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Characterization of RF-sputtered garnet films

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Abstract. Noncrystalline garnet films of nominal composition $Y_3Fe_5O_{12}$ and $Y_2GdFe_5O_{12}$ were synthesized by RF sputtering. The AC and DC resistivity data have been discussed in line with the model of Mott and Davis where conduction occurs through excitation of carriers into localized states at the band edges and hopping at energies close to the band tails.

Keywords. RF sputtering; garnet films.

1. Introduction

Noncrystalline garnets have been synthesized by several methods and characterized before and after crystallization (Popma and Van Diepen 1974; Roy *et al* 1985; Bahadur and Rai 1980). Thin films made by spray pyrolysis (Bahadur *et al* 1986), flash evaporation (Bahadur *et al* 1984) or reactive sputtering (Sawatzky and Kay 1968) yielded an amorphous structure, which upon suitable heat treatment, gave crystalline garnets. Such films showed very interesting structural, electronic and magnetic properties. Garnet films of nominal composition $Y_3Fe_5O_{12}$ (YIG) and $Y_2GdFe_5O_{12}$ (Gd-YIG) by r.f. sputtering and their structural and electronic properties were studied, the results of which are presented here.

2. Experimental

Thin films were made by r.f. sputtering of the hot-pressed target of appropriate composition by Nordiko NM-400 sputtering module on quartz substrates. Gold electrodes were deposited on the film for thickness as well as for electrical measurements. The standard error in thickness measurement is ± 20 Å. The thickness of YIG and Gd-YIG films on which all measurements were carried out were 1400 Å and 1300 Å respectively.

The X-ray diffractions were recorded for the as-prepared and heat-treated samples with a Rich-Seifert isodebyeflex 2002 diffractometer with Cu-K_α target between 2θ values of 25° and 50°. Electron micrographs and diffractions were recorded with a transmission electron microscope (Philips 301). The AC and DC resistivity were measured with a Keithley electrometer and HP impedance bridge (model HP 4192A). I-V characteristics were recorded at intermittent temperatures to see its linearity.

3. Results and discussion

The as-prepared films are amorphous as determined by X-ray diffraction. Partial crystallization occurs only for samples heat-treated above 800°C for both the YIG

and Gd-YIG compositions. It may be noted that the spray-pyrolysed films of the same composition crystallise at 650°C (Bahadur *et al* 1986). Therefore it appears that the r.f. sputtered films are more stable. Secondly, for the spray-pyrolysed films we observe the exsolution of Fe_2O_3 phase along with garnet phase for all the heat treatments we had tried (Bahadur *et al* 1986). In the case of r.f. sputtered films it had been possible to index all the lines to garnet phase for a particular heat treatment. Table 1 lists the *d*- and possible *hkl* values for the sample Gd-YIG heat-treated in two different conditions. When heat-treated at 1100°C for 1 hr, it gives strong lines of both the garnet and orthoferrite phase. The same sample when heat-treated at 1000°C for 2 hr gives a single garnet phase. In this case 1000°C appears as the right growth temperature for the garnet phase. Figure 1 shows a typical electron micrograph for the sample Gd-YIG heat-treated at 700°C. The inset shows its selected area

Table 1. X-ray diffraction data for Gd-YIG film heat-treated in two different conditions (data taken only between $2\theta = 25°$ and $2\theta = 50°$C).

Heat treated at 1000°C for 2 hr		Heat treated at 1100°C for 1 hr	
d value	*hkl*	*d* value	*hkl*
2·96 (S)	400	3·32 (S)	321
2·76 (S)	420	3·02 (S)	400
2·51 (M)	422	2·90 (W)	—
2·19 (W)	440	2·80 (W)	420*
2·09 (W)	532	2·70 (S)	*
1·83 (S)	444	—	—

Note: *hkl* values are w.r.t. YIG phase; The intensity is given in brackets: S, strong; M, medium; W, weak.

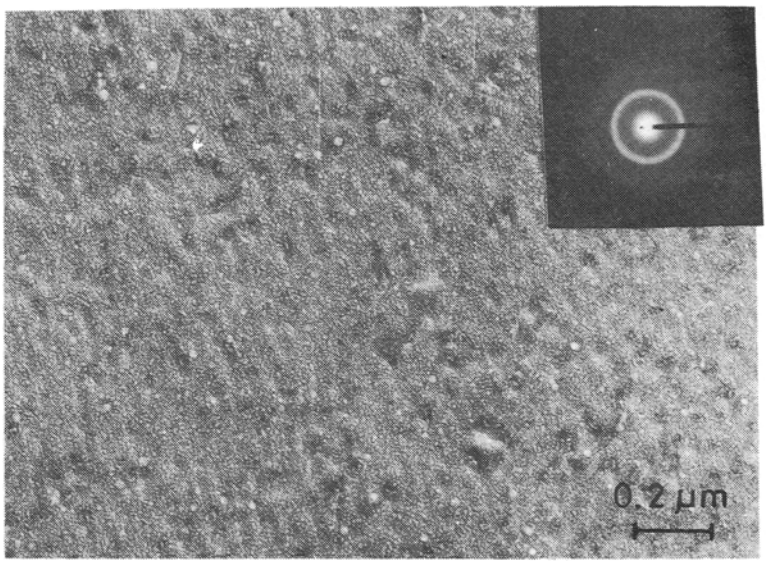

Figure 1. Electron micrograph of nominal composition $Y_2GdFe_5O_{12}$ heat-treated at 700°C for 1 hr. Inset shows the corresponding electron diffraction.

electron diffraction from which an amorphous structure is evident. The micrograph exhibits a fairly homogeneous structure. Figure 2 shows the plot of log ρ_{DC} vs $1000/T$ for YIG and Gd-YIG and figure 3 the representative plot of log ρ_{AC} vs log f for the sample Gd-YIG at two different temperatures. The activation energies evaluated from figure 2 and S values from figure 3 along with temperature ranges are given in table 2.

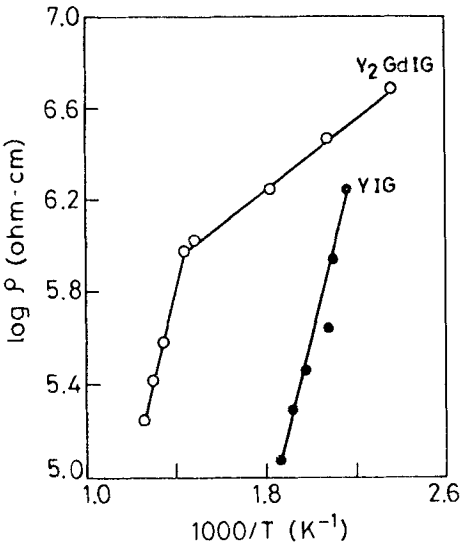

Figure 2. Plot of $\log \rho_{d.c.}$ vs $1000/T$ for films of nominal composition $Y_3Fe_5O_{12}$ and $Y_2GdFe_5O_{12}$.

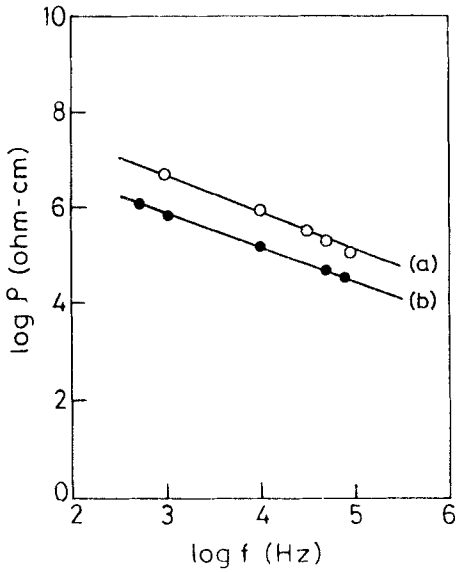

Figure 3. Plot of $\log \rho_{a.c.}$ vs $\log f$ for film of nominal composition $Y_2GdFe_5O_{12}$ at temperatures **a.** 380° K and **b.** 650° K.

Table 2. Activation energies and S values in different ranges for films of YIG and Y_2GdIG.

Sample	Thickness (Å)	Range (K)	Activation energies (eV)	S-values
YIG	1400	420–600	0·34	0·62 (670 K)
				0·93 (RT)
Y_2GdIG	1300	420–690	0·07	0·8 (380 K)
		690–770	0·34	0·75 (650 K)

Note: The parentheses of the last column gives the temperature of measurement.

The sample Gd-YIG exhibits two activation energies whereas the YIG sample gives a single activation energy for the temperature range studied. The value of E_a for YIG is the same as that observed for Gd-YIG in the high temperature region. A similar observation has been made in bulk YIG and Gd-YIG (Bahadur *et al* 1981). It appears, therefore, that the localized sites through which hopping occurs are essentially the same. However, for lower temperature region where Gd-YIG exhibits an activation energy of 0·07 eV, Gd-substitution may be responsible for the generation of some new localized states which is closer to the fermi level. Another noteworthy feature of the DC resistivity data is the lower values of resistivity and activation energies compared to the bulk sample. Lowering of activation energies was similarly observed in flash-evaporated garnet films (Bahadur *et al* 1984). This is attributed to the tails of localized states and the band of compensated levels in amorphous systems which could lower the activation energies. It is interesting that the frequency dependence of resistivity varies approximately as σ^S where S lies between 0·6 and 1.

In the light of these results, it is possible to assign the electronic conduction due to the excitation of carriers into localized states at the band edges and hopping at energies close to band tails (Mott and Davis 1980; Nagels 1979). In this model a narrow tail of localized states at the extremities of the valence and conduction band and a band of localized levels near the middle of the gap exist. According to this, three conduction mechanisms are possible: (i) The extended state conduction, which demands a frequency-independent conductivity is ruled out, (ii) the conduction in localized states at the fermi energy may not be operative as indicated by the exponential dependence of $\rho(f)$ with temperature and (iii) this is then a characteristic of conduction in band tails which appears to be the mode of conduction in the system.

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