Study of magnetic skyrmion properties for spintronics applications

Contact: Helene BEA DRF//INAC/SPINTEC helene.bea@cea.fr 0438780864

PhD may follow: Yes

Summary :

Skyrmions in thin films are spin textures across which magnetization follows a cycloid, rotating in one or the other direction, which defines skyrmion's chirality. These specific magnetic domains can appear in ultrathin trilayers with no inversion symmetry such as heavy metal/ferromagnet/oxide, where an interfacial interaction called Dzyaloshinskii-Moriya (DMI) appears. These topological solitons currently attract a considerable interest both for the underlying physics and for their applicative potential. Since they can be set in motion by electrical current, they could be used as dense storage nanoscale data bits, or for magnetic logic. Furthermore, the possibility to tune magnetic interfacial properties by a gate voltage allows low power control of spintronic devices and provides a versatile, local and dynamic degree of freedom that can be implemented in innovative designs.

In this context, in collaboration with Institut NÃ©el, we have recently shown that a gate voltage can not only switch skyrmions on and off but also tune DMI. The new mechanism leading to DMI revealed by our experiments allows expecting a control of DMI sign, which would lead to an inversion of the skyrmion's chirality.

In this experimental internship, we target to observe the change of DMI sign and to demonstrate the chirality switch. This breakthrough would open new possibilities for skyrmion manipulation, as a change of chirality would invert the direction of current-induced motion. It will also open new and rich physics on the dynamical control of the topology of these solitons.

Full description :

Topologically non-trivial magnetic structures called skyrmions [1] are magnetic bubbles with domain walls of a given chirality: when crossing the skyrmion radially, the magnetization rotates by 360Â° with a given sense of rotation (chirality). They can appear at room temperature in ultrathin trilayer systems, for example consisting of a heavy metal, a ferromagnet and an insulator such as Ta/FeCoB/TaOx, Pt/Co/AlOx and Pt/Co/MgO. Broken inversion symmetry and spin orbit coupling in these trilayers lead to antisymmetric exchange called interfacial Dzyaloshinskii-Moriya Interaction [2] (DMI). This interaction gives rise to non-collinear magnetic textures and its sign determines skyrmion chirality. Skyrmions are currently attracting a wide interest as they could be used as dense bits of information that can be shifted with an electric current via spin-orbit torques: they are thus envisioned for memory or logic applications [3].

In 2007, interfacial magnetic anisotropy has been shown to be controllable with an electric field [4]. This breakthrough has opened a whole new research field and paved the way towards new gate-controlled spintronic devices. This new degree of freedom provides a versatile, local and dynamic tuning that can be implemented in innovative designs. Moreover, controlling by a gate voltage does not require a current flow and is thus energy efficient [5].

In this context, in collaboration with NÃ©el Institute, we have shown the first proof-of-concept of a room temperature skyrmion switch device controlled by a gate voltage: by successively applying positive and negative voltages, the skyrmions appear and disappear [6]. Moreover, we have recently demonstrated that the DMI itself can be tuned by gate voltage [7]. Our result was the first direct proof of an influence of gate voltage on DMI. It also revealed a theoretically predicted mechanism leading to DMI (called Rashba-DMI) that had not yet been experimentally observed. Hence we can expect a sign reversal of DMI for appropriate gate voltages that could ultimately lead to a dynamic chirality inversion. Such chirality switch is very interesting, as it would change the direction of current-induced motion of the skyrmions. It would also open new and rich physics on the dynamical control of the topology of these solitons.

In previous studies, we have observed the formation of skyrmions under various material and magnetic field conditions. They present different thermal stability and different behaviour under the application of magnetic field or electric current.

Within this experimental internship, we thus propose to better understand skyrmion formation in the various conditions. We also plan to study the electric field effects on magnetic properties, and more particularly DMI, for these different types of skyrmions. Finally, we target to observe the change of DMI sign and to demonstrate the chirality switch. This breakthrough would open new possibilities for skyrmion manipulation.

The experimental techniques that will be used are magnetic characterizations (vibrating sample magnetometer), magnetic imaging (magneto-optical Kerr effect microscopy) and electrical characterizations. The candidate will also fabricate samples using micro- and nanopatterning techniques (UV or laser lithography, atomic layer deposition, lift-off). The candidate will be integrated in a team of 3-4 people with daily support and weekly meetings. This project is part of a collaboration with NÃ©el Institute where some experiments will be conducted.

[1] A.N. Bogdanov et al. J. Exp. Theor. Phys. 95, 178 (1989)
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[3] W. Jiang et al., Science 349, 283 (2015), S. Woo et al., Nat. Mater. 15, 501 (2016)
[4] M. Weisheit et al., Science, 315, 349 (2007)
[5] K.L. Wang et al. , J. Phys. D, 46, 074003 (2013)
[6] M. Schott et al. Nano Lett., 17, 3006 (2017)
[7] T. Srivastava et al., Nano. Lett.,18, 4871 (2018)

Requested skills :

Master Physique, nanosciences, bases de magnÃ©tisme