Electrical detection of non-equilibrium spin polarization with one part per million sensitivity based on the anomalous Hall effect

Precise room-temperature measurement and electrical control of spin polarization are a prerequisite for the integration of many novel spintronics devices into consumer electronics. We demonstrate that the principles of the well-known Hall effect can be extended to detect non-equilibrium spins at room temperature with one part per million sensitivity.[1,2]

The exotic phenomena which arise from non-equilibrium spin polarization or magnetization can occur due to tiny net moments,[3] which are beyond the sensitivity of existing measurement techniques. We propose a novel method of detecting such moments using a Hall voltage generated by non-equilibrium magnetization.

Fig. 1 shows a cartoon of our measurement setup. In the presence of a non-equilibrium magnetization, $\tilde{m}$, the spin-up and spin-down electrons are unequally populated in the normal metal and have spin Hall conductivities $\sigma_{SHE}^{\uparrow(\downarrow)}$ depending on the spin-dependent chemical potentials $\mu^{\uparrow(\downarrow)}$. When a charge current, j_c , is applied normal to $\tilde{m}$, a finite anomalous Hall-like voltage is generated. The effect was observed in both Au/YIG and CuIr/YIG bi-layered systems.

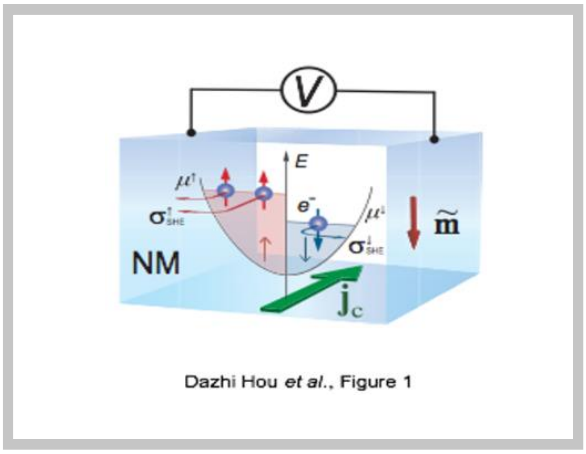

Fig.1 Anomalous Hall effect from non-equilibrium magnetization

This can be understood phenomenologically using a diffusion theory of the spin Hall effect. Microwave excitation is used to pump spins into the normal metal.

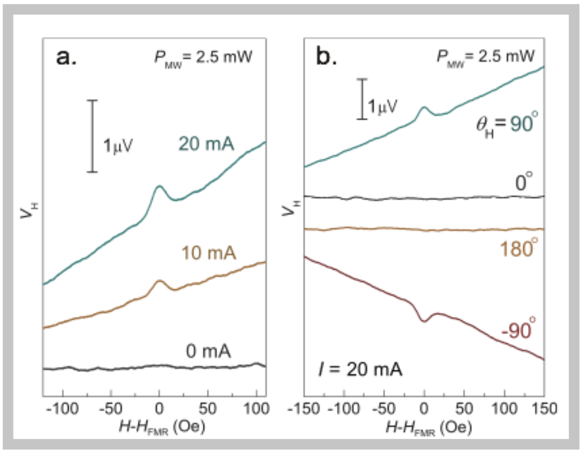

Fig.2 Non-equilibrium anomalous Hall effect in Au/YIG. (a) Hall signal dependence on applied current for P = 2.5 mW. (b) Angular symmetry of the Hall effect for j_c = 20 mA .

Spin accumulation in the metal layer acts as a non-equilibrium magnetization.[4] Under an applied electric field, Hall currents are produced via the spin-orbit interaction.

Fig. 2 shows the Hall signal measured at several currents for a 14 nm Au/YIG sample. Remarkably, this effect can be seen for power as low as 2.5 mW. In the low-power regime, thermal effects are negligible. Peak height scales linearly with current. Angular data (Fig. 2b) excludes an inverse spin Hall effect contribution.[5]

This technique provides a reliable method for non-invasive electrical detection of minute non-equilibrium magnetization in a broad range of materials. Furthermore, the energy derivative of the spin Hall angle, $\partial\theta_{SHE}/\partial\varepsilon$, can be found from the anomalous Hall current, j_{AHE}, using other measurable quantities.[7] Thus the technique also provides access to a new parameter with which to characterize spin Hall materials.

Keywords: spintronic, magnetic insulator, spin excitation
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References

[1] E. H. Hall,. Phil. Mag. 10, 301 (1880)
[2] N. Nagaosa, et al, Rev. Mod. Phys. 82, 1539-1592 (2010)
[3] I. Zutic, et al., Rev. Mod. Phys. 76, 323-410 (2004)
[4] Y. Tserkovnyak, et al., Phys. Rev. Lett. 88, 117601 (2002)
[5] K. Ando, et al., Phys. Rev. B 78, 014413 (2008)
[6] S. Maekawa, et al., Spin Currents, OUP Oxford (2012)
[7] S. Lowitzer, et al., Phys. Rev. Lett. 106, 056601 (2011)

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