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Spin relaxation in 2D systems with boundaries

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The D'yakonov-Perel' spin relaxation mechanism in two-dimensional (2D) systems has attracted wide attention because of its fundamental importance for the field of spintronics. However, while all previous studies of D'yakonov-Perel' spin relaxation have been focused on infinite semiconductor systems, the influence of the sample boundaries (actually existing in any experimental system or device) on spin relaxation has received much less attention. As we discuss below, the sample boundaries can dramatically change the character of spin relaxation, result in an incomplete spin relaxation and spin echo effects.

Specifically, we have found [1] that a homogeneous spin polarization in one-dimensional structures of finite length in the presence of Bychkov-Rashba spin-orbit coupling decays spontaneously toward a persistent spin helix. Such a strikingly different and simple method enables us to generate robust spin structures whose properties can be tuned by the strength of the spin-orbit interaction and/or the structure's length. These results can be generalized for the two-dimensional case predicting the formation of a persistent spin helix in two-dimensional channels from homogeneous spin polarization. Our analysis of the formation of a spin helical state is based on an approach mapping spin drift-diffusion equations into a heat equation for a complex field.

Next, let us consider the problem of D'yakonov-Perel' spin relaxation in two-dimensional circles with Rashba spin-orbit interaction [2]. One may think that in small systems the spin relaxation is incomplete as the spin precession angle across the system is small. However, in such a situation, the different effect plays a role: the noncommutativity of spin rotations. Because of this effect, the electron spin precession angle can largely exceed the maximum rotation angle allowed by naive geometrical considerations.

In Ref. [2] we report an exact solution for the problem of electron spin relaxation. Our analysis shows that the spin relaxation in finite-size regions involves three stages and is described by multiple spin relaxation times (see Fig. 1). It is important that the longest spin relaxation time increases with the decrease in system radius but always remains finite. Therefore, at long times, the spin polarization in small 2D systems always decays exponentially with a size-dependent rate. This prediction is supported by results of Monte Carlo simulations.

Finally, we note that an additional insight on spin polarization dynamics might be obtained beyond the traditional drift-diffusion equations approach. In particular, the use of a more general spin kinetic equation [3] allows obtaining novel features of spin polarization on shorter length and time scales. For example, it is found that a propagating spin-polarization profile reflects from a system boundary and returns back to its initial position similarly to the reflectance of sound waves from an obstacle. In addition, there exists an interesting transformation [3] mapping 1D spin kinetic equation into the Klein-Gordon equation with an imaginary mass. This result establishes a novel connection between semiconductor spintronics and relativistic quantum mechanics.

References

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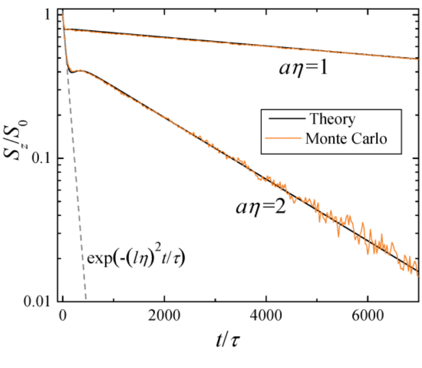

Figure 1: *Time dependence of spin polarization in the center of a 2D circle of radius a (η is the spin rotation angle per unit length).*