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Structural and magnetic properties of Co_2MnSn films and Co_2MnSn/Cr multilayers

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Abstract

Thin films of Co_2MnSn were prepared on MgO(0 0 1) substrates with a Cr-buffer layer from three elemental targets by ultrahigh-vacuum alternate deposition. These films showed good crystallinity, and the epitaxial relations were found to be MgO(0 0 1)//Cr(0 0 1)//Co_2MnSn(0 0 1) and MgO[1 0 0]//Cr[1 1 0]//Co_2MnSn[1 1 0]. $[Co_2MnSn(2.2\,nm)/Cr(0.9\,nm)]_{10}$ multilayers were also prepared with high crystallographic quality. The magnetic properties of Co_2MnSn films were studied by magnetization measurements and ^{119}Sn Mössbauer spectroscopy. Hyperfine fields observed by Mössbauer effect measurements showed that the degree of short range order around Sn in the samples grown at 200 °C was as good as that in bulk samples.

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1. Introduction

Since the discoveries of giant magnetoresistance (GMR) and tunneling magnetoresistance (TMR) in layered structures of magnetic metals and non-magnetic materials [1–3], a new field of spin electronics has emerged up aiming at their applications in magnetic information storage [4]. The increased interest in this field has intensified research on half-metallic materials, in which a band gap opens at the Fermi level for one spin direction, leading to 100% spin polarized conduction electrons [5]. In recent years, high TMR value has been reported in heterostructures of Heusler alloys $Co_2Cr_{1-x}Fe_xAl$ [6] and Co_2MnAl [7]. One of the issues in this field is to prepare half-metallic ferromagnets with high crystallographic quality.

Heusler alloy Co_2MnSn attracts much attention because it is expected to be half-metallic ferromagnet at low temperatures and to remain highly spin polarized at room temperature [8]. Bulk Co_2MnSn crystallizes in an $L2_1$ structure (space group $Fm\bar{3}m$), which consists of four interpenetrating face-centered cubic (fcc) sublattices [9]. The thin film of Co_2MnSn has been grown by sputtering at 470 °C [10]. However, TMR and GMR junctions using Co_2MnSn have not yet reported. The optimization of the thin film preparation is just in the beginning stage. The lattice of Co_2MnSn matches well with that of Cr. It is known that Cr grows epitaxially on MgO(0 0 1) with the structural relations MgO(0 0 1)//Cr(0 0 1) in the growth direction and MgO[1 0 0]//Cr[1 1 0] in the film plane [11]. Therefore, it is expected that epitaxial MgO/Cr/Co_2MnSn thin films can also be prepared by e-gun deposition.

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To address these challenges, in this paper we present an investigation on Co_2MnSn films deposited from Co, Mn, and Sn metallic sources alternately on a MgO(0 0 1) substrate with a Cr-buffer layer at 200 °C and room temperature using e-gun deposition in an ultrahigh-vacuum system (10^{-9} Torr). We also tried to prepare the multilayers $[Co_2MnSn(2.2\,nm)/Cr(0.9\,nm)]_{10}$ and tested a possible appearance of the GMR effect in these structures. The experimental methods are presented in Section 2. The magnetic properties of Co_2MnSn thin films and Co_2MnSn/Cr multilayers are reported in Section 3. The results are summarized in Section 4.

2. Experimental methods

Four Co_2MnSn films shown in Table 1, which are denoted as CMS1, CMS2, CMS3, and CMS4, respectively, were grown on MgO(0 0 1) substrates ($18 \times 18\,mm^2$) using ultrahigh-vacuum deposition technique with e-gun heating. Chemically etched MgO single crystalline (0 0 1) substrates were first baked in a vacuum for 1 h at 400 °C in order to remove the surface hydroxide layer. A Cr buffer layer with 5.0 nm thick was deposited at 200 °C on the MgO(0 0 1) substrate with a deposition rate of 1.2 nm/min, prior to the deposition of the Co_2MnSn film in order to relieve the strain resulting from the MgO substrate. Afterwards the temperature was set at 200 °C or room temperature for the film growth. The three alloy components Co, Mn, and Sn were evaporated from three e-guns alternately. For CMS1 and CMS3 samples, Co was first deposited for one atomic layer (0.2 nm), secondly Mn and thirdly Sn was deposited for half an atomic layer (0.1 nm), and the process was repeated for the designed cycles as shown in Table 1. For CMS2 and CMS4, Sn was secondly deposited and Mn thirdly. In order to prepare each layer with an accuracy of 0.1 nm, the deposition rate was set around 0.6 nm/min. The vacuum during the deposition was in the 10^{-9}-Torr range.

We also prepared multilayers including the Co_2MnSn Heusler alloy as shown in Table 2. Although the four samples have the same nominal structure of $[Co_2MnSn(2.2\,nm)/Cr(0.9\,nm)]_{10}$, the interfacial atoms were designed to be different by changing the deposition sequence of one or half an atomic layer. In CMS5 and CMS6, the interfaces of Co_2MnSn with Cr are designed to be composed of Co atoms and in CMS7 and CMS8 the interfaces of Co_2MnSn are Mn and Sn atoms. By comparing the results for these samples, we can see if the interface atoms have a significant influence on the structural and physical properties of $[Co_2MnSn(2.2\,nm)/Cr(0.9\,nm)]_{10}$. The substrate temperature during the preparation of the multilayers was set at 200 °C, to grow the film expitaxially and avoid excessive interdiffusion at the Co_2MnSn/Cr interfaces.

The quality of the surface crystallographic structure was monitored by in situ reflection high-energy electron diffraction (RHEED) during the growth. The crystallographic structure of the films was characterized by X-ray diffraction (XRD) in high- and low-angle regions using Cu K_α radiation, with the scattering vector perpendicular to the film plane. The composition of the samples was checked by scanning electron microscopy (SEM) with energy dispersive X-ray analysis (EDX).

The magnetization was measured by using a superconducting quantum interference device (SQUID) magnetometer. Current-in-plane giant magnetoresistance (CIP-GMR) measurements were carried out with a conventional four-probe method. In order to check the local magnetic properties ^{119}Sn Mössbauer spectra were measured at room temperature by means of conversion electron Mössbauer spectroscopy using a $Ca^{119m}SnO_3$ γ-ray source and a $He + 1\%(CH_3)_3CH$ gas-flow counter. The direction of the incident γ-rays was set perpendicular to the film plane. The Sn in the samples was enriched with ^{119}Sn to obtain sufficiently strong signals. The isomer shift (δ) is expressed relative to that of $CaSnO_3$.

Table 1
Designed nominal structures of Co_2MnSn films

Sample	Designed structure (nm)	T_{sub} (°C)
CMS1	MgO/Cr(5.0)/[Co(0.2)/Mn(0.1)/Sn(0.1)]$_{100}$/Co(0.2)	200
CMS2	MgO/Cr(5.0)/[Co(0.2)/Sn(0.1)/Mn(0.1)]$_{100}$/Co(0.2)	200
CMS3	MgO/Cr(5.0)/[Co(0.2)/Mn(0.1)/Sn(0.1)]$_{100}$/Co(0.2)	RT
CMS4	MgO/Cr(5.0)/[Co(0.2)/Sn(0.1)/Mn(0.1)]$_{100}$/Co(0.2)	RT

Substrate temperature (T_{sub}) was set at 200 °C when CMS1 and CMS2 were deposited, whereas, CMS3 and CMS4 were deposited at room temperature (RT).

3. Results and discussion

3.1. Co_2MnSn films

The RHEED patterns for Co_2MnSn films are shown in Fig. 1. For CMS1 and CMS2, the streaked RHEED

Table 2
Designed nominal structures of $[Co_2MnSn(2.2\,nm)/Cr(0.9\,nm)]_{10}$ multilayers

Sample	Designed structure (nm)	T_{sub} (°C)
CMS5	MgO/Cr(5.0)/{[Co(0.2)/Mn(0.1)/Sn(0.1)]$_5$/Co(0.2)/Cr(0.9)}$_{10}$	200
CMS6	MgO/Cr(5.0)/{[Co(0.2)/Sn(0.1)/Mn(0.1)]$_5$/Co(0.2)/Cr(0.9)}$_{10}$	200
CMS7	MgO/Cr(5.0)/{[Mn(0.1)/Sn(0.1)/Co(0.2)]$_5$/Mn(0.1)/Sn(0.1)/Cr(0.9)}$_{10}$	200
CMS8	MgO/Cr(5.0){[Sn(0.1)/Mn(0.1)/Co(0.2)]$_5$/Sn(0.1)/Mn(0.1)/Cr(0.9)}$_{10}$	200

The substrate temperature (T_{sub}) during the preparation of the multilayers was set at 200 °C.