Ultrafast manipulation of the magnetization of ferromagnetic semiconductor GaMnAs using a terahertz magnetic field

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Generally, to reverse the magnetization direction, it takes more than a half period of the precession cycle (typically ~a few hundred ps) [1]. Meanwhile, using a terahertz light pulse, we can apply a strong magnetic field to magnetic films within an extremely short time less than ~1 ps. Thus, using a terahertz light pulse, we can expect ultrafast magnetization reversal within a few ps because the influence of damping is negligibly small within the terahertz short pulse [2]. The previous study has revealed that the magnetization of the Co thin film coherently follows the magnetic field of the terahertz pulse [3]; however, the magnetization reversal using a terahertz pulse has not been achieved experimentally [3,4]. Quantitative analysis of magnetization modulation by a terahertz magnetic field B_{THz} is important to achieve the magnetization reversal.

The prototypical ferromagnetic semiconductor GaMnAs is quite sensitive to an external optical stimulus [5,6]. Thus, GaMnAs would be an ideal model system to analyze a terahertz response of the magnetization. We grew a 20-nm-thick $Ga_{0.94}Mn_{0.06}As$ layer after growing a 500-nm-thick $In_{0.2}Al_{0.8}As$ film and a 100-nm-thick GaAs buffer layer on a semi-insulating GaAs (001) substrate by low-temperature molecular beam epitaxy. The $Ga_{0.94}Mn_{0.06}As$ film was annealed at 180 ºC for 68 h. The Curie temperature T_{C} of the film was 125 K. The GaMnAs film has a perpendicular easy magnetization axis and coercivity of 15 mT at 10 K. The terahertz-pump probe measurements were performed using a pulsed-light source with a repetition rate of 1 kHz. Both pump and probe pulses were linearly polarized. The strong terahertz-pump pulse was generated by the optical rectification using a $LiNbO_3$ crystal, and had a centered frequency of 1 THz. The time duration of the probe pulse was 130 fs and the wavelength was 800 nm. The incident angle of the probe pulse was tilted 10 deg from the sample normal toward the in-plane $[\bar{1}\bar{1}0]$ axis. Because B_{THz} is applied in the $[1\bar{1}0]$ direction, the magnetization $\boldsymbol{M}$ is ideally modulated toward the in-plane $\langle\bar{1}\bar{1}0\rangle$ direction by B_{THz} (Fig. 1(a)).

We define $\Delta\theta$ as the difference in the polarization rotation of the probe pulses between when $\boldsymbol{M}$//[001] and $\boldsymbol{M}$//$[00\bar{1}]$ without an external magnetic field. Figure 1(b) shows $\Delta\theta$ induced by B_{THz} at a delay time t measured at 10 K for the $Ga_{0.94}Mn_{0.06}As$ film. We see clear oscillations of $\Delta\theta$ while B_{THz} (green open circles in Fig. 1(b)) is applied to the film. Most importantly, $\Delta\theta$ is not zero (~0.01 deg) even after B_{THz} becomes sufficiently small (see the signal at t>2 ps). From our results, we can estimate that this value of $\Delta\theta$ corresponds to ~2% change of the perpendicular component of $\boldsymbol{M}$. When the measurement temperature T is higher than T_{C}, $\Delta\theta$ becomes zero (main panel and inset of Fig. 1(c)). This confirms that $\Delta\theta$ really reflects the modulation of $\boldsymbol{M}$. Our study shows that $\boldsymbol{M}$ of GaMnAs can be modulated in a ultrafast time (<~1ps) with a terahertz light pulse.

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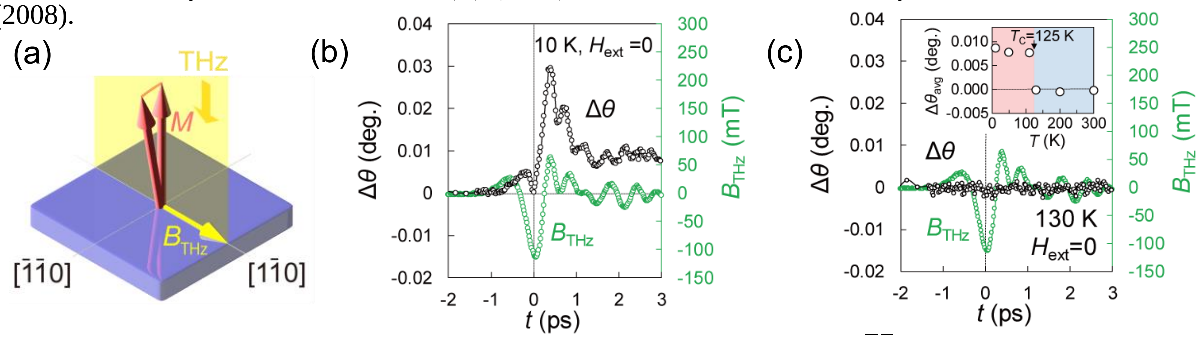

Fig. 1 (a) Measurement set-up. Ideally, $\boldsymbol{M}$ is modulated toward the in-plane $\langle\bar{1}\bar{1}0\rangle$ direction by B_{THz} (b),(c) $\Delta\theta$ (black open circles) induced by B_{THz} (green open circles) at 10 K (b) and at 130 K (c) with the external static field H_{ext}=0 for the $Ga_{0.94}Mn_{0.06}As$ film. Inset shows the average of $\Delta\theta$ from 2 to 3 ps at various T.