# Fabrication of $L1_2$-$CrPt_3$ alloy films using rapid thermal annealing for planar bit patterned media

T. Kato[1], *Member, IEEE*, D. Oshima[1], Y. Yamauchi[2], S. Iwata[1], *Member, IEEE*, S. Tsunashima[2], *Member, IEEE*

[1]Department of Quantum Engineering, Nagoya University, Nagoya, 464-8603, Japan
[2]Department of Electrical Engineering and Computer Science, Nagoya University, Nagoya, 464-8603, Japan

**$SiO_2$ (2 nm) / $Cr_{25}Pt_{75}$ (15 nm) and $SiO_2$ (2 nm) / $Cr_{25}Pt_{75}$ (15 nm) / $SiO_2$ (10, 20 nm) / $Co_{80}Zr_{10}Nb_{10}$ (10 nm) were prepared by magnetron sputtering method and post-annealed by rapid thermal annealing (RTA) at temperatures of 600 – 1000 ˚C for 1 – 60 sec. The saturation magnetization $M_s$ and coercivity $H_c$ measured by applying a maximum field of 18 kOe were 150 emu/cc and 12 kOe, respectively, for the sample after RTA at 1000 ˚C for 30 sec. This means that $L1_2$-$CrPt_3$ phase was obtained by RTA process. The RTA process was applied to fabricate the multilayered structure having $L1_2$-$CrPt_3$ and CoZrNb soft magnetic underlayer (SUL). The polar Kerr loop of $CrPt_3$ (15 nm) / $SiO_2$ (20 nm) / CoZrNb (10 nm) after RTA at 1000 ˚C for 30 sec exhibited a large coercivity $H_c$ > 9 kOe corresponding to that of the $CrPt_3$ single layer. From the compositional depth profile of $CrPt_3$ (15 nm) / $SiO_2$ (20 nm) / CoZrNb (10 nm) processed by RTA at 1000 ˚C for 30 sec, sharp layered structure was confirmed despite the high temperature heat treatment. When the $SiO_2$ thickness was reduced to 10 nm, such a layered structure was completely destroyed due to the interdiffusion between $CrPt_3$ and CoZrNb layers. Thus it was concluded that the RTA process and the interlayer of $SiO_2$ (20 nm) were effective to fabricate layered structure having $L1_2$-$CrPt_3$ and SUL.**

*Index Terms*—**Rapid thermal annealing, Magnetic layered films, Planar bit patterned media, $CrPt_3$**

## I. Introduction

BIT patterned media have attracted considerable interest as future high density magnetic recording media, since they provide a promising technology to postpone the problem of superparamagnetic limit, i.e., thermal instability of the recorded bits in the media. One of the problems for the practical use of the bit patterned media is topography of discrete magnetic bits defined by lithographical fabrication, because the rough surface of the disk disturbs stable flying of the hard disk drive (HDD) head. Ion beam irradiation has been proposed as a new approach to pattern magnetic materials locally without etching magnetic materials, i.e., without altering the surface topography [1, 2], and ion irradiation into Co/Pt [1 - 4] and Co/Pd [5, 6] multilayers (MLs) has been reported for the modification of their perpendicular anisotropies. However, in the Co/Pt and Co/Pd MLs patterned by ion irradiation, the adjacent magnetic bits are not magnetically isolated due to the exchange coupling through in-plane magnetized spacing, which will limit the ultimate recording density of the media.

Previously, we have reported the ion-beam patterned medium using a $CrPt_3$ alloy film [7]. The $CrPt_3$ shows ferrimagnetism when it has an ordered $L1_2$ phase, while paramagnetism when disordered fcc phase, and the ferrimagnetic $L1_2$-$CrPt_3$ was found to be transformed to paramagnetic $Cr_{25}Pt_{75}$ by a quite low ion dose of 2 x $10^{14}$ ions/cm$^2$ with 30 keV $Kr^+$ ions [8]. The amount of ions 2 x $10^{14}$ ions/cm$^2$ corresponds roughly to number of atoms within 0.1 atomic layer of $CrPt_3$, and such a low ion dose has no influence on the surface topology and the thickness of the $CrPt_3$ layer [9]. The $L1_2$-$CrPt_3$ film onto $SiO_2$ substrate exhibits a magnetization of 250 emu/cc and a large perpendicular anisotropy of 5 x $10^6$ erg/cc [7, 10 - 13], which is suitable for the high-density bit patterned media. Thus we consider that $Kr^+$ ion irradiation onto the $L1_2$-$CrPt_3$ film could be a practical approach to achieve planar bit patterned media beyond 1 Tb/in$^2$ recording density. One of the problems to use $CrPt_3$ for the practical application is high temperature heat treatment to obtain $L1_2$ phase $CrPt_3$, which makes difficult to fabricate layered structure for perpendicular recording media. In this study, we report rapid thermal annealing (RTA) processing of $CrPt_3$ and discuss magnetic properties of RTA processed $CrPt_3$. Furthermore we report the application of RTA to the fabrication of multilayered structure having $L1_2$-$CrPt_3$ and soft magnetic underlayer (SUL).

Manuscript received October 30, 2009. Corresponding author: T. Kato (e-mail: takeshik@nuee.nagoya-u.ac.jp).
Digital Object Identifier inserted by IEEE

## II. Experimental method

[Cr (0.4 nm) / Pt (1.5 – 1.7 nm)]$_{10}$ MLs / substrate, $SiO_2$ (2 nm) / $Cr_{25}Pt_{75}$ (15 nm) / substrate, and $SiO_2$ (2 nm) / $Cr_{25}Pt_{75}$ (15 nm) / $SiO_2$ (10, 20 nm) / $Co_{80}Zr_{10}Nb_{10}$ (10 nm) / substrate were prepared by magnetron sputtering method. Fused quartz or thermally oxidized Si was used as a substrate. The $Cr_{25}Pt_{75}$ alloy layer was fabricated by the co-sputtering of Cr and Pt sources. The $Co_{80}Zr_{10}Nb_{10}$ was deposited using an alloy target. $L1_2$ phase $CrPt_3$ were obtained by rapid thermal annealing (RTA) at temperatures of 600 – 1000 ˚C for 1 – 60 sec in $N_2$ atmosphere. The ramp rate was set to 70 ˚C/sec. For comparison, some of the samples were annealed in vacuum at a temperature of 850 ˚C for 15 min. In the vacuum annealing, the cooling rate to room temperature was set at 10 ˚C/min.

Magnetic properties were measured by using alternating gradient field magnetometer (AGM) and polar Kerr loop tracer using polarized angle modulation method. Crystal structure and surface morphology were checked by X-ray diffraction (XRD) with Cu Kα radiation and atomic force microscopy (AFM), respectively. Magnetic domain structure was observed by magnetic force microscope (MFM).

Compositional depth profile was characterized by scanning Auger electron spectrometer (AES) equipped with $Ar^+$ ion beam milling system. The energy of the primary electron for AES measurements was 10 keV, and $Ar^+$ ion beam energy was 3 kV. The primary electron beam was scanned within the region of 200 x 200 $\mu m^2$, which is adjusted around the center of the ion-etching region of 1 mm$\phi$.

## III. Results and discussions

Figure 1 shows the RTA process temperature dependence of (a) saturation magnetization $M_s$ and (b) coercivity $H_c$ of $CrPt_3$ films on $SiO_2$. The annealing time was set at 30 sec. The open and closed circles were obtained by annealing the multilayer sample [Cr (0.4 nm) / Pt (1.51 nm)]$_{10}$ and alloy sample $Cr_{25}Pt_{75}$ (15 nm). Both samples have almost the same chemical composition of Cr 25 at.% and Pt 75 at.%. Upper two figures in Fig. 1 show *M-H* loops of $Cr_{25}Pt_{75}$ (15 nm) annealed at 850˚C and 1000˚C. The saturation magnetization $M_s$ and coercivity $H_c$ were estimated from *M-H* loops taken at a maximum field of 18 kOe. As shown in Fig. 1, the $M_s$ and $H_c$ increased with increasing the process temperature. Furthermore, large perpendicular anisotropy just as the vacuum annealed $CrPt_3$ in the previous reports [7, 8] is confirmed. The disordered $Cr_{25}Pt_{75}$ alloy and Cr / Pt MLs do not show ferro- or ferri-magnetizm, and thus the increase of the magnetization and coercivity are understood by the formation of the ferrimagnetic $L1_2$ ordered $CrPt_3$ phase. The formation of the $L1_2$-$CrPt_3$ was also confirmed by the appearance of the superlattice line of $L1_2$ phase in X-ray diffraction profiles after RTA (not shown here). The RTA made $CrPt_3$ has strong 111 orientation with $\Delta\theta_{50}$ = 6 deg (FWHM of rocking curve for 111 peak). Thus the order parameter *S* of RTA made $CrPt_3$ at 950 ˚C was calculated from the in-plane XRD profile as in the same manner as Ref. [8], and estimated to be $S > 0.9$.

The saturation magnetization of bulk $CrPt_3$ is around 250 emu/cc [10], and the $CrPt_3$ (20 nm) on $SiO_2$ substrate annealed in vacuum at 850 ˚C for 15 min exhibits a large coercivity about 12 kOe [7]. The present sample has almost the same coercivity when the sample was processed at around 1000 ˚C. The $M_s$ of the sample after RTA at 1000 ˚C was around 150 emu/cc, which is smaller than those of the bulk $CrPt_3$ and the vacuum annealed $CrPt_3$ film. The reason of smaller magnetization of the RTA made $CrPt_3$ than that of vacuum annealed $CrPt_3$ is considered to be larger saturation field of RTA made $CrPt_3$ than that of the vacuum annealed one. As for the annealing time dependence, the $M_s$ of $CrPt_3$ processed by RTA 950 ˚C for 1 sec was only 30 % of the samples processed for 30 sec (not shown in the figure), which means 950 ˚C and 1 sec RTA is considered to be insufficient for the formation of $L1_2$-$CrPt_3$. The $M_s$ of $CrPt_3$ obtained by 1 min RTA was almost the same as that by 30 sec RTA.

**FIG. 1 HERE**

Figure 2 shows AFM and MFM images of (a) as-sputtered [Cr (0.4 nm) / Pt (1.51 nm)]$_{10}$ ML, (b) $CrPt_3$ (20 nm) made by RTA at 950 ˚C for 30 sec, and $CrPt_3$ (20 nm) annealed in vacuum at 850 ˚C for 15 min. The $CrPt_3$ films are made out of the Cr / Pt MLs. For the as-sputtered ML, quite flat surface having a surface roughness of $R_a$ = 0.14 nm was confirmed, and no contrast in MFM images indicates that the as-deposited ML is non-magnetic state. When the sample was vacuum annealed, large grain with the diameter of ~ 100 nm was confirmed in the AFM image (Fig. 2 (c)). Accompanied by the growth of $L1_2$-$CrPt_3$ grains, the surface roughness was significantly increased to $R_a$ = 0.70 nm. In the MFM image of Fig. 3(c), clear magnetic contrast resulting from the formation of the ferrimagnetic $L1_2$-$CrPt_3$ was seen. The size of the magnetic domain (or magnetic cluster) was almost the same as the crystal grain size. In the case of RTA made $CrPt_3$, small grain size of ~ 30 nm was confirmed as shown in Fig. 2 (b). The surface roughness was $R_a$ = 0.53 nm, which is smooth compared to the vacuum annealed $CrPt_3$, even though it is still rough compared to the as-sputtered ML. Just as the vacuum annealed sample, the RTA made $CrPt_3$ exhibited clear magnetic contrast in the MFM image (Fig. 2(b)). The domain size or magnetic cluster size was around 30 nm, which is much smaller than that of vacuum annealed $CrPt_3$ and roughly corresponds to crystal grain size.

**FIG. 2 HERE**

Compared to the vacuum annealing, RTA is quite effective to fabricate the recording medium with flat surface. Moreover, it is considered to have a great advantage to make a layered structure having $L1_2$ $CrPt_3$ layer for the magnetic recording, since it can control the interdiffusion between $CrPt_3$ recording layer and soft under layer (SUL). Figure 3 shows polar Kerr loops of $CrPt_3$ (15 nm) / $SiO_2$ (*t* nm) / CoZrNb (10 nm) annealed at 1000 ˚C for 30 sec. The loops were measured by applying a maximum field of 16 kOe and taken at a wavelength $\lambda$ = 800 nm from the film side ($CrPt_3$ side), which means that the loop mainly reflects the hysteresis of the $CrPt_3$ layer. As shown in Fig. 3 (a), for the $SiO_2$ thickness of $t$ = 20 nm, the sample exhibits a large coercivity $H_c$ > 9 kOe indicating large perpendicular magnetic anisotropy. The $H_c$ was comparable to the RTA made $CrPt_3$ single layer (see Fig. 1 (b)), and the loop shape was consistent with that of the RTA made single layer (not shown here) and that of the vacuum annealed $CrPt_3$ [7]. When the $SiO_2$ layer was decreased to $t$ = 10 nm, the coercivity of $CrPt_3$ was found to reduce significantly as shown in Fig. 3 (b). This is considered to be due to the interdiffussion between the $CrPt_3$ layer and CoZrNb SUL.

**FIG. 3 HERE**

In order to clarify the interdiffusion between the $CrPt_3$ and SUL, AES depth profiles were measured for $CrPt_3$ / $SiO_2$ / SUL before and after the RTA process. Si(KLL), O(KLL), Cr(LMM), Co(LMM), Pt(MNN) AES were monitored during the interval of $Ar^+$ ion beam etching. Figure 4 shows the

Auger peak intensities of the above elements as a function of the etching time. The Auger peak intensity was evaluated from the derivative spectra $d(E \cdot N(E)) / dE$. The AES depth profile taken for the as-sputtered $CrPt_3$ (15 nm) / $SiO_2$ (20 nm) / CoZrNb (10 nm) is shown in Fig. 4 (a). The sharp layered structure of $CrPt_3$ / $SiO_2$ / SUL was confirmed. After the sample was annealed at 1000 ˚C for 30 sec, it is confirmed the layered structure still exists as shown in Fig. 4 (b) even though the sharpness of the compositional change at the interface deteriorates slightly. When the $SiO_2$ thickness was reduced to 10 nm (see Fig. 4 (c)), the layered structure was completely destroyed after RTA of 1000 ˚C for 30 sec due to the interdiffusion between $CrPt_3$ layer and CoZrNb SUL. These results are consistent with the Kerr loops shown in Fig. 3. Thus it was concluded that processing by RTA and interlayer of $SiO_2$ (20 nm) were effective to fabricate layered structure having $L1_2$-$CrPt_3$ layer and SUL.

Finally we have to briefly comment on the magnetic properties of SUL after the RTA. When the as-sputtered CoZrNb (20 nm) was annealed at 950˚C for 30 sec, it was confirmed that the $H_c$ significantly increased from 2 Oe to 25 Oe. In the X-ray diffraction profile, no diffraction peaks indicating the formation of the crystalline phase of CoZrNb even after RTA were detected, however, the increase of $H_c$ after RTA may indicate a structural difference between as-sputtered and RTA processed SUL. The increase of $H_c$ will be a problem to achieve a practical recording media having $L1_2$-$CrPt_3$, and the development of the SUL tolerating RTA process and/or the reduction of the process temperature for making $L1_2$-$CrPt_3$ will be necessary.

**FIG. 4 HERE**

## IV. Conclusion

Rapid thermal annealing process was applied to obtain $L1_2$ ordered $CrPt_3$ film with high perpendicular anisotropy, since the RTA process is considered to have a great advantage to make a layered structure having $L1_2$-$CrPt_3$ and soft under layers for the magnetic recording. We confirmed that the $L1_2$-$CrPt_3$ phase was formed by RTA at 950 – 1000 ˚C for 30 sec. From AFM observations, the RTA processed $CrPt_3$ was found to have smooth surface compared to the vacuum annealed $CrPt_3$ due to the suppression of the grain growth in the RTA process. The polar Kerr loop of $CrPt_3$ (15 nm) / $SiO_2$ (20 nm) / CoZrNb (10 nm) annealed at 1000 ˚C for 30 sec exhibits a large coercivity $H_c$ > 9 kOe. This indicates a large perpendicular magnetic anisotropy of the $CrPt_3$ layer even after RTA at 1000 ˚C. From the AES depth profiles of $CrPt_3$ (15 nm) / $SiO_2$ (10 and 20 nm) / CoZrNb (10 nm) annealed at 1000 ˚C for 30 sec, sharp layered structure was confirmed for the $SiO_2$ (20 nm) sample despite high temperature heat treatment of 1000 ˚C. When the $SiO_2$ thickness was reduced to 10 nm, such a layered structure was completely destroyed due to the interdiffusion between $CrPt_3$ and CoZrNb layers. Thus it was concluded that application of the RTA process and the interlayer of $SiO_2$ (20 nm) are effective to fabricate layered structure having $L1_2$-$CrPt_3$ and SUL.

## Acknowledgment

The authors are grateful to Dr. K. Matsumoto, Dr. T. Morikawa, and Dr. K. Ozaki of Fujitsu Laboratories Ltd. for helpful discussions, and would like to thank Mr. M. Kumazawa, and Mr. Y. Adachi of Nagoya University for assistance in the experiments and film composition analysis, respectively.

## References

[1] C. Chappert, H. Bernas, J. Ferré, V. Kottler, J. -P. Jamet, Y. Chen E. Cambril, T. Devolder, F. Rousseaux, V. Mathet, and H. Launois, “Planar Patterned Magnetic Media Obtained by Ion Irradiation,” Science, vol. 280, pp. 1919-1922, Jun. 1998.

[2] B. D. Terris, L. Folks, D. Weller, J. E. E. Baglin, J. Kellock, H. Rothuizen, and P. Vettiger, “Ion-beam patterning of magnetic films using stencil masks,” Appl. Phys., Lett., vol. 75, pp. 403-405, Jul. 1999.

[3] J. Ferré, C. Chappert, H. Bernas, J. -P. Jamet, P. Meyer, O. Kaitasov, S. Lemerle, V. Mathet, F. Rousseaux, and H. Launois, “Irradiation induced effects on magnetic properties of Pt/Co/Pt ultrathin films,” J. Magn. Magn. Mater., vol. 198-199, pp. 191-193, Jun. 1999.

[4] R. Hyndman, P. Warin, J. Gierak, J. Ferré, J. N. Chapman, J. P. Jamet, V. Mathet, and C. Chappert, “Modification of Co/Pt multilayers by gallium irradiation - Part 1: The effect on structural and magnetic properties,” J. Appl. Phys., vol. 90, pp. 3843-3849, Oct. 2001.

[5] E. Suharyadi, S. Natsume, T. Kato, S. Tsunashima, and S. Iwata, “Microstructures and Magnetic Properties of the FIB Irradiated Co–Pd Multilayer Films,” IEEE Trans. Magn., vol. 41, pp. 3595-3597, Oct. 2005.

[6] E. Suharyadi, T. Kato, S. Tsunashima, and S. Iwata, “Magnetic Properties of Patterned Co/Pd Nanostructures by E-Beam Lithography and Ga Ion Irradiation,” IEEE Trans. Magn., vol. 42, pp. 2972-2974, Oct. 2006.

[7] T. Kato, S. Iwata, Y. Yamauchi, S. Tsunashima, K. Matsumoto, T. Morikawa, K. Ozaki, “Planar patterned media fabricated by ion irradiation into $CrPt_3$ ordered alloy films,” J. Appl. Phys., vol. 105, 07C117, Mar. 2009.

[8] T. Kato, S. Iwata, Y. Yamauchi, S. Iwata, “Modification of magnetic properties and structure of $Kr^+$ ion-irradiated $CrPt_3$ films for planar bit patterned media,” J. Appl. Phys., vol. 106, 053908, Sep. 2009.

[9] E. Suharyadi, S. Natsume, T. Kato, S. Tsunashima, and S. Iwata, “Modification of the Microstructure and Magnetic Properties of Ga-Ion-Irradiated Co/Pd Multilayer Film for Future Planar Media,” Trans. Magn. Soc. Jpn., vol. 5, pp. 125-130, Aug. 2005.

[10] S. J. Pickart, R. Nathans, “Alloys of the First Transition Series with Pd and Pt,” J. Appl. Phys., vol. 33, pp. 1336-1338, Mar. 1962.

[11] J. Cho, M. Park, H. Kim, T. Kato, S. Iwata, S. Tsunashima, “Large Kerr rotation in ordered $CrPt_3$ films”, J. Appl. Phys., vol. 86, pp. 3149-3151, Sep. 1999.

[12] T. D. Leonhardt, Y. Chen, M. Rao, D. E. Lauhglin, D. N. Lambeth, M. H. Kryder, “$CrPt_3$ thin film media for perpendicular or magneto-optical recording,” J. Appl. Phys., vol. 85, pp. 4307-4309, Apr. 1999.

[13] T. Kato, H. Ito, K. Sugihara, S. Tsunashima, and S. Iwata, “Magnetic anisotropy of MBE grown $MnPt_3$ and $CrPt_3$ ordered alloy films,” J. Magn. Magn. Mater., vol. 272-276, pp. 778-779, May 2004.

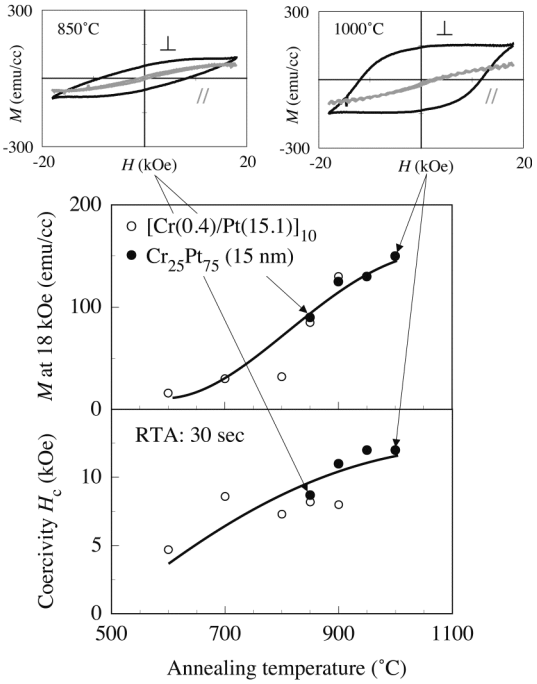


Fig. 1. RTA process temperature dependence of (a) magnetization at 18 kOe and (b) coercivity $H_c$ of $CrPt_3$ films. The annealing time was set at 30 sec. The open and closed circles were obtained by annealing the multilayer sample [Cr(0.4 nm) / Pt(1.51 nm)]$_{10}$ and alloy sample $Cr_{25}Pt_{75}$ (15 nm), respectively. Upper figures are *M-H* loops of $Cr_{25}Pt_{75}$ (15 nm) annealed at 850˚C and 1000˚C.

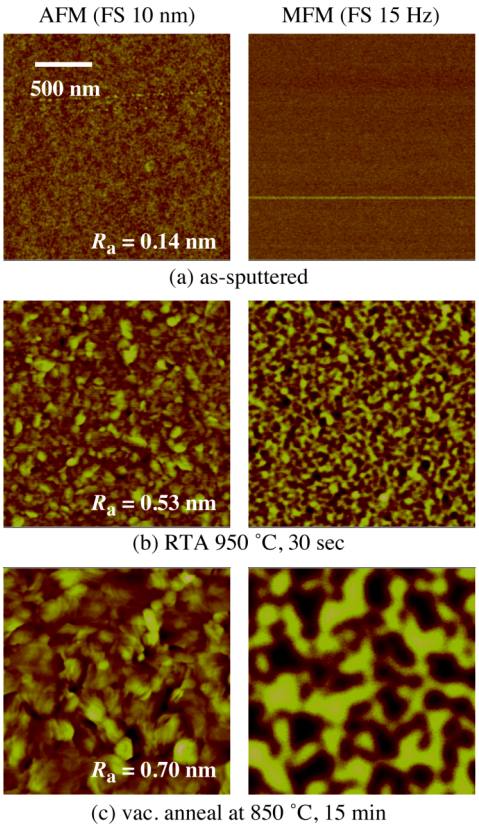


Fig. 2. AFM and MFM images of (a) as-sputtered [Cr(0.4 nm) / Pt(1.51 nm)]$_{10}$ ML, (b) $CrPt_3$ (20 nm) made by RTA 950 ˚C for 30 sec, and (c) $CrPt_3$ (20 nm) annealed in vacuum at 850 ˚C for 15 min. Left are AFM images with a height full scale (FS) of 10 nm, and right are MFM images with a contrast FS of 15 Hz.

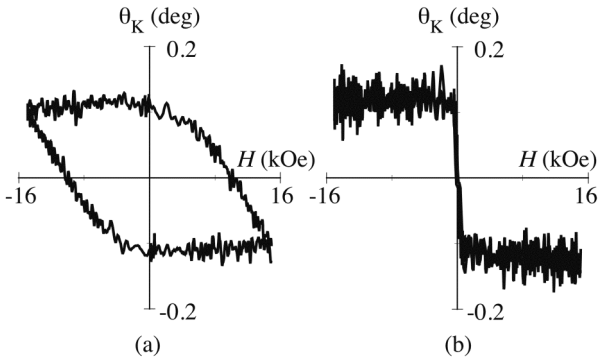


Fig. 3. Polar Kerr loops of $CrPt_3$ (15 nm) / $SiO_2$ ($t$ nm) / CoZrNb (10 nm) annealed at 1000 ˚C for 30 sec. The loops were measured by applying a maximum field of 16 kOe, and taken from film side ($CrPt_3$ side) at $\lambda$ = 800 nm. The $SiO_2$ thickness was $t$ = 20 nm for (a) and $t$ = 10 nm for (b).

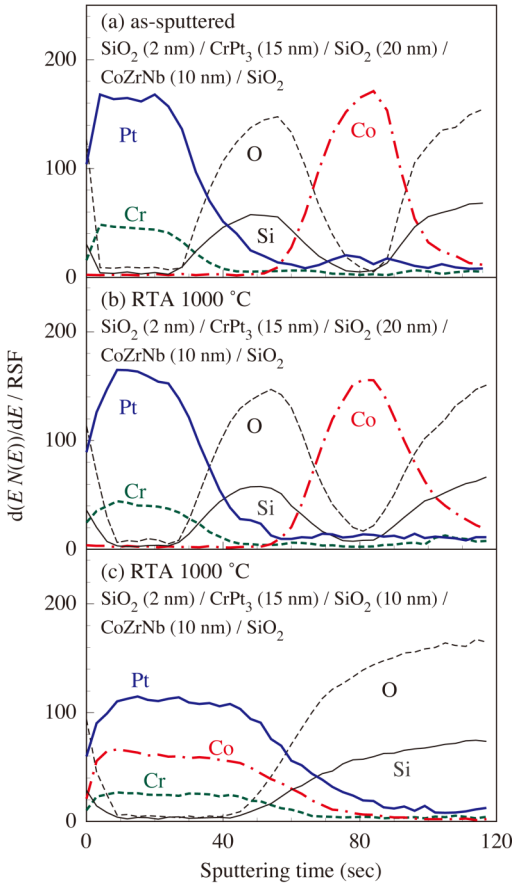


Fig. 4. AES depth profile taken for the (a) as-sputtered $CrPt_3$ (15 nm) / $SiO_2$ (20 nm) / CoZrNb (10 nm), (b) $CrPt_3$ (15 nm) / $SiO_2$ (20 nm) / CoZrNb (10 nm) after RTA at 1000 ˚C for 30 sec, and (c) $CrPt_3$ (15 nm) / $SiO_2$ (10 nm) / CoZrNb (10 nm) after RTA at 1000 ˚C for 30 sec. The Auger peak intensity was evaluated from the derivative spectra $d(E{\cdot}N(E))$ / $dE$ taking into account the relative sensitivity factor (RSF) of each element.