Epitaxial Growth of Quad-Crystal Co-Alloy Magnetic Recording Media

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Abstract — **Quad-crystal Co-alloy/Cr/Ag thin film media were epitaxially grown on hydroflurlc acid etched Si(111) single crystal substrates by sputter deposition. The orientation relationship was studied by x-ray θ/2θ diffraction and pole figure φ-scan, and it was determined to be Co($10\bar{1}1$) ‖ Cr(110) ‖ Ag(111) ‖ Si(111). The Ag layer contains two twin-related orientations of grains. Cr grows with three variants of grains on the Ag(111) layer. Since Co($10\bar{1}1$) contains grains with four possible easy axis directions when grown on each Cr variant, the quad-crystal media consist of grains with twelve easy axis directions and exhibit nearly isotropic in-plane magnetic properties.**

Index Terms — **epitaxy, magnetic media, Co, Cr**

I. INTRODUCTION

Co-based alloys are currently the most popular thin film media materials for magnetic recording. In order to achieve the optimal magnetic properties, control of the Co-alloy film texture is essential, and this is most often achieved by using Cr underlayers [1][2]. One of the epitaxial orientation relationships between the Co and Cr films is the quad-crystal structure [3]. It refers to a Co($10\bar{1}1$) film grown on a Cr(110) underlayer due to the close lattice match as illustrated in Fig. 1. There are four possible orientations for the Co grains, resulting in four easy axis directions tilting out of the plane by an angle of about 28°. Previously quad-crystal Co films were epitaxially grown on single crystal Cr(110) substrates [4]. However, single crystal substrates such as Cr is usually very expensive and the processing is inconvenient; hence, their application in magnetic recording is limited. Recently, we reported the growth of highly oriented magnetic thin films using single crystal Si wafers as substrates, in which bi-crystal, uni-crystal and perpendicularly oriented Co alloy media were epitaxially grown on Si substrates [5-7]. In this work we report the epitaxial growth of quad-crystal cobalt alloy on single crystal Si (111) substrates.

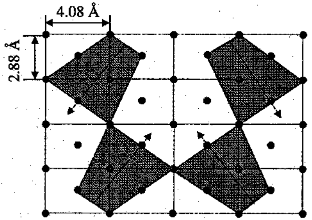

Fig. 1. Lattice match relationship between Co($10\bar{1}1$) and Cr(110) planes.

The epitaxial orientation relationships for the quad-crystal Co/Cr/Ag/HF-Si(111) films are shown in Fig. 2. As we reported earlier, because of the 4:3 match between the Ag and Si lattice parameters, Ag grows epitaxially on Si(111) with a (111) orientation [7]. The Cr layer grows with three variants of grains on the Ag(111) layer, bearing the orientation relationships as listed below:

Cr(110)[001] ‖ Ag(111)[$1\bar{1}0$] ‖ Si(111)[$1\bar{1}0$],
Cr(110)[001] ‖ Ag(111)[$10\bar{1}$] ‖ Si(111)[$10\bar{1}$],
Cr(110)[001] ‖ Ag(111)[$01\bar{1}$] ‖ Si(111)[$01\bar{1}$].

The Co layer contains grains with four possible easy axis directions when grown on each Cr variant. As a result, the quad-crystal media consist of grains, each with one of twelve possible easy axis directions.

II. EXPERIMENTAL DETAILS

Si(111) wafers were first ultrasonically cleaned in organic solvents and rinsed in deionized water. Clean wafers were then immersed in HF to remove the native SiO_2 and obtain a hydrogen-terminated surface. The etched wafers were blown

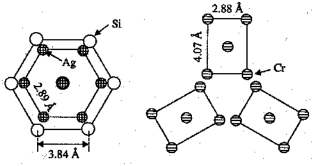

Fig. 2. Orientation and interatomic spacing relationships between Si(111) and Ag(111) and Cr(110) lattices. Note the three possible orientations of Cr(110) on Ag(111).

Manuscript received March 5, 1999.
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This work was supported in part by a grant from NSIC and by the DSSC at CMU under a grant from NSF, #ECD-8907068.

dry using N_2 gas, then placed into the sputtering system, and heated to about 200°C in vacuum before deposition. Ag, Cr, and $Co_{76}Cr_{20}Pt_4$ thin films were then deposited by rf diode sputtering in a Leybold-Heraeus Z-400 sputtering system. The base pressure was below 5×10^{-7} Torr. The Ar sputtering gas pressure was fixed at 10 mTorr and the sputtering power density was about 2.3 W/cm^2.

The epitaxial structure of the films was studied by x-ray θ/2θ diffraction and pole figure ϕ-scan. The magnetic properties of the films were measured using a vibrating sampling magnetometer.

III. Results and Discussions

The θ/2θ x-ray diffraction spectra for a CoCrPt(300 Å)/Cr(500 Å)/Ag(750 Å) film grown on HF-Si(111) is shown in Fig. 3. Only Ag(111), Cr(110) and Co($10\bar{1}1$) diffraction peaks are observed. These very strong diffraction peaks as compared to the background noise level imply the epitaxial nature of the film.

The ϕ-scan spectra of the CoCrPt/Cr/Ag/HF-Si(111) sample are shown in Fig. 4, along with Si (111), Ag (111), Cr (110), and Co ($10\bar{1}1$) stereographic projections that are necessary for the interpretation of the spectra. As can be seen in Figure 4a, the Si{110} pole scan spectrum of the single crystal Si(111) substrate yields three diffraction peaks with 120° separation. They correspond to the three {110} poles in the Si (111) stereographic projection [Fig. 4(a')], which are also 120° apart and are indicated by the dotted circle showing the ϕ-scan path.

While three Ag{110} poles are expected for single crystal Ag(111), six peaks were observed in the Ag{220}-pole scan [Fig. 4(b)] of the Ag(111) film grown on Si(111). This suggests that there exist two twin-related orientations of Ag grains in the Ag(111) film. They may emerge at the Ag/Si epitaxial interface or result from Ag growth twinning. In fcc metals, the (111) plane is the most common twinning plane, and the twinning direction is [$11\bar{2}$]. The extra poles are indicated by the "×" in Fig. 4(b'). Three of the peaks, the first, third and fifth, appear at the same ϕ positions as the three peaks in Si{110}-pole spectrum, confirming the parallel relationship between the Si[$1\bar{1}0$] and Ag[$1\bar{1}0$] directions. The twinning was also confirmed by electron diffraction

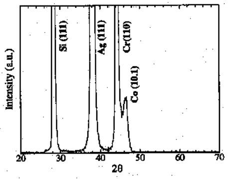

Fig. 3. X-ray diffraction pattern of a CoCrPt(300 Å)/Cr(500 Å)/Ag(750 Å)/Si(111)-HF film.

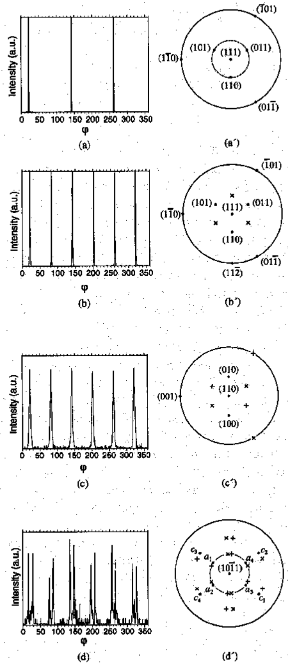

Fig. 4. (a) Si{110}-pole, (b) Ag{220}-pole, (c) Cr{200}-pole, and (d) CoCrPt{$10\bar{1}0$}-pole ϕ-scan spectra of a CoCrPt(300 Å)/Cr(500 Å)/Ag(750 Å)/Si(111)-HF film. The stereographic projections are for (a') Si(111), (b') Ag(111), (c') Cr(110), and (d') Co ($10\bar{1}1$).

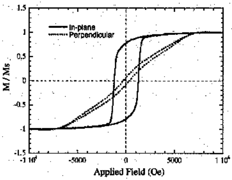

Fig. 5 In-plane and perpendicular hysteresis loops of a CoCrPt(300 Å)/Cr(500 Å)/Ag(750 Å)/Si(111)-HF film.

patterns [7].

Similarly, while two Cr{001} poles are anticipated for single crystal Cr(110), the Cr{002}-pole scan spectrum [Fig. 4(c)] shows six peaks that are 60° apart. They appear at the same locations as the six peaks in the Ag{002}-pole scan. This confirmed not only the three possible growth variants of Cr grains on Ag(111), but also that the three Cr{001} directions are parallel to the three Ag{$1\bar{1}0$} directions. The two extra sets of poles are denoted by "×" and "+" in the streographic projection in Fig. 4(c').

Finally, with four possible orientations of Co grains on each Cr variant, as indicated by four ($10\bar{1}0$) poles (marked a_1 to a_4) or four (0001) poles (marked c_1 to c_4, as these are also easy axis directions), there will be altogether twelve ($10\bar{1}0$) poles. The two extra sets of poles are denoted by "×" and "+". As shown in Fig. 4(d'), the twelve poles can be divided into six groups, inside each group there is a separation of about 10° along the ϕ-scan path, while the neighboring two groups are 60° away from each other. The observed Co($10\bar{1}0$)-pole scan [Fig. 4(d)] agrees well with the projection. Also as expected, each two-peak group is centered about the six Cr peaks in the Cr{002}-pole scan spectrum.

Fig. 5 shows the measured in-plane and perpendicular hysteresis loops of the CoCrPt/Cr/Ag/HF-Si(111) sample. The measured in-plane coercivity is 1270 Oe, while the perpendicular coercivity is 277 Oe. Due to its relatively small saturation magnetization and large magnetocrystalline anisotropy, $Co_{76}Cr_{20}Pt_4$ can be used to fabricate perpendicular media. Hence, the small perpendicular coercivity of this quad-crystal sample also confirmed the growth of the Co($10\bar{1}1$) film with the 28° tilted easy axes. No significant angular dependence was observed in the in-plane coercivity and in-plane torque measurements.

IV. Conclusions

In this work, we have successfully fabricated quad-crystal Co-alloy thin-film media on Cr(110)/Ag(111)/HF-Si(111) by sputter deposition. The epitaxial orientation relationship was determined by x-ray pole figure scan. Two twin-related orientations were found in the Ag(111) layer. Cr grows with three possible variants on Ag(111) and this finally results in twelve easy axis directions in the Co($10\bar{1}1$) layer. By epitaxial growth this media structure can provide a better Co($10\bar{1}1$) texture, and the resulting near-isotropic in-plane magnetic properties make it an interesting possible candidate for magnetic recording.

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