Universality Between Current- and Field-driven Domain Wall Dynamics in Ferromagnetic Nanowires

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1. Introduction

The spin transfer torque has opened great opportunities toward the electrical control of magnetic states. For successful device applications, it is crucial to enhance its efficiency at low current density. Here we report that in metallic ferromagnetic nanowires with small microstructural disorders, the domain wall motion is realized at current density down to 10^9 A/m^2, two orders of magnitude lower than previous reports. At such a low current density with negligible Joule heating, the motion reveals the universality between the current- and magnetic-field-driven dynamics and also distinguishes clearly the roles of nonadiabatic and adiabatic spin transfer torques during the competition with disorders. This finding will expedite technological advances toward successful device applications of the spin transfer torque.

2. Experiments

For this study, Si/100-nm SiO_2/5.0-nm Ta/2.5-nm Pt/0.3-nm Co/1.5-nm Pt ultrathin magnetic films are chosen because these films exhibit clear circular domain expansion with a small propagation field. Such domain motion is observed even under a weak magnetic field much less than 1 mT— almost two orders of magnitude smaller than previous results. Several nanowires with different widths ranging from 280 to 860 nanometres are fabricated from the films via electron-beam lithography and ion milling. A DW is created by local Oersted field from a current pulse through the current line between the Function Generator and the ground. The DW is then pushed to a side by applying current J and/or magnetic field H, with the positive polarities of J and H. The DW arrival time at a position (red circle), 15 μm away from the initial DW position is measured by use of a scanning MOKE microscope.

3. Results and discussion

We report the domain wall (DW) motion driven by either magnetic field or electric current (or by both) in thermally activated regime[1]. By use of Pt/Co/Pt nanowires that exhibit extremely low microstructrual DW pinning, the current-driven DW motion is accomplished at current densities down to 4×10^9 A/m^2 as shown by the inset of Fig. 1. To examine the relation between the magnetic field H and current density *J*, the DW speed vis measured with changing *H* under several *J* bias as shown in Fig. 1. It is interesting that all the measured $v(H,J)$ curves collapse onto a single universal curve, when translating ΔH horizontally as shown in Fig. 2. The effective field ΔH is plotted in the inset of Fig. 2, which reveals that the effective field ΔH is composed of the linear and quadratic contributions of J. To understand the origin of the linear and quadratic contributions, we adopt a well-established simple one-dimensional model and confirm that the linear and quadratic contributions are originated from the nonadiabatic and adiabatic terms in the spin transfer torque (STT), respectively.

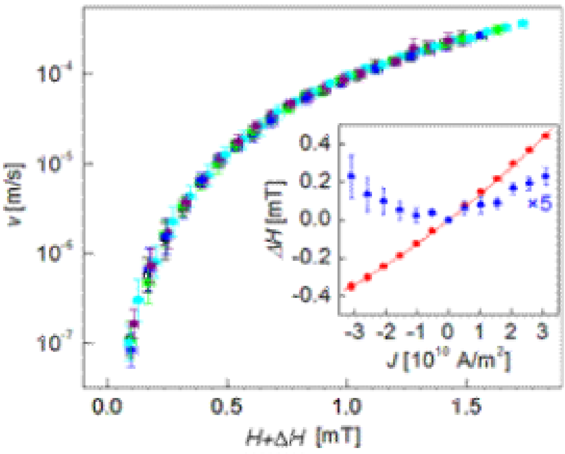

Fig. 1: DW speed v with respect to the magnetic field H for several current density bias J as denoted in the figure. (inset) DW speed v driven solely by the current density J in creep regime.

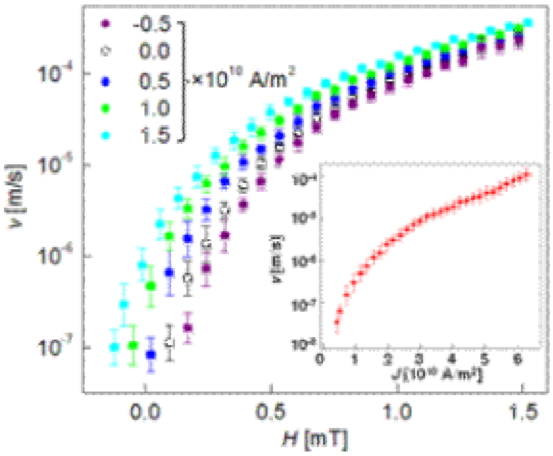

Fig. 2: Universal curve of DW speed v with respect to the total effective magnetic field $H+\triangle H$. All data are rescaled from the Fig. 1. (inset) The red symbols indicate the effective field $\triangle H$ as a function of the current density J. The blue symbols show the quadratic contribution in the effective field $\triangle H$.

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Reference

[1] J.-C. Lee et al. arXiv:0912.5127