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Effect of Oxygen Pressure on Structural and Magnetic Properties of YIG Thin Films

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Abstract The effect of oxygen pressure (P_{O2}) on the Yttrium Iron Garnet (YIG) thin films were grown on silicon substrate by rf sputtering method was studied. The as-deposited films at 300K were amorphous in nature. The crystallization of these films was achieved by annealing at a temperature of 800°C/1hr in air. The structural, microstructural and magnetic properties were found to be dependent on P_{O2}.

Keywords: ferromagnets, magnetic properties of monolayers and thin films.
PACS: 75.50.Gg, 75.70.Ak.

INTRODUCTION

The $Y_3Fe_5O_{12}$ (YIG) has been commercially used in microwave circuits that include resonators, isolators and circulators, and there have been several attempts to fabricate YIG thin films for device applications.

The variation of their chemical, structural, and magnetic properties with oxygen pressure and substrate temperature has not been fully addressed to. In the present investigations, the magnetic properties as a function of low oxygen pressure have been investigated.

EXPERIMENTAL METHOD

In the present investigation, the thin films were grown on silicon substrates by using rf sputtering method. The target of YIG is prepared by solid state method using yttrium oxide and ferric oxide. The target was sintered at 1200°C/6h using conventional sintering method. The radiofrequency used was 13.56 MHz, and the plasma operating power was kept constant at 100W.The distance between target and the substrate was fixed at 4.6cm. The deposition runs were performed under pure oxygen gas pressure of 2.6×10^{-2} mbar. The films were grown in oxygen pressure of 20mT, 30mT, 40mT and 50mT at room temperature for 90 minutes and followed by annealing at 800°C for 1h in air.

The effect of oxygen pressure on the structure of the as-grown films was investigated by X-ray diffractometer (XRD).The thickness of the films was measured by using a surface stylus profilometer (Ambios tech model XP-1). The non-contact mode of an atomic force microscope (AFM) was used for acquiring topographical images, roughness and crystallite size. The magnetic properties of the films were measured using a vibrating sample magnetometer (VSM) in a perpendicular field configuration with the applied field upto 5kOe.

RESULTS AND DISCUSSION

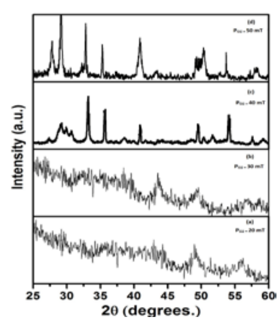

FIGURE 1. XRD patterns of thin film at different oxygen pressures.

Fig.1 (a-d) shows the XRD patterns of YIG films deposited under different oxygen pressures (P_{O2}) and annealed at 800°C/1h. It is observed that as the P_{O2} increases, there is an increase in peak intensities which confirms an increase in crystallite size. The good crystallinity is observed for P_{O2}=50mT. According to the earlier reports, if P_{O2} is less than 30mT, films have oxygen deficiency and if it is greater than 30mT iron and yttrium deficiencies will be created [1]. The large number of YIG peaks detected in the XRD (40mT&50mT) is an indication that the

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films are polycrystalline, possibly with random orientations of the crystal grains. An intermediate phase of YIG, $YFeO_3$ which is weakly magnetic in nature is observed in the XRD patterns at P_{O2}=40 and 50 mT. Dumont et al.[1] have deposited oxygen off-stoichiometric YIG thin films on SiO_2 substrates using PLD by varying the base oxygen partial pressure between 15 and 400 mT. They observed that the polycrystalline single-phase YIG, with slight texture could be grown at 840°C of substrate temperature and 30mT of P_{O2}. The lattice constants obtained in the present studies are given in Table 1. It is observed that lattice constant increased with P_{O2} According to Metselaar et al. the increase of lattice parameter with P_{O2} is due to the formation of oxygen vacancies [2]. Apart from the formation of the oxygen vacancies, this deformation is possibly due to strains occurring at the interface. However, in the present investigation, good crystalline YIG film is deposited at P_{O2}=50mT and substrate temperature of 800°C.

TABLE 1. Structural parameters of the thin films deposited under O_2 environment.

P_{o2} (mT)	Thickness (µm)	RMS (nm)	Grain size(nm)	Lattice constant	M_s (emu/g)	H_c (Oe)
20	0.15	10	90	---	---	---
30	0.65	13	126	---	---	2
40	1.10	19	153	12.362	1.15	12
50	1.32	27	178	12.372	2.00	20

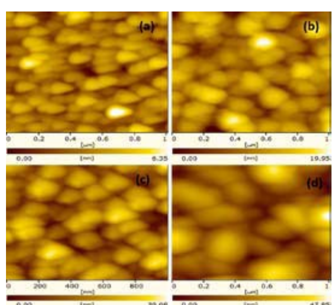

FIGURE 2. AFM images of (a) 20mT (b) 30mT, (c) 40mT and (d) 50mT.

Fig.2(a-d) shows the AFM images of YIG thin films deposited under different P_{O2}. By increasing the P_{O2} the adatoms to the growth steps increases. The increase of growth of grains with P_{O2} increases the thickness of the film and formation of crystalline phase which is evident from fig.2. It was found that films deposited at high oxygen partial pressure had large grains on the surface. The surface roughness of the films is influenced by P_{O2}. The values of RMS, grain size and thickness are given in Table 1. It is seen that the average roughness increased from 10 nm to 27 nm with an increase of P_{O2}. This is due to variation in the distribution of incident angles and energy of depositing atoms at low and high oxygen pressure. The surface roughness does not significantly affect the magnetic properties of present thin films.

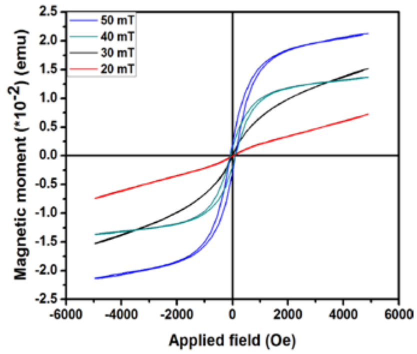

FIGURE 3. M-H loops of YIG thin films deposited at different $P_{O2.}$

Fig.3 shows the magnetization loops of YIG films deposited under different P_{O2}.With an increase of P_{O2} the films are magnetically aligned. The values of saturation magnetization (M_s) and coercive field (H_c) are given in Table.1. The M_s values are found to be small compared to that of bulk values [3]. It is due to the fact that the presence of Orthoferrite phase ($YFeO_3$) with nanocrystalline grains can reduce the magnetic moment. It is generally believed that when the grain sizes are small, a significant ratio of the material lies in the grain boundaries. This grain boundary material is neither properly crystallized nor properly ordered magnetically, and thus is responsible for reduced magnetization. As the grain sizes grow upon annealing, the grain boundary material decreases causing an increase in the magnetization. The values of coercivity for the present films were found to increases with oxygen pressure.

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