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Probing magnetic anisotropies in half-metallic CrO_2 epitaxial films by FMR

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Abstract

Epitaxial (1 0 0) thin films of CrO_2 were fabricated by chemical vapour deposition technique onto TiO_2 (1 0 0) single-crystal substrates. X-band (9.5 GHz) ferromagnetic resonance studies reveal that magnetic anisotropy parameters in the series prepared using CrO_2Cl_2 liquid precursor show only slight variations with thickness, contrary to their strong dependence observed in the CrO_3-based films. The different behaviour was attributed to different morphologies of the films prepared using solid and liquid precursors.

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Keywords: Thin film; Half-metallic material; Magnetic anisotropy; Ferromagnetic resonance

1. Introduction

The highly spin-polarized conduction band of half-metallic ferromagnets makes them ideal candidates for spintronic applications. The half-metallic chromium dioxide (CrO_2) has the highest polarization (~100%) [1–5]. Epitaxial CrO_2 films have been synthesized by chemical vapour deposition (CVD) technique [6], and there are few papers on their electrical and magnetic properties [3–10] Recently, it has been shown that CVD process with a liquid precursor [11] is more advantageous in terms of quality of the films than the solid precursor used previously.

In this work the CrO_2 epitaxial thin films, fabricated by the CrO_2Cl_2 liquid precursor CVD process, were studied by the ferromagnetic resonance (FMR) technique. The magnetic anisotropies of the films have been probed, and compared with the results reported previously [12].

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2. Experimental

Epitaxial (1 0 0) thin films of CrO_2 were fabricated by chemical vapour deposition (CVD) technique with use of the CrO_2Cl_2 liquid precursor onto TiO_2 (1 0 0) single-crystal substrates, as described elsewhere [11]. The film thickness ranged from 350 Å to 1350 Å. *Digital Instruments NanoScope IV* scanning probe microscope was used to study the surface morphology of the films. Ferromagnetic resonance (FMR) studies were performed at the X-band (9.5 GHz) *Bruker EMX* spectrometer at room temperature.

3. Results and discussion

The surface images of the CrO_2 films with a thickness of 350 and 1350 Å obtained in the contact mode are shown in Fig. 1. The individual CrO_2 grains, growing epitaxially on the TiO_2 substrate, forms fairly regular rectangular-shaped blocks with the lateral size of about 150 nm. The roughness of the films decreases drastically for the thicker films, and the grain structure is not clearly observable in AFM scans of the thicker films.

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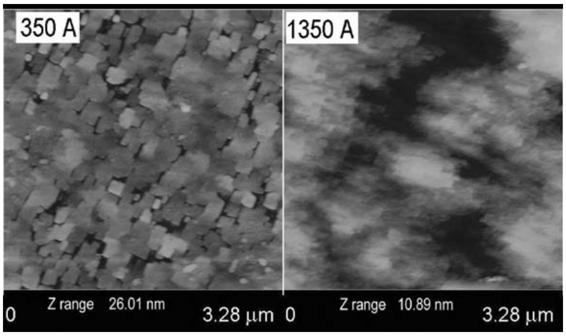

Fig. 1. Height-mode AFM scans of the CrO_2 film with the thickness of 350 Å (left) and 1350 Å (right).

FMR measurements in both "in-plane" and "out-of-plane" geometries of the films with respect to an external DC magnetic field were performed. Highly anisotropic FMR signal was observed, which demonstrates splitting into the surface, bulk, spin-wave and magnetostatic modes (Fig. 2). For instance, the two FMR lines observed along the easy axis direction are the bulk and surface modes.

The dependence of the FMR spectra on orientation was similar to that observed previously in the series of films grown from the CrO_3 solid precursor [12]. The out-of-plane angular dependence exhibits dominant contribution of the shape anisotropy, while the in-plane measurements reveal the essential in-plane magnetocrystalline anisotropy. For all CrO_2 film thicknesses the easy axis of the magnetization at room temperature is aligned along the crystallographic c direction of the single-crystalline films, that agrees with our earlier results for the solid precursor series [12]. It is remarkable that the FMR spectra show very small variation with thickness (Fig. 2). This indicates that the magnetic anisotropy parameters in the CrO_2Cl_2-grown films does not depend on the thickness, contrary to that of the CrO_3-based films, where strong dependence on the thickness was observed [12]. Values of g-factor, effective magnetization and the in-plane anisotropy field were estimated to be about of 1.98, 530 and 700 G, respectively. Furthermore, these parameters are very close to the values for the *thicker* films of CrO_3-based series [12]. We attribute the different behaviour of the magnetic anisotropies as a function of thickness to various morphologies of the films prepared using solid and liquid precursors. It is known that the lattice mismatch produces the magnetoelastic anisotropy in the plane of the CrO_2 film [6]. Obviously, the stress due to the lattice mismatch with the substrate is greatly reduced as a result of the plaquet growth (Fig. 1). Besides, the multiple magnetostatic modes observed in FMR spectra (right panel in Fig. 2) indicate exchange decoupling at plaquet boundaries as well. Therefore, the breaks in the nearest to the substrate layer of the epitaxial CrO_2 film are apparently relevant for relaxation of the tensile stress due to the lattice mismatch, greatly decreasing the magnetoelastic anisotropy in the CrO_2Cl_2 liquid-precursor films.

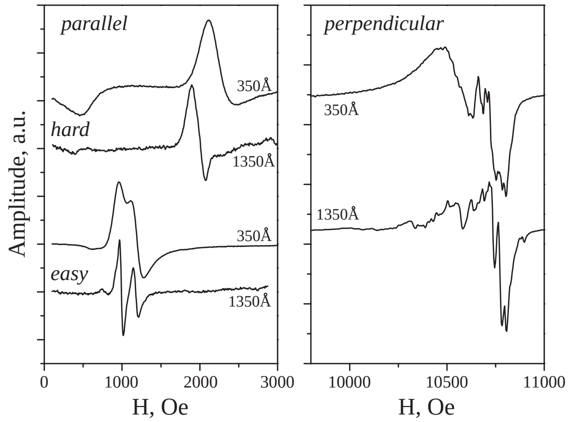

Fig. 2. FMR spectra of CrO_2 films with the thickness of 350 and 1350 Å for perpendicular (right) and parallel (left) orientations of DC magnetic field with respect to the film plane. The easy and hard axis directions are also labelled.

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