Time-resolved imaging of photo-excited spin precession on magnetic thin films by the dual-comb based asynchronous optical sampling system

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Abstract

Optically excited magnons coupled with surface acoustic wave (SAW) have attracted much attention due to their rather long propagation distance compared with magnon. To explore this magnon-phonon coupling, it is important to develop a method to measure the dynamics of spin precession and SAW separately. In this study, we utilized a triggerless asynchronous optical sampling method which enables fast time-resolved measurements of magnons and surface vibrations. We visualized the SAW propagation and spin precession clearly and separately around the pump spot on nanosecond timescales. This method will be useful to elucidate the dynamics of the magnon-phonon coupling induced by pulsed laser excitation.

1. Introduction

In recent years, optically excited magnons coupled with phonons in magnetic thin films have been widely studied [1,2]. While magnons typically have a short propagation distance in ferromagnets, their coupling with surface acoustic waves (SAWs), which have relatively low attenuation, allow magnons to propagate over millimeter distances [3]. Therefore, magnon-phonon coupling is considered to be a useful phenomenon for long-distance information transfer in spintronic devices.

Most studies of the magnon-phonon coupling have focused on investigating either magnetization precession or the surface vibration separately [2,4]. However, there have been few studies on the investigation of both dynamics simultaneously. Therefore, it is important to develop a single optical system capable of measuring both photo-excited magnons and phonons. In this study, we employed a combination of a triggerless asynchronous optical sampling system and a Sagnac interferometer to capture time-resolved images of both magnetization precession and SAW propagation, clearly distinguishing their dynamics.

2. Experiment

We used two frequency-stabilized pulsed lasers to perform triggerless asynchronous optical sampling measurement for time-resolved measurements. This method enables rapid data acquisition and captures a vast number of data points – on the order of hundreds of thousands- that represents the dynamics at different delay times between the pump and probe pulses. We measured the displacement of SAW and spin precession, both induced by a pulsed laser on a permalloy thin film deposited on a silicon substrate. To ensure robustness against vibrational noise of the optical system, we employed a Sagnac interferometer. Additionally, we corrected for phase differences caused by slight misalignments of the optical system using a liquid crystal variable retarder. In order to separate the signal of spin precession and the signal of SAW, we measured the data twice with opposite signs of the applied magnetic field. By adding and subtracting these datasets, we successfully obtained clear time-resolved images of SAW and spin precession separately.

3. Results and discussion

Figure 1(a) and 1(b) show the SAW dynamics and spin precession dynamics, respectively, at various positions x near the pump spot on the sample, where $x = 0$ μm corresponds to the pump spot. These dynamics were extracted by summing and subtracting two datasets obtained under an applied magnetic field of ±379 mT, effectively separating the SAW and spin dynamics. In Fig. 1(a), pump pulse hit the sample at 0 ns and $x = 0$ μm and we clearly observed SAW propagation on a nanosecond timescale. The SAW velocity, calculated from the peak times of the traces at different positions in Fig. 1(a), was approximately 5 km/s, consistent with previous research using the same substrate [5]. We also observed a peak at 0 ns and x~0 μm caused by temperature-induced changes in reflectivity. In Fig. 1(b), the signal shows a significant change at 0 ns due to a sudden change of the magnetization direction, initiating spin precession. We observed spin precession persisting for several hundred picoseconds around the pump spot. Thus, by combining the triggerless asynchronous optical sampling method with a Sagnac interferometer, we clearly visualized the SAW and spin dynamics induced by pulsed laser.

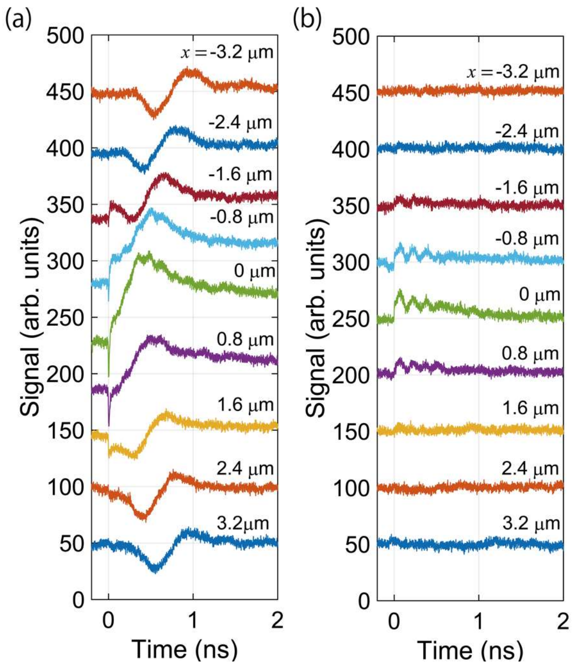

Fig.1 (a) SAW and (b) spin dynamics at a position from the pump spot on the sample x. $x = 0$ μm is the pump position. The data in (a) and (b) correspond to the sum and difference, respectively, of two datasets obtained under an applied magnetic field of ±379 mT.

4. Conclusions

In this study, we employed the triggerless asynchronous optical sampling method for rapid data acquisition, capturing hundreds of thousands of data points over time, combined with a Sagnac interferometer. Using datasets obtained under an applied magnetic field of ±379 mT, we successfully visualized the propagation of SAW and spin precession separately. This approach provides a powerful tool for probing the dynamics of magnon-phonon coupling phenomena induced by pulsed laser excitation.

References

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