Spectroscopic studies in magnetoelectric and spiral antiferromagnets

Summary

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The continuous advance in information technologies - nowadays exemplified by the development of artificial intelligence (AI), machine learning, and the internet of things (IoT) - demands faster and more efficient computational and memory devices. To keep up with these rapidly increasing needs of today's humanity, new platforms are needed. As a possibility, antiferromagnets were suggested to be applied, and this progress of antiferromagnetic (AFM) spintronics gave a new boost to the study of AFM materials. The application of such compounds could have significant benefits as (1) the rich variety of AFM orders offers new possibilities to encode information, (2) their THz dynamics promise great speed, and (3) the absence of net magnetization makes them robust against stray magnetic fields. The deeper understanding of the underlying physical phenomena behind potential materials for applications is key for technological advancement. The aim of my thesis is to contribute to that fundamental knowledge by studying unconventional antiferromagnets, which may open novel routes for applications.

In my dissertation, I studied three antiferromagnets, $BiFeO_3$, $MnSc_2S_4$, and $LiCoPO_4$. They either have non-trivial magnetic orderings, such as $MnSc_2S_4$, or magnetoelectric, like $LiCoPO_4$, or both, as is the case for multiferroic $BiFeO_3$. They all host phenomena that are interesting either because of the technological promises or show novel effects on a fundamental level. The magnetoelectric (ME) effect present both in $BiFeO_3$ and $LiCoPO_4$ makes these a playground for research on the spintronics application of this effect, as magnetic domains can be switched purely with electric fields with no current flow as demonstrated previously.

In the ME collinear antiferromagnet $LiCoPO_4$, I measured the absorption spectra of the two AFM domains in the visible and near-infrared spectral ranges. To select a domain, I implemented the so-called ME poling. I found an absorption difference as large as $\Delta\alpha/\alpha_0 = 34\%$ for the AFM domains of $LiCoPO_4$ at 1597 nm, and it is large even at the telecommunication wavelength 1550 nm. This absorption contrast is the manifestation of the non-reciprocal directional dichroism (NDD) as time-reversal operation transforms one domain to another. I built a simple, low temperature transmission scanning microscopy setup with which I imaged the AFM domains based on their absorption contrast.

I carried out small-angle neutron scattering (SANS) experiments in the room-temperature multiferroic $BiFeO_3$, to study the magnetic-field induced changes in the magnetic structure. Using THz absorption spectroscopy, I investigated the spin-wave excitations of a recently revealed high-temperature magnetic-field-induced transverse conical phase in $BiFeO_3$. I measured the magnetic field dependence of the mode frequencies in the cycloidal, conical and canted antiferromagnetic phases, and compared the magnetic field dependence of the resonance energies with the results of spin dynamics simulation developed by theoretician colleagues (L. Rózsa, L. Udvardi and L. Szunyogh). I also observed NDD for modes in the transverse conical phase.

I studied the field-dependent magnetic resonances of $MnSc_2S_4$ in its low-temperature, magnetically modulated phase, where inelastic neutron scattering measurements combined with Monte Carlo simulations indicated the formation of antiferromagnetic skyrmions at mK temperatures. With a combination of THz and microwave spectroscopy, I aimed to capture the spin-resonances of AFM skyrmions. My measurements revealed a single resonance in the ordered phase with a g-factor close to 2.