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In-plane low damping constant of $LaSrMnO_3$ thin films

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Abstract

High-speed operation and low power consumption of spin dynamic devices require magnetic materials having low damping constant. One of the famous low damping material, i.e. $Y_3Fe_5O_{12}$ (YIG), is usually grown onto $Gd_3Ga_5O_{12}$ (111) substrates with thicknesses in the micron range, hence, hampering some interfacial functionalities (and/or application). In this report, we present the in-plane low damping of $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) epitaxial films ($7 \leq t \leq 53$ nm) grown onto $(LaAlO_3)_{0.3}$-$(SrAl_{0.5}Ta_{0.5}O_3)_{0.7}$ (100) substrates. The effective damping constant (α_{eff}) of 53-nm-thick LSMO showed 7×10^{-4} for magnetic easy axis and 6×10^{-4} for magnetic hard axis at room temperature. The low α_{eff} of LSMO might be considered by the half-metallic band structure which could suppress the spin flipping by the minority spins during precession. This mechanism is similar to the half-metallic Heusler alloy. Thickness dependence of α_{eff} indicates the existence of surface dead layer in LSMO.

1. Introduction

Low magnetic damping materials have an important role in spintronics devices to realize high speed operation and low electric consumption; such as magnetic random access memory, spin wave transmission, spin torque oscillator (detector), and reservoir computing. In the case of metallic materials, Heusler alloys epitaxial films shows the low damping ($\alpha_{eff} = 3 \times 10^{-3}$) constant at room temperature (RT). [1] $Y_3Fe_5O_{12}$ (YIG) epitaxial films are the lowest damping constant ($\alpha_{eff} = 6 \times 10^{-5}$) at RT among the oxide materials. [2] YIG films degrade spin dynamics properties when the thickness of the films enter the nanoscale range. Also, YIG need to be epitaxially grown onto $Gd_3Ga_5O_{12}$ (GGG) (111) substrates to obtain low damping constant. These conditions of YIG are disadvantageous in order to integrate spintronics device application. The cubic perovskite LSMO can be epitaxial grown on various type of single crystal perovskite substrates. The tetragonal LSMO (t = 45 nm) under strong compressive strains from single crystal $NdGaO_3$ (110) substrates showed a low damping constant of 5×10^{-4} to the perpendicular direction at RT. [3] However, in-plane and angular dependence of damping constant for the LSMO films is not clarified yet. In-plane damping constant has important role for the spin wave transmission device in spin-magnonics research fields. [4] In this study, we grew LSMO epitaxial films onto $(LaAlO_3)_{0.3}$-$(SrAl_{0.5}Ta_{0.5}O_3)_{0.7}$ (LSAT) substrates and investigated the damping constant along the in-plane direction of both magnetic easy and hard axes. The lattice constant of bulk LSMO and LSAT substrate is 0.3870 nm and 0.3868 nm, respectively. Being the lattice mismatch very small we can discuss the damping constant for fully relaxed LSMO films.

2. Experimental procedures

The LSMO films were grown by pulsed laser deposition onto 5×5 mm^2 LSAT substrates. A ceramic LSMO target was ablated by a KrF (248 nm) excimer laser. The LSMO deposition was performed keeping the LSAT at 700°C in an oxygen partial pressure of 0.2mbar. The thickness of the samples was changed by deposition time. Dynamic magnetic properties were measured by ferromagnetic resonance (FMR) at RT. FMR measurements were carried out by originally designed coplanar waveguide of transmittance type. Microwaves are generated by signal generator (Keysight; E8257D) which is transmitted by SMA (~ 18 GHz) cables and connectors. The noise was reduced by a lock-in amplifier using ~ 300 kHz of low frequency. The angular dependence was carried out by rotating samples on coplanar waveguide. Static magnetic properties were measured by superconducting quantum interference device (SQUID) magnetometer at 300 K. All magnetic measurements were in-plane direction.

3. Results and discussion

Epitaxial growth of LSMO films onto LSAT substrates was confirmed by X-ray diffraction (XRD) measurements. The XRD peaks of LSMO for out-of-plane direction was almost overlapped to the LSAT substrates which indicates the LSMO grew under very small epitaxial strain owing to small lattice mismatch. The in-plane magnetic easy axis of LSMO was [110] and hard axis was [100] which was evaluated by SQUID magnetometer.

Figure 1 shows (a) FMR spectrum, (b) FMR frequency versus resonance field, and (c) FMR linewidth as a function of frequency for LSMO film (t = 53 nm). External magnetic field was applied in both easy and hard magnetic directions. The FMR frequency was changed between 3 and 18 GHz. Because the transmission coefficient is depending on the frequency, FMR spectra were normalized by maximum absolute absorption intensity for each frequency value. The FMR spectrum [Fig. 1(a)] can be fitted by the Lorentz line shape with the formula combined with absorption and dispersion

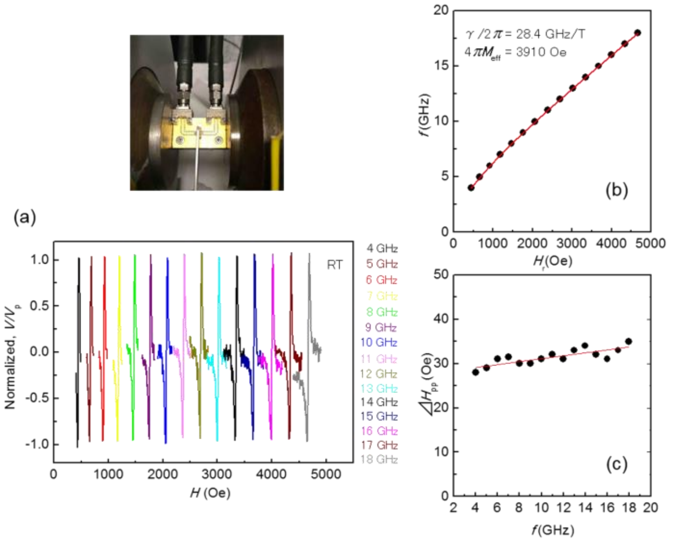

Fig. 1 FMR spectrum of 53 nm-thick LSMO epitaxial films at RT. Magnetic field was applied to easy [110] and hard [100] axes.

line shape. The frequency dependences of the resonance field (H_{res}) for the LSMO films to different directions are shown in Fig. 1(b) and can be used to extract information about the spin dynamic properties and anisotropies of the films. With the applied magnetic field for the in-plane direction, the relation between frequency and H_{res} could be simply described by the Kittel equation. The effective Gilbert damping constant (α_{eff}) of the samples was evaluated by fitting the FMR linewidth (ΔH_{pp}) as a function of frequency (1), where f is the microwave driven frequency and ΔH_0 is the inhomogeneous residual linewidth. [5, 6]

$$\Delta H_{pp} = \frac{2}{\sqrt{3}} \cdot \frac{2\pi}{\gamma} \alpha_{eff} f + \Delta H_0 \qquad (1)$$

In order to exclude the influence of the inhomogeneity of magnetic anisotropy distribution, the linear fitting was carried out above 6 GHz. α_{eff} of LSMO films for the in-plane magnetic easy axis was 7.4×10^{-4}, which is comparable to the damping constant measured along the perpendicular direction for tetragonal LSMO films. [3] Interestingly, α_{eff} of LSMO films is lower than the one measured for metallic materials. [1] Being the LSMO a half-metallic ferromagnet the low damping mechanism can be explained via low spin flipping by lack of density state in minority spins at Fermi level. The α_{eff} increased by one order of magnitude (6.2×10^{-3}) for the magnetic hard axis, which might indicate that α_{eff} is influenced by *s-d* interaction. [7]

Figure 2 shows LSMO thickness dependence of α_{eff} to magnetic easy axis. α_{eff} of LSMO increased by decreasing the thickness of the films. The lattice mismatch between LSMO and LSAT substrate is very small; therefore, the increase of α_{eff} is not caused by the lattice mismatch. The island growth of LSMO is negligible because atomic flat surface was observed by atomic force microscopy. It was reported that the surface Mn moment was drastically decreased by decrease of carrier density at the surface of the LSMO films. [8] It can consider that increase of α_{eff} is due to magnetic dead layer at the surface, so when the capping layer is on LSMO, we can expect low α_{eff} even at a few nanometer-thick LSMO films.

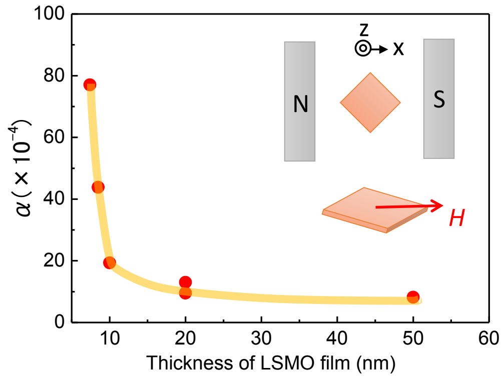

Fig. 2 Thickness dependence of damping constant at RT. The magnetic field was applied to easy axis.

4. Summary

LSMO epitaxial films were grow onto LSAT substrates and in-plane dynamic/static magnetic properties were evaluated at RT. Interestingly, very low α_{eff} of 7.4×10^{-4} was obtained along the [110] magnetic easy axis, which might be attributed to the half-metallic band structure. This low α_{eff} for LSMO can open new paradigms for oxide spintronics applications. By choosing an optimal capping layer could further decrease α_{eff}.

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