Antiferromagnetic domain wall motion driven by spin-orbit torques

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1. Introduction

Antiferromagnets are ordered spin systems in which the magnetic moments are compensated on an atomic scale. The antiferromagnetic order and consequent zero net magnetic moment are maintained by antiferromagnetic exchange coupling of neighboring spins. Any external disturbance competes directly with the large antiferromagnetic exchange, which results in magnetic excitations in terahertz frequency ranges [1]. Furthermore, an antiferromagnet has no magnetic stray field, which is beneficial for integrated circuits because the stray field is a primary source of detrimental magnetic perturbations [2, 3]. These attractive features of antiferromagnets have led to the recent development of antiferromagnetic spintronics, an emerging research field which pursues the use of antiferromagnets as active elements in spintronic based devices [4].

2. Experiment

We investigate SOT-driven antiferromagnetic domain wall motion in antiferromagnet/heavy metal bilayers in the presence of interfacial DMI, based on the collective coordinate approach [5] and atomistic spin model simulations [6].

3. Result and discussion

In order to study AF-DW motion driven by SOT, we derive analytical solution with staggered Landau-Lifshitz-Gilbert equation and collective-coordinate method. We obtain DW velocity $v_{DW} = -\frac{\pi \gamma \lambda B D}{2\alpha} \cos\phi$ (1), where γ is the gyromagnetic ratio, λ is the DW width, B_D is effective field corresponding to damping-like component of SOT, α is Gilbert damping, and ϕ is the DW angle. Figure 1 (a) shows numerical results of the steady-state velocity v_{DW} as a function of the current density. Since Bloch DW has initial $\phi=\pi/2$ or $3\pi/2$, it does not move. Neel DW velocity, however, increases linearly in low current regime, but it saturates and Neel DW emits spin wave in high current regime. We interpret these behaviors to relativistic kinematics. Figure 2 (b) is the snap shot of Neel DW configuration at high current region ($J=2\times10^{11}$ A/m^2) which shows spin wave emission. We find that the spin-wave emission from the antiferromagnetic domain wall is the origin of the v_{DW} saturation. The reason for spin-wave emission is as follows: The damping-like SOT asymmetrically tilts the domains on the right and the left of wall and raises the energy of domain wall. As the wall moves faster, the domain wall is

unstable to sustain its energy and starts to emit spin-waves towards its rear (where the gradient is steeper) to release the energy. Therefore, the spin-wave emission serves as an additional energy dissipation channel and slows down the wall motion. In special relativity, as the velocity of a massive particle approaches the speed of light c, it shrinks via Lorentz contraction and its velocity saturates to c. For the dynamics of antiferromagnets, the speed of light is replaced by the maximum spin-wave group velocity because the antiferromagnetic domain wall can be decomposed into spin-waves and has a finite inertial mass [7]. The relativistically corrected v_{DW} is given as $v_{DW} = \frac{\gamma a l d}{2}\sqrt{1(\lambda/\lambda_{eq})^2}$ (2), where a is the homogeneous exchange constant, $l=2m_s$, m_s is the magnetic moment density of sublattice, d is the lattice constant, and λ_{eq} is the equilibrium DW width. In the poster, we will discuss relativistic kinematics of AF-DW at high current regime in detail.
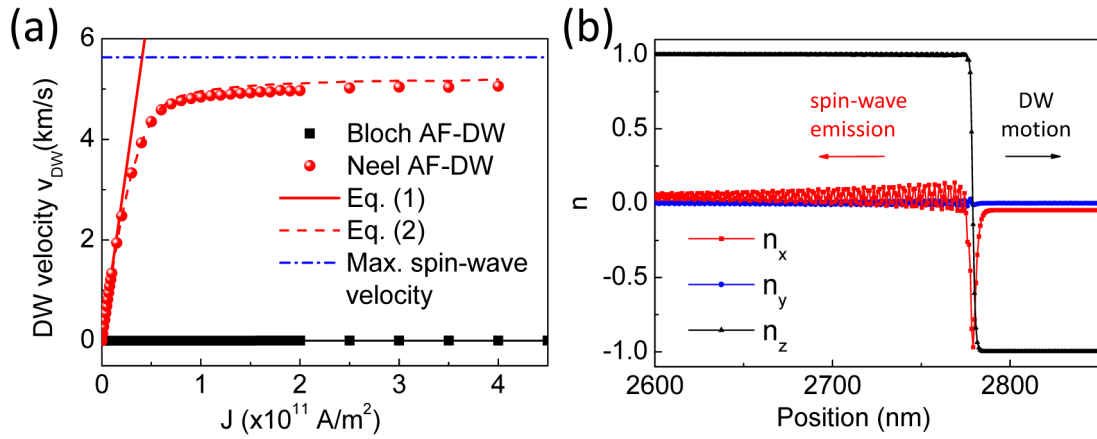

Fig. 1. (a) Steady-state velocity of antiferromagnetic domain wall by SOT. Symbols are numerical results, and lines are analytic solution. (b) Snap shot of Neel DW configuration at high current density ($J=2\times10^{11}$ A/m^2). DW moves with spin wave emission which propagates to opposite direction of DW motion.

4. References

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