Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp1199-1200

Spin Wave Characteristics in Multi-layered Rare-earth Iron Garnet Thin Films with and without Spatial Inversion Symmetry

Ryota Kikuchi[1], Akihiro Katougi[1], Hiroyasu Yamahara[1], and Hitoshi Tabata[1]

[1] Univ. of Tokyo
7-3-1, Hongo, Bunkyo-ku
Tokyo 113-8656, Japan
Phone: +81-3-5841-1870 E-mail: kikuchi@bioxide.t.u-tokyo.ac.jp

Abstract

Multi-layered rare-earth iron garnet thin films with and without spatial symmetry are fabricated by pulsed laser deposition, and their magnetic properties such as magnetic anisotropy, spin damping constant, and inverse spin Hall effect voltage are investigated. The asymmetric films show increase of uniaxial anisotropy constant, furthermore the damping constant decrease when magnetic field is applied in-plane direction. The relation between spatial inversion symmetry and spin wave characteristics in rare-earth iron garnet artificial lattice are discussed in this study.

1. Introduction

In recent years, information technology based on spin wave, namely magnonics is intensively investigated[1] since ultralow power consumption data storage and signal processing are expected. Rare-earth iron garnet (RIG) is a ferrimagnetic insulator and considered as an ideal material for spin wave transport because it shows extremely low Gilbert damping. Furthermore, strain tuning of dielectric and/or magnetic properties is demonstrated in recent studies. For example, enhancement of flexoelectricity[2-4] and control of magnetic anisotropy[5,6] have been reported. In order to generate flexoelectricity, strain-gradient structure that break spatial inversion symmetry is important, where canted spins are expected to show magnetoelectric (ME) effect by Dzyaloshinski-Moriya interaction. However materials for film and substrate are limited to apply appropriate epitaxial lattice strain. In this study, multi-layered RIG thin films, that show symmetric or asymmetric structure in deposition order, are fabricated to investigate the relation between spatial inversion symmetry and spin wave characteristics.

2. Experiment

Multi-layered rare-earth iron garnet thin films are grown by pulsed laser deposition (PLD). Among various rare-earth iron garnets, $Y_3Fe_5O_{12}$ (YIG), $Lu_3Fe_5O_{12}$ (LuIG) and $La_3Fe_5O_{12}$ (LaIG) are selected because their low Gilbert damping constant are expected. First, single-layered RIG films are grown to understand basic spin dynamics of each material. Second, two-layered RIG films with various film thicknesses are fabricated to investigate the magnetic interaction between stacked RIG films. Finally, tricolored artificial lattices of RIG are fabricated. The samples with and without spatial inversion symmetry are prepared by changing the order of deposition.

All films are deposited on $Gd_3Ga_5O_{12}$ (GGG) (001) substrates. Lattice mismatch between RIG films and GGG substrates are calculated to be -0.06% (YIG/GGG), -0.86% (LuIG/GGG), and 3.10% (LaIG/GGG), respectively. Therefore, deposition in the order of LaIG/YIG/LuIG are repeated several times, which shows asymmetrical structure. On the other hand, repetition of LaIG/YIG/LuIG/LuIG/YIG/LaIG shows symmetric structure. The film thickness of each layers are varied from 2.5 nm (~2 u.c.) to 5 nm (~4 u.c.).

The crystalline structures of films are analyzed through an X-ray diffraction. X-ray reciprocal space mappings (RSM) around (408) plane are measured to confirm epitaxial relationship between the films and substrates. The magnetic hysteresis loops are measured by magnetic circular dichroism (MCD) in order to discuss the magnetic anisotropy. Furthermore, ferromagnetic resonance (FMR) studies are carried out to evaluate the Gilbert damping constant in addition to the magnetic anisotropy.

3. Results and discussion

Fig.1(a) shows resonance magnetic fields of two-layered YIG/LuIG film and single-layered YIG and LuIG films. Coupling of the two-layered film at the interface is suggested because of its single resonance peak. Fig.1(b) shows LuIG volume ratio dependence of effective demagnetizing field calculated from resonance magnetic field[5][7]. By varying the LuIG volume, modulation of magnetic anisotropy is confirmed.

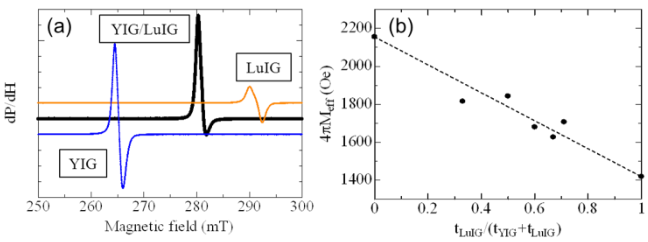

Fig.1 (a) Ferromagnetic resonance of two-layered YIG/LuIG film and single-layered YIG and LuIG films. (b) LuIG volume dependence of effective demagnetizing field calculated from resonance magnetic fields.

Fig.2 shows 2θ-ω X-ray diffraction around GGG (004) of (LaIG/YIG/LuIG) artificial lattices. Each sample shows superlattice diffractions which reflect the thickness of periodic unit structures. From these superlattice diffraction peaks, thickness of unit structure is calculated to be 22 nm, 29 nm, 8 nm, and 17 nm, respectively. These values are respectively close to 15 nm (4 u.c. × 3), 30 nm (4 u.c. × 6), 8 nm (2 u.c. × 3), and 15 nm (2 u.c. × 3), therefore as-designed artificial lattice structure are prepared.

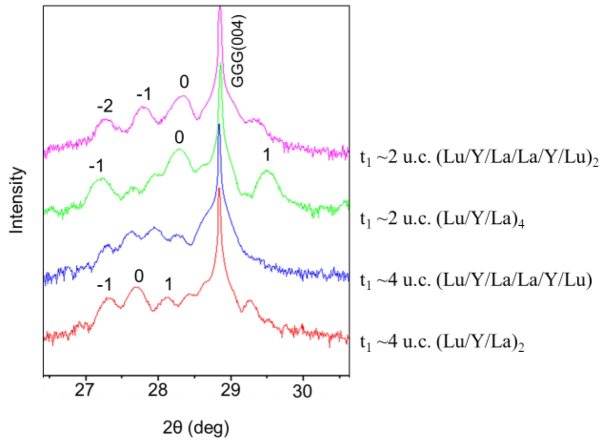

Fig.2 2θ-ω X-ray diffraction around GGG (004). Index numbers represent superlattice diffraction.

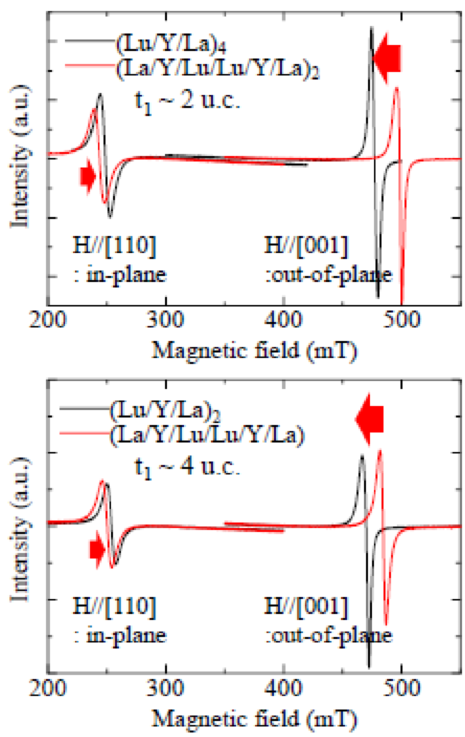

Fig.3 Ferromagnetic resonance applying magnetic field in the in-plane direction or out-of plane direction. Red and black lines describe resonance peaks of artificial lattice films with and without spatial inversion symmetry, respectively.

Fig.3 shows magnetic field sweep of FMR measurement. Comparing the samples with and without spatial inversion symmetry, the former shows larger/smaller resonance magnetic field when magnetic field applied in-plane/out-of-plane directions. This indicates increase of uniaxial magnetic anisotropy constant in asymmetric structure.

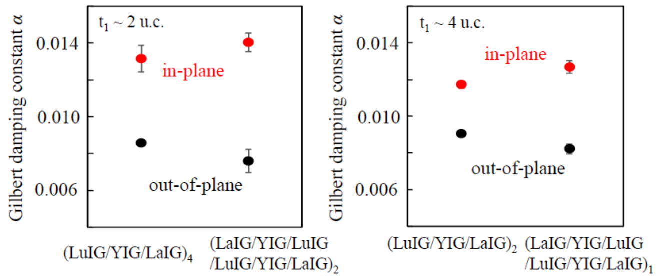

Fig.4 Gilbert damping constant calculated from ferromagnetic resonance line width. Red and black dots are measured when magnetic field is applied in-plane and out-of-plane direction, respectively.

Fig.4 shows Gilbert damping constant calculated from FMR line width using eq. (1).

$$\alpha = \frac{\gamma \Delta H}{2\omega} \quad (1)$$

Asymmetric samples show smaller α than symmetric ones for in-plane magnetic field configuration. On the other hand, symmetric samples show smaller α for out-of-plane magnetic field configuration.

3. Conclusions

We fabricate multi-layered RIG film by PLD. Two-layered YIG/LuIG films show change of effective demagnetizing field by varying LuIG volume ratio. In the tri-colored artificial lattices, samples without spatial inversion symmetry show higher uniaxial magnetic anisotropy compared with samples which have symmetric structure. Furthermore, it is found that Gilbert damping constant varies by changing the symmetry or applying direction of magnetic field.

References

[1] Y. Kajiwara et al. Nature **464** (2010) 262.
[2] J. H. Haeni et al. Nature **430** (2004) 758.
[3] J. H. Lee et al. Nature **466** (2010) 954.
[4] T. D. Nguyen et al. Adv. Mater. **25** (2013) 946.
[5] H. Wang et al. Phys. Rev. B **89** (2014) 134404.
[6] J. Fu et al. Appl. Phys. Lett. **110** (2017) 202403.
[7] M. Farle et al. Rep. Prog. Phys. **61** (1998) 755.