The Korean Journal of Ceramics, **6**[4] 408-411 (2000)

Huge Enhancement of Magneto-optical Kerr Effect of One-dimensional Photonic Crystals with a Ferromagnetic Defect Layer

Mitsuteru Inoue* **, Ken-Ichi Arai*, Toshitaka Fujii† and Masanori Abe‡

*Research Institute of Electrical Communication, Tohoku University, Katahira, Sendai 980-8577, Japan
**PRESTO21, Japan Science & Technology Corpo., Saitama, Japan
†Department of Electrical & Electronic Engineering, Tohohashi University of Technology, Tempaku, Toyohashi 441-8500, Japan
‡Department of Physical Electronics, Tokyo Institute of Technology, Ookayama, Meguro, Tokyo 152-8500, Japan

(Received September 23, 1998)

Although the rotation angle and its spectrum of the magneto-optical Kerr effect are physical quantities determined inherently by the material itself, we found that they can widely be designed by utilizing a one-dimensional photonic crystal with a ferromagnetic defect layer. By suitable choice of the film structure, the rotation angle at a designated narrow wavelength is resonantly enhanced up to as several hundred times larger as ordinary rotation angle of the magnetic material. This is originated by the localization of light at the magnetic layer inside the film.

Key words: Photonic crystal, Magnetic film, Magneto-optical effect, Kerr effect, Magnetophotonic crystal

I. Introduction

Magnetic films which exhibit large magneto-optical (MO) Kerr rotation qK at such a short wavelength as the blue laser wavelength are, nowadays, of a great interest[1-3] from requirement for the read-out signal detectability of ultra-high density MO-recording media with 100 Gbits/inch^2 density. The magnitude of θ_K, which is the material constant, is generally in the order of 10^{-1} degree at room temperature.[4] Multiple-reflection of light is usually employed for the θ_K enhancement by coating a dielectric overlay such as SiO_2 layer on magnetic film, but the enhancement is limited to be at highest in the order of 1 degree.[5] In this article, we demonstrate theoretically and experimentally a huge θ_K enhancement exceeding larger than several degrees at a designated narrow wavelength by the localization of light[6-8] in a one-dimesional photonic crystal with a ferromagnetic defect layer. This technique is based on the multiple interference of light in the multilayer structure, and the huge θ_K enhancement occurs as a result of light resonance in a micro-cavity.[9] This is applicable to both Kerr (reflection mode) and Faraday (transmission mode) effects.

II. Methods

Optical and magneto-optical properties of the one-dimensional photonic crystals with a ferromagnetic defect layer were analyzed using the matrix approach, the detail of which has already described elsewhere.[12]

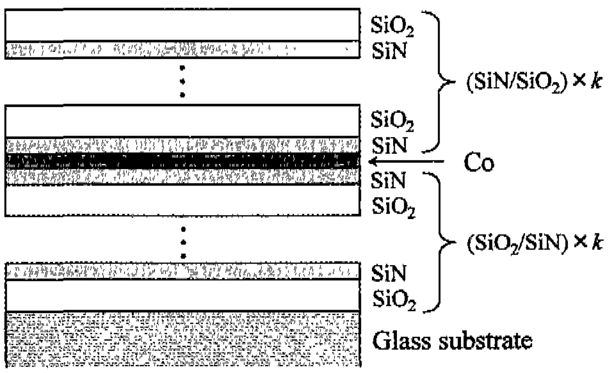

Fig. 1. Structure of the magneto-optical films. The films have multilayer structure of $[SiO_2/SiN]\times k/Co/[SiN/SiO_2]\times k$ with the stacking number of k. The multilayer films were formed on fused quartz substrates using a multi-target sputtering apparatus. The thicknesses of all layers were changed corresponding to the designated localization wavelength of light, and were controlled with ±5% accuracy. The magneto-optical Kerr effect of the films was measured with a linearly polarized light which was incident almost normal to the film plane.

Fig. 1 is the film structure used for the experiment to verify the theoretical prediction. The film structure is expressed by $[SiO_2(d_{SO})/SiN(d_{SN})]\times k/Co(d_{CO})/[SiN(d_{SN})/SiO_2(d_{SO})]\times k$, where d_{SO}, d_{SN} and d_{CO} are the thicknesses of the individual layers and k is the stacking number of the dielectric multilayers. These parameters crucially affect the optical and magneto-optical properties of film. The films were fabricated with a multitarget sputtering apparatus by depositing each layer sequentially. The refractive indices of

SiO_2 and SiN layers at λ=633 nm were 1.50 and 2.18, respectively.

III. Results and Discussion

Fig. 2 is an example of the Kerr rotation θ_K spectrum (the bottom figure) and the reflectivity R spectrum (the top figure) of the film with d_{SO}=117 nm, d_{SN}=80 nm, d_{CO}=20 nm and k=4. The θ_K peaks appeared at λ=438.7 nm and 521.0 nm are considered to be caused by merely ordinary θ_K enhancement by the multiple reflection of light in the dielectric layer. This situation is shown in Fig. 3 (a): The light intensity distribution inside the film is mostly confined in the incidence side of the dielectric layer, indicating that the multiple reflection occurs between the dielectric layer and the Co interlayer. In addition to these θ_K peaks, another sharp θ_K peak which accompanies a strong R- reduction appears at λ=725.2 nm. The light intensity distribution is shown in Fig. 3 (b). In this case, the light is concentrated at the location of Co layer, indicating that this θ_K peak is originated from the localization of light at the Co interlayer.

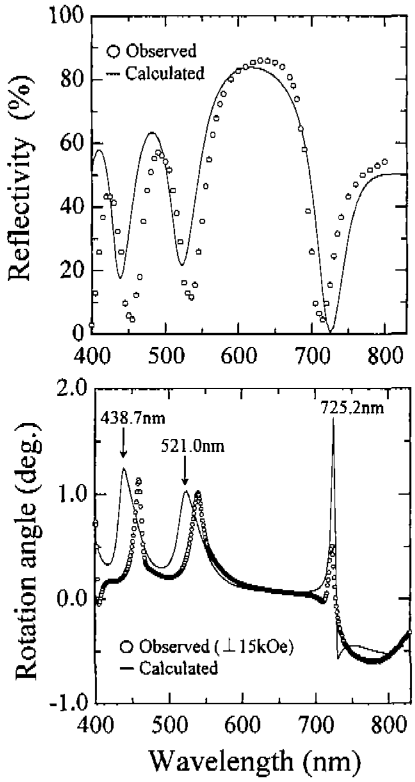

Fig. 2. R- and θ_F-spectra of the $[SiO_2/SiN]\times4/Co/[SiN/SiO_2]\times4$ film with d_{SO}=117 nm, d_{SN}=80 nm and d_{CO}=20 nm. The open circles and the solid curves are, respectively, measured and calculated data. The material parameters used in the calculation were as the following: d_{SO}=117 nm, d_{SN}=81 nm and d_{CO}=20 nm with refractive indices of 1.50 for the SiO_2 layers and 2.12 for the SiN layers. Since the Co film did not saturated magnetically with the magnetic field of 15 kOe applied to the film normal, we used the 38% values of the off-diagonal elements[13] by maintaining their wavelegth spectra.

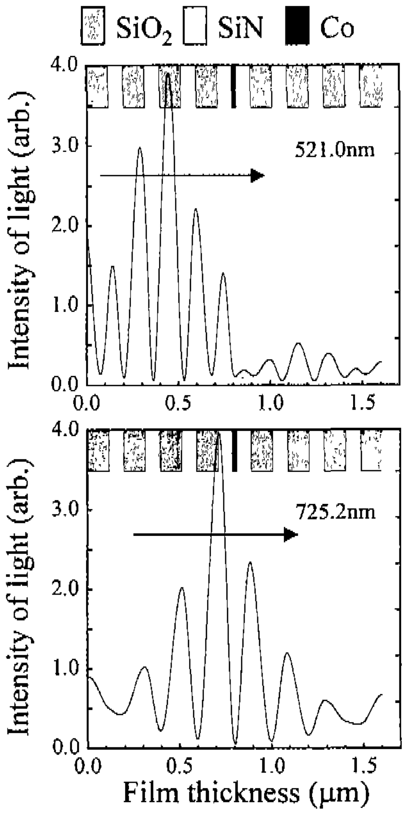

Fig. 3. Calculated distributions of light in the multilayer film in Fig. 2 at wavelengths of 521.0 nm and 725.2 nm. The calculation was done with the numerical parameters described in the caption of Fig. 2. The propagation direction of light is from left to right.

On the basis of the above results, further calculations were performed by changing d_{SO}, d_{SN} and d_{CO} and keeping k=4, to seek the optimum film structure for the localization of light. It was revealed from the calculations that there exists an optimum thickness of the Co layer ($d_{CO}=(d_{CO})_{opt}$) to strengthen the localization of light. The value of $(d_{CO})_{opt}$ to give the strongest localization is determined by the following way: With increasing d_{CO}, θ_K increases until it reaches 180 degrees, and then θ_K abruptly changes its sign from positive to negative. The critical value of d_{CO} that θ_K reverses gives us (d_{CO})opt. For d_{SO}=111 nm and d_{SN}=89 nm and λ=780 nm, the estimated value of $(d_{CO})_{opt}$ is 46.6 nm. According to the calculated result, a film with the above parameters was fabricated. The results are shown in Fig. 4. In agreement with the calculation, a very large q_K peak exceeding 10 degrees appears at λ=780 nm. The narrow θ_K peak suggests that θ_K enhancement occurs resonantly through the spatial localization of light in the vicinity of the Co layer.

Even for such an extraordinary θ_K enhancement, all properties of the MO Kerr effect are retained. The MO Kerr hysteresis loop of this film measured at λ=780 nm is shown in Fig. 5, where a magnetic field was applied to the film normal. Due to the large demagnetizing field of Co thin film, the magnetization component normal to the film plane

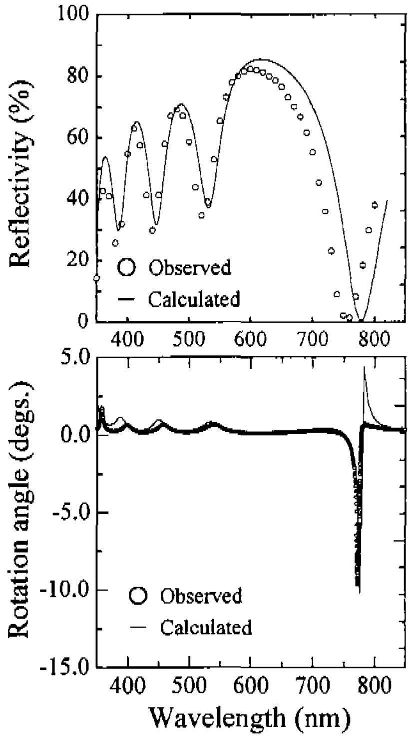

Fig. 4. R- and qF-spectra of the $[SiO_2/SiN]\times4/Co/[SiN/SiO_2]\times4$ film with d_{SO}=111nm, d_{SN}=90 nm and d_{CO}=50 nm. The open circles and the solid curves are, respectively, measured and calculated data. The material parameters used in the calculation were as the following: d_{SO}=111 nm, d_{SN}=88.5 nm and d_{CO}=51.5 nm with refractive indices of 1.50 for the SiO_2 layers and 2.12 for the SiN layers. We used the 45% values of the off-diagonal elements of Co[13] by maintaining their wavelength spectra.

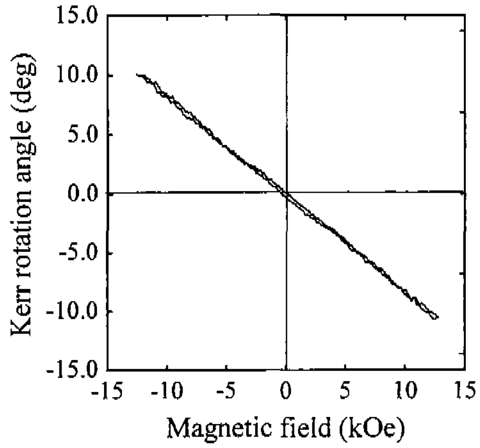

Fig. 5. Magneto-optical Kerr loop of the multilayer film in Fig. 4 at the wavelength of 770 nm.

which contributes to θ_K is small under the field up to 15 kOe, so that the magnetization curve varies linearly with the field. The similar field dependence of θ_K indicates that the Kerr rotation arises from the rotation of the polarization plane of the linearly polarized light.

Another noticeable feature of this technique is that the θ_K

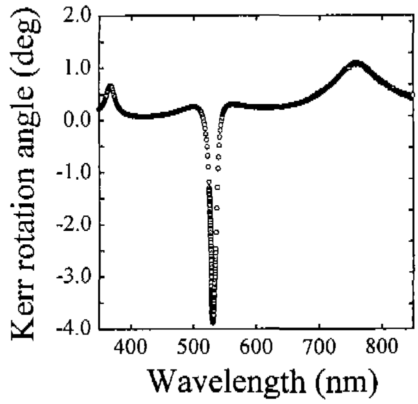

Fig. 6. qK-spectrum the $[SiO_2/SiN]\times4/Co/[SiN/SiO_2]\times4$ film with d_{SO}=71 nm, d_{SN}=60 nm, and d_{CO}=54 nm.

enhancement can be produced at a designated wavelength by choosing the film structure. If we want to obtain, for instance, an MO recording medium operating at λ=500 nm, an example of the designed film structure is given by d_{SO}=71 nm, d_{SN}=60 nm, d_{CO}=54 nm and k=4. The θ_K and R spectra of the film fabricated by this prescription is shown in Fig. 6. A slight shift of wavelength appearing the localization of light from the designed value may be attributed to the deviation of the layer thickness.

A disadvantageous point of the present technique for engineering applications is that the huge θ_K enhancement always accompanies a large reduction of R, i.e. θ_K and R are a trade-off relation to each other. A measure to raise reflectivity retaining large θ_K is to use the film structure with slightly off-resonant condition at the expense of a slight reduction of the θ_K enhancement. As available θ_K of the Co layer used in the present study was small, one must use easily saturable films with perpendicular magnetization such as rare earth-transition metal amorphous alloy films.

IV. Conclusion

We showed that magnetic media with huge MO Kerr rotation at a designated narrow wavelength interval can be realized via the localization light in the multilayer structure. This technique is expected to use a wide variety of MO applications such as MO recording, optoelectronics, MO sensing, and so on.

The authors express their sincere thanks to Dr. K. Matsumoto with Fujitsu Laboratory Ltd. for his great cooperation in achieving the experimental studies. The part of this work was supported by the Ministry of Education, Science, Culture and Sports of Japan.

References

1. G. Q. Di *et al.*, *J. Magn. Magn. Mat.*, **104**, 1023-1024 (1992).
2. M. Kokuryu *et al.*, *J. Appl. Phys.*, **81**, 4779-4781 (1997).
3. W. B. Shu *et al.*, *IEEE Trans. Magn.*, **34**, 447-449 (1998).

4. D. Weller *et al., Phys. Rev. Lett.*, **72**, 2097-2100 (1994).
5. T. Chen *et al., IEEE Trans. Magn.*, **MAG-16**, 1194-1196 (1980).
6. P. E. Wolf *et al., Phys. Rev. Lett.*, **55**, 2696-2699 (1985).
7. S. A. Gredeskul *et al.., Sov. Phys. Usp.*, **33**, 134-146 (1990).
8. M. Inoue *et al., J. Appl. Phys.*, **81**, 5659-5661 (1997).
9. J. Faist *et al., J. Appl. Phys.*, **66**, 1023-1032 (1989).
10. R. Allen *et al., J. Appl. Phys.*, **53**, 2353-2355 (1982).
11. G. S. Krinchik *et al., Soviet Phys., JETP,* **26**, 1080-1085 (1968).
12. M. Inoue *et al., J. Magn. Soc. Jpn.*, **22**, Suppl. S1 141-142 (1998).