Summary of thesis: Nonlinear Spin Dynamics Induced by Intense THz Magnetic Field

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Background

Nonlinear dynamics of many-body spin systems has been an important research topic and attracted considerable attentions from the perspective of fundamental physics and technological applications. Recently, much research interest has been focused on spin dynamics of antiferromagnets whose magnetic response takes place in the terahertz (THz) frequency region due to the large exchange interaction between spins. Direct magnetic excitation with the THz magnetic field resonant to antiferromagnetic mode is most advantageous to investigate spin dynamics suppressing undesirable thermal effects. However, no observation of the nonlinear feature of the THz magnetic response, so far, has been reported due to the lack of sufficient intense THz light sources. It is necessary to explore more efficient excitation methods to drive the antiferromagnetic spin system into the nonlinear regime.

Purpose & Method

In this study, we intend to establish a novel efficient THz magnetic excitation method based on the field enhancement with a metal split ring resonator (SRR), and clarify the nonlinear feature of antiferromagnetic spin dynamics by using this magnetic excitation method. We chose a canted antiferromagnet $HoFeO_3$ crystal as a target sample for the resonant antiferromagnetic excitation, since its THz magnetic response in the linear regime has been well explored. The SRRs array was deposited on the $HoFeO_3$ crystal surface to generate a strong THz magnetic field. According to numerical calculations, a more than tenfold enhancement of the magnetic field is expected at the LC resonance frequency in the near-field region close to the metallic structure of the SRR. We measured time-development of the local magnetization change associated with the antiferromagnetic resonance (AF-mode) induced by the strong THz pulse excitation in the vicinity of the SRR by the time-resolved magneto-optical (MO) microscopy.

Result

Figure 1(a) shows time-development of the magnetization change normalized by the spontaneous magnetization, $\Delta M_z/|M_S|$; the maximum magnetization change reaches

40 % of the spontaneous magnetization M_S, corresponding to the maximum tipping angle of the spins of 15°. Figure 1(b) and(c) show the instantaneous frequency $\nu(t)$ and amplitude $\zeta_0(t)$ of the oscillatory magnetization change determined by the Hilbert transformation of the temporal waveform of the original signal (Fig. 1(a)). The deviation of the instantaneous frequency from the AF-mode resonance frequency in the linear region ν^0_{AF}(= 0.575 THz) is lager than 10 GHz. Observation of the redshift of the antiferromagnetic resonance provides a direct proof of the nonlinearity in the collective motion of the antiferromagnetic spins. To extract the relation between the instantaneous frequency $\nu(t)$ and amplitude $\zeta_0(t)$, we made a parametric plot of these values (Fig. 1(d)). The instantaneous frequency shift has a square dependence on the amplitude such as $\nu=\nu^0_{\mathrm{AF}}(1-\mathrm{C}\zeta_0^2)$. This relation between the instantaneous frequency and amplitude can be reproduced by the analytic expression of the nonlinear resonant frequency of the AF-mode, which can be derived from the Landau-Lifshitz-Gilbert (LLG) model based on the free energy of the spin system in $HoFeO_3$, as plotted in the same figure by the solid line. In addition, we found that the decay time of the magnetization change has strong excitation-intensity dependence, and the nonlinear magnetization dynamics is quantitatively reproduced by a modified LLG equation with a phenomenological nonlinear damping term. One plausible candidate for the nonlinear damping effect is a four-magnon scattering process, where the scattering rate is proportional to the square of the magnon number at k=0.

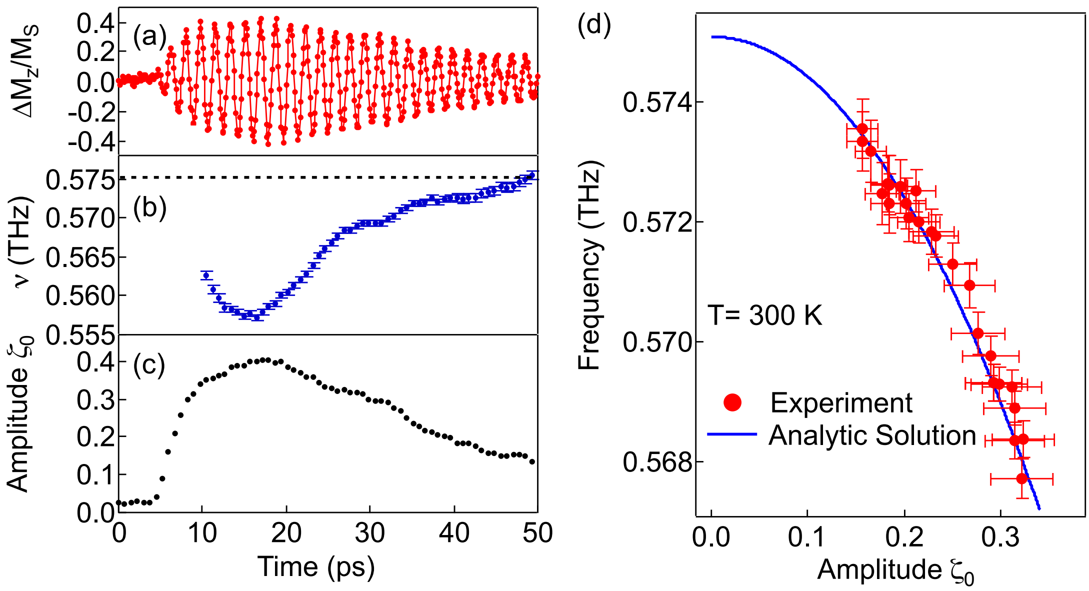

Fig. 1 Temporal waveforms of the magnetization change normalized by the spontaneous magnetization (a), the instantaneous frequency $\nu(t)$, and amplitude $\zeta_0(t)$ of the magnetization change ((b) and (c)). Relation between the instantaneous frequency ν and the amplitude ζ_0 is shown in (d).