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Spatially resolved pump-probe magneto-optical Kerr effect in permalloy films

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Abstract

Measurement set-up of the spatially resolved pump-probe magneto-optical Kerr effect was constructed to investigate laser-induced spin-wave propagation in micrometer region. One dimensional-space and time mapping of laser-induced change in Kerr rotation angle was successfully obtained in permalloy films and the wave packet propagation was clearly observed, which may be attributed to the spin-wave propagation.

1. Introduction

Recently, an information processing by using spin-wave propagation, such as the spin-wave logic gate [1] and magnon transistor [2], has attracted much attention for low power consumption device. In order to excite spin-wave propagation, local microwave field [3] or spin-transfer-torque [4] are mainly used. Spin-wave propagation excited locally by femtosecond laser pulse was reported recently, in which ferrimagnetic insulator was used [5]. Observation of spin-waves in micrometer region is important for investigation of spin-wave propagation in ferromagnetic metal thin films which is much more suitable for practical application in terms of integration into Si technology. In this study, measurement set-up of the spatially resolved pump-probe magneto-optical Kerr effect was constructed to investigate laser-induced spin-wave propagation in micrometer region.

2. Experimental method and sample

Ti; sapphire laser was employed to perform optical pump-probe technique, whose wave length and pulse duration are about 800 nm and 120 fs, respectively. Repetition rate of pulse laser are about 80 MHz. Pump laser light was converted to the second harmonic light with wavelength of about 400 nm to reduce the noise. After the laser beams were divided into pump and probe beam, those were focused onto films using several optics and objective lens. Spot diameter of pump and probe beam are 2.5 and 1 μm, respectively. Position of the probe beam was scanned using an electrically-controlled scanning optical mirror to obtain position dependent Kerr rotation angle. The pump beam was modulated at the frequency of 370 Hz, and the pump laser induced change in Kerr rotation angle of reflected probe beam was analyzed by standard optics and lock-in amplifier with the reference frequency of magneto-optical (MO) Kerr rotation angle of the probe beam was detected. An out-of-plane magnetic field was applied during the measurements using an electromagnet.

A 20 nm-thick $Ni_{80}Fe_{20}$ (NiFe) film was fabricated by using UHV magnetron sputtering method on Si/SiO_2 substrate. Deposition was performed under the magnetic field applied to induce uniaxial magnetic anisotropy in the film plane. Magnetic property was characterized by vibrating sample magnetometer and the films showed small coercivity and uniaxial magnetic anisotropy was about 5 Oe in the film plane.

3. Experimental result and discussion

Schematic illustration of measurement geometry is shown in Fig. 1. Before the sample was placed on an optical stage, it was magnetized by applying magnetic field parallel to the magnetic easy-axis of films. Then, the sample was placed on the optical stage and the out-of-plane magnetic field of 3.5 kOe was applied so that magnetization slightly canted with respect to the magnetic easy-axis. This cant of magnetization is necessary to excite magnetization precession using a pulse laser.

Figure 2 shows typical time-space mapping of the laser induced change in Kerr rotation angle. In this measurements, the scanning direction of the probe beam is perpendicular to the magnetic easy-axis. Very large non-oscillatory change in Kerr rotation angle are observed at the pump-probe beam spot distance x ranged from 0 to about 2 μm in the time t of 0 - 1600 ps. This change is attributed to the reduction of magnetization due to the elevation of temperature which is triggered by the light-electron-spin interaction at sub-ps time scale [7].

In addition, an oscillatory change in Kerr rotation angle are clearly observed in the region of the distance $x = \sim$ 1-10 μm in Fig. 2. This oscillatory changes in the data has a space-time correlation being similar to a wave-packet propagation, so that it may correspond to the spin-wave packet propagation. We also performed the same measurements with different scanning directions, and then found that there were no oscillatory signal observed in case that the scanning direction was parallel to magnetic easy-axis. These observations are consistent with the spin-wave packet propagation in magnetic films, as discussed below.

In-plane magnetized magnetic films have two spin-wave mode depending on the propagating direction in long-wavelength limit. The spin wave mode propagating perpendicular to magnetization is called magnetostatic surface wave (MSSW) and the one propagating parallel to magnetization is called magnetostatic backward volume wave (MSBVW) [6]. Dispersion curves are quite different between two modes and it results in the large asymmetry of group velocity of spin-wave packet. We calculated the dispersion curves of two modes using the formula in Ref. [8] that takes into account the magnetization canting, and then found that the group velocity of MSSW of ~ 10 km/s was roughly consistent with that estimated from the data in Fig. 2. Also, the calculated value of group velocity of MSBVW was very small, which is qualitatively consistent with the fact that the wave packet was not observed in the experiments in the parallel geometry. Further studies, *e.g.* magnetic field dependence of spin-wave propagation and the comparison with the calculation, will be discussed elsewhere [9].

4. Conclusions

Spatially-resolved pump-probe magneto-optical Kerr effect measurement set-up was constructed and the laser-induced spin-wave propagation was investigated in micrometer region. Propagating spin-wave packet in NiFe film was successfully observed in the case that propagation direction is perpendicular to magnetization direction, and its group velocity was roughly consistent with that of magnetostatic surface wave.

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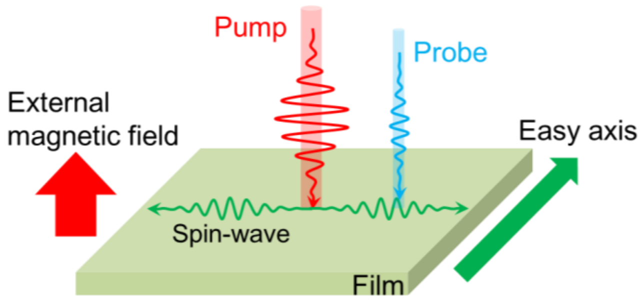

Fig. 1 Schematic illustration of spatially resolved pump-probe technique. Spot diameter of pump and probe beam are 2.5 μm and 1 μm, respectively. Probe beam was scanned to detect spatially dependent spin-wave signal.

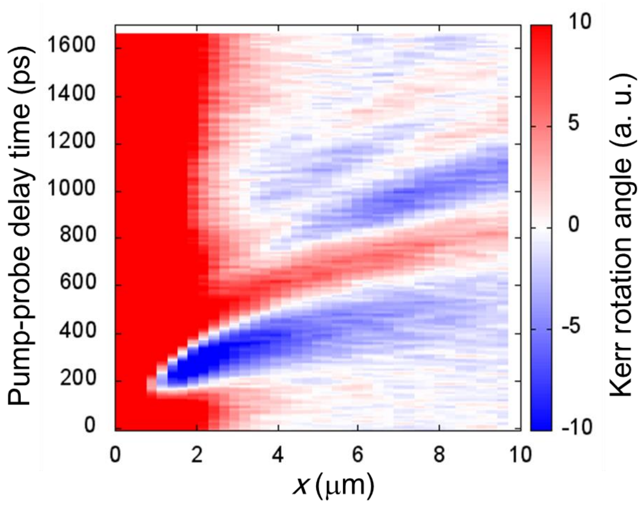

Fig. 2 Laser-induced change in Kerr rotation angle as functions of pump-probe delay time and pump-probe distance *x*. Scanning direction is perpendicular to the magnetic easy-axis.