Spin-orbit torques and magnetic skyrmions in ultrathin magnetic films

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The effect of structural inversion asymmetry (SIA) on the magnetic and electronic transport properties at interfaces of low dimensional magnetic films is currently attracting a growing attention. In the presence of spin-orbit coupling, SIA leads to an additional term in the exchange interaction, namely the Dzyaloshinskii-Moriya interaction (DMI) which tends to make the magnetization rotate around a local characteristic vector D. This can destabilize the uniformly magnetized states leading to novel chiral magnetic orders, such as spin spirals [1], or magnetic skyrmion lattice [2]. Novel out-of-equilibrium transport phenomena have also been demonstrated, such as current induced spin-orbit torques (SOT) induced by the Rashba spin-orbit coupling and/or the spin Hall effect, leading to current induced magnetization reversal [3]. This effect results from the transfer of the lattice orbital momentum to the magnetization via the spin-orbit coupling when injecting current. We have recently shown that SOTs can lead to very fast current induced domain wall motion [4], as well as magnetization switching of ultrathin Pt/Co/AlOx nanomagnet [5]. From an application point of view, the manipulation of magnetization by SOTs has led to a novel concept of magnetic RAM memory, the SOT-MRAM, which combines non volatility, high speed, reliability and large endurance. These features make the SOT-MRAM a good candidate to replace SRAM for non-volatile cache memory application.

In this talk, I will show how the structural inversion asymmetry and high spin orbit coupling in ultrathin heavy metal/ferromagnetic films can be used to manipulate and tailor magnetization at the nanoscale. I will show that the combination of large SOT and DMI in such multilayers can lead to deterministic sub-ns magnetization switching in Pt/Co/AlOx multilayers using SOT [6]. In a more technological approach, we have recently demonstrated a functional perpendicular SOT-MRAM memory cell composed of a three terminal magnetic tunnel junction, where the magnetic bit is written by SOT and its magnetic state read using the tunnelling magnetoresistive signal [7]. Sub-ns switching deterministic switching can be obtained in this device which is promising for power efficient non-volatile cache memory application.

A large Dzyaloshinskii-Moryia interaction is also expected to lead to nm scale chiral magnetic objects, named magnetic skyrmions, which can be manipulated efficiently by current [8]. This has led to novel memory and logic device concepts, where skyrmions are the information carriers. Skyrmion structures has been observed so far at low temperature and in the presence of large external magnetic fields, which prevents any applications. Here I will show that magnetic skyrmions can be stabilized at room temperature without external magnetic field in ultrathin Pt/Co/MgO multilayer nanostructures. Their chiral structure is revealed using high resolution XMCD-PEEM magnetic imaging and can be explained by the large DMI in this film.

[1] M. Bode, M. Heide, K. von Bergmann, P. Ferriani, S. Heinze, G. Bihlmayer, A. Kubetzka, O. Pietzsch, S. Blügel, and R. Wiesendanger, Nature **447**, 190 (2007).

[2] S. Heinze, K. von Bergmann, M. Menzel, J. Brede, A. Kubetzka, R. Wiesendanger, G. Bihlmayer, and S. Blügel, Nat. Phys. **7**, 713 (2011).

[3] I. M. Miron, K. Garello, G. Gaudin, P.-J. Zermatten, M. V. Costache, S. Auffret, S. Bandiera, B. Rodmacq, A. Schuhl, and P. Gambardella, Nature **476**, 189 (2011).

[4] I. M. Miron, T. Moore, H. Szambolics, L. D. Buda-Prejbeanu, S. Auffret, B. Rodmacq, S. Pizzini, J. Vogel, M. Bonfim, A. Schuhl, and G. Gaudin, Nat Mater **10**, 419 (2011).

[5] I. M. Miron, K. Garello, G. Gaudin, P.-J. Zermatten, M. V. Costache, S. Auffret, S. Bandiera, B. Rodmacq, A. Schuhl, and P. Gambardella, Nature **476**, 189 (2011).

[6] K. Garello, C. O. Avci, I. M. Miron, M. Baumgartner, A. Ghosh, S. Auffret, O. Boulle, G. Gaudin, and P. Gambardella, Appl Phys Lett **105**, 212402 (2014).

[7] M. Cubukcu, O. Boulle, M. Drouard, K. Garello, C. O. Avci, I. M. Miron, J. Langer, B. Ocker, P. Gambardella, and G. Gaudin, Appl. Phys. Lett. **104**, 042406 (2014).

[8] A. Fert, V. Cros, and J. Sampaio, Nat. Nanotechnol. **8**, 152 (2013).