# Rashba Spin-Orbit Coupling and Anti-Symmetric Spin Filtering in One-Dimensional Electron Systems

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In the regime of the quantum-coherent transport the Zeeman splitting in combination with a build up potential barrier leads to spin filtering. We argue that in one-dimensional systems with relatively strong spin-orbit coupling associated with the inter-facial electric field the filtering depends on the current direction if the magnetic field of the appropriate strength is applied along the wire. This property has its origin in the breaking of the time-reversal symmetry.

Our analysis concerns the electron systems which can be described by the following unperturbed single-electron Hamiltonian

$$H_0 = \frac{p_x^2}{2m^\star}\,\sigma_0 - \frac{\alpha\langle\mathcal{E}_z\rangle}{\hbar}\,p_x\sigma_y + \frac{\epsilon_Z}{2}\,\sigma_x \quad , \quad k_\alpha \equiv \frac{m^\star}{\hbar^2}\,\alpha\langle\mathcal{E}_z\rangle \quad , \quad E_\alpha \equiv \hbar^2 k_\alpha^2/2m^\star \tag{1}$$

where $m^\star$ is the effective mass, $\langle\mathcal{E}_z\rangle$ represents the effective strength of the Rashba field perpendicular to the wire ($z$-direction), $\epsilon_Z$ is the Zeeman splitting energy, $\sigma_0$ stands for unit matrix, $\sigma_x$ and $\sigma_y$ are Pauli matrices.

Eigenfunction are given as the product of the plane wave and a spin function which in general depends on the wave number $k$. At low magnetic fields, $\epsilon_Z < 4E_\alpha$ the energy dispersion shown in Fig. 1 is composed of two branches that avoid the crossing by forming a local gap of the width just equal Zeeman splitting energy $\epsilon_Z$. In the vicinity of local-gap edges there appears strong tendency of the electron spin to be parallel with the magnetic field direction. Far from this energy region the spin is oriented approximately in the direction perpendicular to the wire, i.e. similarly as in the case of the zero magnetic field.

Within the local-gap region, where the system has one energy branch only, as seen in Fig. 1, the right and left going states are spin-polarized in opposite directions. It means that any current in the system with Fermi energy located within the local-gap region will be strongly polarized and the sign of the polarization will depend on the current direction. Note that this effect is suppressed at higher magnetic fields, for which $\epsilon_Z$ becomes greater than $4E_\alpha$.

The above described property can be used to design an anti-symmetric spin filter. At the interface introduced by a potential step of the height $V_0$, as sketched in Fig. 2, transmission of electrons incoming from the left is controlled by four transmission probabilities: Two of them $t_{\downarrow\downarrow}$ and $t_{\uparrow\uparrow}$ preserve spin orientation. Remaining probabilities $t_{\downarrow\uparrow}$ and $t_{\uparrow\downarrow}$ are controlled by spin-flip processes at the potential edge. Note, that the electron spins at Fermi energy are not parallel and for this reason the used notation $\uparrow$ and $\downarrow$ is related to the orientation of spin component $\sigma_y$. Their dependence on the height of the potential step $V_0$ is shown in Fig.3 and the corresponding spin-polarization of the current injected to the right side is presented in Fig. 4. The Fermi energy is supposed to be well above the local-gap on the right of the potential edge.

The above analysis leads to the conclusion that the potential barrier of the proper height for which the Fermi energy will fall into the local-gap can be used as an antisymmetric spin-filter. By changing the current direction electrons with opposite spin orientation will be filtered out.

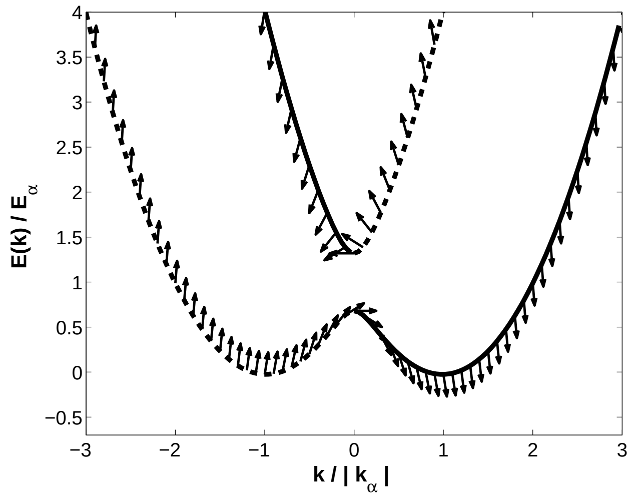


Fig.1: Energy dispersion $E(k)$ for $\epsilon_Z = 0.64 \cdot E_\alpha$. Arrows illustrate spin orientation.

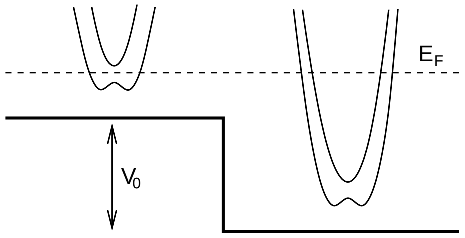


Fig.2: Potential step of the height $V_0$ with sketched energy dispersions of the asymptotic states.

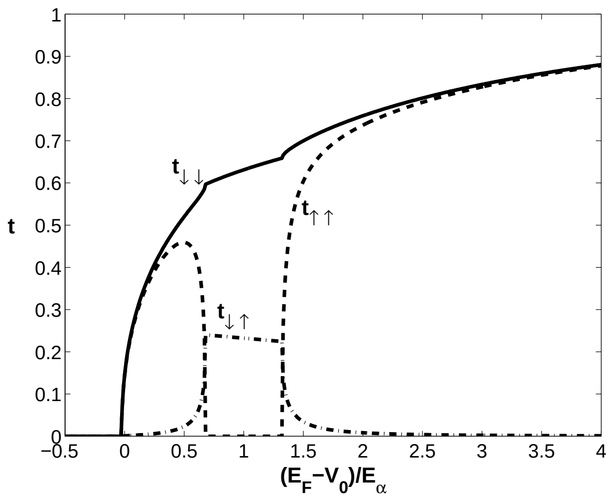


Fig.3: Dependence of transmission probabilities $t_{\downarrow\downarrow}$, $t_{\uparrow\uparrow}$ and $t_{\downarrow\uparrow}$ on the height of the potential step. The probability $t_{\uparrow\downarrow}$ is negligible ($\epsilon_Z = 0.64 \cdot E_\alpha$).

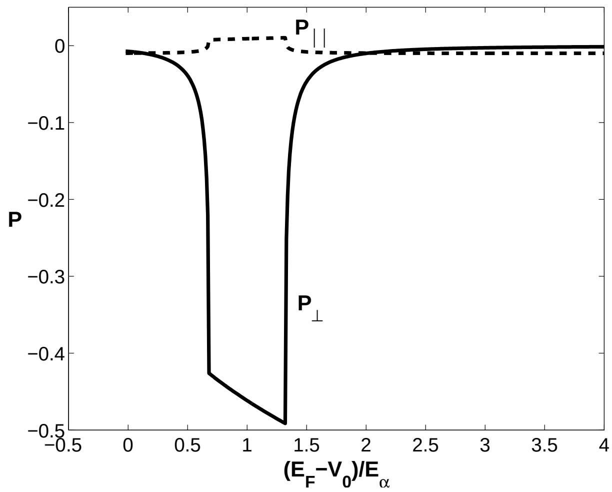


Fig.4: Polarization of the transmitted current as function of $V_0$ ($\epsilon_Z = 0.64\, E_\alpha$). $P_\perp$ (full line) and $P_\parallel$ (dashed line) denote polarization components in the direction perpendicular and along the wire, respectively. Polarization vector $\vec{P}$ is normalized to has unit length for fully polarized current.