Theoretical study of skyrmion stationary behavior and dynamics

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Magnetic skyrmions are topologically protected spin textures which can be potentially used for several applications [1]. The first room-temperature evidences [2,3] have led to open questions on skyrmion stability and dynamics that have to be understood. In particular, a comprehensive theory for the calculation of the skyrmion diameter as a function of temperature (T) and external field (H_{ext}), as well as of the skyrmion velocity and trajectory for the spin-Hall effect (SHE)-driven motion under the effect of interfacial perpendicular anisotropy (IPA) gradient, is still missing.

Here, a ferromagnet coupled to a heavy metal is analyzed, in order to achieve an appreciable interfacial Dzyaloshinskii-Moriya interaction and SHE [1]. A theoretical approach for the skyrmion stability based on magnetic energy minimization using a skyrmion ansatz [4] different from Ref. [5] is developed. This approach allows for the calculation of the skyrmion diameter D_{sk}, whose values were compared with micromagnetic simulations for different T and perpendicular H_{ext} finding a good agreement (Fig. 1(a)). Temperature is included in the analytical theory via the scaling relations of the macroscopic parameters obtained by atomistic simulations. The results also show that skyrmion is characterized by two thermal/field dependences, whose origin can be linked to its energetic configuration. If the skyrmion is metastable (stable), its size exhibits a weak (strong) temperature/field dependence.

An analytical model based on the Thiele's formalism was also developed [1] to investigate the SHE-driven skyrmion motion in presence of an IPA linear gradient, as already experimentally analyzed [3]. Two key dynamics are observed: (i) the presence of only the gradient leads the skyrmion to mainly move in the direction perpendicular to the gradient itself; (ii) the simultaneous action of gradient and SHE yields a skyrmion expansion while it moves, consequently leading to an accelerated motion. Fig. 1b shows a good agreement between analytical and micromagnetic results for the skyrmion velocity along the IPA gradient. These achievements give an understanding of the recent experimental evidences on skyrmion stability and dynamics [2,3].

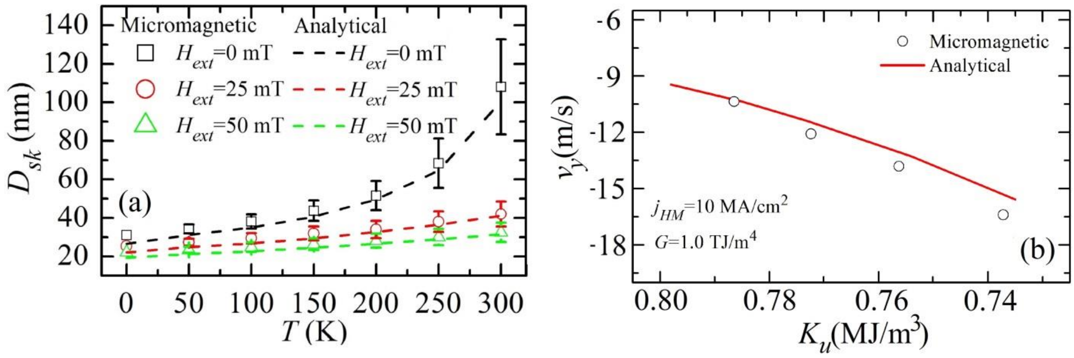

Figure 1. (a) Skyrmion diameter vs temperature for three values of H_{ext}. (b) Skyrmion velocity y-component vs IPA constant K_u along the IPA gradient (G=1.0 TJ/m^4) when the current through the heavy metal is j_{HM}=10 MA/cm^2.

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