Damping modification in epitaxially grown continuous $L1_0$-FePt thin films with different substrates

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$L1_0$-ordered FePt has attracted interest for both magnetic recording and spintronic device applications due to its large perpendicular magnetic anisotropy and large magnetoresistance. However, its practical use in spintronic devices is limited because of its large Gilbert damping constant. In this study, we present a method to reduce the damping constant in $L1_0$-FePt thin films through microstructural engineering. Using time-resolved magneto-optical Kerr effect, we analyzed the magnetization dynamics of FePt films grown on MgO, $MgAl_2O_4$ and $SrTiO_3$ substrates. The FePt film grown on $SrTiO_3$ substrate has a smaller lattice mismatch than FePt grown on MgO and $MgAl_2O_4$ substrates, as well as a significantly lower damping constant of 0.030 compared to 0.059 for the MgO sample. These results highlight the possibility of substrate-induced nanostructure control of the magnetization dynamics toward. Our results show that $L1_0$-FePt is a promising material for spintronic applications which require both large perpendicular magnetic anisotropy and low damping.

All-optical method, L10-FePt, magnetization dyanmics. Time-resolved magneto-optical Kerr effect

I. Introduction

$L1_0$-ORDERED FePt has attracted significant interest as a magnetic recording material, owing to its large perpendicular magnetic anisotropy (PMA), large saturation magnetization, and chemical stability. Beyond recording media application, its large magnetoresistance and high spin injection efficiency make it a promising candidate for spintronic applications, [1,2] including a spin-Hall nano oscillator. [3,4] Theoretically, the large PMA field of $L1_0$-FePt allows for it to be used in spintronic device which can operate at precession frequencies above 100 GHz the point defined as the THz gap. However, despite these promising magnetic properties, the practical application of $L1_0$-FePt in spintronic devices has so far been limited primarily due to an insufficient understanding of its magnetization dynamics.

Only a few experimental studies have reported on the magnetization dynamics of $L1_0$-FePt [5,6], and those that do often cite relatively large Gilbert damping constants—ranging from 0.05 to 0.26. This relatively large damping constant is not suitable for the manipulation of magnetization precession in spintronic devices.

In our research group, we have established advanced measurement techniques to evaluate the fast magnetization dynamics of $L1_0$-FePt thin films. Using time-resolved magneto-optical Kerr effect (TRMOKE), we have explored the magnetization dynamics above 100 GHz in $L1_0$-FePt thin films to discuss the magnetic damping constant. [7,8] In order to get insight into the modification of the magnetic damping constant by controlling the microstructure, we have grown $L1_0$-FePt thin films on different substrates, MgO, $MgAl_2O_4$ (MAO) and $SrTiO_3$ (STO). We found that we could significantly reduce the damping constant of FePt by controlling the lattice mismatch between the $L1_0$-FePt thin film and the substrate. The film grown on the STO substrate had a smaller lattice mismatch and an improved microstructure, which correlated with a substantial reduction in the damping constant down to a value as low as 0.030.

II. Experimental procedure

$L1_0$-ordered FePt thin films with a thickness of 36 nm were fabricated via DC magnetron sputtering on single-crystalline MgO(001), MAO(001) and STO(001) substrates. Prior to deposition, the substrates were annealed at 650 °C for one hour in vacuum to eliminate surface contamination. Films were grown with a substrate temperature of 500 °C.

Structural characterization was performed using X-ray diffraction (XRD) with Cu $K\alpha_1$ radiation. Cross-sectional scanning transmission electron microscopy (STEM) imaging was carried out to characterize the microstructure. TRMOKE measurements were performed using an ultrafast laser system with a center wave length, pulse duration, and repetition rate of 1028 nm, 290 fs, and 10 kHz, respectively. A probe beam with a center wave length of 514 nm was generated using a BBO crystal, and the amplitude of a pump beam was modulated by a mechanical chopper operating at 870 Hz. The pump induced change in the Kerr rotation angle of the reflected probe beam was detected using a balanced photodiode detector and lock-in amplifier by varying the optical delay Δt between the pump and probe laser pulse. An external magnetic field up to 7.0 T was applied at 45° with respect to the film normal during measurements.

III. Results and discussion

As seen in Fig.1, XRD data of the FePt films grown on MgO, MAO and STO substrates showed well-defined superlattice peaks corresponding to the $L1_0$ phase.

TRMOKE data for all samples showed damped oscillational signal relating to the magnetization precession as shown in Figs. 2(a). By fitting these spectra using a damped sinusoidal function, we extracted the precession frequency f and effective damping constants α_{eff} as a function of magnetic field $\mu_0 H$. The solid curves seen in Fig 2(b) represent the fitting of the precession frequency using Kittel's formula with a fixed *g*-factor of 2.002. PMA field for MgO, MAO and STO samples were evaluated to be 6.7, 6.5 and 8.4 T, respectively. In Fig.2(c), the STO sample showed a minimum damping value of 0.030, whereas the MgO and MAO samples exhibited a higher value of 0.059 and 0.037, respectively. Further detailed analysis and microstructure observation data will be discussed in the poster presentation.

Reducing the damping constant whilst maintaining a large PMA field is crucial for the development of high-frequency spintronic devices working in the THz gap. These findings highlight the importance of microstructure and engineering the interface to control the magnetization dynamics of ferromagnetic thin films. Our results provide a practical approach for optimizing $L1_0$-FePt for its use in high-frequency spintronic devices.[6]

This work was partially supported by the Japan Science and Technology Agency (JST) Core Research for Evolutional Science and Technology (CREST) (Grant No. JPMJC22C3), the Ministry of Education, Culture, Sports, Science and Technology (MEXT) Leading Initiative for Excellent Young Researchers (Grant No. JPMXS0320230032), and the Japan Society for the Promotion of Science (JSPS) KAKENHI (Grant Nos. JP21K14218 and JP18H03787).

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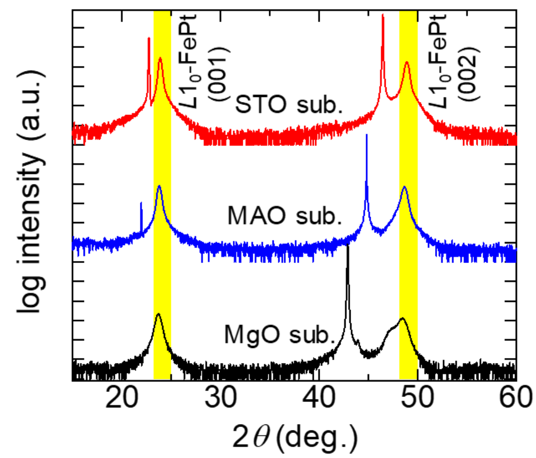

Fig. 1. XRD patterns of FePt thin films deposited on MgO, MAO and STO substrates.

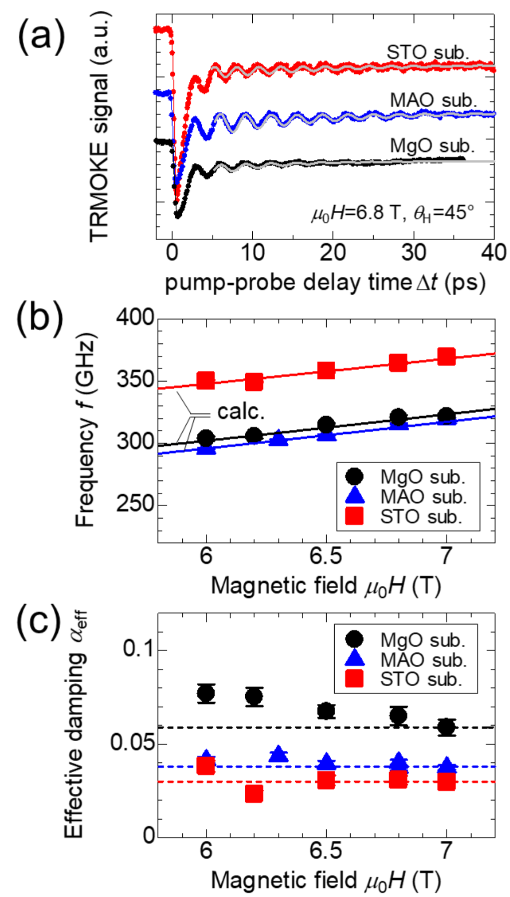

Fig. 2. (a)Typical wave forms of TRMOKE data for the films depositted on MgO, MAO, and STO substrates. Solid curves are the fitting results. (b)Precession frequency f and (c)effective damping constants α_{eff} of FePt thin films. Solid curves show the theoretical fitting results. Dashed lines show the minimum values of α_{eff} for each sample.