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Growth and Magnetic Properties of $Mn_{2.5}Ga$ Films for Spintronic Devices

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1. Introduction

During past decades, physicists have been exploiting the "spin" of the electron rather than its charge to create a remarkable new generation of spintronic devices which will be smaller, more versatile, and more robust than those currently making up silicon chips and circuit elements. As a basic element for spintronics device, magnetic tunnel junctions (MTJs) should have a low critical switching current density and a high thermal stability factor. Recently, MTJs with perpendicular magnetic anisotropy (PMA) have been demonstrated to allow the realization of extremely low-dimensional and highly reliable spintronic devices, e.g. spin-transfer switching magnetoresistive random access memory [1]. However, presently known PMA materials often exhibit a small spin polarization value (P), although high P value is an important factor to obtain high-perfomance spintronic devices [2]. Additionally, adopting materials with low saturation magnetization (M_s) can effectively reduce the switching current density of MTJs [2]. Thus, exploration of new materials that simultaneously possess a high P, a low M_s, and a high PMA is strongly desired to promote further progress of spintronic devices.

Mn_xGa (x=2~3) with tetragonal-DO_{22} crystal structure (DO_{22}-Mn_xGa) has great possibilities to be such material owing to its special crystal and magnetic structure [3-5]. In the DO_{22} structure, an atomic layer of Mn and a layer containing both Mn and Ga atoms are arranged periodically along the *c*-axis. A potential high PMA has been proposed by approximating the *M-H* loops of polycrystalline alloys [3]. Classic neutron scattering experiments showed that this material had a ferrimagnetic structure, consequently, a low M_s can be observed at room temperature though the material's Curie temperature is higher than 770 K [4]. The theoretically calculated large spin polarization value, as high as 88% at the Fermi level [5], originates from the strong difference in conductivity for minority and majority electrons, which is a typical feature in type-III half metals. However, there are few reports on DO_{22}-$Mn_{2\sim3}Ga$ films so far, although it is a preferable for practical applications of this material in spintronic devices. In this study, the microstructure and magnetic properties of the $Mn_{2.5}Ga$ thin films were thoroughly investigated.

2. Experiments and results

The 100 nm thick $Mn_{2.5}Ga$ films were deposited on SiO_2/Si substrates at room temperature by dc magnetron sputtering technique. During deposition, Ar pressure was maintained at 0.1 Pa. Then, 2 nm Ta capping layers were deposited on the surface of $Mn_{2.5}Ga$ thin films for oxidation protection. After deposition, the samples were annealed in vacuum for 60 min at different temperature (T_a) ranging from 300 ℃ to 500 ℃. To check the effects of sputtering power, different sputtering power was employed, namely, 25 W, 50 W, 100 W, and 150 W. With increase of the sputtering power, growth rate increases linearly from 0.0177 nm/s for 25 W to 0.071nm/s for 150 W. The Mn content of the films was determined by inductively coupled plasma mass spectrometer (ICP-MS) method and concentration of Mn is around 70±2%. From X-ray diffraction patterns (XRD), the films were found to be mixed DO_{22} and non-ferromagnetic DO_{19} phases. The lower sputtering power and higher annealing temperature are beneficial for enhancing ratio of DO_{22} phase, as shown in Fig.1. However, it is still impossible to prepare pure DO_{22} structured $Mn_{2.5}Ga$ films on the amorphous SiO_2/Si substrates.

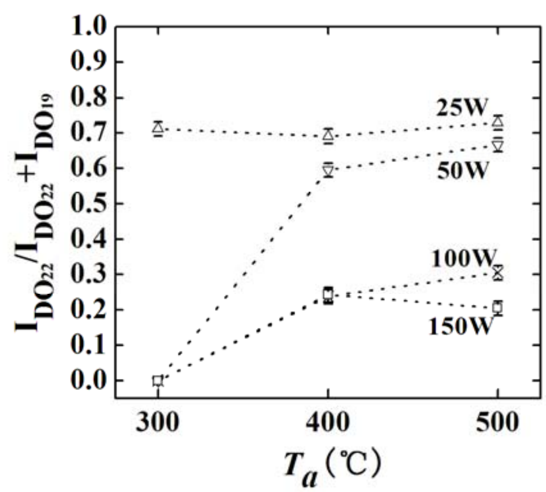

Fig. 1 The dependence of DO_{22} phase ratio on annealing temperature and sputtering power.

Therefore, (001)-oriented $Mn_{2.5}Ga$ films should be obtained because the easy magnetization axis is along [001] direction. In this work, epitaxial (001)-oriented $Mn_{2.5}Ga$ films with pure DO_{22} phase have been successfully grown on Cr-buffer MgO substrates (Fig. 2). And, the films are confirmed to be epitaxial according to pole figure results (not shown here).

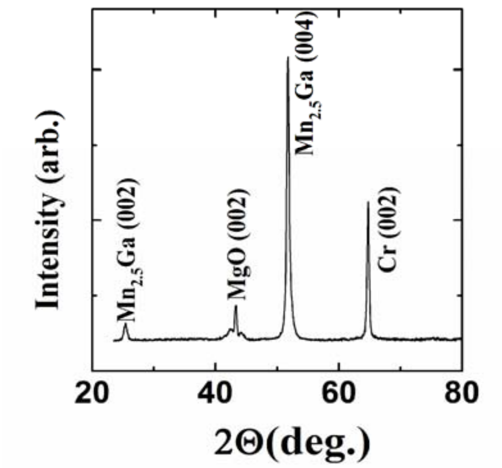

Fig. 2 XRD of the epitaxial $Mn_{2.5}Ga$ films

Representative M-H curves were shown in Fig. 3. The saturation magnetization (M_s) and coercive field (H_c) is 250 emu/cm^3 and 7 kOe, respectively, which is almost consistent with the corresponding value of bulk alloy. A square-like loop is observed for the out-of-plane M-H curve. While the in-plane M-H curve exhibits almost zero remnant magnetization, and cannot be saturated even under a magnetic field of 50 kOe. This result illustrates that the easy magnetization axis of our films is perpendicular to film plane. The effective magnetic anisotropy energy (K_u^{eff}) was estimated to be 1.2×10^7 erg/cm^3 [6], which is comparable to that of other high PMA films, e.g. PtFe and CoFe. It is possible that, in the near further, this material will make revolution to spintronics research, although its high spin polarization value needs to be testified by further experiments.

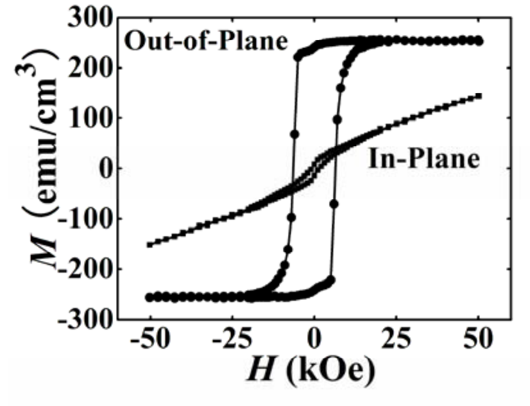

Fig. 3 M-H curves of the epitaxial $Mn_{2.5}Ga$ films

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