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Magneto-Optical Spectra of Single Crystalline CoCrPt Films between 1.2 and 6 eV

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We have succeeded in preparing good quality epitaxial CoCrPt thin films on different substrates (Al_2O_3, $LaAlO_3$, $SrTiO_3$ and MgO) with the c-axis perpendicular to the substrate plane and magnetic properties were investigated. Magneto-optical spectra of the CoCrPt films prepared under different conditions were measured at room temperature between 1.2 and 6 eV, to investigate the physical properties of these films from the fundamental point of view.

Key words: CoCrPt perpendicular recording films, epitaxial growth, magneto-optical spectrum

1. Introduction

Co-based alloy thin films are widely employed as magnetic recording media in hard disk drives. The areal recording density beyond 200 Gb/in^2 with improved thermal stability is expected to be realized in perpendicular recording system using Co-based alloys. To realize such a system, fundamental physical properties should be correctly determined in well-defined single crystal films with known composition ratios, since only available fundamental data are those on polycrystalline films.

Recently, Terayama et al. succeeded in preparing good quality epitaxial Co-based thin films on different substrates (Al_2O_3, $LaAlO_3$, $SrTiO_3$ and MgO) with the c-axis perpendicular to the substrate plane and magnetic properties were investigated. [1,2]

In order to investigate the physical properties from the fundamental point of view, information on the electronic structure of this material is important, to which magneto-optical spectra are expected to give much contribution. However, only available magneto-optical spectra on CoCr-based alloy are limited to those in polycrystalline films in the narrow range of wavelengths.[3] In this paper, we report for the first time on wide-wavelength-range (1.2-6eV) magneto-optical spectra in the single crystalline films of CoCrPt at room temperature.

2. Experiments

Thin films of CoCrPt layers with different Co:Cr:Pt ratios were deposited by dc magnetron sputtering technique in a UHV chamber under an Ar pressure of 3 mTorr at substrate temperatures between 200-290°C. As substrates, single crystals of Al_2O_3 (0001), $LaAlO_3$ (0001), $SrTiO_3$ (111), and MgO (111) were employed taking into account the lattice matching between the film and substrate. Glass substrate is also used for reference. In addition, we

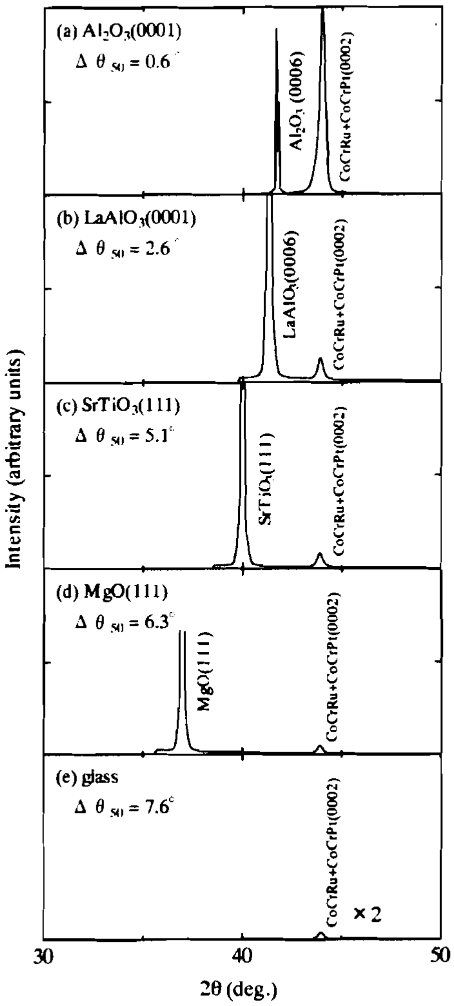

Fig. 1 X-ray diffraction patterns of $Co_{71}Cr_{19}Pt_{10}$(25nm)/$Co_{50}Cr_{25}Ru_{25}$(50nm) grown on (a) Al_2O_3(0001), (b) $LaAlO_3$(0001), (c) $SrTiO_3$ (111), (d) MgO (111), and (e) glass substrates.

introduced suitable buffer layers in order to reduce the crystallographic strain due to lattice mismatch, since the latter have been known to give much influence to magnetic properties of thin films. As a buffer layer, we employed a non-magnetic $Co_{50}Cr_{25}Ru_{25}$ alloy, which are used as an underlayer material to get c-axis orientation.

Crystallographic properties were studied by X-ray diffraction (XRD) and transmission electron microscopy (TEM). Figure 1 shows X-ray diffraction patterns of $Co_{71}Cr_{19}Pt_{10}$(25nm)/$Co_{50}Cr_{25}Ru_{25}$(50nm) grown on various substrates. The full-width at half maximum

(FWHM) Δ_{50} of the rocking curve of each film is presented in each figure.

As reported in our precedent papers,[1,2] epitaxial magnetic films with single-crystalline atomic arrangements were obtained on the Al_2O_3 (0001), the $LaAlO_3$ (0001), and the $SrTiO_3$ (111) substrates, while films became poly-crystalline on the MgO (111) substrate.

X-ray pole figures revealed that the obtained CoCrPt film had a following crystallographic relationship with the substrate:

(a) Al_2O_3 substrate

Al_2O_3 (0001)//CoCrPt(0001)

Al_2O_3 [10.0]//CoCrPt [21.0].

(b) $LaAlO_3$ substrate[1]

$LaAlO_3$ (0001)//CoCrPt (0001)

$LaAlO_3$ [10.0]//CoCrPt [10.0]

(c) $SrTiO_3$ substrate

$SrTiO_3$ (111)//CoCrPt (0001)

$SrTiO_3$ [1 $\bar{1}$ 0] //CoCrPt [10.0].

The best quality epitaxial film with the least lattice distortion was obtained when prepared on the Al_2O_3 (0001) substrate, in which case the full-width at half maximum (FWHM) of the rocking curve was as small as 0.6 deg. [2] High-resolution TEM and electron diffraction observation revealed that the lattice image corresponds to the atomic arrangement of hcp (0001) plane, which is in accordance with the observed electron diffraction pattern of six-fold symmetry. The cross sectional TEM image shows that a good crystallinity and abruptness is maintained at the interface Therefore in this paper we focus attention to the films prepared on the Al_2O_3 substrate.

Polar magneto-optical spectra were investigated at room temperature using a magneto-optical Kerr spectrometer employing the polarization modulation technique described elsewhere. [4] The maximum applied field was 1 T. The photon energy region of measurement was from 1.2 to 6 eV.

Reflectivity spectra were measured using a Hitachi U-3410 spectrophotometer with the help of a normal-incidence reflection attachment. Calibration was done using an aluminum mirror with known reflectivity spectrum.

3. Results and discussion

3.1 Magneto-optical spectra

Figure 2 shows typical spectra of polar magneto-optical Kerr rotation (solid curve) and Kerr ellipticity (dotted curve) of $Co_{66}Cr_{17}Pt_{17}$(50nm)/CoCrRu (50nm) /Al_2O_3(0001) film. The Kerr rotation decreases slightly as the photon energy increases from 1.2 eV and takes a minimum value of 0.12° around 2 eV and increases up to 4 eV, where it takes a maximum value of nearly 0.2°, followed by a rapid decrease with a zero-crossing behavior around 5.5 eV. On the other hand, Kerr ellipticity takes a very small value less than 0.02° below 2.8 eV, above which the absolute value of ellipticity increases until it takes a maximum value of nearly 0.3° at 5.5 eV followed by a decrease toward higher energies. These spectral features are not very similar to those of hcp Co metal, in which Kerr rotation takes a slight minimum at 2.5 eV, a maximum at 3.6 eV and crosses zero above 6 eV.[5] On the other hand, the similar spectral feature of Kerr rotation and ellipticity was reported in $Co_{86}Pt_{14}$ alloy, in which Kerr rotation takes a maximum at 3.6 eV with a zero-crossing behavior at 5.8 eV and Kerr ellipticity is nearly zero below 2.6 eV, above which it increases until it takes maximum at 5.8 eV. [6]

Magneto-optical spectra of CoCrPt/CoCrRu films prepared on Al_2O_3, glass, mica, and silicon substrates are shown in Fig. 3. It is found that spectral shape of Kerr rotation is not very sensitive to substrate materials. It should be noted in particular that the magneto-optical spectrum of the polycrystalline film on the glass substrate is not so much different from that of single crystalline film

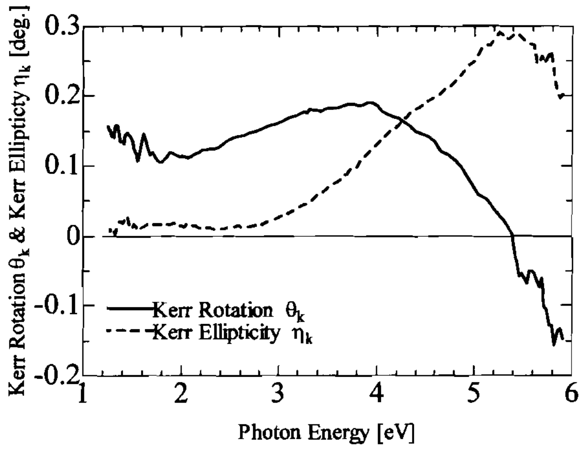

Fig. 2 Typical magneto-optical Kerr spectra of CoCrPt(50nm)/CoCrRu(50nm)/Al_2O_3

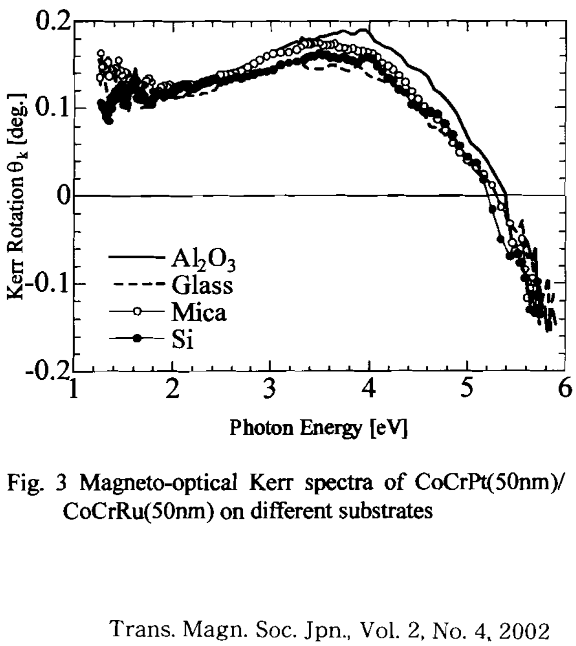

Fig. 3 Magneto-optical Kerr spectra of CoCrPt(50nm)/ CoCrRu(50nm) on different substrates

[1] Indexing as a hexagonal lattice is applied to $LaAlO_3$ for simplicity, despite that it takes an orthorhombic structure.

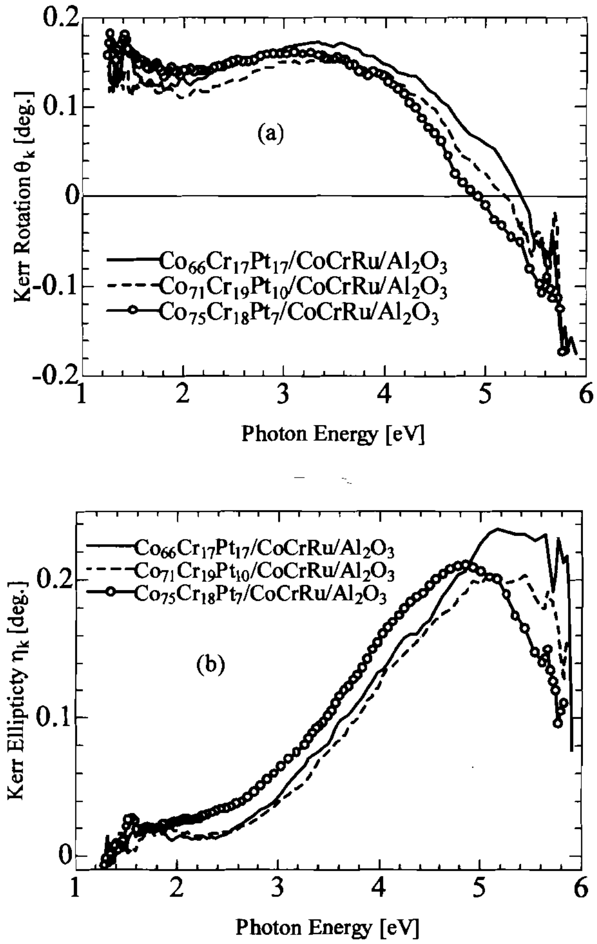

Fig 4 Spectra of magneto-optical Kerr rotation (a) and Kerr ellipticity (b) of CoCrPt with different Pt/Co ratios.

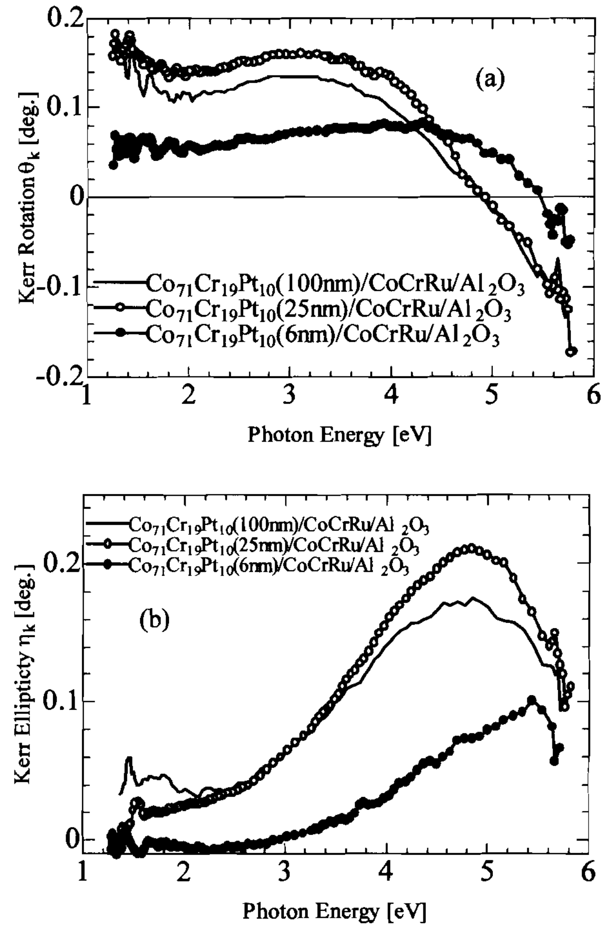

Fig. 5 Spectra of magneto-optical Kerr rotation (a) and Kerr ellipticity (b) of $Co_{71}Cr_{19}Pt_{10}$ films with different thickness values; t=6, 25 and 100 nm.

on the Al_2O_3 single-crystal substrate. We consider that this result provides evidence that the polycrystalline film on the glass substrate is consisting of highly [0001] oriented grains, since the polar magneto-optical effect of uniaxial crystal measured from the c-axis direction is not sensitive to atomic arrangements perpendicular to the c-axis.

Figure 4 shows magneto-optical spectra of three CoCrPt(25nm)/CoCrRu(50nm)/Al_2O_3 films with different Pt/Co ratios; namely $Co_{66}Cr_{17}Pt_{17}$, $Co_{71}Cr_{19}Pt_{10}$, and $Co_{75}Cr_{18}Pt_7$, corresponding to the Pt/Co ratio of 0.25, 0.14 and 0.09, respectively. It is found that the zero-crossing photon energy position of the Kerr rotation, which corresponds to the peak position of the Kerr ellipticity spectrum, undergoes a systematic shift toward lower energies with an increase in the Pt/Co ratio, consistent with change of Kerr spectra peak shifting toward lower energies with Pt in $Co_{1-x}Pt_x$.[6)]

To investigate an influence of the thickness, magneto-optical spectra were studied in three $Co_{75}Cr_{18}Pt_7$ /$Co_{50}Cr_{25}Ru_{25}$/Al_2O_3 films with different values of layer-thickness t; i.e., t=6 nm, 25 nm and 100 nm. Magnitude and spectral shape of the 6-nm thick film is much different from 25-nm and 100-nm thick films; the Kerr rotation shows a broad peak at 4.4 eV, a peak value being as small as 0.1°. Since magneto-optical spectra reflect electronic structures of magnetic materials, this result indicates that the 6-nm thick film is a different alloy from that of thicker films. The thin film may be subjected to a diffusion of Ru atoms from the CoCrRu underlayer to form a CoCrPtRu alloy, while thicker film may be consisting of the dominant CoCrPt layer and the initial CoCrPtRu layers. However, no systematic trend with

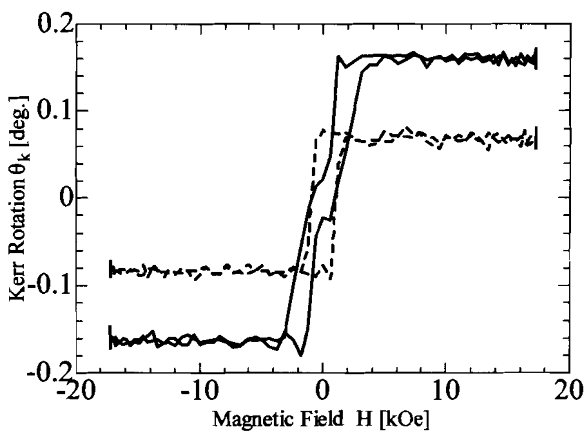

Fig.6 Magneto-optical Kerr hysteresis loops of two $Co_{75}Cr_{18}Pt_7$ films with different thickness values t; t=6 (dotted curve) and 25 nm (solid curve).

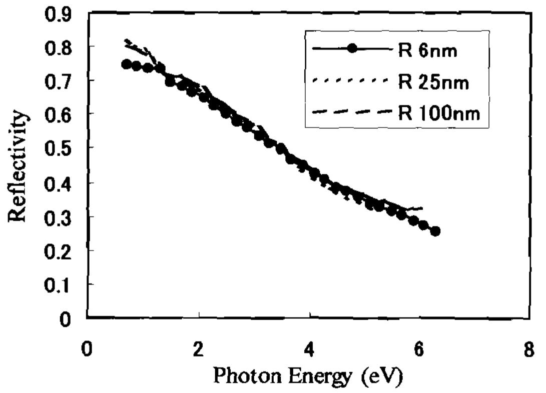

Fig. 7 Reflectivity spectra of $Co_{71}Cr_{19}Pt_{10}$ films with different thickness values; t=6, 25 and 100 nm.

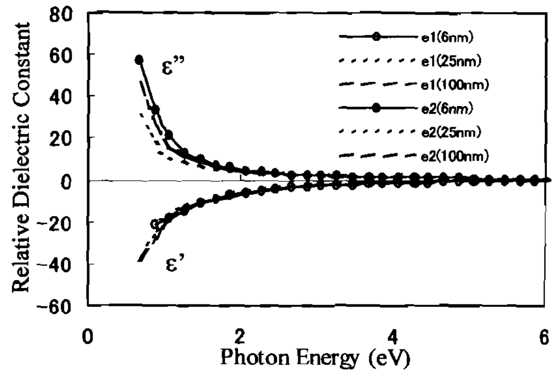

Fig. 8 Spectra of diagonal dielectric constant in $Co_{71}Cr_{19}Pt_{10}$ films with different thickness values;

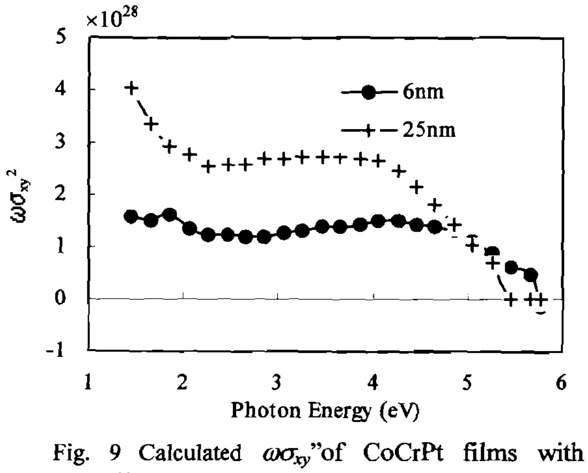

Fig. 9 Calculated $\omega\sigma_{xy}$"of CoCrPt films with different thickness

thickness was observed. An optical simulation assuming multilayers consisting of CoCrPt layers of different compositions is necessary to interprete the results.

Figure 6 shows magneto-optical Kerr hysteresis loops of $Co_{75}Cr_{18}Pt_{7}/Co_{50}Cr_{25}Ru_{25}/Al_2O_3$ with different thickness values. A step-like hysteresis loop is observed in thicker film suggesting the formation of a bilayer structure of the film, while only a simple loop is seen in 6-nm sample.

Such a two-step behavior is only observed in films with small Pt/Co ratios. No step-like behavior was observed in $Co_{66}Cr_{17}Pt_{17}$ even in the 25-nm thick film suggesting that formation of CoCrPtRu layer seems to be suppressed due to high concentration of Pt.

3.2 Reflectivity spectra

Reflectivity spectra of the three $Co_{71}Cr_{19}Pt_{10}$ film with different thickness values are shown in Fig. 7. The structures observed around 1.2-1.5 eV is due to the absorption of water vapor and should be ignored. Reflectivity spectra show large reflectivity values with a monotonous decrease toward higher energies, suggesting Drude-like behavior due to conduction electrons. Real and imaginary parts of the diagonal component of dielectric function are calculated by the Kramers-Kronig analysis and are shown in Fig. 8. Spectral shape is common in three samples of different thickness values, suggesting that no optical interference phenomena are involved. Using Kerr parameters (rotation and ellipticity) and optical constants (n and k) deduced from ε_{xx}, the $\omega\sigma_{xy}$"(imaginary part of off-diagonal element of conductivity multiplied by angular frequency) was calculated. Obtained spectra of $\omega\sigma_{xy}$" in two CoCrPt films with different thickness values(6 nm and 25 nm) are plotted in Fig. 9. Two spectra are essentially different. Therefore we can conclude that the difference in the magneto-optical spectra observed between the 6-nm thick film and thicker films is not due to any optical effect, but due to difference in electronic structures of individual materials.

4. Conclusion

Magneto-optical spectra in wide photon energy region between 1.2 eV and 6 eV were measured for the first time in single crystal films of CoCrPt grown on single crystalline substrates. Off-diagonal conductivity tensor elements were deduced using the magneto-optical parameters and optical constants. Magnetic layer with different composition seems to be formed at the very initial stage of growth in CoCrPt films with a small Pt/Co ratio.

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