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Structural and magnetic properties of $Co_2Cr_{0.6}Fe_{0.4}Al$ thin films epitaxially grown on GaAs substrates with MgO interlayer

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Abstract

The structural and magnetic properties of $Co_2Cr_{0.6}Fe_{0.4}Al$ (CCFA) thin films epitaxially grown on GaAs substrates by sputtering were investigated. The CCFA film directly grown on GaAs showed a cube-on-cube crystallographic relation, while it was rotated by 45° in the (001) plane when a thin MgO layer was inserted between the CCFA and GaAs. Both samples showed strong magnetic anisotropy, in which a uniaxial anisotropy with an easy axis of $[110]_{GaAs}$ or $[1-10]_{GaAs}$ dominated with a slight cubic anisotropy having easy axes of $\langle 110\rangle_{CCFA}$ superimposed. The uniaxial anisotropy constants were approximately 1.6 times as large as the cubic anisotropy constants for both samples.

Keywords: Heusler alloy; CCFA; Magnetic anisotropy; GaAs

1. Introduction

Co-based full-Heusler alloy thin films are promising ferromagnetic electrode materials for spintronic devices because of their intrinsically high spin polarization at room temperature (RT). Relatively high tunnel magneto-resistance (TMR) ratios were recently observed in magnetic tunnel junctions (MTJs) using Co-based full-Heusler alloys such as $Co_2Cr_{0.6}Fe_{0.4}Al$ (CCFA) [1–3], Co_2MnGe [2,3], or Co_2MnSi [4]. In experiments on spin injection from Heusler materials into semiconductors, however, relatively low spin injection efficiency was achieved [5,6]. One reason for the low efficiency could be the formation of a magnetically-dead layer due to an interface reaction between Heusler materials and semiconductors [7]. Furthermore, it is theoretically predicted from first-principle calculations that the half-metallicity is locally lost at the Heusler material/semiconductor interface [8]. Insertion of a thin MgO layer between the Heusler material and the semiconductor is expected to be a useful approach for achieving a high spin injection efficiency. In fact, we have successfully demonstrated relatively high TMR ratios in MTJs using a combination of either CCFA [1–3] or CMG [2,3] and a MgO tunnel barrier (TMR ratios of about 42% at RT for CCFA-MTJs [1,3]), indicating that the spin polarization at the Heusler material/MgO interface was kept high. In addition, Wang et al. demonstrated a high spin injection efficiency of 55% at 100 K in a CoFe/MgO/GaAs structure [9].

Although there have been several reports on the characterization of Heusler materials directly grown on GaAs [7,10,11], no study on Heusler materials grown on MgO/GaAs has been reported. In this paper, we discuss on the preparation of CCFA thin films epitaxially grown on GaAs substrates by magnetron sputtering with a MgO interlayer and our investigation of their structural and magnetic properties.

2. Experimental procedures

Layer structures consisting of 400-nm-thick undoped GaAs and 50-nm-thick n-GaAs ($Si=3\times10^{18}$ cm^{-3}) were grown by molecular beam epitaxy (MBE) at 580 °C on GaAs(001) substrates. Each sample was then capped with an arsenic protective layer and transported in air to an ultrahigh vacuum chamber equipped with magnetron sputtering cathodes and an electron beam (EB) evaporator. Prior to the growth, the arsenic cap was removed by heating the sample to 400 °C. A 1.5-nm-thick MgO layer was then grown by EB evaporation at 400 °C. Last, a 50-nm-thick CCFA film was grown on the MgO/GaAs

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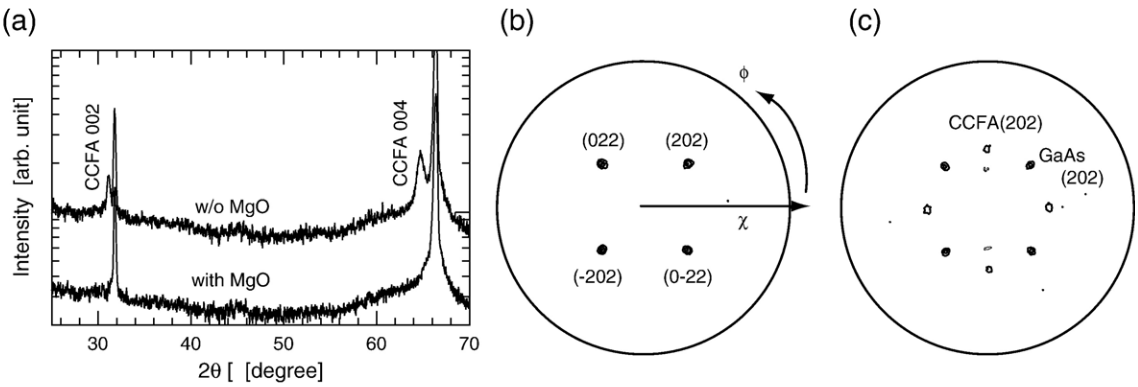

Fig. 1. (a) X-ray θ–2θ curves for the CCFA films, (b) pole figure of 022 diffraction for CCFA/GaAs, (c) pole figure of 022 diffraction for CCFA/MgO/GaAs. In the pole figures, GaAs 022 peaks were also seen due to a small lattice mismatch.

by RF-magnetron sputtering at 400 °C. We also prepared a reference sample for comparison which consisted of a 50-nm-thick CCFA film directly grown on the GaAs at 400 °C after removal of the arsenic cap. The crystalline structures of the fabricated CCFA thin films were characterized using X-ray $\theta-2\theta$ scans and X-ray pole figure measurements with a collimated K_α line of Cu as an X-ray source (Bruker AXS D8 DISCOVER Hybrid). Magnetic properties were measured using a superconducting quantum interference device magnetometer (Quantum Design MPMS).

3. Results and discussion

3.1. Structural properties

Fig. 1(a) shows X-ray $\theta-2\theta$ patterns for samples with and without the MgO layer. The CCFA film directly grown on the GaAs showed clear 002 and 004 peaks, indicating the *c*-axis orientation. Furthermore, the pole figure measurement (Fig. 1 (b)) revealed CCFA 022 diffraction peaks with four-fold symmetry with respect to the sample rotation angle, ϕ, at a tilt angle, χ, of 45°; this provides direct evidence of epitaxial growth. Here, we set the GaAs [110] direction to the origin of ϕ. The crystallographic relationship with respect to the GaAs was CCFA(001) [110]||GaAs(001) [110]; *i.e.*, a cube-on-cube relation.

We also observed CCFA 022 diffraction peaks with four-fold symmetry for the CCFA film grown on GaAs with a MgO interlayer (Fig. 1(c)), which clearly indicated epitaxial growth of the CCFA film. In this case, though, the peak intensities were lower than those of the sample without MgO. Interestingly, since the 022 peaks of the CCFA with the MgO layer were shifted by 45° with respect to those of the GaAs, the crystallographic relation was CCFA(001) [110]||GaAs(001) [100].

The *B*2 structure was dominant for the CCFA directly grown on the GaAs since we observed 222 and 002 diffractions, but no 111 diffraction. On the other hand, the *A*2 structure (one more disordered than the *B*2 structure) was dominant for the CCFA with the MgO layer since we observed 022 diffraction, but neither 111 nor 222 diffraction. These results indicate that

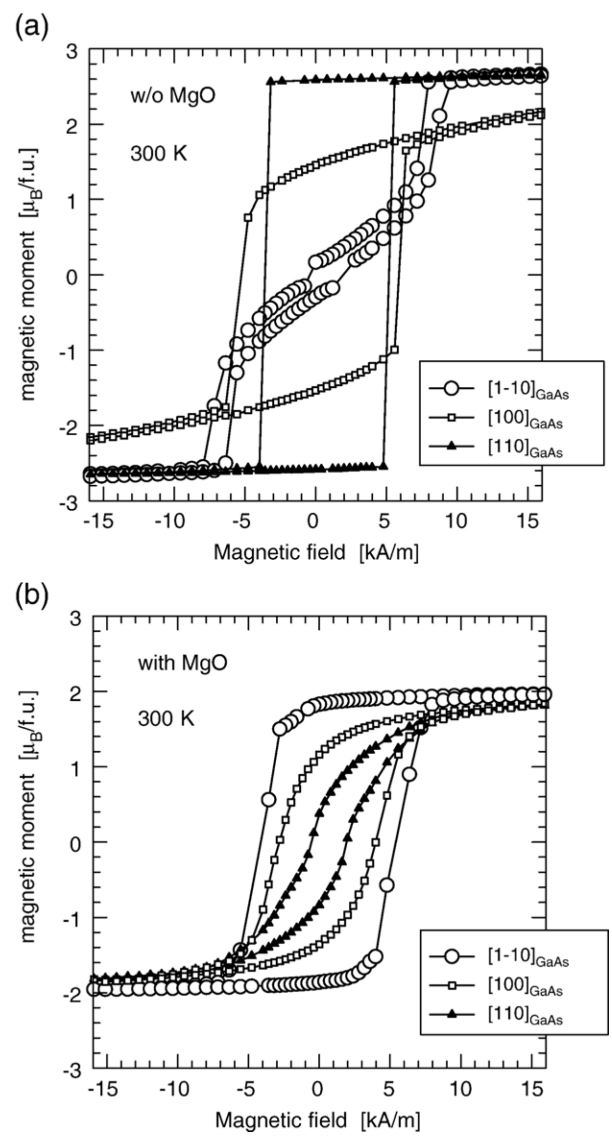

Fig. 2. Magnetic hysteresis curves for the CCFA films (a) without MgO and (b) with MgO.