## Enhanced spin orbit effects in ultrathin magnetic films with nanoscale engineered structural broken inversion symmetry

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Any practical application of spin-orbital effects, such as the interfacial Dzyaloshinskii-Moriya interaction (iDMI), spin-orbit torque (SOT), spin Hall effect (SHE) and chiral damping, requires to develop energy efficient thin film-based nanostructures with broken inversion symmetry for manipulation of skyrmions on a racetrack or for field-free sub-ns magnetization switching at low current densities. To implement efficient room-temperature skyrmionic devices, there are a few main issues have to be solved: (i) decrease of skyrmion size down to sub-10 nm size, (ii) development of mechanisms of skyrmion generation, (iii) time-resolved control of their movement. The very important problem is the defect-dependent behavior of small skyrmions in crystalline systems leading to their distortion. One of the promising solution is to used amorphous or epitaxial magnetic layers due to the low level of disorder. The development of SOT-MRAM requires heavy metal (HM)/ferromagnet (FM) films with high SHE angle and intermediate iDMI. However, simultaneous implementation of this condition using just one HM is difficult, because of the high SHE angle does not guarantee reasonable iDMI and perpendicular magnetic anisotropy (PMA). In an ideal for applications system, a FM layer has to be sandwiched between two HMs: one can give a high SHE angle (e.g. Pt, W) meanwhile the second one will induce strong iDMI (e.g. Ru, Pd, Hf). In this talk, we will focus on recent findings of our group addressed to solve the mentioned problems using the following modification mechanisms: (i) modulated interface roughnesses, (ii) temperature annealing for properties transformation, (iii) introduction of ultrathin heavy metal layers into HM/FM interfaces. At the first time we demonstrate the significant enhancement of roughness-dependent iDMI (up to 2.5 times) and spontaneous skyrmion (with size of 150-200 nm) nucleation in spatially modulated Pd/Pt/CoFeSiB/Ru(Ta) films with amorphous magnetic layer. We propose a simple model describing the roughness-induced iDMI in layered systems in order to precise control the spin-orbit effects including SOT. We will demonstrate that in W/CoFeB/MgO trilayers with PMA, originated after magnetic annealing, the W layer thickness significantly affects iDMI, which is explained in terms of the structural and morphological transformation of W. Spin Hall measurements in presence of small in-plane magnetic field revealed the contributions from the field-like and damping-like torques. Furthermore, we will show the remarkable influence of an ultrathin W layer (less than 0.4 nm) on magnetic properties of Ru/Co/W/Ru films. Moreover, an insertion of 0.23 nm thick W layer between Co and Ru induces strong iDMI with the maximum value ~-3.1 mJ/m$^2$ [1]. As a result, in films with $t_{Co}$ = 1.1 nm, the spontaneous skyrmion nucleation and stabilization is observed in applied magnetic fields.

[1] A.G. Kolesnikov et al. https://arxiv.org/abs/1709.01229