NdFeCo TRILAYER AMORPHOUS FILMS WITH HIGH KERR ROTATION AT SHORT WAVELENGTHS

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Abstract — Magneto-optical recording materials with high remanent Kerr rotation at short wavelengths were successfully obtained in a trilayer form. A NdFeCo amorphous film with in-plane magnetization, but with a large saturation Kerr rotation angle at short wavelengths, was sandwiched between TbFeCo amorphous films with strong perpendicular anisotropy and high coercivity. The trilayer film, Tb₂₀Fe₇₄Co₆ (10 nm) / Nd₁₆Fe₅₇Co₂₇ (7.5 nm) / Tb₂₀Fe₇₄Co₆ (100 nm), shows a remanent Kerr rotation angle $\theta_{Kr} = 0.32^\circ$ at a wavelength of 400 nm, coercivity $H_c = 2.4$ kOe, and a good square loop ($\theta_{Kr}/\theta_{Ks} \sim 1$).

KEYWORDS: TRILAYER FILM, NdFeCo, SHORT WAVELENGTHS, EXCHANGE COUPLING

INTRODUCTION

Magneto-optical (M.O.) materials with high Kerr rotation at short wavelengths have recently received much attention for their potential use in future high-density magneto-optical recording [1 – 6]. We previously reported that we had successfully obtained such an M.O. medium by employing a trilayer NdCo amorphous alloy film, which showed good squareness in its Kerr hysteresis loops and a high coercive force H_c (2 kOe) [7, 8]. In these layered structure, a NdCo amorphous film with an in-plane magnetization are sandwiched between TbFeCo films with strong perpendicular anisotropy and high coercivity.

In this report, we describe our subsequent attempt to obtain a larger remanent Kerr rotation angle by employing a NdFeCo film as a middle layer. We used NdFeCo because it has a larger magneto-optical effect than NdCo at short wavelengths of around 400 nm. [3 – 7]. One of key features of the proposed trilayer structure is that the middle layer (NdFeCo) is thick enough to give rise to a high Kerr rotation, but thin enough to reorient the magnetization in a direction perpendicular to the film surface through the whole film thickness by exchange coupling.

As a result, we successfully obtained a remanent Kerr rotation angle of 0.32 degree at a short wavelength of 400 nm with a good square loop ($\theta_{Kr}/\theta_{Ks} \sim 1$) and a coercivity of 2.4 kOe. The figure of merit, $(\sqrt{R}\theta_K)$, of this trilayer film is 0.21 at a wavelength of 400 nm, which is larger than that of the previous NdCo trilayer film [8].

EXPERIMENT

Trilayer NdFeCo films (TbFeCo/NdFeCo/TbFeCo)

were prepared on glass substrates by using d.c. magnetron sputtering without breaking a vacuum during the multilayer process. The background vacuum before sputtering was less than 1.0×10^{-6} Torr. Ar pressure during sputtering was 5.0×10^{-3} Torr. We employed targets for NdFeCo, Nd sheets on the Fe-Co alloy target, and for TbFeCo, Tb sheets on the Fe-Co alloy target. The magnetic properties of the trilayer films were measured with a vibrating sample magnetometer (VSM) in fields up to about 20 kOe, and the magneto-optical properties were obtained with a Kerr loop tracer in fields up to 15 kOe. The atomic compositions of NdFeCo and TbFeCo were measured by using an inductively coupled plasma spectrometer (ICP). The anisotropy constant for NdFeCo was obtained from the torque curves, measured in a field of about 19 kOe, and that for TbFeCo was measured by the Miyajima method [9] in fields up to 19 kOe.

RESULTS AND DISCUSSION

The schematic cross-section of the trilayer films investigated is shown in the insert of Fig. 1. The atomic composition of the first and third (TbFeCo) layers is Tb 20%, Fe 74%, and Co 6%, while that of the second (NdFeCo) layer is Nd 16%, Fe 57%, and Co 27%. The Tb₂₀Fe₇₄Co₆ amorphous films shows coercivity $H_c = 9.8$ kOe, saturation magnetization $M_s = 84$ emu/cc, effective perpendicular anisotropy $K = 5.3 \times 10^6$ erg/cc, and Curie temperature $T_c = 205^\circ\text{C}$, while the Nd₁₆Fe₅₇Co₂₇ amorphous films give figures of $M_s = 1.1 \times 10^3$ emu/cc, and $K = -4.4 \times 10^6$ erg/cc. To optimize the trilayer structure, the thickness of the first and third (TbFeCo) layers were fixed at 10 and 100 nm, respectively. The thickness of the second (NdFeCo) layer was varied from

Fig. 1 Remanent Kerr rotation angle θ_{Kr} , saturation Kerr rotation angle θ_{Ks} , and reflectivity R as a function of the second layer thickness (NdFeCo) t_2 , measured at 400 nm

0 to 50 nm. Fig. 1 shows the remanent Kerr rotation angle θ_{Kr} , the saturation Kerr rotation angle θ_{Ks} , and the reflectivity R , measured at $\lambda = 400$ nm through a glass substrate, as a function of the second (NdFeCo) layer thickness (t_2). As the thickness of the second layer increases, the remanent Kerr rotation angle increases, reaching a peak around the second layer thickness of 7.5 nm. With a further increase in the second layer thickness, θ_{Kr} starts to decrease. The initial increase in the remanent Kerr rotation angle is associated with an increase in the depth of effective light penetration into the second layer (NdFeCo), whose magnetization is effectively reoriented by the first and third layers in the direction normal to the film plane. All the above Kerr loops and magnetization curves show good squareness. A decrease in the remanent Kerr rotation angle above the second layer thickness of 7.5 nm is due to an increase in the in-plane magnetization of the second (NdFeCo) layer. This means that the first and the third (TbFeCo) layers cannot reorient the magnetization of the second (NdFeCo) layer sufficiently in the direction normal to the film plane. On the other hand, the saturation Kerr rotation angle θ_{Ks} becomes larger as the thickness of the second layer increases from $t_2 = 0$ to 20 nm. Above the second layer's thickness of 25 nm, the saturation Kerr rotation angle becomes almost constant, $\theta_{Ks} = 0.38^\circ$. Since the total saturation Kerr rotation angle measured is the weighted average of the portions of the top, middle, and bottom layers that the light reaches, as stated above, this result indicates that the penetration depth in the second layer is about 20 nm. Note that the thickness of the second layer when the remanent Kerr rotation angle is at a maximum is less than that of the NdCo trilayer film previously reported [9], because a NdFeCo amorphous thin film has large

demagnetization field as a result of NdFeCo having a higher magnetization than NdCo. The reflectivity R of trilayer films at $\lambda = 400$ nm shows an almost constant value (42.7%), which means that the multi-reflection of the second layer does not contribute to the enhancement of the Kerr rotation angle, because it reduces the reflectivity.

Representative Kerr hysteresis loops at a wavelength of 400 nm and magnetization curves for the samples at $t_2 = 7.5$ and 25 nm in Fig. 1 are shown in Figs. 2(a) and 2(b), respectively. Both curves in Figs. 2(a) show good squareness ($M_r/M_s \sim 1$) and high coercivity ($H_c = 2.4$ kOe). The direction of magnetization is reversed abruptly. This means that the each layer in a trilayer film is well coupled by exchange coupling. On the other hand, the Kerr loop and the magnetization curve in Figs. 2(b) show poor squareness, because of the relative increase in the in-plane magnetization of NdFeCo in the second (NdFeCo) layer of the trilayer film. Both curves in Figs. 2(b) have a shoulder when the magnetization of the film is changed. These shoulders are caused by the state in which the magnetization of the first layer is antiparallel to the magnetization of the third layer [12].

A typical torque curve of trilayer films is shown in Fig. 3. The sample is the same as that shown in Fig. 2(a). This curve also has a shoulder when the sign of

Fig. 2 Kerr hysteresis loops and magnetization curves for trilayer films

Fig. 3 A torque curve for a $\text{Tb}_{20}\text{Fe}_{74}\text{Co}_6$ (10 nm) / $\text{Nd}_{16}\text{Fe}_{57}\text{Co}_{27}$ (7.5 nm) / $\text{Tb}_{20}\text{Fe}_{74}\text{Co}_6$ (100 nm) trilayer film, measured in a field of 19 kOe

the torque is reversed. These shoulders most likely are created when the magnetization direction of the first layer is antiparallel to that of the third layer [12].

Figure 4 shows the wavelength dependence of the Kerr rotation θ_{Kr} and reflectivity R for samples of a $\text{Tb}_{20}\text{Fe}_{74}\text{Co}_6$ (10 nm) / $\text{Nd}_{16}\text{Fe}_{57}\text{Co}_{27}$ (7.5 nm) / $\text{Tb}_{20}\text{Fe}_{74}\text{Co}_6$ (100 nm) trilayer film (T-NdFeCo) and of a $\text{Tb}_{23}\text{Fe}_{72}\text{Co}_5$ (10 nm) / $\text{Nd}_{20}\text{Co}_{80}$ (10 nm) / $\text{Tb}_{23}\text{Fe}_{72}\text{Co}_5$ (100 nm) trilayer film (T-NdCo). The dependence of a $\text{Tb}_{20}\text{Fe}_{74}\text{Co}_6$ single film with the same composition as the first and third layers of NdFeCo

Fig. 4 Light wavelength dependence of remanent Kerr rotation θ_{Kr} and reflectivity R

trilayer films is also shown for comparison. Note that the remanent Kerr rotation angle of the present NdFeCo trilayer film (T-NdFeCo) is larger than that of the former NdCo trilayer film (T-NdCo) above a wavelength of 600 nm, and larger than that of a TbFeCo single-layer film throughout the measured range. This most likely reflects the fact that a NdFeCo film has a larger intrinsic magneto-optical effect than a TbFeCo film and a NdCo film throughout the measured wavelength region. The NdFeCo trilayer film (T-NdFeCo) has almost the same remanent Kerr rotation angle as the NdCo trilayer film (T-NdCo) at wavelengths from 400 to 550 nm, even though the thickness of the second layer (7.5 nm) is thinner than that of the NdCo trilayer film (10 nm). This results from the fact that the second layer (NdFeCo) has a higher saturation magnetization and a higher saturation Kerr rotation angle than NdCo. This is in turn because the remanent Kerr rotation angle of these trilayer films is determined by the weighted average of the saturation Kerr rotation angle, the magnetization component perpendicular to a film surface, and the thickness of each layer. The reflectivity of the NdFeCo trilayer film (T-NdFeCo) decreases monotonically as the wavelength decreases, and shows a slightly higher value than that of the other films throughout the measured range.

The figure of merit, $\sqrt{R}\theta_{\text{Kr}}$, for the same samples, calculated from the data in Fig. 4, is plotted as a function of wavelengths in Fig. 5. For comparison, the figures of merit of Pt/Co multilayer films are also shown in Fig. 5. [10, 11]. The value of $\sqrt{R}\theta_{\text{Kr}}$, which is proportional to a readout signal in M.O. recording, is higher in the trilayer films than in TbFeCo and in the trilayer film with NdCo throughout the measured wavelength range, $\lambda = 400 - 850$ nm. Furthermore, the figure of

Fig. 5 Light wavelength dependence of figure of merit $\sqrt{R}\theta_{\text{Kr}}$

Fig. 6 Temperature dependence of saturation Kerr rotation angle θ_{Ks} and coercivity H_c in T-NdFeCo sample.

merit in the present trilayer film is larger than in Pt/Co multilayers above 600 nm.

Figure 6 shows the representative temperature dependence of θ_{Ks} and H_c for the NdFeCo trilayer film (T-NdFeCo) sample. These data are taken from the Kerr loops, measured at a wavelength of 830 nm. Note that the coercivity H_c decreases much faster than θ_{Ks} and reaches almost zero value at temperatures of around 220°C. This indicates that the coercive force of NdFeCo trilayer films is controlled by the coercivity of the top and bottom TbFeCo layers. The saturation Kerr rotation angle above 220°C is determined mainly by the contribution of the second (NdFeCo) layer, because NdFeCo has a higher Curie temperature than TbFeCo. This tendency is quite similar to that of NdCo trilayer films [9]. In view of these results, NdFeCo trilayer films are also expected to have a potential for high-density magneto-optical recording at short wavelengths, as well as the NdCo trilayer films reported previously [9].

CONCLUSION

We investigated the effect on the magnetic and magneto-optical effects of trilayer films of using NdFeCo for the second layers. A trilayer film, Tb₂₀Fe₇₄Co₆ (10 nm)/Nd₁₆Fe₅₇Co₂₇(7.5nm)/Tb₂₀Fe₇₄Co₆(100nm), was obtained, with remanent Kerr rotation angle $\theta_{Kr} = 0.32^\circ$ at $\lambda = 400$ nm, coercive force $H_c = 2.4$ kOe, and a good square loop. The figure of merit ($\sqrt{R\theta_K}$) of this trilayer film is 0.21 at a wavelength of 400 nm.

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