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## MAGNETIC PROPERTIES OF AMORPHOUS $Dy_xFe_{1-x}$ THIN FILMS

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**Abstract.** - Magnetic properties of amorphous  $Dy_xFe_{1-x}$  ( $x = 0.15, 0.21, 0.25$ ) with the random anisotropy and exchange were investigated by the measurements of magnetization and Hall effect *vs.* temperature and external field  $H$ . Sperrimagnetic behavior was shown in all samples measured for  $H = 1$  kOe. A reentrant phenomenon from ferrimagnetic to speromagnetic behavior was observed for  $x = 0.25$  with coherent perpendicular anisotropy. At  $H = 12$  kOe, all samples show ferrimagnetic behavior.

In the last decade, the experimental [1] and theoretical studies [2, 3] for the effects of random anisotropy on the ferromagnetism have been extensively developed. Rare-earth rich amorphous alloys such as DyCu [4],  $Dy_xGd_{1-x}Ni$  [5],  $Gd_{65-x}Tb_xCo_{35}$  [6],  $Dy_{60}Fe_{30}B$  [7], show a transition to a speromagnetic [1] (spin-glass-like) state. Recent neutron [1], susceptibility [6], magnetization measurements [8] suggests that the system cross over to the asperomagnetic (or ferromagnetic) state in a large external field  $H$ .

The spin system such as heavy-rare-earth-iron amorphous system has two subnetworks coupled antiferromagnetically, though individually coupled ferromagnetically. The random anisotropy give a similar effect on such ferrimagnetic systems, however it has not sufficiently clarified for the iron rich or moderately rare-earth containing compositions.

In this paper, we investigated the magnetic properties of amorphous  $Dy_xFe_{1-x}$  ( $x = 0.15, 0.21, 0.25$ ) by the measurements of magnetization and Hall effect against temperature and external field  $H$ . The Hall effect is very sensitive methods to study the critical behavior both for spin-glass such as AuFe [9] and for rare-earth-transition-metal ferrimagnet [10]; the Hall resistivity  $\rho_H$  in the amorphous rare-earth-transition alloy exhibits the fairly large anomalous Hall component reflecting the magnetization of the subnetwork(s), then  $\rho_H$  changes the sign at the compensation temperature  $T_{comp}$ .

The amorphous  $Dy_xFe_{1-x}$  films were prepared by r.f. sputtering technique from a composite target onto glass substrates under the Ar pressure of  $5 \sim 20 \times 10^{-3}$  Torr. The film composition was determined by ICPS technique, and the film thickness by a stylus step method, which are of the order of  $1.3 \mu m \sim 1.7 \mu m$ . The amorphous character was checked by X-ray scattering. Temperature dependence of magnetization was measured by a vibrating-sample magnetometer. Hall resistivity was measured at current  $I = 1$  mA.

For magnetization measurements,  $H$  was applied in the easy axis direction of DyFe films; normal to the film plane for samples with the coherent perpendicular anisotropy ( $x = 0.21, 0.25$ ), parallel to the plane for

$x = 0.15$ . Hall effect measurements were performed by applied  $H$  normal to the films.

Figure 1a shows magnetization of amorphous  $Dy_xFe_{1-x}$  for  $x = 0.15$  and  $0.25$  at  $H = 1$  kOe as a function of temperature.  $\rho_H$  corresponding to the

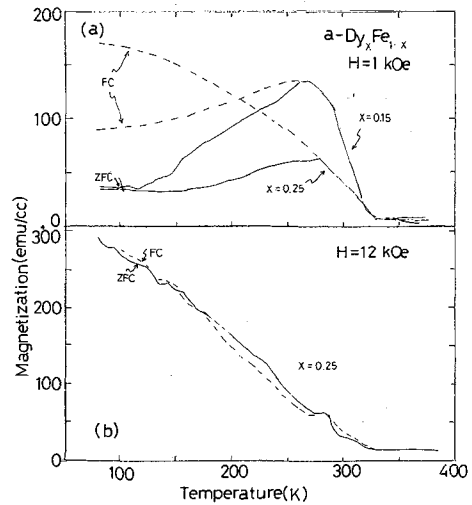


Fig. 1. - Magnetization of amorphous  $Dy_xFe_{1-x}$  films for (a)  $x = 0.15, 0.25$  at external field  $H = 1$  kOe, (b)  $x = 0.25$  at  $H = 12$  kOe as a function of temperature.

two samples in figure 1a are shown in figure 2a. For  $x = 0.21$ , only  $\rho_H$  is plotted in figure 2b. The temperature dependence of magnetization resembles to that of  $\rho_H$ , though  $-\rho_H$  ( $x = 0.25$ )  $>$   $\rho_H$  ( $x = 0.15$ ). The field-cooled (FC) and zero-field-cooled (ZFC) magnetization or  $\rho_H$  becomes to behave differently at low temperature indicating that all samples measured exhibit the spero or spin-glass like behavior at 1 kOe. Figure 2a shows that the sign of  $\rho_H$  ( $x = 0.25$ ) and  $\rho_H$  ( $x = 0.15$ ) are different. This is because that for  $x = 0.25$  sample there is  $T_{comp}$  at about 327 K as indicated by an arrow in figure 2a. The  $Dy_{0.25}Fe_{0.75}$ , therefore, exhibits a reentrant behavior from paramagnetic to ferrimagnetic (or sperimagnetic) to speromagnetic phase with decreasing temperature.

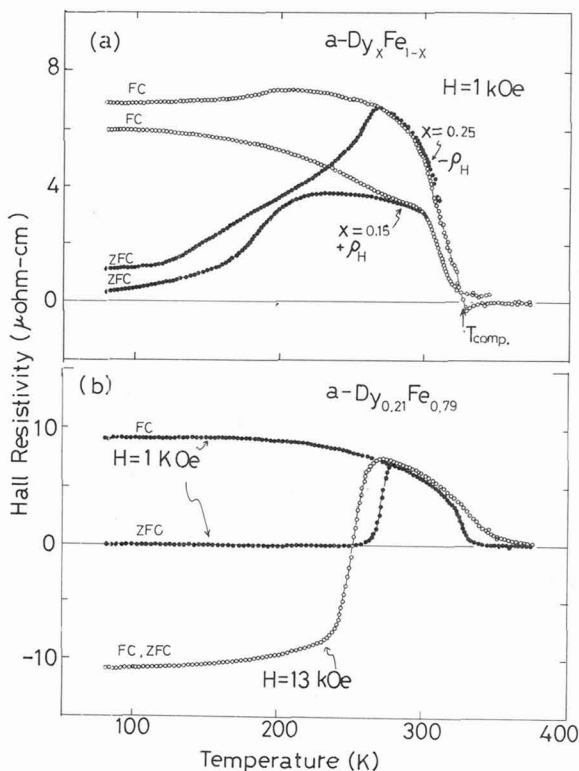


Fig. 2. - Hall resistivity  $\rho_H$  of amorphous  $\text{Dy}_x\text{Fe}_{1-x}$  for (a)  $x = 0.15, 0.25$  at  $H = 1 \text{ kOe}$ , (b)  $x = 0.21$  at  $H = 1 \text{ kOe}$  as a function of temperature.

In figure 2b,  $\rho_H$  at  $H = 13 \text{ kOe}$  is shown. The speromagnetic behavior of  $\rho_H$  at  $H = 1 \text{ kOe}$  converts drastically into ferrimagnetic state with  $T_{\text{comp}} \approx 250 \text{ K}$ . Figure 1b also exhibits the change to the ferrimagnetic state for  $x = 0.25$  sample at  $H = 12 \text{ kOe}$ ; there is almost no difference between FC and ZFC, also for  $x = 0.15$ , though not shown in the figure.

The external field ( $H = 12 \text{ kOe}$ ) sensitively converts the speromagnetic state at  $1 \text{ kOe}$  into ferrimagnetic state for all samples measured, and the one ( $x = 0.25$ ) with the perpendicular anisotropy exhibits a reentrant behavior at  $1 \text{ kOe}$ . For  $x = 0.21$ , with also perpen-

dicular anisotropy, the magnetic state above the speromagnetic freezing temperature  $T_f \approx 280 \text{ K}$  may be ferrimagnetic state, though the compensation point is not seen because  $T_{\text{comp}}$  lies below  $T_f$ . The reentrant phenomenon was also reported in  $\text{GdErCo}$  system [11]. From above results, the coherent uniaxial anisotropy and the large uniform external field seem to stabilize the ferrimagnetic state.

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