Anomalous magnetoresistance in (110) quantum wells

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After intensive study of spin-dependent phenomena in traditional two-dimensional systems in the last decade, the attention of semiconductor spintronic community is shifting now to specially designed structures where more subtle spin effects can be observed. One of the most interesting systems are symmetrical quantum wells (QWs) grown in [110] direction which have unusual spin properties due to absence of relaxation for spin component oriented along the growth direction. However, the symmetrically doped (110) QWs shown in Fig. 1 are symmetric only in average with the domains of the nonzero electric field produced by non-mirror symmetric impurity distributions in the doping layers equally remoted from the QW center. These electric fields result in a random spin-orbit coupling via the Rashba effect and, in turn, in a finite spin-relaxation time τ_s.

Electron spin properties can be probed in both optical and transport experiments, and one of the powerful tools for its study is measurements of the low-temperature resistance in classically-weak magnetic fields. It is well known that the magnetoresistance is caused by *weak localization* effect consisting in the interference of electron scattering paths. In this work we develop a theory for the low-field magnetoresistance in symmetrically doped (110) QWs. Analytical expressions for the magnetoconductivity are obtained with account for the spin relaxation processes in the random field of impurities. In Fig. 1 the magnetoconductivity is shown for different values of the spin relaxation rate. The magnetic field is given in units of the 'transport' field $B_{tr} = \hbar/(2el^2)$, where l is the electron mean free path. The minimum is present in the magnetoconductivity due to spin relaxation demonstrating antilocalization effect. Figure 1 demonstrates a shift of the minimum to the fields $B > B_{tr}$ at $\tau/\tau_s > 0.2$, where τ is the transport relaxation time. The dashed lines represent the results obtained in the 'diffusion' approximation where the traditional Hikami-Larkin-Nagaoka expression is valid. Comparison with the exact calculation shows that for $\tau/\tau_s \geq 0.1$ the diffusion approximation is inadequate even at low fields, and one should use exact expressions for fitting of the experimental data. To summarize, we demonstrated that the random spin-orbit coupling affects strongly the anomalous magnetoconductivity, and this can be observed in experiments.

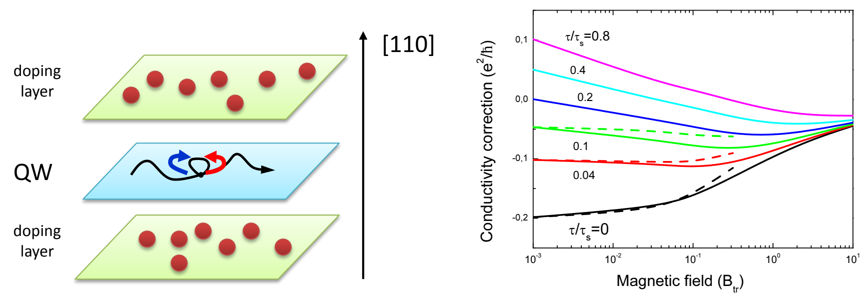

Figure 1: Left: Symmetrically doped (110) QW structure. Electrons propagating in the QW plane interfere due to the presence of self-intersecting paths. Non-mirror symmetric positions of impurities in the doping layers lead to spin relaxation. Right: Magnetoconductivity in symmetrically doped (110) QWs at different values of the spin relaxation time.