Magneto-optical and optical properties of Pt/Co GMR films with capping layer

T. Ishibashi1, M. Naganuma1, S. Tang1, T. Honma1, T. Komatsu1, K. Machida2, K. Furukawa3, K. Aoshima2, N. Funabashi2, K. Kuga2, N. Shimidzu2

1Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan
2Science & Technology Research Lab., Japan Broadcasting Corporation, 1-10-11 Kinuta Setagaya, Tokyo 157-8510, Japan
3Tokyo Denki Univ., 2-2 Kanda-Nishiki-cho, Chiyoda-ku, Tokyo 101-8457, Japan

E-mail: t_bashi@mst.nagaokaut.ac.jp

Abstract. As a light modulating device used in high resolution magneto-optical spatial light modulator (MO-SLM), giant magneto resistance (GMR) devises driven by spin-injection is promising. In this paper, we report on optical and magneto-optical (MO) properties of GMR films, Si/SiO$_2$/bottom electrode/TbFeCo (9 nm)/Cu (4 nm)/(Pt/Co (6 nm))/X (X = Ta, Au, Pt (3 nm)). Kerr rotation spectra of those films with Ta, Au, Pt capping layer ranging between 260 - 700 nm have features similar to those of Pt/Co multilayers reported previously. However, peak positions and rotation angles are slightly different; peak positions of Ta, Au, and Pt are 4.1, 4.3 and 3.8 eV, respectively, and maximum Kerr rotations are 0.35, 0.25 and 0.23°, respectively.

Optical constants measured by ellipsometry revealed that those values were changed due to the capping layers with a thickness of 3 nm. These results indicate that the non-magnetic layers should be mentioned as well as the magnetic layers to design MO properties of the light modulating devices for MO-SLM.

1. Introduction

Magneto-optical spatial light modulator (MO-SLM) is a promising device for applications of holography, such as 3 dimensional (3D) holographic display, because its pixel size can be reduce to less than 1 μm which is required for practical use of 3D holographic display [1, 2, 3]. In order to realize the MO-SLM, a giant magneto resistance (GMR) devise using an Magneto-optical (MO) material as a free layer driven by spin-injection has been proposed as a light modulating device because of its high speed operation, submicron-size, as well as MO effect. However, MO and optical properties of the GMR devices has not been investigated, because it has a thickness thin enough for a visible light to pass through and it has a complicated structure including a bottom electrode, pinned layer, nonmagnetic layer, free layer, capping layer and top electrode. To understand and control the MO and optical properties, contribution from each layers should be understand. In this paper, we focus on the MO and optical properties of GMR films that has complicated structures of Si/SiO$_2$/bottom electrode/TbFeCo (9 nm)/Cu (4 nm)/(Pt/Co (6 nm))/(capping layers of Ta, Au and Pt), because capping layer made of normal metals deposited on the GMR devices could change its properties while it is indispensable to protect the GMR devices from a deterioration suffered by device fabrication processes.
2. Experiments

A Pt/Co GMR structure, Si/SiO₂/bottom electrode/TbFeCo (9 nm)/Cu (4 nm)/(Pt/Co (6 nm)), with perpendicular magnetic anisotropy was deposited on a Si/SiO₂ substrate by DC magnetron sputtering with a base pressure of less than $2 \times 10^{-6}$ Pa. The film was annealed in vacuum at 190°C for an hour in the absence of a magnetic field. Finally, capping layers of Ta, Au and Pt with a thickness of 3 nm were deposited on top of the films. A schematic drawing of the structure is shown in Fig. 1(a).

![Diagram of GMR structure](image_url)

**Figure 1.** (a) a schematic drawing of the GMR structures, and (b) a simplified structure consisting of Si/SiO₂/X/Capping layer for an analysis.

Kerr rotation spectra were measured by an MO spectrometer using the polarization modulation technique with a wavelength between 260 - 900 nm. To measure Kerr rotation of free layers, MO spectra were obtained as an average of two spectra measured with magnetic fields of ±2 kOe that is higher enough than the coercivity of the free layers (~ 1 kOe) and lower than that of pinned layers (> 5 kOe).

Optical constants were measured by using ellipsometer (HORIBA JOBIN YVON: MM-16) with a wavelength between 430 - 700 nm. Optical properties were analyzed by using optical simulation by using software (HORIBA: Delta Psi2). In this experiment, to simplify the optical analysis, the complicated structure was assumed to be 4 layer consisting of Si/SiO₂/X/Capping layer, where X includes bottom electrode/TbFeCo (9 nm)/Cu (4 nm)/(Pt/Co (6 nm)) as shown in Fig. 1(b). Optical constants of Au, Ta and Pt used in the optical analysis were measured for each films deposited on Si substrate by the ellipsometer, and those of Si and SiO₂ were obtained from a reference [8].

3. Results and discussion

Figure 2 shows MO spectra of free layers with different capping layers, Ta, Au, and Pt. A feature that has peak around 4 eV is similar to those of Pt/Co multilayered reported previously [4, 5]. This result indicates that those Kerr rotation spectra are mostly showing a characteristic of Pt/Co multilayer used as free layers. However, it was found that values of Kerr rotation and peak positions seem to depend on material of the capping layers. The peak positions of those spectra are 4.1, 4.3 and 3.8 eV and the values of maximum Kerr rotation are 0.35, 0.25 and 0.23° for samples with Ta, Au and Pt capping layer, respectively.
Is known that MO effect, such as Kerr effect and Faraday effect, is evaluated using a real and an imaginary part of the off-diagonal element of the optical conductivities, $\sigma'_{xy}$, $\sigma''_{xy}$, and the refractive index $n$ and the extinction coefficient $\kappa$ [5]. It means that a value of MO effect could be changed not only by the off-diagonal element of the optical conductivities, but also by optical constants, $n$ and $\kappa$. In Fig. 3, refractive indices and extinction coefficients of those samples measured by means of ellipsometry are shown. It is found that they have different values and structures in those spectra as well as Kerr rotation spectra shown in Fig. 2. In order to find a contribution from the capping layers, optical constants of each layers should be analyzed. However, we had to simplify them as 4 layers consisting of Si/SiO$_2$/X/Caping layer as shown in Fig. 1(b), since the samples used in this study have complicated structures.

Therefore, we obtained optical constant of the effective layer X by analyzing the optical constants of the GMR structure with Pt and Au as shown in Figure 4. Although the fitting was well done for both samples with Au and Pt, they were quite different for each other. We consider that it could happen, since it is known that the multilayer of metal have a peculiar electronic structure which can not be explained only by assuming a stack of metals as observed in Pd/Co and Fe/Au multilayers [6, 7]. Therefore, we consider that the differences in Fig. 4 may be due to the change in electronic structures. For Ta, we could not obtained good result in the optical analysis. We consider that the reason is due to oxidation of Ta. If Ta were oxidized, it could contribute to large Kerr rotation as observed in Fig. 2.

The optical constants of the GMR structures were reconstructed by the simulation using the optical constants of Si, SiO$_2$, X obtained from the GMR structure with Pt capping layer, and the capping layer (Ta, Pt and Au) as shown in Fig. 5. It is found that the optical constant of the sample with Pt capping layer is reproduced properly. In addition, the optical constants for the sample with Au capping layer are rather consistent with the experimental data shown in Fig. 3. In particular, the refractive index of those two samples are well agree with those of experimental data. This result indicate that a capping layer with a thickness of 3 nm could make a large contribution for the optical constants. On the other hand, the optical constants for Ta did not agree with the experimental data. It must be due to the oxidization of Ta as mentioned above. In the case of Au capping layer, we could not obtain good results from the simulation, it suggests that the electronic structure of Pt/Co multilayer underneath the Au capping layer was affected resulting in the sift of peak of the Kerr spectrum.

These results suggest that capping layers contribute the change in the optical constants even if it has a thickness of several nm and it also could change the MO properties. In order to understand the effect, further study for all the layers in the GMR structures and an MO

**Figure 2.** MO spectra of the GMR films with different capping layers, Ta, Au, and Pt.
simulation are needed.

Figure 3. Refractive indices and extinction coefficients of the GMR films with different capping layers, Ta, Au, and Pt, measured by an ellipsometry.

Figure 4. Refractive index and extinction coefficient of the effective layer X obtained by analyzing the optical constant of the GMR structure with Pt and Au capping layer.

Figure 5. Refractive indices and extinction coefficients of the GMR films with different capping layers, Ta, Au, and Pt, reconstructed by a simulation.
4. Summary
MO and optical properties of the GMR structures with different capping layers with a thickness of 3 nm were studied. It was found that MO spectra and optical constants had different values and structures. Simulation was revealed that the capping layers could change the optical constants of the GMR structures. We consider that the change in the optical constants is one of the reason of the change in the MO spectra.

Acknowledgments
This research is supported by the National Institute of Information and Communications Technology (NICT).

References
[1] K. Aoshima, N. Funabashi, K. Machida, Y. Miyamoto, N. Kawamura, K. Kuga, N. Shimizu, F. Sato, T. Kimura, Y. Ohtani, 2007 Appl. Phys. Lett. 91 p.052507.
[2] K. Machida, N. Funabashi, K. Aoshima, Y. Miyamoto, N. Kawamura, K. Kuga, N. Shimizu, 2008 J. Appl. Phys. 103 p.07A713.
[3] K. Aoshima, N. Funabashi, K. Machida, Y. Miyamoto, N. Kawamura, K. Kuga, N. Shimizu, Y. Ohtani, F. Sato 2009 IEEE trans. magn. 44 p.2491.
[4] W. B. Zeper, F. J. A. M. Greidanus, P. F. Carcia, C. R. Fincher, 1989 J. Appl. Phys. 65 p.4971.
[5] K. Sato, H. Hongu, H. Ikekame, J. Watanabe, K. Tsuzukiyama, Y. Togami, M. Fujisawa, T. Fukazawa, 1992 Jpn. J. Appl. Phys. 31 p.3603.
[6] Y. Tosaka, H. Ikekame, K. Urago, S. Kurosawa, K. Sato, S. C. Shin, 1994 J. Magn. Soc. Jpn. 18 p.389.
[7] K. Sato, E. Takeda, M. Akita, M. Yamaguchi, K. Takanashi, S. Mitani, H. Fujimori, Y. Suzuki, 1998 J. Magn. Magn. Mater. 18 p.177.
[8] G.E. Jellison, Jr., 1992 Optical Materials 1, p.41.