DP-02

MAGNETIC SKYRMIONIUM: A NEW BUILDING BLOCK FOR RACETRACK MEMORY

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I. INTRODUCTION

Magnetic skyrmionium is a non-topological soliton with a doughnut-like spin texture [1, 2], which can be phenomenologically viewed as a coalition of a skyrmion and an anti-skyrmion, as shown in Fig. 1. It has been theoretically suggested that the skyrmionium can be created and remain stable in magnetic nanodisks with the Dzyaloshinskii-Moriya interaction (DMI). In this work, we systematically study the generation, manipulation and motion of a skyrmionium in nanostructures with a magnetic field or a spin current. We demonstrate the degeneration of a skyrmionium with $Q = 0$ into a skyrmion with $Q = +1$ or $Q = -1$ triggered by a magnetic field pulse. We show the transformation of a skyrmionium with $Q = 0$ into two skyrmions with $Q = +1$. In addition, we investigate the motion dynamics of a skyrmionium as well as a bilayer-skyrmionium compared to that of a skyrmion. The velocity of a skyrmionium driven by vertical current can be faster than that of a skyrmion at a reasonable driving current density. The results have technological implications in the emerging field of skyrmionics.

II. RESULTS

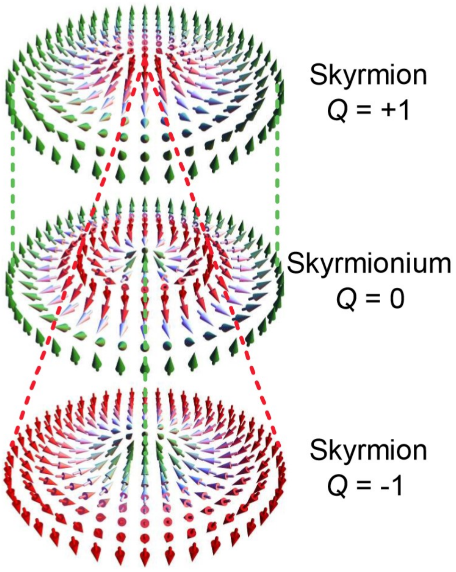

Fig. 1 Illustration of a magnetic skyrmionium.

First we compare the energy level of the skyrmionium with possible states, that is, the ferromagnetic (FM) state, the skyrmion, and the 3π rotation state, in a magnetic nanodisk with the DMI. The radius of the nanodisk is fixed. By giving the FM state, skyrmion, skyrmionium, and 3π state as the initial magnetization configuration of the nanodisk separately, we calculate the total micromagnetic energy E_{total} of the relaxed nanodisk as a function of the DMI constant D. For our parameter set, the FM state is the most stable state when $D < 3.8$ mJ m^{-2}, while skyrmion and skyrmionium become more stable than the FM state when $D > 3.8$ mJ m^{-2}. When $D > 4$ mJ m^{-2}, the 3π state also become more stable than the FM state. Larger D favors higher magnetization rotation in the nanodisk, especially when the nanodisk radius is larger than the anisotropy-free period $L_0 = 4\pi A/D$, and A is the Heisenberg exchange constant. For the parameter set in this work, we have $L_0 = 47$ nm at $D = 4$ mJ m^{-2}; thus it is reasonable to obtain a stable skyrmionium in the nanodisk with $r = 1.6\ L_0$. A stable skyrmionium in the nanodisk can be obtained by applying a spin-polarized current locally with the current-perpendicular-to-plane (CPP) geometry in this work.

We also investigate the spin-polarized current-driven motion of a skyrmionium. For the CPP geometry, a spin-polarized current is injected into the nanotrack from the bottom. For the CIP geometry, a spin-polarized current is injected into the nanotrack from the left end. For contrast and comparison

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purposes, we simulate the spin-polarized current-driven motion of skyrmion in the same device. The results are shown in Fig. 2. For the case of CIP geometry, the skyrmionium and skyrmion attain the same current-velocity (j-v) relation for the given range of driving current density. Indeed, both v_{skium} and v_{sk} at a given j increase with the strength of nonadiabatic spin-transfer torque (STT) β. By contrast, for the case of CPP geometry, v_{skium} is clearly higher than v_{sk} when $j > 2$ MA cm^{-2}. And the velocity difference between v_{skium} and v_{sk} increases with increasing j. When the driving current with the CPP geometry $j > 15$ MA cm^{-2}, the moving skyrmionium will be destroyed caused by the skyrmion Hall effect. Similarly, when the driving current density with the CPP geometry $j > 17$ MA cm^{-2}, the moving skyrmion will be destroyed at the upper edge of the nanotrack. Because the distortion and destruction of the skyrmionium in the high-speed operation are detrimental to practical applications, we therefore construct the bilayer skyrmionium in a nanotrack consisting of two antiferromagnetically exchange-coupled FM layers, similarly to the bilayer skyrmion reported in Ref. [3]. The steady velocity of the bilayer-skyrmionium $v_{\mathrm{bi\text{-}skium}}$ as a function of current density j is also shown in Fig. 2. The bilayer skyrmionium has the same j-v relation as the skyrmionium for the case of CIP geometry. However, for the case of CPP geometry, $v_{\mathrm{bi\text{-}skium}}$ is basically a half of v_{skium} at a certain j. The reason is that for the CPP geometry the current is only injected into the bottom FM layer, but drives both skyrmioniums in the bottom and the top FM layers.

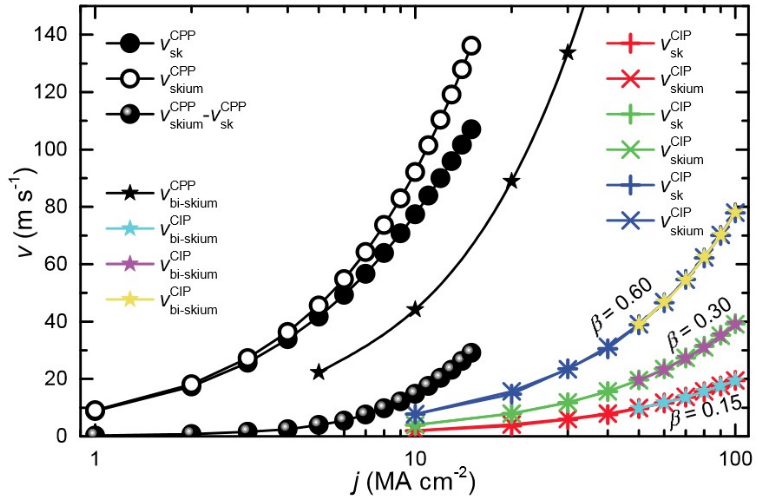

Fig. 2 Velocity for the skyrmion v_{sk}, skyrmionium v_{skium}, and bilayer skyrmionium $v_{\mathrm{bi\text{-}skium}}$ driven by the spin-polarized current with the CPP or CIP geometry as a function of the driving current density j in the nanotrack.

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