Novel spin–orbit induced phenomena in terahertz magnon dynamics

(complete result)

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Spin–orbit coupling (SOC) is a fundamental physical interaction describing the microscopic coupling between the spin and orbital degrees of freedom of electrons in solids. This interaction is an essential ingredient for describing many emergent phenomena observed in solids, e.g., the presence of the chiral magnetic interaction, known as Dzyaloshinskii–Moriya interaction (DMI) in chiral magnets.

We will present our recent experimental results on the dynamics of terahertz (THz) magnons in layered magnetic structures, epitaxially grown on substrates with a large SOC. The results were obtained by means of spin-polarized electron energy-loss spectroscopy (SPHREELS), which provides a momentum-space representation of THz magnons over a wide range of momentum and frequency.

First, we will introduce a novel mechanism, which leads to a giant nonreciprocity of ultrafast THz magnons in ferromagnetic films and multilayers with a large SOC. The mechanism is based on the competition between the exchange and spin–orbit scattering. During the scattering process, when electrons excite THz magnons, the two spin-dependent scattering processes, i.e. spin–orbit and exchange processes, compete with each other. On the one hand, SOC couples the spin to the crystallographic directions. On the other hand, in ferromagnets the time-reversal symmetry is naturally broken. These facts lead to a substantially different excitation cross-section of THz magnons propagating along opposite (but crystallographically equivalent) directions (see Fig. 1). We anticipate that the effect can be utilized to excite nonreciprocal or even unidirectional THz magnons in a large class of ultrathin films and nanostructures grown on substrates with a large SOC.

Second, we will discuss how a careful investigation of THz magnon dynamics enables one to quantify the atomistic DMI in layered structures and resolve the complex pattern of DMI in 2D systems. We present the results of a model system, i.e., an epitaxial Co double layer grown on Ir(001). We unambiguously demonstrate the presence of a chirality-inverted DMI, i.e., a sign change in the chirality index of DMI from negative to positive, when comparing the interaction between nearest neighbors to that between neighbors located at longer distances. The effect is in analogy to the change in the character of the Heisenberg exchange interaction from, e.g., ferromagnetic to antiferromagnetic. By comparing the results to those of first-principles calculations, we discuss the origin of the observed chirality-inverted DMI in layered structures.

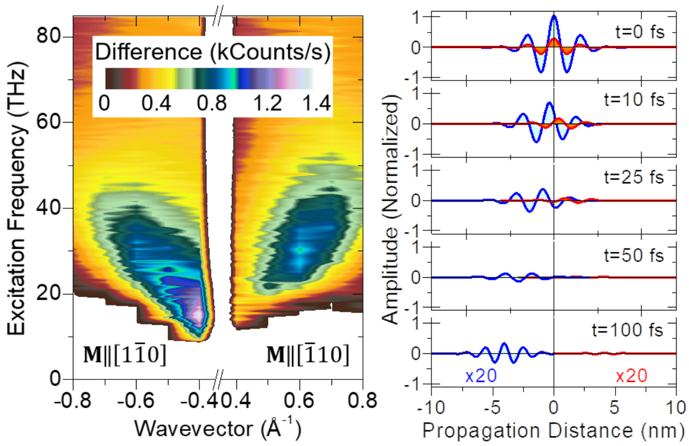

Fig. 1. (left) The frequency–momentum map of the excitation spectra recorded for the two opposite directions of the magnetization, i.e., $M||[1\bar{1}0]$ and $M||[\bar{1}10]$. The color scale represents the amplitude of coherently excited magnons. Data with the positive (negative) value of wavevector indicate the cases for which $M||[1\bar{1}0]$ ($M||[\bar{1}10]$) and the propagation direction along the $[110]$- ($[\bar{1}\bar{1}0]$-) direction. (right) The evolution of the magnon wave packets with the momentum of 0.4 Å^{-1} in real time and space. The blue (red) wave packet propagates along the $[110]$- ($[\bar{1}\bar{1}0]$-) direction.