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Effects of Tb content on the microstructure and magnetic properties of $Co_{85-X}Tb_XDy_{15}$ films

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Abstract

The $Co_{85-X}Tb_XDy_{15}$ films ($x = 0-24$ at%) were prepared at room temperature by DC magnetron sputtering. Transmission electron microscopy analysis indicated that all the films were amorphous. The magnetization measurement revealed that increasing Tb content would reduce the saturation magnetization M_s of the film but the out-plane coercivity $H_{c\perp}$ was increased. The M_s and $H_{c\perp}$ values of the $Co_{85}Dy_{15}$ film ($x = 0$ at%) were about 640 emu/cm^3 and 50 Oe, respectively. However, the M_s and $H_{c\perp}$ values of the $Co_{61}Tb_{24}Dy_{15}$ film ($x = 24$ at%) were about 20 emu/cm^3 and 10 kOe, respectively.

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Keywords: $Co_{85-X}Tb_XDy_{15}$ thin films; Saturation magnetization; Out-plane coercivity

Amorphous rare-earth-transition metal (RE-TM) alloy films have special perpendicular anisotropy and have been widely studied by many investigators [1–3]. We have reported an as-deposited CoTb amorphous film with large perpendicular coercivity, and a nearly magnetically isotropic amorphous CoTb film could be obtained by annealing this film in vacuum at 250°C for 60 min [4]. In this work, we studied the effects of Tb content on the microstructure and magnetic properties of the $Co_{85-X}Tb_XDy_{15}$ film.

The $Co_{85-X}Tb_XDy_{15}$ films with $x = 0-24$ at% were deposited on natural-oxidized silicon wafer substrates by DC magnetron sputtering at room temperature. The target was a Co disk overlaid with Dy and Tb pieces, to yield the desired film composition. The film thickness was 100 nm and the film was sandwiched between two SiN_x protective layers that were prepared by rf magnetron sputtering of Si_3N_4 target. The thickness of the SiN_x protective layer was 15 nm. The structures of the films were investigated by transmission electron microscopy (TEM). The composition of the film was determined by energy-dispersive spectroscopy (EDS). The thickness of the film was measured by atomic force microscope (AFM). The magnetic properties of the film were measured by a vibrating sample magnetometer (VSM) at room temperature with a maximum applied field of 13 kOe.

The $Co_{85-X}Tb_XDy_{15}$ films were examined by TEM to understand the effect of Tb content on the structure of the CoDy film. It was found that all the $Co_{85-X}Tb_XDy_{15}$ films ($x = 0-24$ at%) were amorphous. Fig. 1(a) shows a TEM bright field image of the $Co_{74}Tb_{11}Dy_{15}$ film and Fig. 1(b) shows, the electron selected area diffraction (SAD) pattern of Fig. 1(a). There are no crystal grains and the shape of the SAD pattern is a broad halo, implying that the film is amorphous.

Fig. 2 shows the variations of saturation magnetization M_s, out-plane coercivity $H_{c\perp}$ and in-plane coercivity $H_{c\parallel}$ with Tb content of the $Co_{85-X}Tb_XDy_{15}$ film. The M_s value decreases with increasing Tb content. M_s value of the $Co_{85}Dy_{15}$ film ($x = 0$) is about 640 emu/cm^3. It decreases to about 20 emu/cm^3 as x is increased to 24. CoDy alloy is sperimagnetic [5], and the magnetization of

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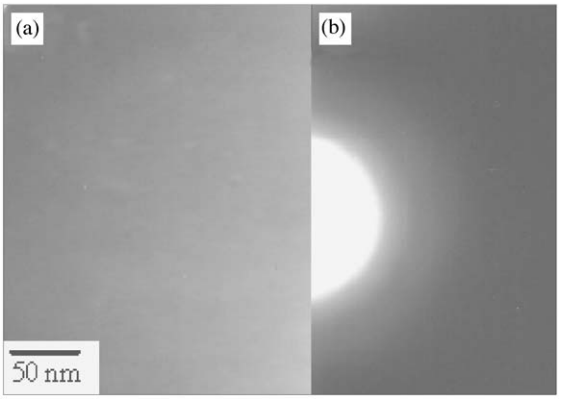

Fig. 1. (a) TEM bright field image and (b) electron diffraction pattern of the $Co_{74}Tb_{11}Dy_{15}$ film.

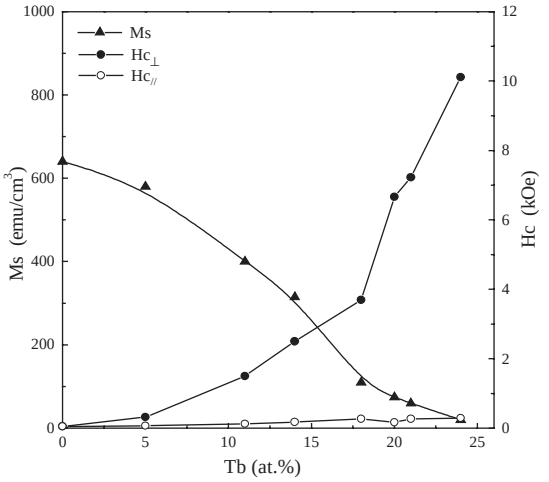

Fig. 2. Variations of M_s, $H_{c\perp}$ and $H_{c\parallel}$ with Tb content of the $Co_{85-X}Tb_XDy_{15}$ film.

Co subnetwork is antiparallel to that of Dy subnetwork. Net magnetization of $Co_{85}Dy_{15}$ alloy is parallel to that of Co subnetwork. The decrease of M_s of the $Co_{85-X}Tb_XDy_{15}$ film with increasing Tb content is due to the fact that the direction of net moment of the Tb atoms is opposite to that of Co atoms. The variation of $H_{c\parallel}$ with Tb content is small but the $H_{c\perp}$ value is increased rapidly with increasing Tb content as $x > 11$. The $H_{c\perp}$ value increases from about 1.5 kOe for $x = 11$ to about 10 kOe for $x = 24$. Magnetic easy direction of the film is changed from isotropy to perpendicular gradually as the Tb content is increased, because Tb atoms have large out-plane magnetic anisotropy constant $Ku_\perp$ [5].

Fig. 3 shows the variations of out-plane squareness $S_\perp$ and in-plane squareness $S_\parallel$ with Tb content of the $Co_{85-X}Tb_XDy_{15}$ film, where $S_\perp = M_{r\perp}/M_s$ and $S_\parallel = S_\parallel/M_s$ $M_{r\perp}$ and $M_{r\parallel}$ are the out-plane and in-plane remanent magnetization, respectively. The $S_\perp$ of CoTb-Dy film is increased with increasing Tb content. $S_\perp$

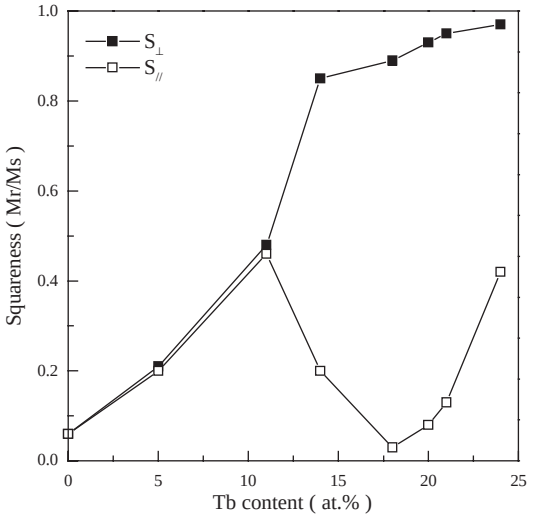

Fig. 3. Variations of $S_\perp$ and $S_\parallel$ with Tb content of the $Co_{85-X}Tb_XDy_{15}$ film.

increases from 0.07 to about 1 as x increases from 0 to 24. This is due to the fact that Tb has large $Ku_\perp$. The $S_\perp$ was larger than 0.85 as $x > 14$ at%. The curve of $S_\parallel$ versus Tb content is like the peak behavior. The peak of $S_\parallel$ occurs at $x \sim 11$ that is about 0.45. When Tb content is more than 18 at%, $S_\parallel$ is increased with increasing Tb content. As $x > 11$ at%, $S_\perp$ of the $Co_{85-X}Tb_XDy_{15}$ film is larger than $S_\parallel$.$S_\parallel$ of the film is always lower than 0.5 when $0 \leqq x \leqq 24$, as shown in Fig. 3.

We have investigated the effects of Tb content on the magnetic properties and microstructure of the $Co_{85-X}Tb_XDy_{15}$ films ($x = 0-24$ at%). TEM analysis indicated that all the films were amorphous. The magnetization measurement revealed that the addition of Tb would reduce the M_s value of the $Co_{85}Dy_{15}$ film but $H_{c\perp}$ was increased. $S_\perp$ was about 1 and $H_{c\perp} \sim 10$ kOe as the Tb content increased to 24 at%.

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