Spin – Orbitronics: chiral spin structure dynamics due to spin-orbit effects

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Spintronics promises to be a paradigm shift from using the charge degree of freedom to using the spin degree of freedom. To this end three key requirements are: (i) stable spin structures for long term data retention; (ii) efficient spin manipulation for low power devices and (iii) ideally no susceptibility to stray fields as realized for antiferromagnets.

We explore different materials classes to tackle these challenges and explore the science necessary for a disruptive new technology.

To obtain ultimate stability, topological spin structures that emerge due to the Dzyaloshinskii-Moriya interaction (DMI), such as chiral domain walls and skyrmions are used. These possess a high stability and are of key importance for magnetic memories and logic devices [1,2]. We have investigated in detail the dynamics of topological spin structures, such as chiral domain walls that we can move synchronously with field pulses [3]. We determine in tailored multilayers the DMI [4], which leads to perfectly chiral spin structures.

For ultimately efficient spin manipulation, spin transfer torques are maximized by using highly spin-polarized ferromagnetic materials that we develop and we characterize the spin transport using THz spectroscopy [2]. Furthermore we use spin-orbit torques, that can transfer 10x more angular momentum than conventional spin transfer torques [4-6].

We then combine materials with strong spin-orbit torques and strong DMI where novel topologically stabilized skyrmion spin structure emerge [5]. Using spin-orbit torques we demonstrate in optimized low pinning materials for the first time that we can move a train of skyrmions in a “racetrack”-type device [1] reliably [5,6]. We find that skyrmions exhibit a skyrmion Hall effect leading to a component of the displacement perpendicular to the current flow [6]. We study the field - induced dynamics of skyrmions [7] and find that the trajectory of the skyrmion’s position is accurately described by our quasi particle equation of motion. From a fit we are able to deduce the inertial mass of the skyrmion and find it to be much larger than inertia found in any other magnetic system, which can be attributed to the non-trivial topology [7].

Going beyond ferromagnets, we finally we explore spin-orbit effects in antiferromagnets. In particular we develop Mn_2Au and show that by spin-orbit torques we can switch the Néel vector in this material [8].

References:

[1] S. S. P. Parkin et al., Science 320, 190 (2008);
O. Boulle et al., Mater. Sci. Eng. R 72, 159 (2011).
[2] M. Jourdan et al, Nat. Comm. 5, 3974 (2014); Z. Jin et al, Nat. Phys. 11, 761 (2015).
[3] J.-S. Kim et al., Nat. Comm. 5, 3429 (2014).
[4] R. Lo Conte et al.; Phys. Rev B 91, 014433 (2015); D. Han et al., Nano Lett. 16, 4438 (2016).
[5] S. Woo et al., Nat. Mat. 15, 501 (2016); S. Jaiswal et al., Appl. Phys. Lett. 111, 022409 (2017).
[6] K. Litzius et al., Nat. Phys. 13, 170 (2017)
[7] F. Büttner et al., Nat. Phys. 11, 225 (2015)
[8] A. Sapozhnik et al., Phys. Stat. Sol. RRL doi:10.1002/pssr.201600438 (2017); S. Bodnar et al., arxiv:1706.02482