Evolution of Structure and Magnetic Properties of Sputter-deposited CoPt Thin Films on MgO(111) Substrates: Formation of the $L1_1$ Phase

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8-circle diffractometer at beamline 17B1 was used to study the structure evolution of CoPt thin films grown on MgO(111) substrate prepared by sputtering. Three structures, A1, L11 and L10 have been observed in the CoPt films that had been prepared at various temperatures.

L11 phase is metastable with crystal structure of a CuPt-type rhombohedral lattice, whose unit cell consists of alternating close-packed atomic layers of Co and Pt along the [111] direction. The angle α between the crystal axes of the rhombohedral cell and lattice parameter a were estimated to be 61.5˚ and 0.534 nm, respectively. The ABC stacking structure of CuPt type exhibits a very large perpendicular MCA of approximately 2×106 J/m3.

Conventional θ-2θ X-ray diffraction reveals the formation of L11 phase by the presence of superlattice peaks of (111) and (333). In order to distinguish A1 and L10 phases, the superlattice diffractions such as (001) and (110) of the ordered phase must be examined. A (6 + 2) Huber goniometer was employed to obtain (001), (110), {200}, and {220} diffraction peaks in a (111)-textured samples with χ-rotation. By adjusting the ψ angle, the angle between film normal direction and scattering plane, to the normal directions of (001)/{200} or (110)/{220}, the related fundamental and superlattice peaks can be detected. To detect (001)/{200} diffractions, the χ-axis should be rotated from ψ = 0˚ (normal to the film surface) to 54.7˚. To examine the (110)/{220} group, the rotation angle should be 34.9˚. Additionally, the distinct symmetry between cubic and rhombohedral lattices enables us to identify A1, Ll0, and Ll_1 phases.

Figure 1 displays the XRD results for the CoPt films at various temperatures from RT to 750˚C. The CoPt film grown at RT and 200˚C yield three fundamental peaks associated with (111), (200) and (220), indicating the disordered A1 structure. A superlattice peak from the (111) plane of the $L1_1$ phase appeared at 2θ = 20.43˚ from the film with T_s = 250˚C, revealing the onset of $L1_1$ ordering. The L11(111) peak is quite broad with a full width at half maximum (FWHM) of 2.04˚. Three fundamental peaks remained. The absent of (001) and (110) diffraction peaks indicates $L1_0$ CoPt are not formed. As T_s was increased to 300˚C, the intensities of the L11(111) and fundamental peaks increased dramatically; the L11(111) peak was broadened with a FWHM of about 5˚. The highest L11(111) peak was obtained at Ts = 350˚C with the narrowest FWHM of 2.02˚. Another superlattice peak of L11(333) was present at 2θ = 65.57˚. When Ts reached 400˚C, the L11(111) peak becomes lower and broader, whereas the intensities of the three fundamental peaks were higher again, implying that the A1 phase had gradually replaced the L11 phase. The ordering of L11 phase degraded in the 500˚C-grown sample and completely disordered at Ts = 600˚C. L10 ordering does not begin until Ts is increased to 700˚C, as revealed by the presence of (001) and (110) peaks and asymmetric (200) and (220) peaks in Fig. 1. The value of S calculated from the integrated areas under the (001) and (002) peaks is around 0.41. As Ts was increased to 750˚C, the superlattice peaks of (001) and (110) became narrow, with an FWHM of only 0.4˚, suggesting grain growth. S increased to 0.72. The structural analysis confirms that the structure of CoPt films that are deposited on MgO(111) substrates at temperatures from RT to 750˚C evolves in the sequence A1 (disordered) →L11 →A1 → L10. Therefore, when Ts is increased over a threshold temperature of 350˚C, the ordered phase should be replaced by a disordered A1 phase rather than L10. After the film has become fully disordered, the L10 phase begins to form.

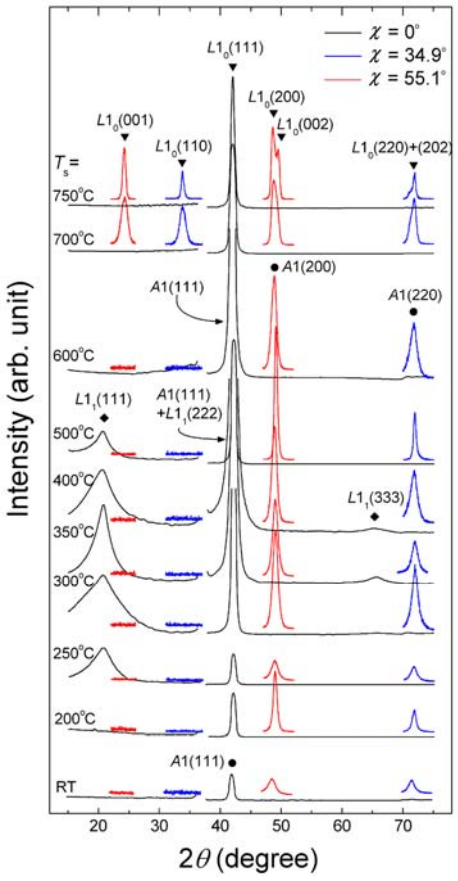

Fig. 1: XRD θ-2θ diffraction patterns for CoPt films deposited at various temperatures from RT to 750˚C at χ angles of 0˚, 34.9˚, and 55.1˚.