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MAGNETIC AND ELECTRICAL STUDIES ON $Y_{1-x}Gd_xFe_2$

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ABSTRACT

The structural, electrical and magnetic properties of cubic Laves phase compounds viz., $Y_{1-x}Gd_xFe_2$ with x = 0, 0.25, 0.5, 0.75 and 1, have been investigated through x-ray diffraction, electrical resistivity and magnetization measurements. The lattice parameter is found to increase with increasing Gd concentration. The Curie temperature is found to increase with increasing x. Compensation is observed in the temperature dependence of the magnetization for the composition $Y_{0.5}Gd_{0.5}Fe_2$. All the materials are seen to exhibit metallic behavior and the resistivity behavior is explained on the basis of electron-magnon scattering and electron-phonon interaction.

Keywords: Magnetic materials, Magnetic properties, Compensation temperature, electrical resistivity

1. INTRODUCTION

The RFe_2 (R = rare earth) Laves phase compounds are known to possess large cubic anisotropy and highest Curie temperature (T_C) of all RT_2 compounds (T = transition metal). RFe_2 compounds crystallize in cubic $MgCu_2$ (C15) type structure. These compounds are known to exhibit diverse magnetic properties due to the competing effects of exchange interaction and crystalline electric field effects [1,2]. The magnetic properties of these alloys are of significant interest due to the presence of localized 4f electrons as well as itinerant 3d electrons. The density of states (DOS) at the Fermi level of the 3d band plays a crucial role in determining the magnetic state of the 3d electrons. The Fermi level is situated in a position where it can display different kinds of magnetic properties when Fe is replaced by another transition metal or a non-magnetic atom [3]. In addition interstitial modification in these compounds modifies the magnetic and electrical properties considerably [4-8]. Exact determination of the iron moments and investigations into their dependence on the polarizing influence of the rare earth moments are seriously handicapped by the uncertainties due to the crystal field effects from the rare-earth moments. Gadolinium has the advantage that its moment is not affected by crystal fields. In order to obtain a better insight into the way in which the Fe moments are enhanced in these compounds, we have studied the magnetic properties of the series of $Y_{1-x}Gd_xFe_2$.

2. EXPERIMENTAL DETAILS

The alloys were prepared by arc melting Y and Gd of purity 99.9% and Fe of 99.95% purity, under argon atmosphere. The melting was carried out several times to obtain homogeneous compounds. The weight loss after the final melting is less than 0.1%. The arc-melted ingots were homogenized in vacuum at 1170 K for a week and then were furnace cooled. Powder X-ray diffraction studies were carried out on the compounds employing FeK_α radiation, for structural characterization. Magnetization measurements were carried out on powder samples

using a PAR 155 vibrating sample magnetometer at 300 K and also in the temperature range 300–850 K up to an applied field of 12 kOe. Electrical resistivity (ρ) measurements were carried out using the Van der Pauw technique, in the temperature range 30 – 300 K. A Keithley 224 constant current source delivering 100 mA and a Keithley 181 nano-voltmeter were used in the measurement of electrical resistivity.

3. RESULTS AND DISCUSSION

All the compounds of $Y_{1-x}Gd_xFe_2$ with x = 0, 0.25, 0.5, 0.75 and 1 have been found to form in C15-type cubic Laves phase, through the analysis of the X-ray diffractograms [Fig. 1]. For compositions x = 0.25, 0.5 and 0.75 traces of RFe_3 were also observed. The lattice parameter 'a' increases with Gd concentration as shown in Table 1. This is due to the fact that the atomic radius of Gd is more than that of Y.

Fig. 2 shows the variation of magnetization with applied magnetic field for $Y_{1-x}Gd_xFe_2$ with x = 0, 0.25, 0.5, 0.75 and 1 at 300 K. The saturation magnetization is found to decrease up to the concentration x = 0.5 and then it increases [Table 1]. The decrease in the magnetization with the concentration of Gd up to x = 0.5 can be due to the gradual growth of Gd moments that are anti-parallel to the Fe moments thus reaching a low value before increasing with further addition of Gd. However, the nonlinear changes in the magnetization with Gd concentration may have contribution from the small but finite polarization of the Fe moments due to Gd moments.

The temperature variation of magnetization carried out in the temperature range 300 – 850 K at an applied magnetic field of 50 Oe shows that the Curie temperature increases with increasing Gd concentration [Fig.3]. The compositions corresponding to x = 0.25, 0.5 and 0.75 exhibits two transitions, one corresponding to the RFe_2 phase and the other corresponding to that of RFe_3 phase. The temperature variation of magnetization carried out at higher fields doesn't seem to exhibit the transition corresponding to the RFe_3 phase [9]. Generally in R-Fe intermetallics the dominant contribution of the Curie temperature is from the Fe-Fe exchange interactions. In the present case, the increase in T_C can be understood as due to the additional contribution to the exchange from the Gd-Fe and Gd-Gd interactions. Another interesting feature is the observation of compensation [of the moments of the Fe and Gd sublattices] temperature (T_{Comp}) for the composition $Y_{0.5}Gd_{0.5}Fe_2$. This is seen as a minimum in the temperature variation of magnetization in $Y_{0.5}Gd_{0.5}Fe_2$ around 400 K [Fig. 3]. In the other compounds, this effect is either not present or weakly present.

The results of electrical resistivity (ρ) studies carried out in the temperature range 30 – 300 K are shown in Fig. 4. The variation of resistivity with temperature shows a metallic behavior.

At low temperatures, the total resitivity is given by [10]

$$\rho(T) = \rho_0 + AT^2 \exp(-\Delta/KT) \qquad (1)$$

where ρ_0 is the residual resistivity, k is the Boltzmann constant and A is a material dependant constant. For systems possessing large magnetic anisotropy, a minimum energy Δ is required to excite magnons in the presence of an anisotropy field. The experimental data was fit to the above equation in the temperature range 30 – 100 K. From the fit it is observed that the value of (Δ / KT) is very small, of the order of 10^{-2}. Therefore, neglecting the contribution from Δ, the above expression could be rewritten as

$$\rho(T) = \rho_1 + AT^2 \qquad (2)$$

From the fit it is found that the value of A is found to be in of the order of 2 x 10^{-2} n Ω cm K^{-2} suggesting that the electron-magnon scattering is the dominant factor in determining the electrical resisitivity in the temperature range 22 – 100 K. This is corroborated with the

experimental values obtained in the case of RFe_2 [5, 6], $R_3Co_{11}B_4$ [11], R_6Fe_{23} [12] and R_2Fe_{17} [13] compounds for electron-magnon scattering. If the electron-electron scattering dominates, the value of A should be small (of the order of 2.5 x 10^{-2} n Ω cm K^{-2}), as in the case of pure Nickel [10].
At high temperatures (100 – 300 K) the resistivity shows a linear behavior, which is attributed to electron-phonon scattering.

4. SUMMARY AND CONCLUSIONS

The lattice parameter of cubic Laves phase compound $(Y,Gd)Fe_2$ is found to increase with increasing Gd concentration which is due to the large atomic radius of Gd. The decrease in magnetization with the addition of Gd has been explained on the basis of the anti-parallel alignment of the Gd and Fe moments. An increase in the T_C with increasing Gd content is attributed to the contributions from Fe-Fe, Gd-Fe and Gd-Gd exchange interactions. Compensation temperature is observed for the composition $Y_{0.5}Gd_{0.5}Fe_2$. All the materials are seen to exhibit metallic behavior. The resistivity behavior is explained on the basis of electron-magnon scattering mechanism and electron-phonon interaction.

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TABLES

Table 1 Variation of lattice parameter, magnetization and Curie temperature with Gd concentration in $Y_{1-x}Gd_xFe_2$.

Concentration of Gd x	**Lattice parameter (Å) ±0.001**	**Magnetization (emu/g) at 300 K**	**Curie Temperature (K)**
0	7.365	73	552
0.25	7.372	36	622
0.5	7.380	11	690
0.75	7.385	39	745
1	7.391	59	788

FIGURES

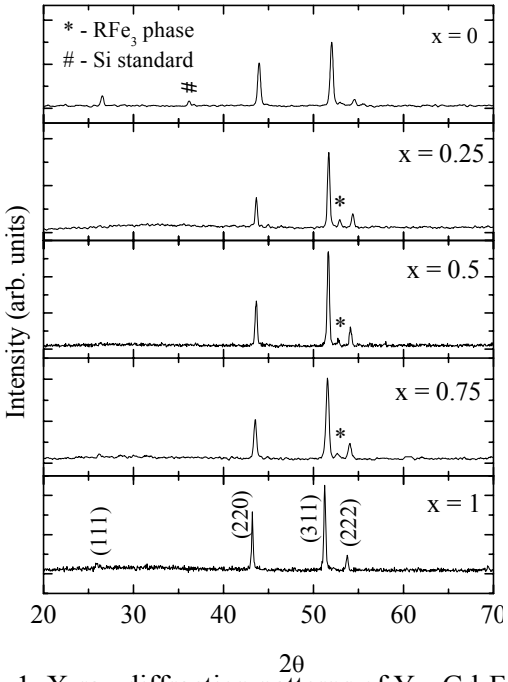

Fig. 1. X-ray diffraction patterns of $Y_{1-x}Gd_xFe_2$

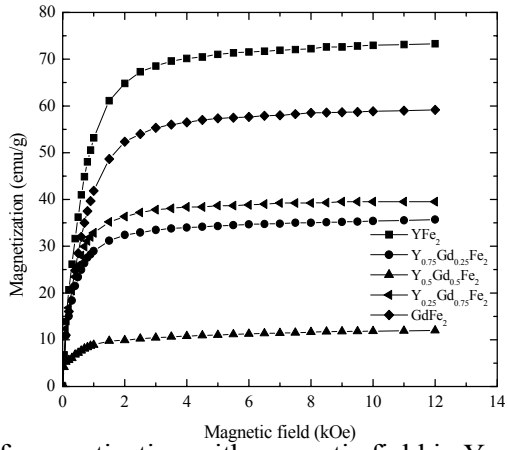

Fig. 2 Variation of magnetization with magnetic field in $Y_{1-x}Gd_xFe_2$ at 300 K

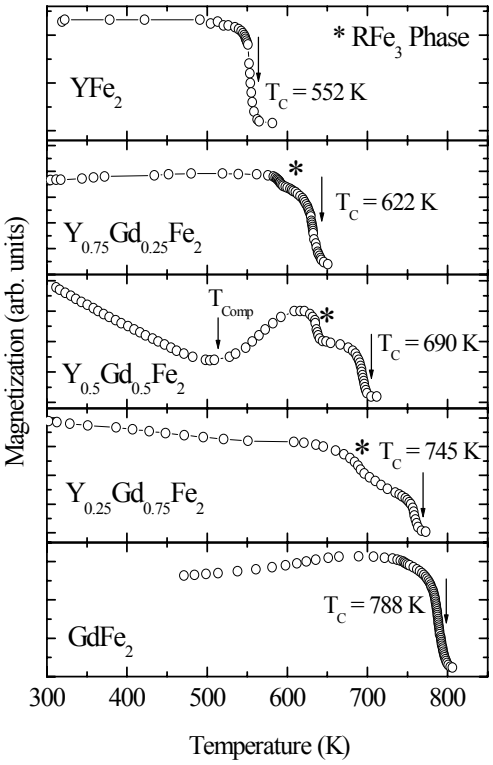

Fig. 3 Temperature dependence of low field (50 Oe) magnetization of $Y_{1-x}Gd_xFe_2$

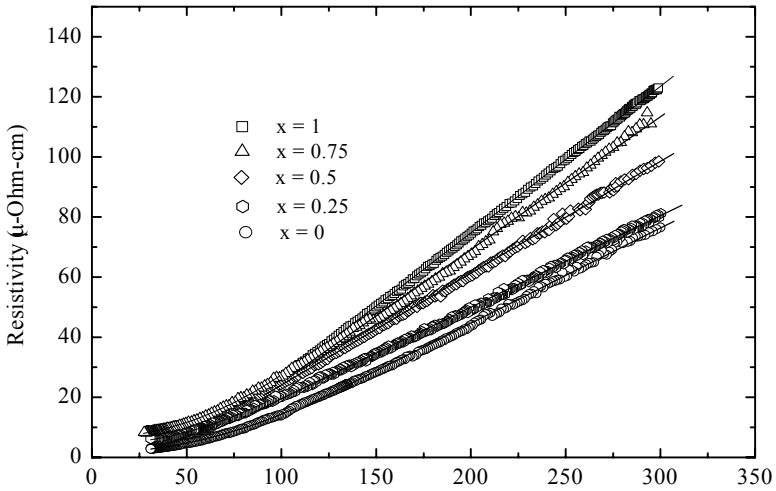

Fig. 4. Temperature variation of electrical resistivity for $Y_{1-x}Gd_xFe_2$. Solid lines show the fit