A terahertz view on magnetization dynamics

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Summary

The advances in spintronics have seen a great revolution in technology in the last few decades. In order to develop spintronics further into high-frequency regime (at sub-picosecond timescale or at THz frequencies), it is important to study spin-dependent physical properties of magnetic materials at such high-frequency regime. The work described in this thesis is a contribution towards the understanding of the physics behind the high-speed ultra-fast spintronics.

Laser-driven tunable, narrow-band THz emission from ferrimagnetic Heusler alloys. First, we study $Mn_{3\text{-}X}Ga$ ferrimagnetic thin films for laser-driven THz emission. We observe the tunable, narrow -band in the range of 0.15 THz - 0.5 THz as a function of Mn content, temperature, and applied magnetic field. In this work we emphasis on the THz emission spectroscopy technique for characterization of magnetization dynamics in the sub-THz frequency regime. We observed that THz emission spectroscopy is an efficient technique to study ferromagnetic modes as compared to time-resolved magneto-optical probe techniques in the sub-THz frequency range. This project also resulted in THz emission spectroscopy end-station which allowed us to do interesting scientific and technologically relevant experiments.

This work shows that $Mn_{3\text{-}X}Ga$ thin films can be used as a free layer in spin transfer torque devices which will allow using these devices in the THz frequency range. The frequency of such devices can be further increased by changing the magnetic properties of these films or with atomic substitutions. One can also use these materials for making an on-chip narrow-band, tunable THz source.

THz induced ultra-fast demagnetization in amorphous CoFeB. This experiment allows us to study the frequency dependence of ultra-fast demagnetization in THz regime. The time scales involved in this experiment are very similar to fundamental timescales of scattering processes, which allows to study spin-dependent scattering events and its effect on magnetization dynamics in sub-picosecond timescale. The non-monotonic dependence of ultra-fast demagnetization on the THz pump frequency is

explained using the Elliot-Yafet type spin-flip scattering mechanism and Drude conductivity model. This type of experiments allows one to study the fundamental physics at very short timescales.

Such experiments will allow us to study electron, spin, and phonon dynamics at sub-picosecond timescale which is very important to understand spin transport at such ultra-short timescales. Another importance of this experiment would be to study the effect of spin-orbit coupling on spin transport at a sub-picosecond timescale to design efficient data storage devices.

THz control of antiferromangetic mode in NiO. In this experiment, we use an intense THz pump to resonantly excite the antiferromagnetic (AFM) mode in NiO. The resonant excitation allows us to study the AFM mode as a function of temperature and externally applied magnetic field. A new magnetic mode was observed and it was shown that the two sub-lattice model is not enough to explain the observed results. We used more detailed eight sub-lattice model to explain our results. We also established that dipolar-interactions and magneto-crystalline anisotropy are of great importance to describe spin dynamics accurately.

Experiments of these kinds are essential to gain control over the magnetic order of the material. The ultra-fast switching of magnetic order at THz frequencies will be helpful for spintronics memory devices.

To summarize, this work discusses the magnetization dynamics at THz frequency range which will enable to understand fundamental physics at play at sub-picosecond timescales. This work may provide a pathway to deepen our knowledge of spin dynamics at speeds which are technologically relevant for efficient spintronics devices.