Enhancement of Magneto-optical Effects through NdCo and Pt in TbFeCo

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(Received: June 5, 1998            Accepted: August 26, 1998)

Magneto-optical effects of TbFeCo/NdCo and TbFeCo/Pt multilayer films and Nd[TbFeCo alloy films prepared by sputter deposition are discussed in conjunction with the multilayer structure and the composition. The contribution to the polar Kerr spectra due to NdCo and Pt layers is significantly found at ultraviolet photon energies for both cases. In TbFeCo/NdCo multilayers, it is found that the enhancements of Kerr rotation \( \theta_K \) and ellipticity \( \gamma_K \) increase with NdCo layer thickness and become saturated at \( t_{\text{NdCo}} = 15 \text{ Å} \) for the case of \( t_{\text{TbFeCo}} = 30 \text{ Å} \). In TbFeCo/Pt multilayer, the \( \theta_K \) and \( \gamma_K \) are also enhanced with Pt layer thickness and become saturated at \( t_{\text{Pt}} = 12 \text{ Å} \).

Key words: magneto-optical, TbFeCo, NdCo, Pt, multilayer

1. Introduction

The optimization of compositions and fabrication conditions of thin films and multilayers for short wavelength magneto-optical recording is key for future high density recording. Light rare-earth transition-metal (RE-TM) alloys such as NdFeCo are known to exhibit a higher Kerr rotation angle at short wavelengths than that of TbFeCo. Polarized Pt atoms are also known to enhance the magneto-optical effect at such wavelengths, as demonstrated in Co/Pt multilayers. Accordingly, TbFeCo films containing Nd or Pt are potential candidates for future short wavelength recording media. However, Nd-TM alloy films are known to show the in-plane magnetization, although an intrinsic perpendicular magnetic anisotropy is present. Furthermore, the perpendicular magnetic anisotropy is strongly dependent on substrate temperature, concentration, and film thickness. Thus, it is difficult to obtain all the requirements as a magneto-optical recording medium in a single film. Some works have been carried out by means of multilayer structure to maintain high squareness of hysteresis and high coercivity in addition to the enhancement of the magneto-optical effect at short wavelengths.

In order to understand the effect of NdCo and Pt additives in TbFeCo on the magneto-optical Kerr effect, multilayers such as TbFeCo/NdCo and TbFeCo/Pt, and Nd[TbFeCo single films were fabricated, and a systematic study has been made as a function of NdCo and Pt layer thickness.

2. Experimental

TbFeCo/NdCo and TbFeCo/Pt multilayer films and Nd[TbFeCo alloy films were fabricated by sputter deposition in an Ar atmosphere. The multilayer structure was obtained by rotating the substrate holder on TbFeCo target and NdCo or Pt target and interrupting the vapor streams alternately for programmed times with shutters. The base pressure prior to the deposition was better than \( 5 \times 10^{-5} \text{ Torr} \). The Ar gas pressure was 5 mTorr during deposition. Films were deposited onto glass substrates. The substrate temperature was kept at an ambient temperature during deposition. The layer thicknesses of TbFeCo, NdCo, and Pt were varied in \( t_{\text{TbFeCo}} = 5 - 100 \text{ Å}, t_{\text{NdCo}} = 5 - 50 \text{ Å}, \) and \( t_{\text{Pt}} = 0.5 - 30 \text{ Å} \), respectively. The composition of the TbFeCo layer was \( \text{Tb}_{0.2}\text{Fe}_{0.8}\text{Co}_8 \) measured by electron probe microanalyzer (EPMA). For the measurement of the magneto-optical polar Kerr effect, very thin multilayers with a total thickness of 250 - 300 Å were deposited on a 750 Å thick Pt reflective layer. Neither any overcoat nor enhancing layer was deposited for the multilayers. This structure is suitable for obtaining an intrinsic Kerr spectrum without optical interference effects. The magneto-optical Kerr effect and optical constants were measured right after the deposition from the film side using a Kerr spectroscope in a photon energy from 1.4 to 6.8 eV (\( \lambda = 182 - 886 \text{ nm} \)).

3. Results and Discussion

3.1 TbFeCo/NdCo multilayer

Figure 1 shows the polar Kerr hysteresis loops at \( \lambda = 400 \text{ nm} \) for single films of TbFeCo and Nd[TbFeCo and TbFeCo/NdCo multilayers. It is noted that the single film of \( \text{Nd}_{0.2}\text{Tb}_{0.8}\text{Fe}_{0.8}\text{Co}_8 \) exhibits a high squareness of the curve, but the \( \text{Nd}_{0.2}\text{Tb}_{0.8}\text{Fe}_9\text{Co}_{21} \) film does not, indicating the in-plane magnetization. On the other hand, the multilayer film of TbFeCo 30 Å / NdCo 30 Å exhibits a high squareness. The content of Nd in this multilayer is nearly the same as that of \( \text{Nd}_{0.2}\text{Tb}_{0.8}\text{Fe}_9\text{Co}_{21} \). This result indicates that the high perpendicular magnetic anisotropy is present in the multilayer structure.

Figure 2 shows a summary of the coercivity \( H_c \) as a function of NdCo layer thickness \( t_{\text{NdCo}} \) for various TbFeCo layer thicknesses \( t_{\text{TbFeCo}} \). \( H_c \) decreases drastically in the \( t_{\text{NdCo}} \) range of 10 Å. For the case of \( t_{\text{TbFeCo}} = 50 \text{ Å} \), \( H_c \) remains nearly constant for the thicker values.

Figure 3 shows the photon energy \( E_\gamma \) dependence of (a) Kerr rotation angle \( \theta_K \), (b) Kerr ellipticity \( \gamma_K \), and
Fig. 1 Kerr hysteresis loops at $\lambda = 400$ nm for (a) Tb$_{3}$Fe$_{9}$Co$_{8}$, (b) Nd$_{3}$Tb$_{3}$Fe$_{9}$Co$_{8}$ and Nd$_{37}$Tb$_{63}$Fe$_{9}$Co$_{2}$, (c) TbFeCo 30 Å / NdCo 5 Å multilayer, and (d) TbFeCo 30 Å / NdCo 30 Å multilayer.

(c) Kerr signal $S = R(\theta_K^2 + \gamma_K^2)^{1/2}$, where $R$ is the reflectivity of sample calculated from measured optical constants, for various NdCo layer thicknesses $t_{NdCo}$ in TbFeCo/NdCo multilayers with $t_{TbFeCo} = 30$ Å. The spectrum of TbFeCo single film with the same composition as the TbFeCo layers of those multilayers, i.e., $t_{NdCo} = 0$, is also given in Fig. 3 for comparison. As seen in this figure, the enhancement of $\theta_K$ due to NdCo layers becomes evident at $E_p$ beyond 3 eV and increases with $t_{NdCo}$. On the other hand, the $\gamma_K$ spectra shift to positive direction with $t_{NdCo}$ for $E_p$ below 5 eV and to negative beyond 5 eV. These $\theta_K$ and $\gamma_K$ enhancements become saturated at $t_{NdCo} = 15$ Å for the case of $t_{TbFeCo} = 30$ Å. This result indicates that the thickness of NdCo layer, in which the whole layer is strongly coupled with TbFeCo layers, is up to about 15 Å. In Fig. 3 (c), the value of Kerr signal $S$ decreases monotonously for all the samples as photon energy increases. The $S$ value of multilayers is smaller than that of TbFeCo almost over the whole measured photon energy, although the spectrum change is less steep. It is mainly because the reflectivity is smaller than that of TbFeCo.

Figure 4 shows the photon energy $E_p$ dependence of (a) Kerr rotation angle $\theta_K$ and (b) Kerr ellipticity $\gamma_K$ of a TbFeCo/NdCo multilayer film and NdTbFeCo alloy films with different compositions. The spectra of TbFeCo and NdCo single films are also given in Fig. 4. In the figure, the $\theta_K$ spectra of multilayer and alloys shift to positive direction at long wavelengths and change to negative at around 3 eV for shorter wavelengths compared with the spectrum of TbFeCo. The $\gamma_K$ spectra shift to positive in the $E_p$ below 5.4 eV. Those enhancements become more distinctive as Nd concentration increases. The spectral curves of the multilayer and one of NdTbFeCo alloys (Nd$_{2}$Tb$_{7}$Fe$_{9}$Co$_{8}$) show good coincidence each other. This seems to suggest that the magneto-optical effect in the multilayer is essentially the same as that in the alloy.

3.2 TbFeCo/Pt multilayer

The absolute magnitude for $\theta_K$ increases with $t_{Pt}$ at photon energy $E_p$ beyond 3 eV, suggesting the enhancement due to Pt layers. The peak position of the $\theta_K$ enhancement is about 5 eV. Pt layers also affect the enhancement of $\gamma_K$ negatively at $E_p$ below 5 eV and positively at beyond 5 eV for the absolute value. It is found that the enhancements of both $\theta_K$ and $\gamma_K$ appear even at $t_{Pt} = 3$ Å, i.e., the level of one atomic layer, and become saturated at $t_{Pt} = 12$ Å. The enhancement is considered to originate from polarized Pt atoms. This result is of interest since one can estimate a range from the interface to be 6 Å (half of the $t_{Pt} = 12$ Å), under which Pt atoms are likely being polarized, giving rise to the higher Kerr activity.

Fig. 2 Coercivity as a function of NdCo layer thickness for various TbFeCo layer thicknesses.
Fig. 3 (a) Kerr rotation angle, (b) ellipticity, and (c) Kerr signal of TbFeCo 30 Å / NdCo 1 Å multilayers with various NdCo layer thickness as a function of photon energy.

Fig. 4 (a) Kerr rotation angle and (b) ellipticity of a TbFeCo/NdCo multilayer film and NdTbFeCo alloy films with different compositions as a function of photon energy.

Acknowledgements  The present work has been partially supported by the Original Industrial Technology R & D Promotion Program from the New Energy and Industrial Technology Development Organization (NEDO) of Japan (8C-039-1) and by the research fund by HOYA Corporation. One of the authors wishes to thank TOYOTA MOTOR Corporation for the assistance in acquiring the composition data.

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