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Amorphous thin film disk for magneto-optical memory

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Abstract

Amorphous rare earth-transition metal films as media of magneto-optical memory are described. Improvements of amorphous GdCo film in stabilizing recorded bits and in making uniform film were performed. High speed recording and reading experiment were carried out on GdCo disk of 150 mm in diameter, and excellent stability of recorded bits, considerable uniformity, and high sensitivity for recording were confirmed. Thermal stability and spectra of Kerr rotation angle of GdCo film were also measured. It is shown that GdCo film is very promising material for magneto-optical memory.

Introduction

Requirements for erasable media and system in and with which informations are recorded of a high density and a high speed are increasing. Magneto-optical recording is a promising system owing to following advantages: This method is (1) erasable, (2) non-contact, (3) random accessible, and (4) non-volatile.

In 1973, GdCo amorphous magnetic thin film was presented by Chaudhari et al. as a material for a magnetic bubble device, and it was also pointed out that it can be used for magneto-optical memory.[1] In the past several years, many studies in GdCo film and in new combinations of rare earth metal (RE) and transition metal (TM) were performed. It became clear that amorphous magnetic thin films are promising materials for magneto-optical memory in high density and with high rate.

In this paper, improvements in amorphous RE-TM thin films, especially in GdCo films, for the application to magneto-optical recording, and results of measurements on thermal stability and on the spectra of Kerr rotation angle of GdCo films are presented. Experimental results of high speed recording on GdCo disk and of reading from it are also described.

Amorphous magnetic thin films

Amorphous RE-TM films can be prepared easily by sputtering and evaporation technique on various substrates. In the case of GdCo film magneto-optical recording is carried out at compensation temperature. Curie temperature recording is carried out on TbFe[2,3], GdTbFe[4] and other materials.

Principle of compensation temperature recording

We show a principle of magneto-optical recording on GdCo film. The compensation temperature varies with the composition of this alloy film. GdCo film having the compensation temperature near room temperature is suitable for recording.

Figure 1 shows a typical temperature dependence of coercive force of GdCo film prepared by rf sputtering method, and Fig. 2 shows schematically the mechanism of magneto-optical recording. The film has an axis of easy magnetization perpendicular to the film plane (Fig. 2(a)). A small region of the film is heated by a short pulse of laser beam focused on the film. The coercive force of the heated region decreases abruptly, as shown in Fig. 1, and the direction of magnetization of the small region turns around with the help of weak external bias fild (He) of about 100 Oe (Fig. 2(b)). Thus, information is recorded as a small cylindrical magnetic domain. For the purpose of erasing the recorded bit selectively, it is enough to heat the bit by the laser beam with negative bias field. Recorded information is read out by the use of polar Kerr effect.

Figure 3 shows the dependence of laser power which is necessary to record a bit of 1μm in diameter on duration of laser pulse. The film thickness is 150 nm. The laser power was measured before the objective lens which focuses the laser beam on GdCo film. By extraporating the data obtained experimentally, it can be said that information of the rates of 100 Mbits/s can be recorded with a laser power of only 6 ∿ 7 mW.

Merit of amorphous thin films

As shown in GdCo film, amorphous RE-TM films have following advantages as materials for magneto-optical memory:

(1) Because compensation temperature or relatively low Curie temperature is used, the sensitivity for recording is high.

(2) Since they have an axis of easy magnetization perpendicular to the film plane, information can be recorded in very high density.

(3) A large signal to noise ratio (SNR) is obtained because of a large polar Kerr rotation angle and because of the absence of grain boundaries.

Classification of amorphous films

Amorphous RE-TM films for magneto-optical memory are classified into two groups: cobalt alloys and iron alloys.

In the case of iron alloys, signals are recorded by the use of Curie temperature. The advantage of iron alloy films lies in the easiness of film preparation. They can be prepared by evaporation as well as sputtering method. It is easy to prepare uniform films for magneto-optical memory because of a weak dependence of the Curie temperature on composition. Recently, a ternary alloy film of GdTbFe[4] and a double layered film of GdFe and TbFe[5] were proposed in order to suppress following disadvantages:
(a) a low Kerr rotation angle of TbFe film and
(b) a low stability of bits recorded on GdFe film.
A dynamic recording experiment on GdTbFe film with a diode laser was also presented.[4]

Among cobalt alloys, we selected GdCo film to be investigated. Preparation of GdCo film with the magnetization perpendicular to the film plane is difficult by means of the evaporation, but easy by sputtering method. GdCo film has following advantages:

(1) It has higher sensitivity to recording than iron alloy films owing to a sharp decrease of coercivity with temperature above its compensation temperature. This advantage is favorable for using a diode laser.

(2) It is stable against the repeated irradiation of laser pulses, because bits are recorded with a laser beam of low power.

(3) Since it has high Curie temperature, the decrease of Kerr rotation angle is small when laser beam for reading raises film's temperature.

(4) It has more excellent thermal stability than GdFe.[6]

(5) Cobalt alloys are much stronger against rust than iron alloys. We confirm that after more than two years there is no degradation of bits recorded on GdCo film even if the film is not overcoated when we read bits through substrate glass.

Although GdCo film has these advantages it has some problems:
(i) Small bits recorded on it are not stable.
(ii) It is difficult to prepare a film with uniformity over a wide area.
However, we have removed these drawbacks by means of the techniques described below.

Improvement of GdCo film

Stability of recorded bits

Stabilization of small bits recorded on GdCo film was achieved by making multi-layered film.[7] Multi-layered film was prepared by changing a sputtering condition during deposition. There are three reasons for the stabilization of recorded bits on multi-layered film:

1) Domain walls of recorded bits are pinned by the boundary region of these layers.[8]

2) There exists considerably large demagnetizing field even near the compensation temperature of one of layers. We describe this mechanism in the case of double layered film. First, layer of GdCo (I) (shown in Fig. 4) is deposited onto the glass substrate. In the case of reading signals through the substrate, the compensation temperature of the GdCo (I) is selected to be just below the room temperature, so that cylindrical recorded bits of single domain are obtained. Its thickness is so large that laser beam does not penetrate into the second layer (GdCo (II)). The layer of GdCo (II), the compensation temperature of

which is lower than that of GdCo (I), is deposited on GdCo (I). There occurs no problem unless GdCo (II) is used for recording media. The radius r of stable domain is given by [9]

$$\left| \frac{\sigma_w}{2rM_s} - H_d \right| \leqq H_c , \qquad (1)$$

where σ_w denotes the wall energy density, M_s the saturated magnetization, H_d the demagnetizing field, and H_c the coercive field. In the case of small bits on GdCo film,

$$\frac{\sigma_w}{2rM_s} \leqq H_c + H_d . \qquad (2)$$

At room temperature, M_s and H_d of GdCo (I) are very small, but those of GdCo (II) are large. The demagnetizing field of the GdCo (II) stabilizes the small bits recorded on double layered GdCo film.

3) The magnetization often inclines from perpendicular direction because of the oxidation or large demagnetizing field. If the magnetization of the layer of GdCo (II) inclines, the recorded bits are stabilized as Honda et al. described.[10]

Recently we obtained the experimental results that bits recorded on ternary GdTbCo film are stable even if the film is a single layer film. Results described below are, however, those of GdCo films.

Uniformity

The compensation temperature of GdCo film deposited with a target of a uniform GdCo alloy decreases from the center toward the edge of the film. We found that the non-uniformity of magnetic property is mainly attributed to the non-uniformity of oxygen distribution.[11] We also found that a negative dc bias applied to the substrate makes the distribution of the oxygen quantity uniform and a considerable uniformity in magnetic property is achieved.[12]

Thermal stability

Since amorphous materials are in a quasi-equilibrium state, it is important to evaluate their thermal stabilities, particularly for the magneto-optical recording. We evaluated thermal stability of non-biased GdCo films through measurements of electrical resistivity.[13]

Typical temperature dependences of the resistivity ρ of a non-biased and a biased GdCo film, both single layered, are shown in Fig. 5. The bias voltage was -100 V. It can be said from Fig. 5 that :
(i) The temperature at which the ρ of a biased film begins to decrease slowly is much higher than that of a non-biased film. This decrease of ρ may be attributed to a structural relaxation of the amorphous film.
(ii) The temperature at which the ρ of a biased film changes suddenly is also much higher than that of a non-biased film. This sudden change is considered to correspond to the crystallization.
From the present work, it becomes clear that the application of bias voltage during deposition makes GdCo film stronger against heating.

We also measured the dependence of the ρ of a non-biased GdFe film, and obtained the similar result as non-biased, less stable GdCo films. In the case of Gd-Fe films, only the non-biased ones are available for the magneto-optical recording because a biased Gd-Fe film does not have magnetization perpendicular to the film plane, even if it were thermally more stable than non-biased films.

From the present result, we conclude that for the magneto-optic memory GdCo film has more excellent thermal stability than GdFe film.

Spectra of Kerr rotation angle

The wavelength dependence of Kerr rotation angle of GdCo film was measured in order to select the most proper laser for reading signals recorded on GdCo film. Figure 6 shows the result obtained through glass substrate by a piezo-birefringent modulator method.[14] It is seen from these spectra that Kerr rotation angle increases slightly toward the longer wavelength, and that a hump appears at about 1μm. Such a behavior is more apparent in a biased film than in a non-biased film. From the present work, it becomes clear that it is desirable to use a near-ir semiconductor laser for reading signals.

Experiments on rotating disk memory exerciser

Amorphous GdCo film was deposited on a disk of glass of 1.1 mm in thickness and of 150 mm in diameter. A dc bias voltage of -100 V was applied to the disk. Two layered film was made by changing sputtering conditions during the deposition. The film thickness is 0.2 μm.

Figure 7 shows the schematic diagram of the rotating disk exerciser. Figure 8 shows its photograph. A beam from a 25 mW He-Ne laser is modulated by an acousto-optic modulator. The output beam is focused onto the plane of GdCo film with a focusing servo system. The N.A. value of the objective lens is 0.45. The rotation speed of the exerciser is variable up to 1800 rpm. After signals are recorded, the disk is transferred to a reading position. The same laser as that for recording is used for reading. The optical system for reading is equipped with servo systems of forcusing and tracking.

The recording and reading are carried out through the glass substrate in order to minimize the influence of oxidation of the film and of dusts on the disk. No trouble caused by a reflecting light from the air-glass interface occurs to focusing servo system.

Figure 9 shows the bits recorded on the GdCo disk at a rotating speed of 1800 rpm, and with a bit rate of 1 MHz. The laser power on the disk surface was 5.6 mW, and the external bias field was 80 Oe. Bits of approximately 1 μm in width were written. Signals were read out with a laser power of about 2 mW. So far, signal to noise ratio (SNR) of about 32 dB has been obtained for reading signal with a bandwidth of 100 kHz. Tracking servo and laser-noise reduction system are now examined, which will bring about higher SNR.

Summary

Amorphous GdCo film suitable for magneto-optical memory is prepared by making multi-layered film and by controlling distribution of oxygen quantity through the application of bias voltage. By using these techniques, amorphous GdCo disk of 150 mm in diameter was prepared, and high speed recording and reading experiment with a disk exerciser were performed. Excellent stability of recorded bits, considerable uniformity, and high sensitivity for recording were confirmed.

It becomes clear that the application of bias voltage also makes GdCo film more stable against heating. The observed spectra of Kerr rotation angle show that it is desirable to use a near-ir semiconductor laser.

GdCo film is more stable against heating and is much stronger against rust than rare earth-iron alloy film. It becomes evident that GdCo film is a most promising material for magneto-optical memory.

References

1. Chaudhari, P., Cuomo, J.J. and Gambino, R.J., "Amorphous metallic films for magneto-optic application," Appl. Phys. Lett., Vol. 22, pp.337-339. 1973.

2. Matsushita, S., Sunago, K. and Sakurai, Y., "Thermomagnetic Writing in Tb-Fe films," Jpn. J. Appl. Phys., Vol. 15, pp.713-714. 1976.

3. Mimura, Y., Imamura, N. and Kobayashi, T., "Curie Point Writing in Amorphous Magnetic Films," Jpn. J. Appl. Phys., Vol. 15, pp.933-934. 1976.

4. Imamura, N. and Ota, C., "Experimental Study on Magneto-Optical Disk Exerciser with the Laser Diode and Amorphous Magnetic Thin Films," Jpn. J. Appl. Phys., Vol. 19, pp.L731-L734. 1980.

5. Tsunashima, S., Tsuji, H., Kobayashi, T. and Uchiyama, S., "Thermomagnetic writing on exchange-coupled amorphous rare-earth iron double layer films," IEEE Trans. Mag., Mag.-17 (1981), to be published.

6. Buschow, K.H.J. and Dirks, A.G., "Crystallization of amorphous alloys of rare earths and 3d transition metals," J. Electrochem. Soc., Vol. 127, pp.2430-2432. 1980.

7. Togami, Y., "Stability of small bits written in amorphous GdCo thin films, "Appl. Phys. Lett., Vol. 32, pp.673-675. 1978.

8. Togami, Y., "Amorphous GdCo Thin Films for High Density Thermomagnetic Recording," Supplement of Jpn. J. Appl. Phys., Vol. 18, pp.231-234. 1978.

9. Huth, B.G., "Calculation of Stable Domain Radii Produced by Thermomagnetic Writing," IBM J. Res. Develop., Vol. 18, pp.100-109. 1974.

10. Honda, S., Ueda, K. and Kusuda, T., "Dynamic behavior of small bits written by laser irradiation on GdFe films," J. Appl. Phys., Vol. 52, pp.2295-2297. 1981.

11. Kobayashi, K., Togami, Y. and Teranishi, T., "Influence of Oxygen on the Uniformity of RF-Sputtered Amorphous GdCo Films," Jpn. J. Appl. Phys., Vol. 19, pp.L581-L584. 1980.

12. Togami, Y. and Kobayashi, K., "Increase in Uniformity of Amorphous GdCo Films by Control of Oxygen Quantity," Jpn. J. Appl. Phys., Vol. 20, pp.1457-1465. 1981.

13. Kajiura, M., Togami, Y., Kobayashi, K. and Teranishi, T., "Relaxation of Amorphous Gd-Co Film through Electrical Resistivity Measurement," Jpn. J. Appl. Phys., Vol. 20, pp.L389-L391. 1981.

14. Sato, K., "Measurement of Magneto-optical Kerr Effect by Using a Piezo-birefringent Modulator," Jpn. J. Appl. Phys., Vol. 20, No.12. 1981. to be published.

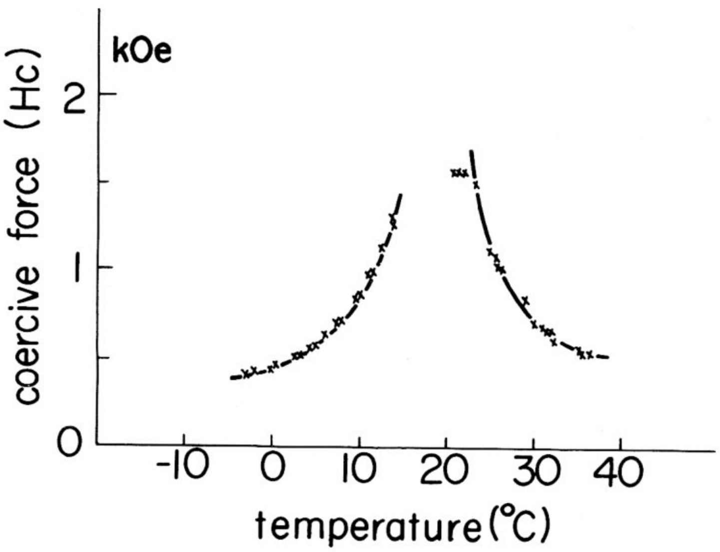


Figure 1. Temperature dependence of coercive force of a GdCo film.

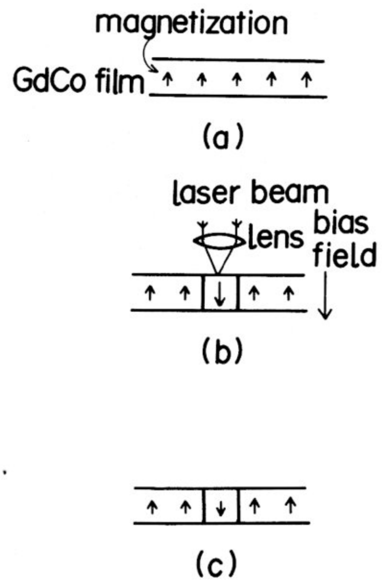


Figure 2. Magneto-optical recording process.

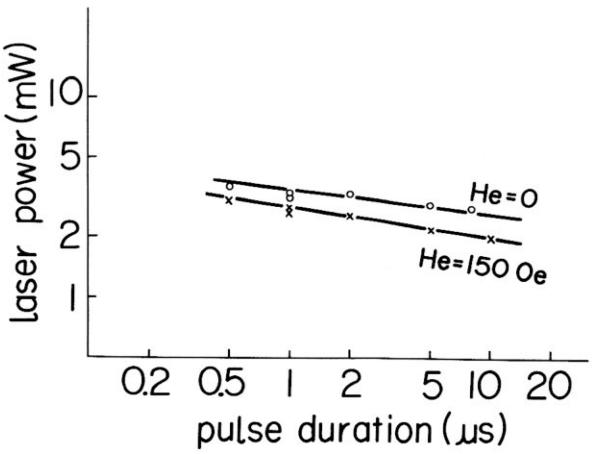


Figure 3. Laser power required for recording a bit of 1 μm in diameter.
He: external bias field.

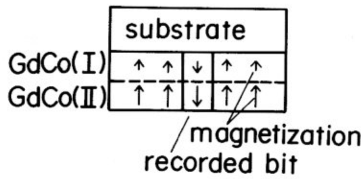


Figure 4. Construction of double layered GdCo film.

Ms(GdCo (II)) > Ms(GdCo (I))
Ms: saturated magnetization.

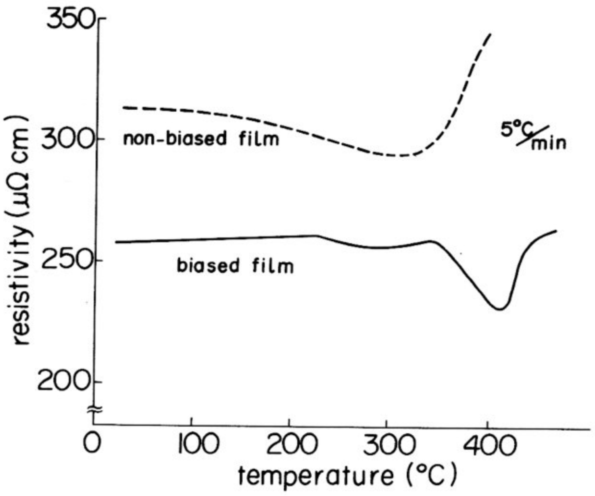


Figure 5. Temperature dependence of resistivity of GdCo films. Heating rate is 5°C/min.

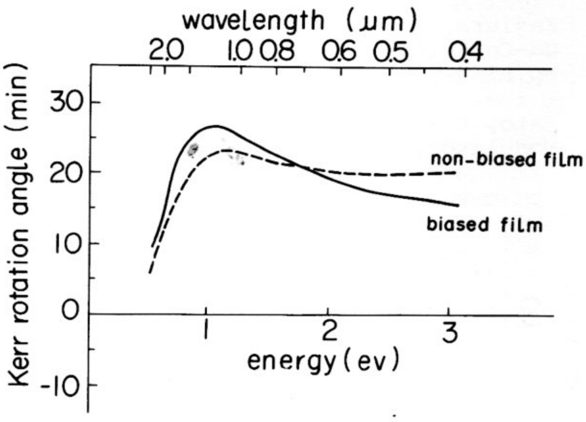


Figure 6. Spectra of polar Kerr rotation angle of GdCo films.

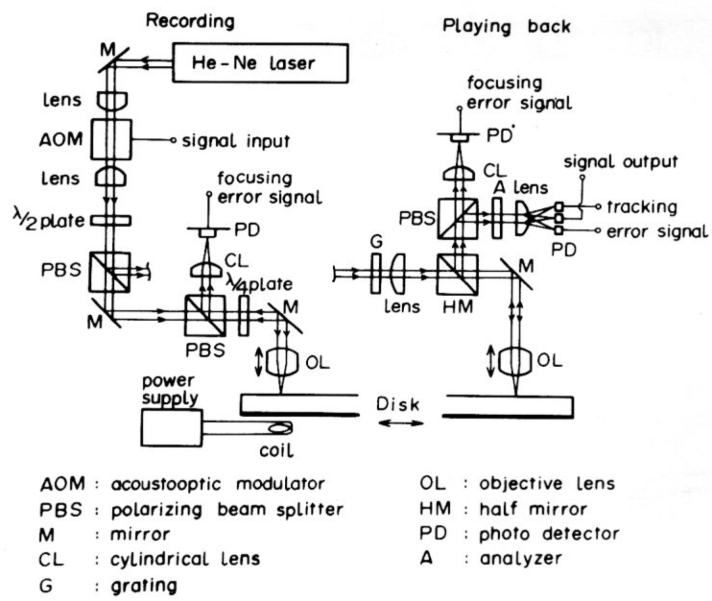


Figure 7. Schematic diagram of magneto-optical disk exerciser.

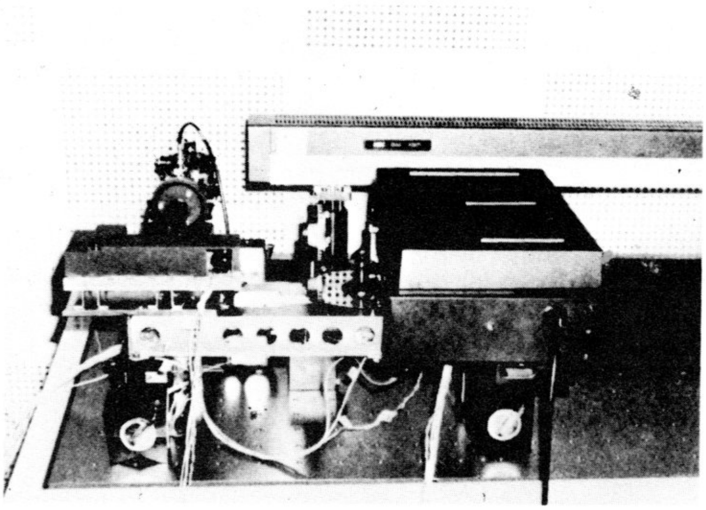
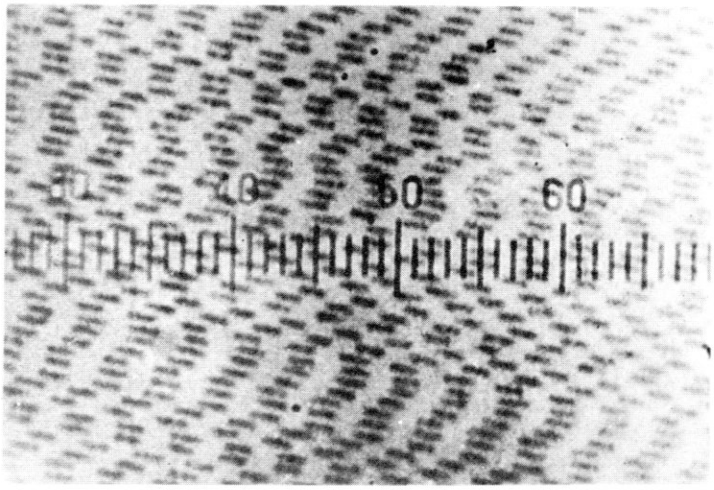


Figure 8. Photograph of exerciser.



10 μm

Figure 9. Recorded bits on GdCo disk.
Rotating speed :1800 rpm,
frequency : 1 MHz,
laser power : 5.6 mW,
bias field : 80 Oe.