IMAGING AND MANIPULATING ELECTRON SPIN FLOWS IN SEMICONDUCTORS

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Introduction

Using methods for scanning Kerr microscopy, we acquire 2D images of spin-polarized conduction electrons flowing laterally in bulk epilayers of n-type GaAs. The images directly reveal the spatial dependence of spin diffusion and spin drift in the presence of applied electric, magnetic, and - in particular - strain fields [1]. Controlled uniaxial stress along the <110> axes induces spin precession, revealing the direct (k-linear) spin-orbit coupling of electron spin to the off-diagonal components of the strain tensor $\varepsilon$. The coupling may be characterized by an effective strain-induced magnetic field $B_\varepsilon$, which is shown to be orthogonal to the electron momentum $k$, and therefore chiral for radially-diffusing spins. $B_\varepsilon$ scales linearly with $k$, yielding a spatial precession of electron spins that is independent of electrical bias and is considerably more robust against the randomizing (ensemble dephasing) effects of spin diffusion as compared with precession induced by external magnetic fields.

Results and Discussion

The samples are 1 $\mu$m thick, silicon-doped (n-type) GaAs epilayers grown by molecular beam epitaxy on [001]-oriented semi-insulating GaAs substrates. The samples were mounted in vacuum on the cold finger of an optical cryostat. To apply controlled uniaxial stress along the [110] axis at low temperature, the cold finger incorporated a small cryogenic vise, whose lead screw was adjusted via a retractable actuator. A local, steady-state source of electrons, spin polarized along the [001] sample normal, was provided by a circularly-polarized 1.58 eV laser focused to a 4 $\mu$m spot on the epilayer. These polarized electrons subsequently drift and/or diffuse laterally away from the point of generation. 2D images of the resulting z-component of electron spin polarization were acquired by measuring the polarization (Kerr) rotation imparted on a linearly-polarized probe laser that was reflected from the epilayer surface and raster-scanned in the x-y epilayer plane (see Fig. 1). Figure 2 demonstrates the spin-orbit coupling of the electron spin to the strain tensor $\varepsilon$. Stress along the <110> axes of GaAs induces k-linear spin splittings in the conduction band through the off-diagonal (shear) elements of $\varepsilon_{xy}$. The strain Hamiltonian is $H_5 = c_3 \sigma \cdot \phi$, where 

$$\phi = (\varepsilon_{xy} k_y - \varepsilon_{xz} k_z, \varepsilon_{yz} k_z - \varepsilon_{yz} k_y, \varepsilon_{zz} k_z - \varepsilon_{yy} k_y), (x,y,z)$$

are the principle <100> crystal axes, and the constant $c_3$ depends on the interband deformation potentials. Stress applied along the [110] or [1-10] axis of GaAs gives in-plane shear $\varepsilon_{xy} = \varepsilon_{yx} \neq 0$. Thus for electrons moving in the x-y plane, $H_5$ describes an in-plane effective magnetic field $B_\varepsilon$ orthogonal to $k$, with magnitude linear in $|k|$. Line cuts along [110] (Fig. 2e) show many precession cycles (>5$\pi$ rotation). The inset of Fig. 2e confirms that the spatial frequency of the induced precession ($-B_\varepsilon$) scales linearly with the observed bandshift $\sim \varepsilon_{xy}$.

References

[1] S. A. Crooker et al., cond-mat/0411461