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Structure and perpendicular magnetic anisotropy of MBE-grown Pt–Co alloy films

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Abstract

$Pt_{75}Co_{25}$ alloy films were grown by the MBE method onto heated MgO(1 0 0) and (1 1 1) substrates. It is found that the film with an $AuCu_3$-type structure is grown onto the (1 0 0) substrate at a temperature of 400°C. Whereas, the crystal structure of the films grown at 200°C becomes AuCu type with FCT lattice. The film of the AuCu type exhibits a very large perpendicular magnetic anisotropy of 1.7×10^7 erg/cm^3, due to the layered structure along the film normal direction. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: MBE growth; Ordered alloy; AuCu-type structure; Perpendicular magnetic anisotropy

The Pt–Co alloy films prepared under specific conditions exhibit perpendicular magnetic anisotropy, which is an important requirement for application to magneto-optical recording media. Recently, a large perpendicular anisotropy has been reported in the $Pt_{25}Co_{75}$ film with NiAs structure [1,2] and the $Pt_{50}Co_{50}$ film with CuPt structure [3] grown onto single-crystal substrates by the MBE method. On the other hand, Tyson et al. have demonstrated that a directional anisotropy in the number of Co–Co bonds contributes to the perpendicular anisotropy in polycrystalline $Pt_{0.72}Co_{0.28}$ alloy films [4].

In this paper, we have prepared $Pt_{75}Co_{25}$ films by the MBE method and measured their magnetic anisotropy. Since the structure of a conventional Pt_3Co ordered alloy is of cubic $AuCu_3$-type, it is difficult to induce the perpendicular anisotropy by controlling the crystal orientation of a film. However, in our experiment, the MBE grown $Pt_{75}Co_{25}$ film with (0 0 1) orientation exhibits a large perpendicular anisotropy. Therefore, we investigated the origin of the perpendicular anisotropy of $Pt_{75}Co_{25}$ films by analyzing the crystallographical structure of the films.

The $Pt_{75}Co_{25}$ alloy films were grown onto MgO(1 0 0) and MgO(1 1 1) substrates by the MBE method. After heat treatment at a temperature of 1000°C in 1 atm O_2 atmosphere, polished MgO substrates were loaded to MBE chamber and preheated at 850°C. In the first place, Ag (40 nm) and Pt (10 nm) underlayers were grown onto MgO substrates at a temperature of 40°C and then the $Pt_{75}Co_{25}$ alloy layer was co-evaporated from electron beam heated sources of Pt and Co. The growth temperature T_g of the $Pt_{75}Co_{25}$ alloy layer was varied from 40°C to 500°C. The deposition rate of the $Pt_{75}Co_{25}$ layer was 3 nm/min and its thickness was 100 nm. Finally, in order to avoid surface oxidization, a Pt capping layer of 2 nm was deposited below 150°C.

The structure of the films was characterized by in situ refraction high-energy electron diffraction (RHEED) and ex situ X-ray diffraction (XRD). The Co content of the Pt–Co alloy layer was confirmed to be within the range of 23–27% by electron probe microanalysis (EPMA). The magnetic anisotropy of the films was determined by the 45° method using a torque magnetometer [5].

From the observation of the RHEED patterns during the deposition, it was confirmed that the Ag, Pt and

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Pt–Co layers were epitaxially grown onto (1 0 0) and (1 1 1) substrates Fig. 1 shows the θ–2θ scans of XRD for the (100) films grown at various temperatures. In the sample grown above 200°C, strong diffraction peaks are seen at $2\theta = 20°$ and 75° in addition to the fundamental (0 0 2) peak from the FCC or FCT lattice. This fact implies the formation of an ordered phase with CuAu($L1_0$) or $CuAu_3$($L1_2$) type. However, it is difficult to distinguish between CuAu and $CuAu_3$ structure from the diffraction patterns of θ–2θ scan. Therefore, we carried out the two-dimensional XRD scan in the reciprocal space with Q_z and Q_x axes, where Q_z is the film normal component of the momentum transfer vector and Q_x the in-plane component parallel to the [1 0 0] direction [6].

Fig. 2 illustrates the expected reciprocal space map for CoPt (■) and $CoPt_3$ (□ + ■) ordered phase with AuCu and $AuCu_3$ structure, respectively, where the c axis of CoPt phase is assumed to be parallel to the film normal. In the map, (1 0 4) and (1 0 3) diffraction spots for the $AuCu_3$-type are seen while they are not seen for the AuCu-type because of the extinction rule.

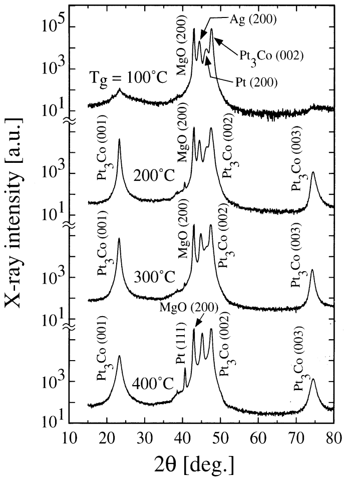

Fig. 1. X-ray diffraction patterns of the Pt (2 nm)/$Pt_{75}Co_{25}$ (100 nm)/Pt (10 nm)/Ag (40 nm)/MgO(1 0 0) films with various growth temperature T_g.

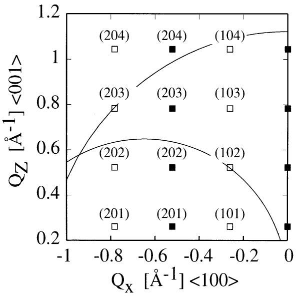

Fig. 2. Expected reciprocal space maps for PtCo ordered phase with AuCu structure and Pt_3Co ordered phase with $AuCu_3$ structure, where the diffraction peaks from PtCo phase appear as closed squares and those from $PtCo_3$ phase appear as closed and open squares.

Fig. 3a and Fig. 3b show the reciprocal space map for (0 0 1) films grown at 400 and 200°C, respectively. In the map (a), the (2 0 3), (1 0 4) and (1 0 3) diffraction peaks due to a superlattice in the $Pt_{75}Co_{25}$ layer can be observed together with strong peaks of MgO(2 0 4) and Ag(2 0 4). This result reveals that the structure of the film grown at 400°C is of $AuCu_3$ type, which is the ordered phase that appeared in the phase diagram. On the other hand, in the map (b), the (2 0 3) peak is seen but the (1 0 4) and (1 0 3) peaks are not seen. This means that the film structure is of AuCu-type with FCT lattice whose c-axis is along the film normal. Therefore, the crystal structure of the film is considered to be composed of stacks of Pt and $Pt_{50}Co_{50}$ monolayers in the (0 0 1) plane. A similar structure has been proposed for $Pt_{25}Co_{75}$ films with an NiAs structure [7].

Fig. 4 shows the hysteresis loops of (0 0 1) films grown at 100, 200, 300 and 400°C. The film grown at 200°C exhibits a strong perpendicular anisotropy and high coercivity of 5 kOe.

Fig. 5 shows the growth temperature dependence of perpendicular magnetic anisotropy K_u for (0 0 1) and (1 1 1) films, where the K_u is the sum of effective perpendicular anisotropy K_{eff} and demagnetizing energy $2\pi M_s^2$. The K_u of the (1 1 1) films is very small while the K_u of the (0 0 1) films shows a very large maximum at $T_g = 200°C$. As mentioned above, the film of $T_g = 200°C$ has the FCT

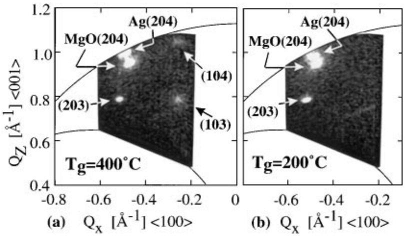

Fig. 3. Reciprocal space map for the (0 0 1) films grown at 400°C (a) and at 200°C (b).

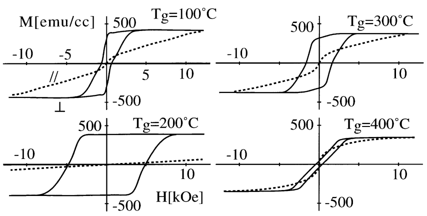

Fig. 4. Hysteresis loops of (0 0 1) films grown at 100, 200, 300 and 400°C, where the solid lines are for perpendicular applied field and dotted lines for in-plane field.

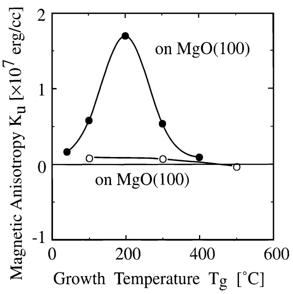

Fig. 5. Growth temperature T_g dependence of the perpendicular magnetic anisotropy K_u.

lattice with AuCu-type, which has a layered structure along the *c*-axis. Therefore, the large K_u of the film of $T_g = 200°C$ is considered to be due to the crystal anisotropy along the *c*-axis since the *c*-axis of the FCT lattice is grown along the film normal. The magnitude of K_u of $T_g = 200°C$ is comparable with those for bulk Pt–Co ordered alloy [8] and $Pt_{25}Co_{75}$ with an NiAs structure [7].

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