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Spintronics: Chiral damping

Kyoung-Whan Kim and

Center for Nanoscale Science and Technology, National Institute of Standards and Technology, Gaithersburg, Maryland 20899-6202, USA and also in the Maryland NanoCenter, University of Maryland, College Park, Maryland 20742, USA

Hyun-Woo Lee

Department of Physics, Pohang University of Science and Technology, Pohang 37673, Korea and also in the Department of Physics, University of Toronto, Toronto M5S 1A7, Canada

Kyoung-Whan Kim: kyoungwhan.kim@nist.gov; Hyun-Woo Lee: hwl@postech.ac.kr

Abstract

The analysis of the magnetic domain wall motion in a nanostructured magnetic system with strong spin-orbit coupling shows that the energy dissipation can be chiral when the inversion symmetry is broken.

Spiral objects with a tendency for a particular handedness or chirality are rather common in nature. For instance, 90% of the sea snails have right-handed helical spiral shells [1]. Favoured chirality is observed also on smaller scales in numerous systems. For example, chiral spin arrangements arise in certain physical systems such as manganese layers on tungsten substrates [2]. An important source of the chirality is the energy, which can be lower for one particular handedness due to a special type of spin-spin interaction called the Dzyaloshinskii-Moriya [3, 4]. Such chiral interaction energy can also lead to the formation of topological spin whirls called magnetic skyrmions [5] in magnetic thin films. Now Emilie Jué and colleagues [6] demonstrate that not just the energy, but also the energy dissipation can be chiral.

For chiral energy and chiral damping to emerge, inversion symmetry should be broken. Otherwise, the right-handed and left-handed whirling configurations of spins (Fig. 1a) should exhibit the same physical properties and be equally likely to arise since they are not independent but instead space inversed images of each other under the symmetry. Only when the inversion symmetry is broken the two configurations become independent and may exhibit different properties.

Observing chiral damping in experiments requires moving out of the equilibrium and exploring spin dynamics. Moreover, one needs to distinguish chiral damping from the effects of the chiral energy on the spin dynamics. Jué and coworkers [6] investigate a Pt/Co/Pt trilayer; although both Pt and Co in their bulk forms exhibit inversion symmetry, this is broken in the system as a whole due to the differences between the Pt/Co and the Co/Pt interfaces. Thus the inversion symmetry is weakly broken, which facilitates the distinction between both types of effects since the chiral energy effect is well understood [7] for such systems with weak inversion asymmetry. The strategy followed by these authors is to

identify experimental signals that cannot be explained by the chiral energy effect and associate them to the chiral damping.

In their trilayer system, the chiral energy is dominated by the perpendicular magnetic anisotropy of the system and spins form, in most area, uniformly magnetized domains along the $+z$ ($\uparrow$) or $-z$ ($\downarrow$) direction. Chiral spin configurations appear only at boundaries between the domains, or domain walls, in which the spins gradually change their orientation, as shown in Fig. 1b. The chiralities of the $\uparrow\downarrow$ and $\downarrow\uparrow$ domain walls can be set by applying an in-plane magnetic field H_{ip} . When H_{ip} along $+x$ direction is sufficiently strong (but not too strong to ruin the perpendicular magnetic anisotropy), the $\uparrow\downarrow$ and $\downarrow\uparrow$ domain walls acquire right-handed and left-handed cycloidal configurations respectively, since other chirality choices become unstable energetically. Then, in order to study the dynamics of the domain walls, they apply a weak magnetic field H_z along $-z$ direction, which induces the expansion of the down ($\downarrow$) domain and the motion of the right- and left-handed domain walls in opposite directions. If the inversion symmetry were not broken, the speeds v of the both domain walls should be the same and follow the same creep law $v=v_0 \exp(-E|H_z|^{-1/4}/k_B T)$ [8] for small $|H_z|$, where $k_B T$ is the thermal energy and v_0 and E are constants independent of H_z and handedness. In contrast, when the inversion symmetry is broken, both v_0 and E can in principle depend on handedness and the two domain walls may move at different speeds. A previous analysis [7] revealed that the chiral energy makes E handedness-dependent. Interestingly, Emilie Jué and colleagues [6] find (Fig. 2) only v_0 to be handedness-dependent. Based on this observation, they conclude that the chiral energy is negligible in their system and the chiral damping is responsible for the handedness-dependent speeds that they observe.

This experimental evidence of chiral damping in field-driven spin dynamics may have implications also to the spin dynamics driven by electric currents. In particular, it is necessary to re-examine previous works [9, 10] that ignored chiral damping and attributed handedness dependence of current-driven spin dynamics entirely to chiral energy and chiral torque due to current, or chiral spin torque. Another implication of chiral damping lies in the potential tunability of the net damping. The net damping is the sum of the chiral damping and the conventional damping that is independent of the handedness. Since chiral damping changes its sign with handedness, which can also be modified (for instance by applying an in-plane field as in the experiment by Jué and collaborators), net damping may be reduced through proper control of handedness. Its significant reduction could lead to the development of new magnonic devices.

It is premature to judge the full implications of chiral damping. For further development, however, at least two things are clear. Firstly, one needs to establish a better procedure to quantify chiral damping. The procedure reported by Emilie Jué and colleagues is limited to systems with weakly broken inversion symmetry yet more interesting implications of chiral damping will probably arise when the inversion symmetry is strongly broken. One possible direction is to augment their procedure by combining it with temperature-dependent measurements. Secondly, chiral damping needs to be understood theoretically [11]. Microscopic theories will facilitate its quantification and may even uncover a way for its

enhancement. When these issues are clarified, one may be ready to fully explore and make use of the exotic properties of chiral materials.

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Figure 1. Handness and domain wall formation

a, Two spin structures with opposite handedness. Top and bottom configurations amount to left-handed and right-handed whirls, respectively, when the thumb of a left/right hand is pointed into the page and the other four fingers follow the red arrows. **b**, Domains and domain walls form in the trilayer Pt/Co/Pt. When an in-plane magnetic field H_{ip} is applied along +x direction, the magnetization at the center the domain walls is saturated along the +x direction. Then, the $\uparrow\downarrow$ and $\downarrow\uparrow$ domain walls acquire right- and left-handed cycloidal configurations, respectively. A driving field along -z direction pushes the two domain walls in opposite directions in order to expand $\downarrow$ domains

Figure 2. Domain wall speed v for the two domain walls with the opposite handedness
For both domain walls, $\log v$ as a function of $H_z^{-1/4}$ forms straight lines, yet the dependence is different depending on the handedness.