MODELING SPIN FLOWS IN SEMICONDUCTORS

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Introduction

A new generation of electronic devices, with the potential to outperform conventional electronic circuits in speed, integration density and power consumption, has been proposed based on the ability to manipulate electron spin in semiconductors. To design semiconductor structures whose function is based on electron spin, it is necessary to understand spin dynamics and spin-polarized transport, and in particular, how they are affected by electric, magnetic and strain fields. To this end we derive a complete set of spin drift-diffusion equations in 2D that describe the flow of spin polarized electrons in semiconductors, in the presence of applied electric, magnetic, and strain fields.

Results and Discussion

We microscopically derive an equation of motion for the electron Green's function giving a full quantum-mechanical description of electron spin dynamics and transport in the presence of electric, magnetic and strain fields [1]. From this equation of motion we construct a semiclassical kinetic theory of electron spin dynamics and transport in the presence of these fields. From the semiclassical kinetic theory, we derive a set of spin-drift-diffusion equations for the components of the spin density matrix for the case of spatially uniform fields and electron density. Our approach extends beyond the two-component drift-diffusion model, because the spin distribution function has the form of a spin-density matrix to account for spin coherence effects. We are particularly interested in describing the effect of spin-strain coupling (which is linear in electron wave vector) on electron spin transport. Because the spin-strain coupling depends on electron wave vector, the diffusion coefficient and mobility appear in the strain coupling terms of the spin-drift-diffusion equation. We solve the spin-drift-diffusion equations numerically and compare the results with scanning Kerr microscopy images of spin-polarized conduction electrons flowing laterally in bulk epilayers of n-type GaAs. We find very good agreement between the theoretical and experimental results (see Fig. 1).

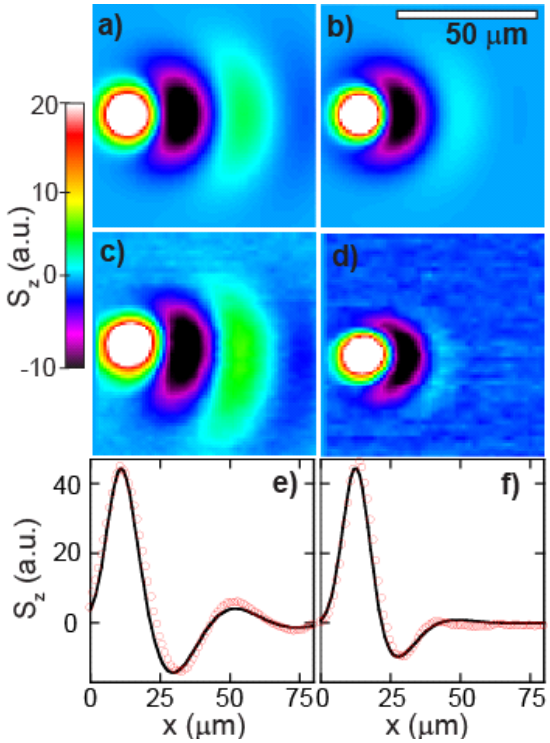

Fig. 1. a) A comparison of actual data (below), and the results of a model (above) that is based on the spin drift-diffusion equations. Spin polarized electrons, optically injected into GaAs (red dot), subsequently diffuse and drift to the right under the influence of a small lateral electric field. Spin precession is caused by the application of a uniaxial stress to the GaAs sample (a and c), and by the application of a real 16G magnetic field (b and d).

We contrast the effects of magnetic and strain fields on electron spin transport. Both magnetic fields and strain fields (with off-diagonal strain components) lead to electron spin precession in zincblende semiconductor structures. However, the form of spin-strain coupling is different than that for spin-magnetic field coupling in that spin-strain coupling is linear in electron wave vector whereas spin-magnetic field coupling is independent of electron wave vector. This difference in the form of the spin coupling for these two kinds of fields leads to qualitatively different behavior for spin transport in strain and magnetic fields. We present calculations that contrast spin transport in strain and magnetic fields and then present a series of theoretical predictions for (and calculated images of) spin transport in geometries that correspond to optical spin injection (see Fig. 1) and in geometries that correspond to electrical spin injection into lateral devices.[1]

References

[1] Hruska, M., *et al*., *cond-mat/0511038*.