Magnetic properties of pulsed laser ablated YIG thin films on different substrates

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Abstract

Thin films of yttrium iron garnet (YIG) were deposited on single crystals of gadolinium gallium garnet (GGG) (111) and Si (1 0 0) substrates by pulsed laser deposition (PLD). The films deposited at substrate temperature ($T_s$) of 750°C on GGG substrates show textured YIG phase. However, films deposited on Si substrates at $T_s$ of 600–750°C, show YFeO$_3$ phase along with one YIG (400) peak. For a $T_s$ of 850°C only one peak of very low intensity is observed which is close to (820) of YIG and (231) of YFeO$_3$.

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1. Introduction

Polycrystalline yttrium iron garnet (YIG) films have been deposited in recent time for a range of magnetic, magneto-optical and microwave applications [1]. Pulsed laser deposition (PLD) has recently emerged as a useful technique to deposit the films of multi component oxide materials. The present work is focused on the structural and magnetic studies of YIG thin films deposited by PLD on different substrates in our laboratory.

2. Experimental

A polycrystalline ceramic target with a nominal yttrium iron garnet composition of Y$_3$Fe$_5$O$_{12}$ has been fabricated by solid state reaction method. YIG films were deposited by PLD on single crystals of Si (1 0 0) and GGG (1 1 1) substrates in oxygen atmosphere at 0.16 mbar. Prior to the deposition, chamber was evacuated to a base vacuum of $4.0 \times 10^{-6}$ mbar. The third harmonic (335 nm) of Nd:YAG laser, with 10 Hz repetition rate and 5–6 ns pulse width was used to ablate a polycrystalline YIG target. The substrate temperature ($T_s$) was varied from 600°C to 850°C during deposition.

The thicknesses of the films were measured by a stylus profilometer (DekTak IIA). Vibrating sample magnetometer (VSM) was used to measure the saturation magnetization ($4\pi M_s$) by applying the magnetic field parallel to the film plane. Ferromagnetic resonance (FMR) measurements were carried out on a Varian E-line spectrometer.

3. Results and discussion

YIG films were deposited on GGG (1 1 1) substrates, at $T_s$ of 750°C with varying thickness. XRD of the films deposited on GGG substrates show (1 1 1) oriented YIG film. We used perpendicular and parallel FMR to determine the Lande ‘$g$’ factor and the effective
magnetization \((4\pi M_{\text{eff}})\) for the films with thickness 140–1100 Å, where \(4\pi M_{\text{eff}}\) is defined as \((4\pi M_s - H_k)\) with \(H_k\) being the uniaxial anisotropy field.

Fig. 1 shows \(4\pi M_{\text{eff}}\) as a function of films thickness for the films. \(4\pi M_{\text{eff}}\) varies as a function of thickness. The value of \(4\pi M_{\text{eff}}\) for 140 Å sample is 1239 G, which is only 70% of the bulk value. It is interesting to note that the value of \(4\pi M_{\text{eff}}\) goes up as a function of thickness and reaches a value of 2200 G for 1100 Å, which is higher than the bulk (1800 G) [2].

The value of Lande ‘\(g\)’ factor calculated by FMR, on the other hand, was 2.10 for 140 Å and 2.01 for 1100 Å thickness. Normally, one would have expected that (111) being easy direction in YIG, the value of \(4\pi M_{\text{eff}}\) should have been smaller than the bulk. Hence, in these PLD YIG films either the magnetization is inherently large or some other strong from of the in-plane anisotropy is present. Unfortunately, saturation magnetization \((4\pi M_s)\) of these films (140–1100 Å thickness) could not be measured using the VSM because of large paramagnetic contribution of GGG substrate. Popova et al. [3] have recently reported a study on PLD YIG film on quartz substrates and observed increase in magnetization in their films as a function of thickness.

Our earlier studies on sputter deposited strontium ferrite show negligible effect of substrate [4]. Hence, we deposited YIG films on Si substrate to get an idea of \(4\pi M_s\) in these films. Fig. 2 shows the X-ray diffraction (XRD) of thin films deposited on Si substrates as a function of substrate temperature. The thickness of these films was around 2500 Å. The film deposited at a \(T_s\) of 600°C shows number of diffraction line corresponding to YFeO\(_3\) phase along with a single (400) YIG peak. As the substrate temperature goes up the most intense peak of YFeO\(_3\) phase (corresponding to 112 plane) disappears entirely and the (400) peak of YIG becomes the most intense. At a substrate temperature of 800°C no sharp peak is observed and at a \(T_s\) of 850°C one peak of very low intensity is observed which is very close to (8 2 0) of YIG and (2 3 1) of YFeO\(_3\). Saturation magnetization \((4\pi M_s)\) of the films deposited in the range 600–750°C was around 100–150 G, which is close to the bulk value of YFeO\(_3\) (100 G) [5]. On the other hand, films deposited at 850°C exhibit a \(4\pi M_s\) of 500 G, which is much higher than the bulk value of YFeO\(_3\) and smaller than the bulk value of YIG. The absence of XRD peaks indicates that the films are likely to be nanocrystalline and the magnetization of 500 G could be because of nanocrystallinity and the mixture of YFeO\(_3\) and YIG phase.

Thus the present studies indicate that the magnetic and structural properties of PLD YIG films are dependent on the substrates on which they are deposited.

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References