Ultrafast Dynamics and Control of the Spin Systems using Terahertz Magnetic Field

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Terahertz time domain spectroscopy (THz-TDS) based on femtosecond laser has become an established method for studying low-energy excitation dynamics. Especially, the usage of the magnetic field component of THz radiation was recognized as a powerful tool for investigating spin dynamics via magnetic dipole interaction. Up to now, we have demonstrated the applicability of this method to study spin states and dynamics in picosecond region for various materials [1-5]. This presentation aims to giving a brief overview of the study of spin manipulation with THz magnetic fields we have pursued so far, focusing mainly at the coherent spin manipulation in ferro-[1] and weak ferromagnets [2,3]. Specifically, here we show the capability of plasmonically-enhanced intense THz magnetic nearfield to coherent control of macroscopic magnetization in weak ferromagnet $ErFeO_3$ during spin reorientation phase transition (SRPT), which opens new route for the future spintronics devices.

The ever-growing demand for high speed spintronics devices propelled extensive searches of spin-manipulation methods based on ultrafast optical techniques, attempting to control the coherent spin dynamics and macroscopic magnetic order. Recent advancements in the THz time-domain spectroscopy techniques enabled direct visualization of ultrafast spin dynamics in the picosecond time scales. As the photon energy of THz region lies far below that of most electronic transitions, in this frequency region the magnetic field component of the THz pulse can directly access magnetic-dipole transition of electron spins without supplying excess heat into the system. In this presentation, we demonstrate some of our recent achievements of coherent control of macroscopic magnetization in spin systems using such THz magnetic fields. It is based on the plasmonic enhancement of magnetic fields in the nearfield region to locally amplify the spin precession motion, and the usage of an intrinsically magnetic fluctuation-sensitive process of SRPT.

The $ErFeO_3$ (001) single crystal, which is a canted antiferromagnet, was used as a sample. It shows SRPT between 85 and 96 K accompanying continuous orientation change of magnetization from *a*-axis to *c*-axis at low and high temperatures, respectively. The THz pulse with peak electric field up to 300 kV/cm were generated from $LiNbO_3$ crystal by the pulse front tilting method and used to pump a split-ring-resonator (SRR) structure fabricated on the sample surface. The spectral amplitude of the THz magnetic field was enhanced by over an order of magnitude by the SRR with a dimension of 200 x 200 μm^2 [4], to drive spin precession motion around the SRPT temperature (T=84K), which was probed by near-infrared (NIR) Faraday rotation. At the moment of spin precession we apply an NIR pulse to heat up the sample above SRPT temperature into the high-temperature phase. As a result of symmetry breaking of the directionality of SRPT caused by THz-induced spin precession, we succeeded in generating almost uniformly magnetized states in the final state, with its direction selectable by controlling the arrival timing of the heating pulse relative to the THz pulse (Fig.1). The final magnetization is over 80 % of saturation value. Our results indicate that even the small-amplitude spin precession can induce macroscopic change of spin order by utilizing phase transition process, extending the potential of THz application to controlling magnetic domains within picoseconds time- and subwavelength spatial resolution.

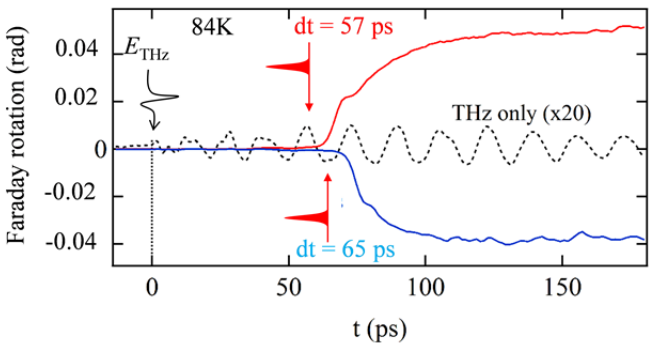

Fig. 1 Typical temporal evolution of out-of-plane magnetization measured by THz-pump optical Faraday probe experiment: Heating pulses arrive 57 ps (red) and 65 ps (blue) after THz irradiation at t = 0 ps. Black dotted curve shows spin precession without heating pulse.

References
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