PROPERTIES OF NdDyFeCoTi MAGNETO-OPTICAL MEDIA MADE FROM CAST ALLOY TARGET

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ABSTRACT

We have developed a magneto-optical recording media having a high performance and good reliability using more abundant rare earth elements than Tb. By using a Nd-Dy-Fe-Co-Ti composition, the alloy target is easily formed by the casting method. As a result, the oxygen content restricted to under 400 ppm. That enables the media to have a high performance and it is easy for mass production. Each element of Nd, Dy, Fe, Co and Ti plays an essential role in magneto-optical properties, magnetic properties, reliability and realization of the cast alloy target.

1. INTRODUCTION

Thin films composed of a Tb are reliable rare earth transition metal alloy films for high density magneto-optical recording. Because they have an amorphous structure and a large perpendicular magnetic anisotropy as well as an adequate Curie temperature T_c , ideal magneto-optical media can be produced by using a Tb compound in the laboratory.[1] However, if one tries to produce a large number of these media at a mass production level at low cost, there are some problems to be solved. These problems are here listed.

(1) The amount of natural resources of Tb is very small. That makes Tb metal very expensive. Additionally, most Tb is utilized in fluorescent materials. Therefore, there are only small amounts of Tb left for use in producing magneto-optical recording media.

(2) This film of magneto-optical media is mainly produced by a sputtering method. In that method, an alloy target which contains all the elements needed for a film is desirable. However, TbFe or TbFeCo is too fragile to obtain an alloy target if it is made by casting. Accordingly, the powder metallurgical method is adopted to obtain such target. That results in a high oxygen content (> 1000 ppm) and involves complex production steps.

In order to solve the above problems we have been studying a more viable alloy system with the following conditions. Namely, it should be composed of more abundant rare earth elements than Tb. This alloy system also should enable the alloy target to be manufactured by simple casting. The magneto-optical medium made from this alloy system should have better properties than that containing Tb.[2,3]

2. EXPERIMENTAL

Alloy targets composed of Nd-Fe, Nd-Dy-Fe and Nd-Dy-Fe-Co-Ti were melted and cast into ingots in an induction furnace. These ingots were formed into disk-shaped targets for sputter deposition. The diameter and thickness of these targets were 10.16 cm (4 inches) and 0.4 cm, respectively. Usually the oxygen content was as much as 400 ppm. The MO layer or alloy film was deposited by dc sputtering. Before sputter deposition, the chamber was evacuated to less than 5×10^{-7} Torr. Deposition rates ranged from 10 to 100 nm/min. In the experiment of the Nd-Dy-Fe-Co system, a Nd-Dy and Fe target were used. Co tips was laid on a Fe target to adjust the Co content. To investigate the effects of the M (M=Ti, Cr, Al) element in the Nd-Dy-Fe-Co-M system, a Nd-Dy and a Fe target were used and M tips were also laid on Fe targets together with Co.

Glass substrates and polycarbonate disks were used for measuring magnetic properties and for evaluating read/write characteristics, respectively.

Magnetization(M), coercive force(Hc) and T_c of the films were measured by a vibrating-sample magnetometer. The Kerr or Faraday rotation angle was measured at a wavelength of 780nm. An inductively coupled plasma analysis was used to determine the composition of the films. The amorphous structure of the film was confirmed by X-ray and electron diffraction.

3.RESULTS

Generally, the light rare earth-iron system (LR-Fe) forms fewer intermetallic compounds than the heavy rare earth-iron system (HR-Fe). Therefore LR-Fe alloys have larger mechanical strength than HR-Fe alloys. The latter is very fragile. If magneto-optical recording media with good properties can be obtained by using the LR-Fe system, an alloy target for sputtering can be formed by simple casting. This is the starting point of our experiment.

First, we chose Nd as LR and made a $\text{Nd}_a\text{Fe}_{100-a}$ alloy target to produce magnetic thin films. As a result, it was found that these films had an amorphous structure in the range of $a=20-40$. In the range of $a=15-30$, the anisotropy constant K_1 , which is determined by the equation $K_1 = K_u - 2\pi M_s^2$, was positive. The angle of Kerr rotation is about 15 min and T_c is 80 °C when $a=30$. These values are relatively good, however, the H_c of the Nd-Fe thin film had a low value of 10 or 20 Oe. From this experiment we conclude that Nd can be used at least as one rare earth element in forming a magneto-optical recording medium by the R-Fe system.

In order to obtain a higher H_c value while assuring that the film has good magneto-optical characteristics, and that an alloy target can be formed by casting, we investigated combination of Nd and heavy rare earth (HR). As the HR, we chose Dy because Dy is a more abundant element and about ten times cheaper than Tb. It is therefore not critical as a natural resource.

We studied the $(\text{Nd}_x\text{Dy}_{1-x})_{25}\text{Fe}_{75}$ system and obtained the results shown in Fig.1. As $K_u > 2\pi M_s^2$ is the condition to get a perpendicular magnetized film, this system is worth studying for a magneto-optical medium in the range of $x < 0.8$. However, H_c is still low even at $x=0.6$, where H_c is about 500 Oe. In order to realize a higher H_c than that in the above systems, the range of $x < 0.5$ is investigated, so that H_c over 1 kOe is feasible in the range of $x < 0.6$. H_c reaches around 10 kOe at $x=0.3$ or 0.2 if the sputtering conditions are adequate.

Next, we studied the effect of Co using the composition of $(\text{Nd}_{0.4}\text{Dy}_{0.6})_{30}(\text{Fe}_{1-x}\text{Co}_x)_{70}$. In this system Co had no effect on H_c but it had a great effect on the Kerr rotation angle. This is shown in Fig.2. However, in other systems such as $(\text{Nd}_{0.4}\text{Dy}_{0.6})_{35}(\text{Fe}_{1-x}\text{Co}_x)_{65}$, an increase of H_c up to $x=0.3$ was observed. Of course, an increase in the Kerr rotation angle was also confirmed in this system.

Fig.1 Dependence of M_s (●) and K_u (▲) on Nd content in Nd-Dy-Fe amorphous alloy.

Fig.2 Dependence of Kerr rotation angle (■) and coercive force (▲) on Co content in $\text{NdDy}(\text{Fe}_{1-x}\text{Co}_x)$.

As a result of these experiments and other similar ones, we have obtained an optimum composition range for a magneto-optical medium in the Nd-Dy-Fe-Co system. The typical composition is $(\text{Nd}_{0.2}\text{Dy}_{0.8})_{25}(\text{Fe}_{0.7}\text{Co}_{0.3})_{75}$.

In order to make the production of the alloy target easier by enhancing the mechanical strength of the cast alloy, M was added to the Nd-Dy-Fe-Co system. The special effects of Al, Cr or Ti were investigated, because these elements were reported to improve the reliability of the magneto-optical media in previous work[4]. If a certain element of those tested proved to have an important effect on making an alloy target simultaneously, it would be a significant breakthrough. As a result of serial work, we found that Ti had the greatest effect on improving the mechanical strength of an alloy while maintaining its magneto-optical and magnetic properties at a high level relative to the extent of Ti content. Table 2 shows magneto-optical and magnetic properties of the developed film containing Ti of 4at%. This composition, $(\text{Nd}_{0.23}\text{Dy}_{0.77})_{25}(\text{Fe}_{0.55}\text{Co}_{0.40}\text{Ti}_{0.05})_{75}$ shown in Table 1, is the optimum composition in the Nd-Dy-Fe-Co-Ti alloy system. Using this composition, the alloy target is easily cast.

Properties	Value
Magnetization (emu/cc)	40
Coercive force (KOe)	8
Curie temperature (°C)	220
Crystallization Temperature (°C)	420
Faraday Rotation angle (deg/cm)	2.0×10^5

Table 1. Magnetic properties of (Nd_{0.23}Dy_{0.77})₂₅(Fe_{0.55}Co_{0.40}Ti_{0.05})₇₅

Fig.3 Structure of MO media.

Fig.4 Kerr hysteresis loop of Nd-Dy-Fe-Co-Ti deposited on polycarbonate substrate.

We produced the magneto-optical (MO) media, in which the composition is the same as the one shown in Table 1, by sputtering an alloy target containing 5 elements. The structure of the media is shown in Fig.3. We used the polycarbonate substrate and inorganic materials as a protective layer of which the thickness is 100 nm and the refractive index is 2.0. Fig.4 shows the Kerr hysteresis loop of the fabricated media. The recording characteristics of this media were measured according to the conditions shown in Table 2. Fig.5 illustrates the relationship between the carrier to noise ratio (CNR) and the magnetic field during recording. Fig.6 shows the dependence of CNR on the laser power during recording. An optimum CNR of over 50 dB was obtained at the recorded domain length of 1.7 μm by using a recording layer of 100 nm.

Contents	Value
Recording Power	6.2 mW
External Field	200 Oe
Carrier Frequency	1.0 MHz
Linear Velocity	3.5 m/sec
Duty Ratio	50 %
Bit length	1.7 μm
Track pitch	1.6 μm
RBW	30 kHz

Table 1. Conditions for read/write characteristics evaluation.

Fig.5 Dependence of CNR on magnetic field.

Fig.6 Dependence of CNR on recording power.

Fig.7 illustrates the long term stability of the given media under the condition of 90% RH at 70 °C. It remained stable after aging for over 1000 hours.

In this diagram, critical times under certain conditions are shown, having been determined by Arrhenius's method.

We have found that Nd played an important role not only in forming the alloy target[2] but also in improving the recording characteristics of the magneto-optical medium.[3] Nd can also greatly improve the squareness of hysteresis near T_c (Magnetic field vs. Kerr or Faraday rotation Angle), if Nd is added to the Dy-Fe-Co-Ti system. We believe this is a reason why the Dy-Fe-Co-Ti medium is improved by adding Nd. Fig.8 shows the spectrum of readback signal from a MO medium having a composition of $(Nd_{0.2}Dy_{0.8})_{25}(Fe_{0.58}Co_{0.38}Ti_{0.04})_{75}$. The writing noise coincides with the disk noise. That means that the above mentioned medium generates extremely low noise.

Fig.7 Change in number of bit error and carrier to noise ratio (CNR) as a function of aging time. The environment is maintained at 70 °C 90%RH. The lines (a) and (b) show a lifetime of ten years at 25 °C 90% RH and 30 °C 90%RH, respectively.

$(Nd_{0.2}Dy_{0.8})_{25}(Fe_{0.65}Co_{0.30}Ti_{0.05})_{75}$

Fig.8 Spectrum of readback signal of NdDyFeCoTi

4.SUMMARY

(1) We have developed a magneto-optical recording media having both high performance and good stability using rare earth elements which are more abundant than Tb.

(2) By using a Nd-Dy-Fe-Co-Ti composition, an alloy target is easily formed through a casting method. As a result, oxygen content restricted to under 400 ppm, which enables the media to have both a high performance and the ability to be easily produced through mass production.

(3) Nd and Ti play important roles in the realization of the cast alloy. Ti is also supposed to contribute towards improving the reliability of the medium. Nd has also been found to improve the recording characteristics of the medium.

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