A New Magneto-optical Recording Material : $CrPt_3$ Films

Developing the data storage devices with higher recording capacity has been a key subject in the advanced information technology. Conventionally, the medium is recorded longitudinally onto the plane of the recording device like disks or tapes made from magnetic materials. In this way, many intrinsic problems, such as the thermal instability produced by the magnetic recording head, limit the recording capacity. One possible means to extend the recording capacity is to record the medium perpendicular rather than longitudinal to the plane of the recording device. The related physical property has been known as the perpendicular magnetic anisotropy (PMA) effect. The principle of perpendicular magneto-optical recording is schematically illustrated in Fig.1. The writing process is done by using a focus laser beam to locally heat up a recording unit around its Curie temperature and applying a magnetic field from the underlying electromagnet to select the magnetic moment of the recording unit. A recording bit "1" ("0") can be defined as up (down) magnetic moment, or the other way around. The reading process is carried out by the use of the so-called perpendicular magneto-optical Kerr effect (PMOKE). Linear polarized light shines on the perpendicular magnetized recording unit. The polarization of the reflection beam will rotate by an angle θ_k (or $-\theta_k$) corresponding to the up (or down) magnetic moment of the recording unit, as shown in Fig. 1(b).

It is well known that the magnetization of a magnetic material usually prefers to point in certain easy crystallographic axes. For magnetic thin films, the easy directions typically lie in the plane of films. However, certain magnetic alloyed films have been demonstrated to have strong PMA effect and polar Kerr rotations, and are therefore the promising materials for making the recording device with higher capacity. For example, the chemically ordered MPt(001) (M= Fe, Co) film is one of such kind of materials. It has been shown that the reduction of the thickness of the M layer to a single monolayer together with the symmetry breaking in the M-Pt(001) interface results in the magnetization aligned perpendicularly to the plane of the film.

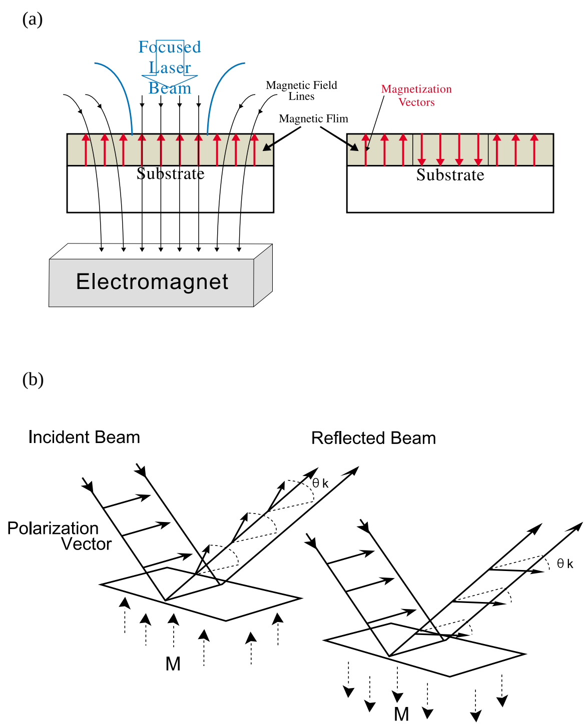

Fig. 1: Schematic diagrams showing the perpendicular magneto-optical recording (a) writing process and (b) reading process.

Another compound family MPt_3 (M= Mn, Co, Fe, Cr) has also attracted considerable interests because of their rich magnetic structures and the potential of being applied in high recording density devices. Experimentally, it has been shown that ordered MPt_3 films all have the cubic Cu_3Au ($L1_2$) crystal structure, but could display distinct magnetic ordering depending on the alloying process. Ordered $MnPt_3$ films have large Kerr effect and exhibit in-plane magnetization. Fully ordered $CoPt_3$ films also show in-plane ferromagnetism, whereas partially ordered $CoPt_3$ films exhibit good PMA effect. Furthermore, an ordered stoichiometric $FePt_3$ compounds may show anti-ferromagnetic ordering. In contrast, ordered $CrPt_3$ compound shows the ferrimagnetism with the magnetic moment of Cr and Pt aligned anti-parallel to each other.

For the binary alloy systems, such as MPt and MPt_3, PMA and Kerr effect are sensitive to the crystal orientation, alloying process, and chemical ordering of the alloy films. Thus, a systematic study of these binary systems is important for further understanding of the origin of the perpendicular magnetization effect. Using a special designed growth method, we are able to investigate the correlation of the PMA effect and the structural ordering on the $CrPt_3$ films as a function of the growth temperature (T_g).

The $CrPt_3$ films were grown by a molecular beam epitaxy (MBE) system. Pure (99.99%) Cr and Pt elements were evaporated from a separate e-beam source onto the substrate. A special designed wedge was used as a sample holder, shown in Fig. 2. One end of the wedge was in contact with the heater

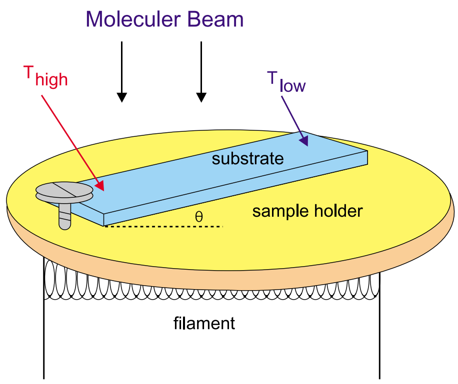

Fig. 2: Schematic diagrams showing the temperature-wedge sample holder. The angle theta is out of the plane of the holder.

block by a metallic clamp and holding screws, and the other end was out of contact with the heater block. By adjusting holding screws, the substrate can be tilted an angle (from the surface of heater block. This design allows the growth temperature being monotonically changed from one to the other side of the substrate. The substrate temperature was measured by two thermocouples at the ends of the substrate. Since the theory of heat diffusion suggests a nearly parabolic decrease from high-temperature side to the low-temperature side, the local temperature of the temperature wedge was thus estimated using the parabolic approximation given the boundary conditions at both ends. The $CrPt_3$ films were grown in the form of multilayer with 20 periods of Cr(<10A<t_{Cr}<20A)/Pt(35A) bilayers. The growth at high temperatures enables good alloying effect between Cr and Pt layers. This multilayer growth method provides good control in the thickness of Cr and Pt layers, and thus a more precise alloy composition, as compared to the co-deposition technique.

The deposition rate of the Cr or Pt layer was controlled at ~ 0.1Å/sec with the growth pressure below 5×10^{-9} torr, and was measured by a quartz crystal monitor near the sample holder. The crystal structure and order parameters were studied using X-ray diffraction (XRD). MO and magnetic properties were investigated by polar magneto-optical Kerr effect (PMOKE) using He-Ne laser (λ~632.8 nm)and vibration sample magnetometer (VSM).

Good PMA effect was observed in both VSM and PMOKE measurements. The perpendicular magnetic anisotropy Ku is 2.4×10^6 erg/cm^3 for the $CrPt_3$(111) samples grown at the optimal growth temperature 850℃. Fig. 3(a) shows the PMOKE hysteresis loops of the temperature wedge $CrPt_3$(111) samples. The optimal polar Kerr effect and loop squareness occur at T~ 850℃$\pm$25℃, as shown in Fig. 3(b)-(c). The synchrotron XRD measurements show that the out-of-plane order parameters of the $L1_2$ structure have a peak position at growth temperature around 850℃$\pm$25℃, as shown in Fig. 4. Note that the order parameter S here is determined by the ratio of the integrated intensities I of both tilted (113) and (112) X-ray diffraction peaks after normalization of the structure factor and correction for sample

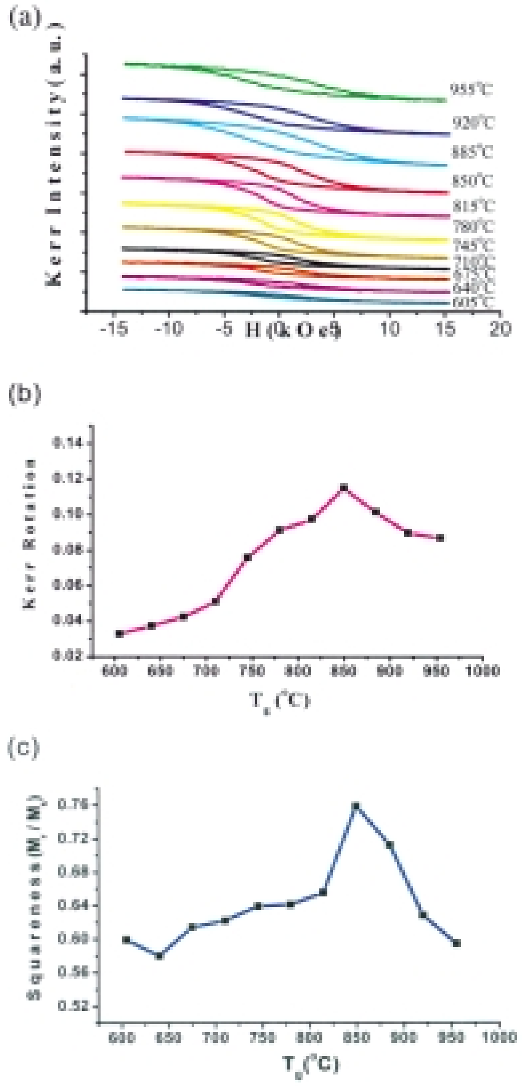

Fig.3: (a) PMOKE hysteresis loops scanned from $CrPt_3(111)$ temperature wedge samples grown on $Al_2O_3(0001)$ substrate. (b) and (c) are the corresponding Kerr rotation and loop squareness as a function of growth temperature T_g. Lines in (b) and (c) are for guiding the eyes.

absorption, Debye-Waller and Lorentz factors

$$S = \frac{F_{113}}{F_{112}} \sqrt{\frac{I_{112} A_{113} L_{113}}{I_{113} A_{112} L_{112}}}$$

where I_{hkl}, F_{hkl}, A_{hkl}, L_{hkl} are the integrated intensity, structural factor, absorption factor and Lorentz factor for the *hkl* reflections, respectively. The order parameter is a characteristic of the long-range order of the $L1_2$ structure (i.e., ordered $CuAu_3$ type). Our results suggest that PMA and Kerr effects are strongly correlated with both out-of-plane and in-plane order parameters of the $L1_2(111)$ structure for $CrPt_3$ films. It is worthy to mention that the optimal growth temperature of $CrPt_3$ films is lower than the order-disorder transition temperature (~1100℃) of bulk $CrPt_3$ compound, suggesting the importance of the surface kinetics, e.g., surface disordering, during MBE thin film growth processes.

A strong bulk contribution to the PMA can occur in the hexagonal or tetragonal structures. Question arises why a good PMA effect occurs in $CrPt_3$ films, which have the cubic $CuAu_3$ structure? To answer this question, we probed the projection of the in-plane order parameters of the $CrPt_3$ films by tilted (-113) and (-112) XRD scans using synchrotron radiation source. Interestingly, the results indicate that the (nearly) in-plane ordering (open squares in Fig. 4) is systematically worse than the plane-normal ordering (solid squares in Fig. 4) for the temperature range (600-900℃). In addition, the (nearly) in-plane order parameter is closer to the plane-normal order parameter as the temperature above 850℃, suggesting that the $CrPt_3$ films become more chemically isotropic at the elevated temperature. The origin of anisotropic ordering is still unclear so far. It could be related to the multilayer growth method (not enough annealing) and anisotropic diffusion along the in-plane and plan-normal directions. The anisotropy of the $L1_2(111)$ order parameter suggests that the $CrPt_3$ films are chemically *inhomogeneous* between the in-plane and plane-normal direction. However, the degree of sample compositional uniformity across the temperature wedge of the $CrPt_3$ temperature-

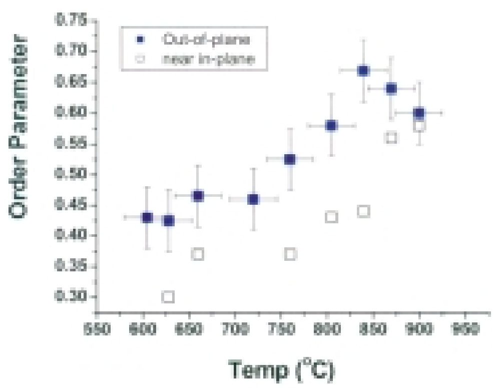

Fig. 4: Order parameters of the $CrPt_3(111)$ films as a function of growth temperature T_g.

wedge films was examined by RBS and no significant difference, within 5% of experimental error, was found for samples grown between 850℃ and 700℃. Similar results (i.e., good uniformity across the sample) were also obtained by X-ray reflectivity measurements.

It is likely that the PMA effect of the $CrPt_3$ films is mainly due to the incomplete and anisotropic ordering of the $CrPt_3$ films. Because the alloying process is incomplete (only about 0.67 along the plane-normal), there could exist local regions in which the ordered and disordered alloys are in different stoichiometry (e.g., from $CrPt_3$ to CrPt). In other words, the relative concentrations of Cr and Pt are locally different as viewed from the plan-normal and the in-plane directions. The existence of the (minor) $L1_0$ CrPt layers may be responsible for the symmetry breaking of the structure along the plane-normal direction with respect to that of the in-plane. From the temperature dependence of the plane-normal and (nearly) in-plane order parameter, it is likely that the optimal PMA is a trade-off between the different alloying processes occurring at the both ends of the substrate. In other words, only a little alloying occurs and less ferromagnetic material is formed at the low temperature side, and too much alloying at the other end, so that the interface does not exist any longer to create a PMA.

The spin alignment of both Cr and Pt elements in $CrPt_3$ films is of central importance in understanding the PMA effect. The degree of spin polarization of Pt (induced by Cr) is also of great interest. These questions could be answered by MCD experiments in the near future.

Beamline:

17B1 Wiggler beamline

Experimental Station:

X-ray diffraction end station

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