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MAGNETIC PROPERTIES OF AMORPHOUS Dy$_x$Fe$_{1-x}$ THIN FILMS

T. Saito, J. Maedomari, K. Shinagawa and T. Tsushima

Department of Physics, Faculty of Science, Toho University, Funabashi, Chiba 274, Japan

Abstract. Magnetic properties of amorphous Dy$_x$Fe$_{1-x}$ ($x = 0.15, 0.21, 0.25$) with the random anisotropy and exchange were investigated by the measurements of magnetization and Hall effect vs. temperature and external field $H$. Speromagnetic 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 \cite{1} and theoretical studies \cite{2, 3} for the effects of random anisotropy on the ferromagnetism have been extensively developed. Rare-earth rich amorphous alloys such as DyCu \cite{4}, Dy$_x$Gd$_{1-x}$Ni \cite{5}, Gd$_{65-\gamma}$Tb$_\gamma$Co$_{35}$ \cite{6}, Dy$_{65}$Fe$_{30}$B \cite{7}, show a transition to a speromagnetic \cite{1} (spin-glass-like) state. Recent neutron \cite{1}, susceptibility \cite{6}, magnetization measurements \cite{8} suggests that the system cross over to the speromagnetic (or ferromagnetic) state in a large external field $H$.

The spin system such as heavy-rare-earth-iron amorphous alloy 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$_x$Fe$_{1-x}$ ($x = 0.15, 0.21, 0.25$) 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 \cite{9} and for rare-earth-transition-metal ferrimagnet \cite{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$_x$Fe$_{1-x}$ 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$_x$Fe$_{1-x}$ for $x = 0.15$ and 0.25 at $H = 1$ kOe as a function of temperature. $\rho_H$ corresponding to the 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. 1. Magnetization of amorphous Dy$_x$Fe$_{1-x}$ 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.](image-url)
Fig. 2. - Hall resistivity $\rho_H$ of amorphous Dy$_x$Fe$_{1-x}$ for (a) $x = 0.15, 0.25$ at $H = 1$ kOe, (b) $x = 0.21$ at $H = 1$ kOe as a function of temperature.

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

The external field ($H = 12$ kOe) sensitively converts the speromagnetic state at $1$ kOe into ferrimagnetic state for all samples measured, and the one ($x = 0.25$) with the perpendicular anisotropy exhibits a reentrant behavior at $1$ kOe. For $x = 0.21$, with also perpen-
dicular anisotropy, the magnetic state above the speromagnetic freezing temperature $T_f \approx 280$ K may be ferrimagnetic state, though the compensation point is not seen because $T_{comp}$ lies below $T_f$. The reentrant phenomenon was also reported in 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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