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Spin-orbit effects for topological spin structures and their dynamics [1]

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In our information-everywhere society IT is a major player for energy consumption and novel spintronic devices can play a role in the quest for GreenIT. Reducing power consumption of mobile devices by replacing volatile memory by fast non-volatile spintronic memory could also improve speed and a one-memory-fits-all approach drastically simplifies the microelectronic architecture design. However there are key requirements for the implementation of future spintronic devices: (i) large read-out signals, (ii) stability of the magnetic information and (iii) fast and efficient manipulation. In this tutorial we will introduce the physics of magnetic nanostructures, such as domain walls and skyrmions and spin currents in metallic materials that can lead to novel devices. We will present the micromagnetic model for a theoretical description we will discuss various experimental investigations of these nanoscale physics determining the magnetostatic spin structures and magnetodynamics of the switching. Beyond using magnetic fields to manipulate magnetization, one can also use alternative approaches that exhibit better scaling. For example, when combining transport with magnetic materials on the nanoscale, a range of exciting and novel phenomena emerge. The effect of the spin polarized currents on the magnetization leads to a spin transfer torque effect and resulting in current-induced domain wall motion, which has become the focus of intense research in the last few years due to a strong interest in the fundamental interaction between spin polarized currents and the magnetization in ferromagnets. However in this spin transfer torque approach each electron transfers for adiabatic transport only one unit of spin angular momentum (1 hbar) thus limiting the intrinsic spin manipulation efficiency The transfer of orbital angular momentum can overcome this limit (more than 1 hbar/e-) and is thus potentially much more efficient. Such Spin Orbit Torques (SOTs) can then lead to fast magnetization switching at ultra-low current densities. Two mechanisms for SOTs have been identified in asymmetric systems: the Inverse Spin Galvanic effect, where electric fields resulting from the asymmetry lead to effective magnetic fields that can manipulate the magnetization and the spin Hall effect that converts a charge current into a spin current that can induce magnetization switching. Finally to enhance the stability, spin structures can be stabilized based on spin-orbit interaction effects (SOI), by going beyond the commonly used Heisenberg exchange interaction, which dominates conventional spintronics. In systems without inversion symmetry, SOI leads to spin structures with topological protection that are stabilized by additional chiral exchange interactions such as the Dzyaloshinskii Moriya interaction (DMI). These include chiral domain walls and skyrmions, which are topologically distinct from the single domain state and thus topologically stabilized and can be just a few nm in diameter enabling high densities.

Together the highly stable chiral spin structures due to DMI and the efficient manipulation using SOTs can then be used to build novel devices, such as the skyrmion racetrack with a number of skyrmions beaded in a nanowire. The stable dynamics of the novel spin structures is governed by the topology and excitations by spin orbit torques are predicted to be very efficient thus potentially leading to novel spintronics devices for GreenIT.

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