Spin Hall Effects:

From Spin Current Detection to Manipulation of Skyrmions

A. Hoffmann

Materials Science Division, Argonne National Laboratory, Argonne, IL 60439, USA

Spintronics is expected to play an important role towards the quest for more power efficient electronics, by utilizing besides the charge degree of freedom also the electron spin. Key physical phenomena to enable efficient charge-to-spin current conversion, and vice versa, are spin Hall effects, which generate transverse spin current from charge currents even in non-magnetic conductors. In order to gain insight into the underlying physical mechanism and to identify technologically relevant materials, it is important to quantify the spin Hall angle γ, which is a direct measure of the charge-to-spin conversion efficiency [1]. We developed a measurement approach based on spin pumping, which enables us to quantify even small spin Hall angles with high accuracy [2,3]. Spin pumping utilizes microwave excitation of a ferromagnetic layer adjacent to a normal metal to generate a homogeneous *dc* spin current over a macroscopic area. Thickness dependent measurements also allow the determination of spin diffusion lengths, which are essential for a proper quantification of spin Hall effects [4,5]. This approach can be used to detect spin Hall effects in a wide variety of materials, including metallic antiferromagnets [6]. Furthermore, we have shown how magnetic proximity effects can reduce spin Hall conductivities in one of the most widely used material for spin current detection: Pt.

In the second part of my presentation, I will discuss how spin Hall effects can be used for the manipulation of spin textures. In magnetic films with perpendicular anisotropies, magnetostatic interactions can stabilize magnetic skyrmion bubbles. By adding an additional layer with strong spin-orbit coupling to the ferromagnet, it is possible to generate an interfacial chiral Dzyaloshinskii Moriya interaction, which stabilizes the skyrmion spin structure in the magnetic bubble domain wall. Using spin Hall effects these magnetic skyrmion bubbles can then be electrically manipulated. This is demonstrated for completely metallic systems, where we can generate skyrmions through inhomogeneities of electric charge currents in a process that is remarkable similar to the droplet formation in surface-tension driven fluid flows. This provides a practical approach for skyrmion formation on demand.

This work was supported by the U.S. Department of Energy, Office of Science, Materials Sciences and Engineering Division.

References

[1] A. Hoffmann, IEEE Trans. Magn. **49**, 5172 (2013)

[2] O. Mosendz, J. E. Pearson, F. Y. Fradin, G. E. W. Bauer, S. D. Bader, and A. Hoffmann, Phys. Rev. Lett. **104**, 046601 (2010).

[3] O. Mosendz, V. Vlaminck, J. E. Pearson, F. Y. Fradin, G. E. W. Bauer, S. D. Bader, and A. Hoffmann, Phys. Rev. B **82**, 214403 (2010).

[4] V. Vlaminck, J. E. Pearson, S. D. Bader, and A. Hoffmann, Phys. Rev. B **88**, 064414 (2013).

[5] W. Zhang, V. Vlaminck, J. E. Pearson, R. Divan, S. D. Bader, and A. Hoffmann, Appl. Phys. Lett. **103**, 242414 (2013).

[6] W. Zhang, M. B. Jungfleisch, W. Jiang, J. E. Pearson, A. Hoffmann, F. Freimuth, and Y. Mokrousov, Phys. Rev. Lett. **113**, 196602 (2014).