Measurement of Thermal Conductivities of SiN and TbFeCo Films

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Abstract—**The effective thermal conductivities of SiN and TbFeCo thin films were measured by comparing the length and width of polarizing microscope image of thermo-magnetically written domains with those of calculated isotherms for the trilayer structure of substrate/Si_3N_4/$Tb_{22}Fe_{70}Co_8$/Si_3N_4. The resulting data were applied to the quadrillayer structure of substrate/ Si_3N_4/$Tb_{22}Fe_{70}Co_8$/Si_3N_4/Al, and the length of calculated isotherms was turned out to agree with that of written domain.**

I. INTRODUCTION

Since most magnetic properties of a magneto-optic (MO) disk are temperature dependent, any quantitative study on writing and readout characteristics requires temperature profile in the layers of an MO disk. Particularly, in mark length recording a general method for reducing mark edge shift is modifying temperature profile itself by laser pulse modulation[1]. Temperature profile in the layers of an MO disk is hard to be measured directly and thus, it is generally obtained by solving the heat transfer equation, which requires various material constants and system parameters as input data. Most of these data can be measured directly, but the heat capacity and the thermal conductivity are very difficult to measure for very thin films. Furthermore, since an MO recording layer of rare-earth transition-metal film is overcoated with a dielectric layer to prevent from oxidation, it is impossible to separately measure the recording layer. The heat capacity of thin film is known to be not much different from that of bulk material, while the thermal conductivity is changed up to 100 times as the thickness is varied[2]. Hence, the thermal conductivity is the most crucial physical quantity to be determined for understanding of laser-heating process.

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In this paper we have attempted to determine the thermal conductivities of both $Tb_{22}Fe_{70}Co_8$ and Si_3N_4 by comparing the length and width of microscope image of written domain with those of calculated isotherms for the trilayer structure of substrate/SiN/TbFeCo/SiN. Results are compared with previously measured data and the problems in this method are discussed.

II. EXPERIMENTAL METHOD AND RESULTS

Trilayer structure of Si_3N_4/$Tb_{22}Fe_{70}Co_8$/Si_3N_4 was deposited on glass substrate by sputtering and magnetic domains were written by irradiation of a focused SHG green laser($\lambda = 532$ nm). In order to eliminate the effect of groove on domain shape, we have used ungrooved glass substrate and had only focusing servo on and moved an optical pick-up manually to get spiral pattern of domains. System parameters and test conditions of a dynamic tester are listed in Table I, and typical magnetic domain image taken by a polarizing microscope (LEICA DM) is shown in Fig. 1.

As mentioned earlier, we have tried to measure the thermal conductivity by comparing microscope image of domain with calculated isotherms. The isotherms at the temperature where the coercivity meets an external magnetic field are assumed to coincide with the written magnetic domain in size, because potential energy due to an external field

TABLE I
SYSTEM PARAMETERS

wavelength	532.0 (nm)
beam diameter	247.0 (nm)
bias magnetic field	330.0 (Gauss)
ambient temp. in drive	40.0 (℃)
r.p.m.	1800.0
position from center	45.0 - 55.0 (mm)
writing power	4.0, 5.0 (mW)
writing frequency	1.57 (MHz)
pulse duration	160.0 (nsec)

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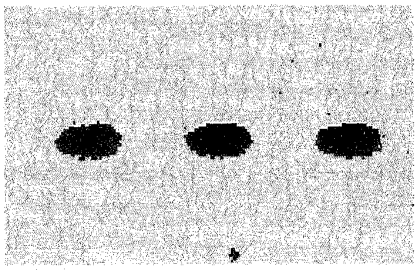

Fig.1. Polarizing microscope images of magnetic domains.

predominates over various kinds of energies involved in magnetic domain-reversal process[3]. The methods of calculating isotherms for an optical disk were published by many authors and we used the computer program written by Mansuripur[4],[5].

III. DISCUSSION AND CONCLUSIONS

Fig.2 shows the temperature dependence of coercivity for $Tb_{22}Fe_{70}Co_8$. All material constants except the thermal conductivities are listed in Table II. The heat capacities of TbFeCo and SiN were taken from Ref. 1, and other data were actually measured by us. Typical isotherms calculated from those data are shown in Fig. 3.

In principle, two unknown thermal conductivities of TbFeCo and SiN films could be determined by comparing the calculated domain length and width with the measured ones. Fig. 4 shows two lines, where one line satisfies the correct domain length and the other one the correct domain width. These

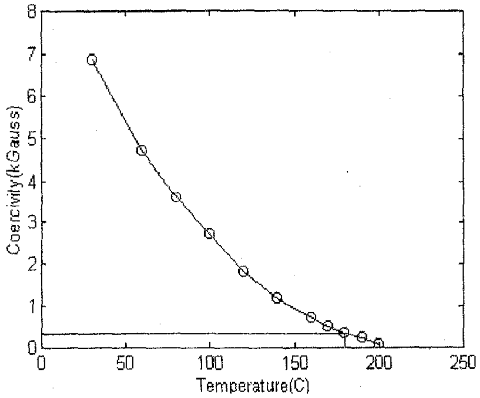

Fig. 2. Temperature dependence of the coercivity of TbFeCo films. External magnetic field meets this curve at 180 ℃.

TABLE II
MATERIAL CONSTANTS USED IN CALCULATING ISOTHERMS

Refractive Index(n) of Glass at 532 nm	1.53
n of SiN at 532 nm	2.08
n of TbFeCo at 532 nm	$2.74 + 3.42i$
Heat Capacity(Cp) of Glass	1.95 (J/cm³/℃)
Cp of SiN	2.0 (J/cm³/℃)
Cp of TbFeCo	3.0 (J/cm³/℃)
Thermal Conductivity(κ) of Glass	0.0015 (W/cm/℃)

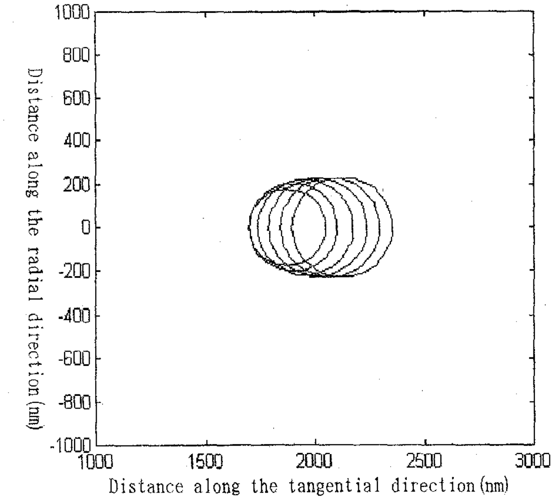

Fig. 3. Numerically computed isotherms to determine magnetic domain size.

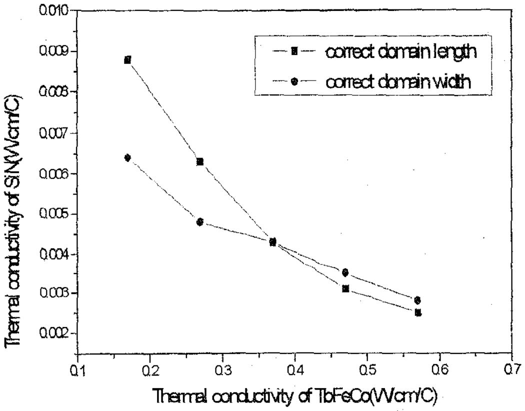

Fig. 4. One line satisfies the correct domain length and the other line the correct domain width. The two lines meet at just one point.

two lines meet just at one point and one can get the thermal conductivities of TbFeCo and SiN simultaneously. We have repeated this procedure under different writing conditions of different power, pulse duration and linear velocity. We present our results of TbFeCo films in Table III and SiN films in Fig. 5, together with data in Refs. 1 and 2.

Our results of $Tb_{22}Fe_{70}Co_8$ films agree well with previously published data, but those of Si_3N_4 films show some discrepancy. But, both data exhibit very strong thickness dependence in common, which is ascribed to the great portion of interfacial thermal resistance in the thin film limit[2]. To test the accuracy of our results, we have deposited an 1000-Å-thick Al reflection layer on the trilayer structure to make quadrilayer structure, and compared the recorded domain size with calculated isotherms. Since the Al layer is not transparent, domains are not directly observable in this case. But we found out that the ratio of the domain length to the spatial period of domains recorded by uniformly pulsed laser was constant with approximately 67 %, if domains were written under the condition to make its carrier-to-noise ratio(CNR) maximum. This fact enables us to get the length of domain without direct observation. The bulk values of the heat capacity and the thermal conductivity are used for the Al layer in calculating isotherms. As seen in Fig. 6, all the domain lengths are approximately 0.61 μm which is 67 % of spatial period of domains. We reason about the discrepancy between our results and others mentioned above. One reason might be the difference in interfacial thermal resistance, which induces great effects on the thermal conductivity of thin film. The Si_3N_4 layer in Ref. 2 was deposited on single crystal Si substrate and contacted with air, while our SiN layer was deposited on glass substrate and contacted with TbFeCo. The other reason is that data in Ref. 2 are purely transverse ones across the thickness of Si_3N_4 layer, but ours are averaged values of the transverse and tangential directions to the layer which has no interface. In order to have more accurate results, it is desirable that these two kinds of thermal conductivity should be treated separately in both numerical computations and measurements.

TABLE III
THERMAL CONDUCTIVITY OF Tb22 Fe 70Co8(W/cm/℃)

Our Results	Data from [1]
0.42(40.0 nm)	0.40
0.37(80.0 nm)	

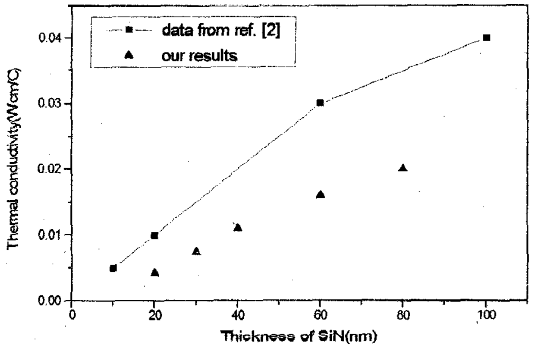

Fig. 5. Thermal conductivity of Si3N4. The data from [2] are shown for comparison.

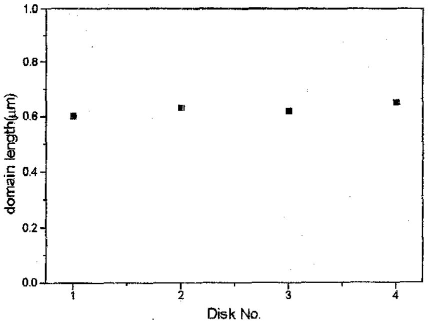

Fig. 6. Numerically computed length of isotherms for the quarilayers of thickness #1 : 43/21/28/60, #2 : 40/25/20/60, #3 : 50/25/25/50, #4 : 65/25/30/60. The unit of thickness is nm. In this calculation the writing laser power of maximum CNR was used as an input parameter, which were 3.0, 3.2, 2.8, 3.0 mW repectively, and writing frequencies were all 6.27-MH. The length of written domain was 0.61 μm. All our results agreed well with this value.

REFERENCES

[1] H.Ide, T.Toda, F.Kirino, T.Maeda, F.Kugiya, S.Mita, and K. Shigematsu: Jpn. J. Appl. Phys. 32, 5342-5348 (1993).
[2] A.J.Griffin, Jr. and F.R. Brotzen: J. Appl. Phys. 76, 4007-4011 (1994).
[3] B.G.Huth: IBM J. RES. DEVELOP. 18, 100-109 (1974).
[4] M.Mansuripur, G.A.N.Connell, and J.W.Goodman: Appl. Opt. 21, 1106-1114 (1982).
[5] M.Mansuripur, G.A.N.Connel: Appl. Opt. 22, 666-670 (1983).