Investigation of non-thermal process in the dynamics of photo-induced FMR in (Ga,Mn)As

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Abstract We report experimental results which indicate the contribution of non-thermal process in photo-induced ferromagnetic resonance (FMR) in (Ga,Mn)As excited by weak, fs laser pulses.

Introduction

In metallic systems, it has been recognized that randomization of ordered spin systems by the intense laser irradiation (mJ/cm^2) is the fundamental process to realize ultra-fast magnetic excitation [1,2]. In (Ga,Mn)As, photo-induced FMR (ph-FMR) could be triggered by a few μJ/cm^2 laser pulse without an external magnetic field [3,4]. There have been two different arguments to account for the basic mechanism: the ultra-fast spin randomization (thermal process) [4,5], and excitation of electronic states associated with ordered spins (non-thermal process) [3]. We report here that, in the time-resolved magneto-optical (TRMO) measurements for the weak excitation regime ($\leq$ 10 μJ/cm^2), signals due to the ultra-fast randomization have been hardly observed, and the onset of ph-FMR strongly depends on excitation wavelength. These results suggest significant contribution of non-thermal effect.

Experimental method

TRMO measurements were carried out at 10 K with one-color pump and probe technique. The light source and the sample were a mode-locked Ti:sapphire laser (a pulse width of 150 fs with repetition rate 76 MHz) and a 100 nm-thick $Ga_{0.98}Mn_{0.02}As$ grown on GaAs(001), respectively. Experimental setup has been detailed in Ref.3. The wavelength has been varied in the range λ = 750 - 900 nm, whereas the polarization plane was fixed at the [010] GaAs axis for both pump

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and probe beams. The fluence of the probe beam was fixed at 84 nJ/cm^2, whereas that of the pump (P*) was varied between 0.34 μJ/cm^2 and 10 μJ/cm^2.

Results and discussion

Characteristic oscillatory signals due to ph-FMR have been observed for the wavelengths of λ = 880 nm or shorter. We have found a striking difference concerning *the onset of oscillation* between the data obtained with λ < 820 nm, the region S, and those with λ > 820 nm, the region L. TRMO data obtained with P* = 1.7 μJ/cm^2 are shown in Figs.1(a) and (b). Oscillation starts immediately after the excitation in the region L, whereas it is accompanied with noticeable time delay in the region S. Note that, in the ultrafast time regime (≦ 2 ps), signals due to ultrafast demagnetization have hardly been observed (Fig.1(b)).

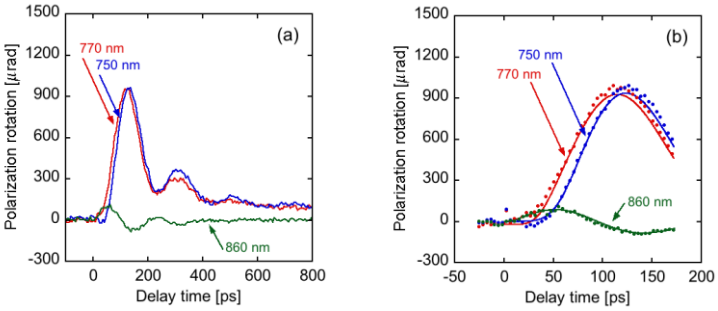

Fig. 1. Photo-induced FMR in (Ga,Mn)As measured at long time scale (a), and short time scale (b). Lines and dots in (b) are experimental and calculated TRMO data, respectively.

Magnetization dynamics was calculated numerically by solving LLG equation. We have added a new *delay term* into the dynamics of an effective field that was developed earlier [3]. Before excitation, the effective field $\boldsymbol{H}$ and the magnetization $\boldsymbol{M}$ both lie along the in-plane [100] direction; with certain time delay τ_g after the excitation at t = 0 ps, $\boldsymbol{H}$ rotates toward the out-of-plane [001] direction and relax back to the [100] direction, with its time constant τ_1 and τ_2, respectively. During this event, $\boldsymbol{M}$ precesses around $\boldsymbol{H}$ with natural damping. With this scenario, the angle $\theta(t)$ of $\boldsymbol{H}$ with respect to the [100] axis was formulated as follows:

$$\theta(t) = \mathrm{erf}(t - \tau_g)\exp(-t/\tau_1)\{1 - \exp(-t/\tau_2)\} \quad (1)$$

Here, the delay term is expressed by the error function erf(t) with the retardation time τ_g. Our approach has reproduced successfully the experimental data, from which τ_g is extracted and summarized in Fig. 2 as a function of excitation photon energy and wavelength. Reflecting the instantaneous oscillations, τ_g = 0 in the region L. This fact indicates the presence of electronic states which allow di-

rect access to the spin subsystem (Fig.3). In the region S, the τ_g value increases with increasing photon energy. This fact suggests that we enter into the region in which another states, presumably the states associated with a host semiconductor, is first excited, and the excess energy is then transferred to the spin subsystem (Fig.3). A dip observed at 790 nm is presumably due to enhanced LO phonon scattering [6].

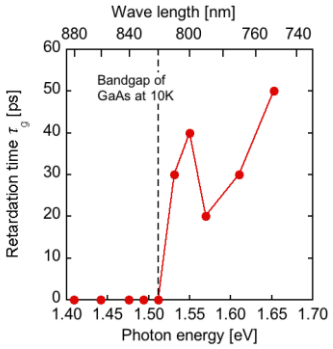

Fig. 2. Photon energy and wavelength dependence of retardation time τ_g.

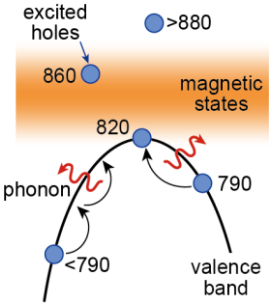

Fig. 3. Schematic illustration of the excitation process for the ph-FMR. Values in the figure indicate the excitation wavelength.

Conclusions

We have found the presence of two different excitation channels for the photo-induced ferromagnetic resonance in (Ga,Mn)As. In the region L ($820 < \lambda \leq 880$ nm), magnetization precession occurs instantaneously with pulsed laser excitation. In the region S ($\lambda < 820$ nm), the precession is accompanied with retardation whose retardation time varies with the wavelength.

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