A-4-04

Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp43-44

Current-driven Switching of Antiferromagnets

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Abstract

We investigate the current-induced switching of the Néel order in NiO(001)/Pt heterostructures, which is manifested electrically via the spin Hall magnetoresistance. Significant reversible changes in the longitudinal and transverse resistances are found at room temperature for a current threshold lying in the range of 10^7 A/cm^2. The order-parameter switching is ascribed to the antiferromagnetic dynamics triggered by the (current-induced) antidamping torque, which orients the Néel order towards the direction of the writing current. This is in stark contrast to the case of antiferromagnets such as Mn_2Au and CuMnAs, where field-like torques induced by the Edelstein effect drive the Néel switching, therefore resulting in an orthogonal alignment between the Néel order and the writing current. Our findings can be readily generalized to other biaxial antiferromagnets, providing broad opportunities for all-electrical writing and readout in antiferromagnetic spintronics.

1. Introduction

Antiferromagnets exhibit ultrafast spin dynamics with characteristic frequencies in the THz range, produce negligible stray fields and are robust against magnetic perturbations, offering prospects for the design of reliable high-density memories with fast operation speeds [1]. Thus, it is crucial to develop new avenues for manipulating the antiferromagnetic (AFM) order, of particular interest being electrical methods based on the spin-transfer effect. Recently, Wadley et al. [2] reported a current-induced switching of the AFM order in CuMnAs, setting a milestone for the manipulation of the staggered order parameter. In such material, where the breaking of inversion symmetry occurs at the sublattice level, opposite spin polarizations are induced in the two (inversion-partner) sublattices, $p_1 = -p_2$, via the Edelstein effect. The underlying inverse spin-galvanic mechanism imposes stringent requirements on the crystallographic structure and quality of the antiferromagnet, namely global centrosymmetry plus broken sublattice inversion symmetry. At present, only a few antiferromagnets such as CuMnAs and Mn_2Au can meet this demand

Antidamping torques have also been proposed to trigger oscillations and even the switching of AFM moments regardless of the crystal symmetries [3]. This antidamping switching mechanism could be extended to a wide range of antiferromagnets with biaxial anisotropy, allowing for the extensive materials usage. However, no conclusive experimental observation of the antidamping torque-induced switching has been reported yet in AFM/HM (heavy metal) heterostructures [4]. For this talk, we investigate the switching of AFM moments mediated by antidamping torques in the biaxial NiO(001)/Pt heterostructure. We utilize the spin Hall magnetoresistance (SMR) as a probe for the (dynamicsof the) magnetic moments of this AFM insulator. We observe significant changes in the longitudinal and transverse resistances when current pulses are applied along the orthogonal easy axes of NiO, corresponding to the Néel switching towards the direction of the current [5].

2. Results

The in-plane biaxial NiO films were obtained by deposition under compressive strain on $SrTiO_3$ substrates by using magnetron sputtering at 473 K, and capped with 5 nm-thick Pt after cooling down to room temperature. Afterwards, the NiO(5 nm)/Pt(5 nm) bilayers are patterned to the desired geometry by using electron beam lithography and Ar ion etching. Based on the lattice parameters deduced from XRD, first-principles calculations of the magnetocrystalline anisotropy (MCA) of the tetragonal NiO were performed. Note that [1-10] and [001] are the easy and hard axes of the NiO sample, respectively, while a second (local) easy axis aligns along [110]. For the measurements, the writing current channels along the two orthogonal directions [110] and [1-10] of the NiO film, allow for the control of the spin polarization of the injected spin current, where the critical current pulse density for the switching is 4×10^7 A/cm^2 and 1 ms. The [100] and [010] channels are used for probing AFM moments via the longitudinal and transverse SMR.

The change in the Hall resistance is 30 mΩ, corresponding to a ratio of 0.05% when divided by the longitudinal resistance. The gradual change in the Hall resistance with consecutive current pulses indicates the multidomain switching behavior. Writing protocols along [110] (high resistance) and [1-10] (low resistance) correspond to the rotation of 45°and 135°, respectively, i.e. the AFM order switches towards the direction of the writing current. In contrast, the current-induced Néel switching in our Mn_2Au control samples for the identical experimental configuration [6]. The concomitant sign of the changes in the Hall resistance is opposite to that of the NiO/Pt scenario, because the (fieldlike) Edelstein SOT would switch the Néel order towards the spin polarization direction, which is transverse to the writing current, similar to the CuMnAs case [2].

Using the equation of motion, we simulate the switching process. Contrary to the ferromagnetic case, this configuration of the Néel order is unstable against perturbations, as predicted by the stability analysis of the motion equation [5,7]: Thermal fluctuations will induce slight deviations of the Néel order (l) from the ground state l // p, which, above some current threshold, will evolve in time towards the plane perpendicular to the spin polarization. That is, writing currents along orthogonal (easy-axis) directions allow for the reversible manipulation of the AFM moments between the easy axes. It is worth remarking that reactive fieldlike torques are forbidden for the sublattice symmetry. Note that The calculated critical current is 5.8×10^{8} A/cm^2. Such a experimental and calculated difference is mainly due to multi-domain switching. As depicted in Fig. 1, the switching process can be divided into two processes, (i) deviation from easy axis and confinement to the plane perpendicular to the spin polarization, (ii) switching towards the local easy axis contained in the same plane.

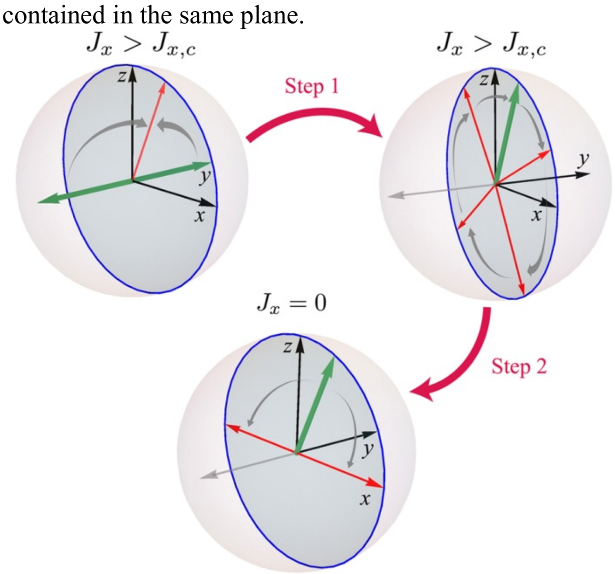

Fig. 1 Schematic of the two-step process involved in the antidamping torque-induced switching. Green (red) arrows depict initial (final) configurations for the Néel order. Blue circle depicts the limit cycle in the *xz* plane.

3. Conclusions

We demonstrate antidamping torque-induced switching in biaxial antiferromagnetic insulators. The current-driven antidumping torque switches the antiferromagnetic moments towards the current direction. The finding can be generalized to other biaxial antiferromagnets for all-electrical writing and readout in antiferromagnetic spintronics.

Acknowledgements

The work was partially supported by the National Key R&D Program of Chinaunder Grant No. 2017YFB0405704, and the NSFC under Grant Nos. 51671110, 51571128 and 11704135. Thework at UCLA was supported by NSF-funded MRSEC under Grant No. DMR-1420451 and NSF under Grant No. DMR-1742928.

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