Electron transport in non-crystalline garnet films

D BAHADUR, D ROY, B SINGH* and D SARAN*

Advanced Centre for Materials Science, Indian Institute of Technology, Kanpur 208 016, India

*Department of Physics, Indian Institute of Technology, Kanpur 208 016, India

Abstract. Thin films of yttrium iron garnet (YIG) and Gd-substituted YIG of different thickness have been prepared by flash evaporation. The surface DC and AC electrical resistivity and thermopower in these films have been studied. The results are explained on the basis of Mott and Davis model in which narrow tails of localised states exist at the extreme valence and conduction bands and a band of localised levels near the middle of the gap. For the temperature range studied, the main conduction mechanism is on account of excitation of carriers into localised states at the band edges and hopping at energies close to the band tails.

Keywords. Thin films; non-crystalline garnet; electron transport; activation energy.

1. Introduction

The electron transport on polycrystalline and single crystals of yttrium iron garnet and its derivatives has been studied and understood in the last couple of decades (Elwell and Dixon 1968; Larsen and Metselaar 1976; Bahadur *et al* 1981). Some attempts have also been made to prepare non-crystalline garnets and characterise them (Popma and Van Diepen 1974; Cuomo *et al* 1972). We have recently prepared non-crystalline garnet by flash evaporation and investigated the magnetic domains and structural transformations (Bahadur and Rai 1980). To get further insight into the electronic behaviour of these films, a number of films of YIG and Y_2 GdIG have now been prepared and its electron transport behaviour has been studied. The electron transport in bulk samples has been studied recently (Bahadur *et al* 1981). It was therefore considered worthwhile to investigate the effect of disorder and film thickness on the electron transport studies on the films of the same compositions.

2. Experimental

The polycrystalline samples of YIG and Y_2 GdIG were prepared by the usual ceramic method of mixing and sintering of constituent oxides at 1350°C. These samples were characterised by x-ray diffraction for a single phase. All the oxides were of high purity. Thin films of these garnets were deposited on a clean glass and quartz substrate by flash evaporation in an ultimate vacuum of 2×10^{-5} torr. Gold electrodes were deposited on the film for electron transport studies. Thickness of these films was measured. The standard error in thickness measurement is ± 20 Å. Before the electron transport measurements, the films were annealed at 450 K for about 72 hr. The surface electrical resistivity (AC and DC) was measured using a Keithley electrometer and 1610 GR impedance bridge with RC oscillator and null detector. I-V characteristics were tested at intermittent temperatures to check its linearity. Thermo-eme was measured using Leeds and Northrup potentiometer.

3. Results and Discussion

All the films are amorphous in nature as evident from x-ray and electron diffraction. The thickness of different γIG films were 230, 560 and 1330 Å. A typical plot of the surface electrical resistivity (DC) versus inverse of temperature for γIG film of 230 Å is given in figure 1. Table 1 gives the activation energies of conduction for different ranges for γIG films. Resistivity data was taken while decreasing the temperature and the activation energy was seen to be lower. This could be due to the increase in grain size after crystallisation reducing the discontinuity in the film which gave an additional activation energy for the film. However, no such marked change was observed for higher thickness. Resistivity also decreases as the thickness increases and this agrees with the studies on semi-conducting films (Chopra 1969). Activation energy also shows a similar trend. We have taken thermoelectric power data versus temperature for two of the γIG films of thicknesses 560 and 1300 Å and the plot for the first is given in figure 2.

Figure 1. Plot of surface electrical resistivity (DC) versus inverse of temperature for γIG film of thickness 230 Å.

Table 1. Activation energies in different ranges for thin films of γIG

Sample's thickness (Å)	Range (K)	Activation energies (eV)
230	300–570	0.20
	570–725	1.06 (0.62)*
560	400–550	0.16
	550–730	0.80
1300	450–540	0.07

*In parenthesis is given the value of activation energy while lowering the temperature

Figure 2. Plot of thermo-electric power versus inverse of temperature for YIG film of 560 Å thickness.

From figure 1 and table 1, we observe two ranges for activation energies of conduction similar to that found in bulk YIG earlier (Bahadur *et al* 1981). However, the values are less than what is observed for bulk YIG. This is to be expected if we assume band model for amorphous systems (Mott and Davis 1979; Nagels 1979) where tails of localised states and band of compensated levels within the gap could, in principle, cause lowering of activation energies.

Thermoelectric power, α , versus inverse of temperature plot shows that α is positive and increases with temperature showing that the holes are the majority charge carriers. However, the values are less than the bulk values which is possibly due to higher density of states at the fermi energy.

A typical plot of surface electrical resistivity (DC) for Y_2GdIG thin film of 420 Å thickness is given in figure 3. For the same film, the log of AC resistivity is plotted against log of frequency in figure 4. The resistivity between 290 and 490 K was measured for three samples of Y_2GdIG . The activation energies of conduction and S values are given in table 2. Only a small change is seen in the activation energies near 390 K for all the three samples. However, no such change was observed in YIG films around this temperature. This change appears to be characteristic of gadolinium substitution; the change is nearly same in all the three samples. In fact, in bulk Y_2GdIG also, an additional range of activation energy has been observed earlier (Bahadur *et al* 1981).

It is interesting that the frequency dependence of resistivity varies approximately as ω^S where $S < 1$ and lies between 0.65 and 0.9. In figure 3(b), it is observed that the S value at room temperature is 0.81 whereas at 475 K, it is 0.78. It has also been observed that $\rho(\omega)$ for this sample exponentially depends upon temperature.

Based on the above observations, we propose that the electronic conduction is on account of excitation of carriers into localised states at the band edges and hopping at energies close to band tails; DC resistivity in such a situation will be given by (Mott and Davis 1979).

$$\rho = \rho_0 \exp[(E_a - E_f + W)/kT],$$

where E_a corresponds to the band edge, W is the activation energy for hopping and ρ_0 is the pre-exponential factor which depends upon the density of states near E_a , hopping distance and the bandwidth of localised states. The essential feature of the Davis and Mott model is the narrow tails of localised states at the extremities of the valence and

Figure 3. Plot of surface electrical resistivity (DC) versus inverse of temperature for Y_2GdIG film of 420 Å thickness.

Figure 4. Plot of AC resistivity versus frequency for Y_2GdIG film of 420 Å thickness.

Table 2. Activation energies in different ranges for thin films of Y_2GdIG

Sample's thickness (Å)	Range (K)	Activation energies (eV)	S value at 290 K
420	290–380	0.14	0.78
	380–475	0.11	
570	330–390	0.20	0.65
	390–485	0.17	
1300	290–380	0.16	0.88
	380–455	0.13	

conduction bands and furthermore of a band of localised levels near the middle of the gap. According to this model, three different conduction mechanisms are possible.

Extended state conduction requires a frequency-independent resistivity and the slope for S and $\log \rho vs 1/T$ be the same which are not found in the present results. However, at higher temperature, it is not ruled out. Since, most of our results are between 290 and 550 K, our discussion would be limited for this region only. For this range of temperature it appears that the conduction in localised states at the fermi-energy would not be operative. This is indicated by the exponential dependence of $\rho(\omega)$ on temperature which is characteristic of conduction in band tails. Again, it is possible that at low temperature, the conduction is through variable range hopping due to the Anderson localised states at the fermi-energy (Anderson 1958; Rao *et al* 1975). Detailed low temperature studies are in progress to ascertain these facts.

Acknowledgement

Thanks are due to Department of Atomic Energy for the award of research grants.

References

- Anderson P W 1958 *Phys. Rev.* **109** 1492
Bahadur D and Rai K N 1980 *Mater. Res. Bull.* **15** 551
Bahadur D, Parkash O and Kumar D 1981 *Bull. Mater. Sci.* **3** 325
Chopra K L 1969 *Thin film phenomena* (New York and London: McGraw-Hill)
Cuomo J J, Sadagopan V, Deluco J, Chaudhary P and Rosenters R 1972 *Appl. Phys. Lett.* **21** 581
Elwell D E and Dixon A 1968 *Solid State Commun.* **6** 585
Larsen P K and Metselaar R 1976 *Phys. Rev.* **B14** 2520
Mott N F and Davis E A 1979 *Electronic processes in non-crystalline materials* (Oxford: Clarendon) p 199
Nagels P 1979 in *Amorphous semi-conductors* (ed.) M H Brodsky (Berlin, Heidelberg and New York: Springer Verlag) p 113
Popma J A Th and Van Diepen A M 1974 *Mater. Res. Bull.* **9** 1119
Rao C N R, Bhide V G and Mott N F 1975 *Philos. Mag.* **32** 1277 (and references therein)