Terahertz magnons in atomically designed low-dimensional magnets: From magnetic monolayers to multilayers and nanostripes

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We shall present our recent results on terahertz (THz) magnetic excitations in various low-dimensional magnets, including ultrathin films (thicknesses down to one atomic layer), specifically designed magnetic multilayers, as well as arrays of magnetic nanostripes. For that we grow several synthetic magnetic nanostructures on both the reconstructed and unreconstructed Ir(001) surfaces and demonstrate the possible tuning of the properties of THz magnons in such structures via tuning the fundamental magnetic interactions on the atomic scale.

First, we report on the first full experimental magnon spectrum in a Ni monolayer. In order to be able to excite the Ni magnons by means of spin-polarized electrons we couple the Ni monolayer to one and two atomic layers of Co and probe the magnon dispersion relation up to the Brillouin zone boundary. Comparing to the results of *ab initio* calculations, we quantify the complex pattern of the magnetic exchange interaction in the Ni monolayer. We show that, although the magnons in this system are rather stiff, the Heisenberg exchange coupling between the Ni spins is weak. We unravel the origin of the observed large magnon stiffness constant, being a consequence of the small spin density of Ni [1].

Second, we demonstrate both experimentally and theoretically that the nonreciprocity of THz magnons can be largely tuned by changing both the magnitude and the chirality of the atomistic Dzyaloshinskii–Moriya interaction (DMI). Such modifications of the atomistic DMI can be realized by changing the number of the unpaired *d*-state electrons as well as the number and sequence of the atomic layers within the structure [2,3].

Third, by growing ultrathin Co nanostructures on a 1×5 reconstructed Ir(001) surface, we create well-ordered periodic magnetic nanostripes. We demonstrate that such atomically architectured nanowaveguides not only provide a versatile platform for an efficient generation of THz magnons but also allow for their fast propagation (see Fig. 1). Our results reveal the complex nature of the spin dynamics within such designed nanowaveguides and pave the way for designing ultrafast THz magnon-based logic elements [4].

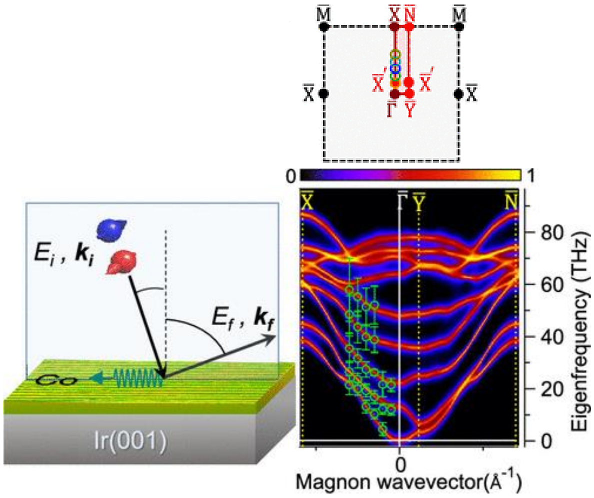

Fig. 1. (left) The scattering geometry used to probe THz magnons excited in Co nanostripes grown on the 1×5 reconstructed Ir(001) surface. The system may be regarded as the first experimentally realized one-dimensional THz magnonic crystal. The wave vector was parallel to the nanostripes. E_i ($\boldsymbol{k_i}$) and E_f ($\boldsymbol{k_f}$) represent the energy (momentum) of the incident and scattered electrons, respectively. (right) The dispersion relation of all THz magnons expected in such a system. The points represent the experimental data and the colour map represents the calculated magnonic Bloch spectral function. The surface Brillouin zone and its corresponding high symmetry points are also shown on top. Figure is taken from [4].

[1] Zakeri, von Faber, and Ernst, Phys. Rev. B (Letter) **109**, L180406 (2024).

[2] Zakeri, von Faber, Mankovsky, and Ebert, arXiv:2402.18466 (2024).

[3] Zakeri and von Faber, Phys. Rev. Lett. **132**, 126702 (2024).

[4] Zakeri and Ernst, Nano Letters **24**, 9528 (2024).