)
\]

Assumption: Contribution coming from 3rd order angular momentum. We used the equivalence of the Cooperon spectrum and \( \Delta \sigma \).

References