Structure and magnetic properties of Co/Pt single- and bi-crystal multilayers

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Abstract

Both FCC(1 1 1) single- and bi-crystal [Co(3 Å)/Pt(10 Å)]\textsubscript{23} multilayers have been successfully grown on sapphire (0 0 0 1) and yttria-stabilized cubic zirconia (1 0 0) substrates, respectively, by molecular-beam epitaxial technique. The coercivity of single crystal films decreased monotonically as elevating post-annealing temperature. However, bicrystal films displayed a larger coercivity than the other. Moreover, the coercivity of bicrystal films did not decrease until the annealing temperature >400°C. The difference in magnetic behavior between single- and bi-crystal multilayers could be originated from the demagnetizing factors resulted by different grain and surface structures.

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1. Introduction

The CoPt alloys and [Co/Pt]\textsubscript{n} multilayers are promising materials for magneto-optical and perpendicular magnetic recording because they display a large Kerr rotation angle in the short-wave band and a strongly perpendicular magnetic anisotropy (anisotropy constant, $K_u \approx 5 \times 10^6$ erg/cm$^3$), respectively [1–4]. The magnetic properties of CoPt alloys and [Co/Pt]\textsubscript{n} multilayers are strongly correlated with the composition, crystal structure, and interfacial effect. Therefore, choosing of good underlying templates (substrates or buffer layers) for films deposition were important [5,6]. Moreover, because the lattice parameter of cubic zirconia ($a = 5.14$ Å) is much larger for 3d transition metals, it is possible to grow special structures like Co bicrystal films [7,8]. Therefore, in this study, cubic zirconia stabilized with 9.5% mol Y$_2$O$_3$ (YSZ) with (100) crystal orientations was chosen as a substrate to study the crystal structure and magnetic behavior of Co/Pt multilayers.
2. Experiment and results

In this study, 300 Å thick single- and bi-crystal [Co(3 Å)/Pt(10 Å)]23 multilayers were grown on Al2O3(000 1) and yttria-stabilized cubic zirconia, YSZ (1 0 0) substrates, respectively, by molecular-beam epitaxial (MBE) technique at 100°C. The deposition rates of the Co and Pt were smaller than 0.05 Å/s. Before preparing the Co/Pt multilayers, a 100 Å thick Pt buffer layer was deposited on the substrates at 600°C. The details of substrates cleaning and films growth were elaborated elsewhere [7–9]. The crystal structures of the epitaxial films were examined by in situ reflection high-energy electron diffraction (RHEED) and ex situ θ–2θ X-ray diffraction (XRD). The magnetic properties of the Co/Pt multilayers were studied by magneto-optical Kerr effect (MOKE). The surface morphology was imaged by atomic force microscopy (AFM).

Fig. 1 showed the XRD of Co/Pt multilayers grown on (a) Al2O3(000 1) and (b) YSZ(1 0 0) substrates. The peaks located at 2θ = 40° and 40.9° were Pt(1 1 1) and CoPt3(1 1 1), respectively. The Laue oscillations, labeled as ‘L’ in Fig. 1, around the Pt(1 1 1) Bragg reflection were evidence for an atomically flat Pt surface. The satellite peak, labeled as ‘S’ in Fig. 1(a), which corresponds to the bilayer thickness of Co/Pt multilayers. It indicated that a good Co/Pt layer structure was achieved for films deposited on Al2O3 substrates. However, for the Co/Pt on YSZ substrates, good layer structures were not obtained because the satellite peaks which associated with the Co/Pt bilayer thickness were not observed in the X-ray spectrum, as shown in Fig. 1(b).

The RHEED patterns were depicted in Figs. 2(a) and (b) for Co/Pt multilayers grown on Al2O3 substrates with probe e-beam parallel to [0 1 1] and [–2 1 1] in-plane directions. They showed typical RHEED images of a FCC(1 1 1) single crystal structure. For the RHEED images of Co/Pt multilayers on YSZ(1 0 0) with probe e-beam parallel to YSZ[0 1 0] in-plane direction, Fig. 2(c) displayed a combination of Figs. 2(a) and (b). As previous reports on Co bicrystalline structures [7,8], it indicated that Co/Pt multilayers have two FCC(1 1 1) variants that meet at an angle of 30°. In fact, the formation of Co/Pt bicrystalline structures originated from the Pt buffer layer. Because of the small in-plane lattice mismatch \((ap_{[1-21]}-a_{YSZ})/a_{YSZ} = \frac{4.8-5.14}{5.14} \approx 6.6%\) between Pt(1 1 1) buffer layers and YSZ(1 0 0) substrates, the Pt(1 1 1) buffer layer was epitaxially grown on YSZ(1 0 0) substrates. Due to crystal symmetry, there were two possible selections for Pt(1 1 1) lattices to deposit on the YSZ(1 0 0) surface, that is, Pt[1 –2 1] || YSZ[0 1 0] or Pt[1 –2 1] || YSZ[0 0 1]. Therefore, the Pt(1 1 1) buffer layer grown on YSZ(1 0 0) possessed two variants and resulted in Co/Pt bicrystal structures.

According to the MOKE measurements, as-deposited samples have a perpendicular magnetic anisotropy. The coercivity of as-deposited single- and bi-crystal films was around 500 and 700 Oe, respectively, for the external magnetic field perpendicular to the film plane. After post annealing at different temperatures for 1 h, the coercivity of Co/Pt(1 1 1) single crystal decreased monotonically with annealing temperature. But the coercivity of Co/Pt on YSZ substrates remained unchanged until the annealing temperature <400°C, as depicted in Fig. 3. For both cases, as elevating...
post-annealing temperature, the decreasing of coercivity should be strongly influenced by the intermixing of Co and Pt layered structures [10].

The surface morphology of as-deposited single- and bi-crystal films was investigated by AFM as depicted in Figs. 4(a) and (b), respectively. Co/Pt single crystal displayed an atomically flat surface with a root-mean-square roughness = 1.8 Å. But
the Co/Pt bicrystal showed sharp grain boundaries and rough surfaces with root-mean-square roughness = 6.8 Å. The formation of rough surface should due to the formation of FCC(111) twin structures. It is well known that different grain and surface structures resulted in quite different demagnetizing factors that strongly affected the magnetic properties of thin films [11]. The difference in the coercivity distribution between Co/Pt single- and bicrystal films possibly originated in quite different grain and surface structures.

3. Summary

Co/Pt(111) single- and bi-crystal multilayers were successfully prepared on Al₂O₃(0001) and YSZ(100) substrates. Bi-crystal multilayers displayed a larger coercivity and clearer grain distribution than the other. For both cases, the coercivity distribution as a function of annealing temperature strongly depended on surface roughness, grain distribution and Co/Pt layered structures.

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References