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Magnetic and electronic properties of epitaxial Mn_2CoAl films

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Abstract

We have tried fabricating high-quality Mn_2CoAl films for novel spintronic applications using spin gapless semiconductors (SGS). Epitaxial Mn_2CoAl films were obtained on $MgAl_2O_4$ substrates by using ion-beam assisted sputtering (IBAS). The Mn_2CoAl films showed ferromagnetic hysteresis at room temperature, temperature-independent resistivity with relatively small resistivity of ~700 μΩcm as semiconductors, and anomalous Hall effects, which agree well with zero band-gap features of SGS. These results indicate high-quality Mn_2CoAl films, which show SGS-like properties, can be formed on $MgAl_2O_4$ substrates by IBAS.

1. Introduction

Spin-gapless semiconductors (SGS) are magnetic semiconductors with zero-gap and half-metallic characters, simultaneously because of their special band structures (Fig. 1), and they have high potential for fabricating novel spintronic devices. The advantage for using SGS as spintronic devices is that no-energy is necessary to excite electrons from valence to conduction band, and the excited carriers are fully spin-polarized and expected to have high mobility. Many compounds are predicted as SGS by theoretical calculations, however there's no concrete evidence for SGS properties of these compounds at present. An inverse Heusler compound, Mn_2CoAl (MCA), is one of promising candidates for SGS because SGS-like transport properties (temperature-independent conductivity, linear MR, etc.) have already been reported for bulk MCA [1]. Preparation of SGS in film form is necessary to fabricate spintronic devices, however there are only a few reports on the growth of MCA films, which have much room for improvement [2, 3]. In this study, we have tried fabricating high-quality MCA films toward novel spintronic applications using SGS.

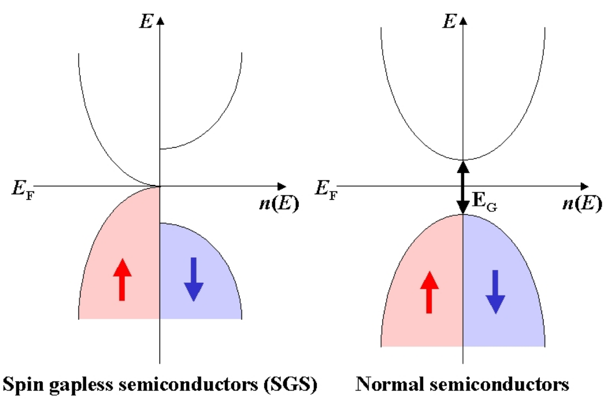

Fig. 1 Typical density of states (DOS) of spin gapless semiconductors (SGS) (left figure). The DOS of normal semiconductors with bandgap of E_G is also shown as comparison (right figure).

2. Experimental

MCA films (Thickness: ~80 nm) were fabricated by Ar ion-beam assisted sputtering (IBAS), which was effective to obtain Heusler films at lower growth temperature [4, 5]. Structural characterization of the MAO films was carried out by a X-ray diffraction (XRD) measurement system using Cu K_α radiation. Magnetization measurements were performed using a vibrating sample magnetometer (VSM). The electrical resistivity was measured in the temperature range from 4 to 300 K by the standard four-probe method. Hall measurements were carried under a magnetic field of ~1.5 T using the van der Pauw method.

3. Results and Discussion

The MCA films were grown on MAO substrates, which are often used for the growth of the Heusler compounds because of smaller lattice mismatch between them. The lattice mismatch between MCA films and MAO substrates is ~1.4%. In the out-of-plane XRD patterns, only (00*l*) peaks of the MCA films, except for substrate peaks, were observed for the growth temperature (T_g) of 300~600°C, indicating c-axis orientation of the MCA films [Fig. 2(a)]. Low glancing angle (0.4°) in-plane XRD measurements (ϕ-scan) revealed that both (400) peaks of the MCA films and MAO substrates have four-fold symmetry, and the ϕ values of the MCA (400) peaks are shifted by 45° with respect to those of the MAO peaks [Fig. 2(b)]. These results indicate that the MCA films were epitaxially grown on MAO substrates with epitaxial relationships of MCA (001)[110]// MAO (001)[100].

The MCA films showed ferromagnetic hysteresis at room temperature. The *c*-axis lattice constant and saturation magnetization (M_s) increased as the growth temperature (T_g) decreased. They became c= 0.5792 nm and M_s= ~240 emu/cc with H_c of ~70 Oe for T_g= 300°C, which are comparable to those for bulk MCA (c= 0.5798 nm; M_s: ~350 emu/cc, H_c: ~100 Oe). One of possible reasons for smaller *c*-axis and M_s at higher T_g is interfacial reaction and/or diffusion between MCA and MAO.

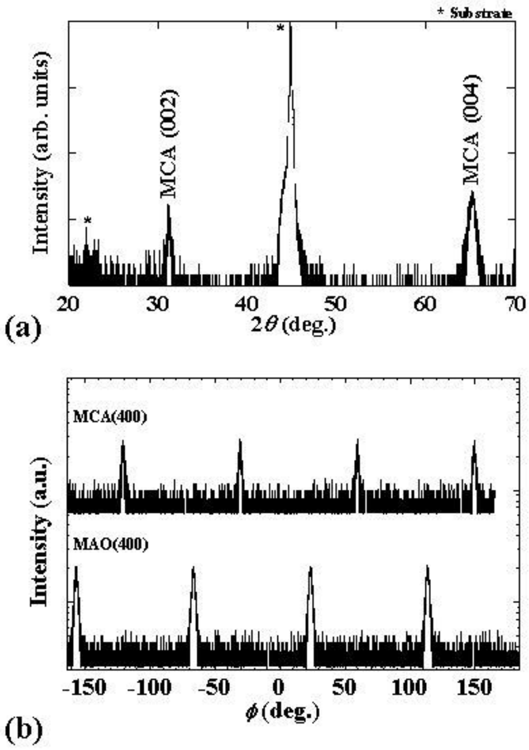

Fig. 2 (a) Out-of-plane and (b) in-plane XRD patterns for MCA films on MAO substrates (T_g= 550°C).

The MCA films showed semiconducting behaviors with very small activation energy of ~3 meV and relatively small resistivity of ~700 μΩcm for semiconductors, which agree with zero band-gap features of SGS. The electron concentration and mobility of the MCA films formed at 300°C deduced from Hall resistivity measurements (ρ_{xy}) was ~7*10^{20} cm^{-3} and ~12 cm^2/Vs at 4 K, respectively (Fig. 3), which were comparable to the reported values for MCA films. These results indicate high-quality MCA films can be obtained on MAO by IBAS.

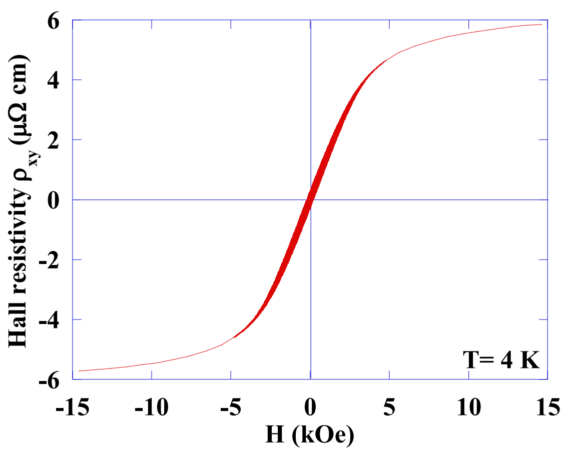

Fig. 3 Hall resistivity (ρ_{xy}) of MCA films formed at 300°C as a function of the applied magnetic field (H) measured at 4 K.

4. Conclusions

We have fabricated MCA films for novel spintronic applications using SGS. MCA films were epitaxially grown on MAO substrates (epitaxial relationship: MCA (001)[110]// MAO (001)[100]) at T_g of 300~600°C. The MCA films showed ferromagnetic hysteresis at room temperature. The *c*-axis lattice constant and the M_s increased as T_g decreased, and they became 0.5792 nm and ~240 emu/cc with H_c of ~70 Oe for T_g= 300°C, which are comparable to those for bulk MCA. The films showed semiconducting behaviors with very small activation energy of ~3 meV and relatively small resistivity of ~700 μΩcm, which agree well with zero band-gap features of SGS. The electron concentration and mobility was ~7*10^{20} cm^{-3} and ~12 cm^2/Vs at 4 K by Hall resistivity measurements, which were comparable to reported values for Mn_2CoAl films. These results indicate high-quality MCA films can be obtained on MAO by IBAS.

Acknowledgements

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