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Full Length Article

A realization scheme of metamagnetic phase transition in FeRh films grown on glass substrates

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ABSTRACT

Metamagnetic phase transition in FeRh films has attracted a great deal of attention due to their potential applications in heat-assisted magnetic recording. Conventionally, FeRh films were deposited on expensive single crystal substrates, such as MgO and PMN-PT. Here, a facile method to prepare FeRh films (~30 nm) on glass substrates with magnetron sputtering has been proposed by introducing MgO and CrRu as buffer layers. Metamagnetic phase transition in the FeRh films have been successfully realized, and the transition behavior was modulated by TiO_2 doping. From the resistance-temperature (R-T) and magnetization-temperature (M-T) curves, an optimized doping concentration (15 vol. %) has been found which has a distinct metamagnetic phase transition near room temperature. The resistance jumps from 12.5 Ω in cooling process to 13.1 Ω in warming process at 350 K, and producing a thermal hysteresis of ~20 K. Comparing with FeRh films deposited on costly single crystal substrates, the present results indicate a feasible method for promising commercial FeRh films due to their low-cost.

1. Introduction

The binary alloy FeRh is one of the distinctive antiferromagnetic (AFM) materials near room temperature, which exhibits a first-order transition from AFM to ferromagnetic (FM) state around 350 K and accompanied by a temperature hysteresis about 10 K between warming and cooling processes [1–3]. It is found that there is a coexistence of AFM and FM states during metamagnetic phase transition. During the phase transition, there will be a well-defined change in out-of-plane lattice parameter and a subtle change in in-plane lattice parameters when being doped with TiO_2 [4]. In addition, this transition can also be driven by temperature [3], strain [5,6], spin polarized current [7] and external magnetic field [8], which may arise from the strong coupling between crystal lattice and magnetic moments [9]. It has been found that the phase transition is always accompanied by physical properties changes, such as volume expansion about 1% [2], resistivity variation [10] and a significant change in entropy [11]. Consequently, the property changes in magnetic material have triggered increasing research in practical applications such as heat-assisted magnetic recording [12,13], magnetic refrigerators [14], and room-temperature AFM memory resistors [15,16].

Recently, some works reported the metamagnetic phase transition in FeRh thin films which was induced by the interaction between single crystal substrates and FeRh thin films. For instance, Marti et al. investigated the metamagnetic phase transition in FeRh films sputtered on MgO substrates [15]. Hu et al. reported the $FeRh_{0.96}Pd_{0.04}$ films grown on PMN-PT [17]. Nevertheless, with the rapid development of integrated devices today, cost may be a crucial factor that determines their markets. Therefore, the superior performances of some single crystal substrates were sharply limited by their high price for practical applications. In addition, the conventionally used tune manners of phase transition temperature (T_t) by rare metal, such as Ir or Pt, are complex and costly [1,9].

In this work, CrRu and MgO were used as buffer layers and TiO_2 was used to tune lattice parameters, producing inner strain to induce phase transition in FeRh films. The resistance as function of temperature was used to reflect the phase changes in FeRh films. Only when proper amount of TiO_2 is doped, the transition can be observed significantly. The optimized value (15 vol. %) was found to produce distinct metamagnetic phase transition. The temperature-

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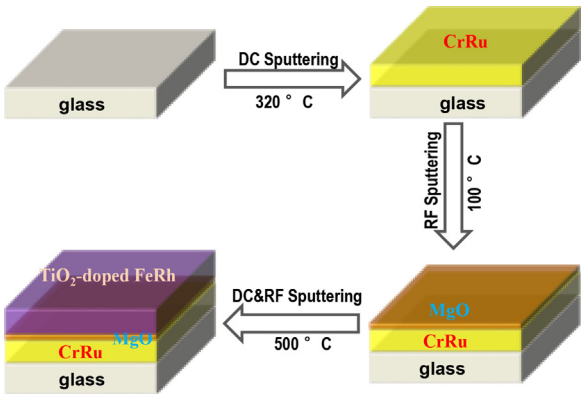

Fig. 1. Schematic description of the fabrication procedures of the multi-layer films.

dependent magnetizations of the optimized FeRh films were also investigated under various magnetic fields.

2. Experimental

2.1. Preparation of FeRh films

FeRh-TiO_2 films with a structure of FeRh-TiO_2/MgO/$Cr_{90}Ru_{10}$/glass (30 nm, 0–20 vol. %) were prepared by magnetron sputtering (con-focal target sputtering) with procedures as diagramed in Fig. 1. The CrRu and FeRh targets were DC sputtered while MgO and TiO_2 targets were RF sputtered in Ar. The film thickness of CrRu and MgO were fixed at 30 nm and 4 nm, respectively. The deposition temperatures for CrRu and MgO layers were fixed at 320 °C and 100 °C, respectively. The working pressure of co-depositing FeRh-TiO_2 layer was 15 mTorr and the deposition temperature was 500 °C.

2.2. Characterization

X-ray diffraction (XRD, X' Pert PRO PHILIPS with Cu Kα radiation) was employed to study the crystal structure. The phase transition of FeRh films was investigated by both resistance and magnetization measurement. The magnetization measurements were carried out with a vibrating sample magnetometer (VSM, MicroSense EV9). The temperature dependence of resistance of the FeRh thin films from 300 K to 500 K were carried out in a typical four-point probe technique in a temperature control chamber and the electrical signal was applied and measured with both Keithley 34,420 and Keithley 2400. Transmission electron microscopy (TEM, TecnaiTM G2F30, FEI, USA) and selected area electron diffraction (SAED) observation were carried out using FEI Tecnai G2F30 to analyze the structure of FeRh thin films and the lattice orientation.

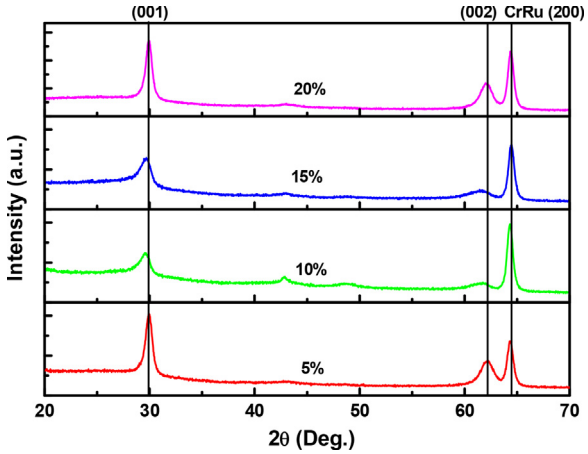

Fig. 3. Structural characterization of the FeRh thin films doped with various volume of TiO_2 measured by XRD.

3. Results and discussion

3.1. Morphology and microstructure

The microstructure of the FeRh-TiO_2/MgO/$Cr_{90}Ru_{10}$/glass (30 nm, 15 vol. %) film was observed using TEM. In Fig. 2(a), there is a clear boundary line between the glass substrate and the whole film. At the same time, it can be observed that the film and CrRu layer is separated by a thin layer of MgO with the thickness of about 4 nm. The reason of using MgO as a buffer layer is that there is a lower lattice mismatch existing between FeRh and MgO layers. Fan et al. showed that the mismatch for FeRh/MgO interfaces is about −0.5% [18]. It can also be seen that the top of the film is covered with a layer of metal Pt, which acts as a protective layer when fabricating sample by focused ion-beam. Fig. 2(b) shows a high resolution transmission electron microscopy (HRTEM) image. The FeRh film with (001) plane was measured by TEM and analyzed using the Gatan Digital Micrograph software, demonstrating that the FeRh film has a chemically order phase at room temperature. Fig. 2(c) shows the SAED pattern which indicates that the sample is polycrystalline film.

3.2. Crystal structure

Typical XRD patterns of TiO_2 doped FeRh thin films with different TiO_2 volume fraction are shown in Fig. 3. All the peaks were attributed to CrRu and FeRh, indicating that the amorphous glass substrate rendered the differentiation of amorphous TiO_2 matrix difficulty in the XRD spectra. Due to the insulation of glass substrate, CrRu buffer layer was introduced aiming to increasing the electrical and thermal conductivity. Moreover, XRD patterns reflect the high degree of chemical ordering of the films with different TiO_2 volume

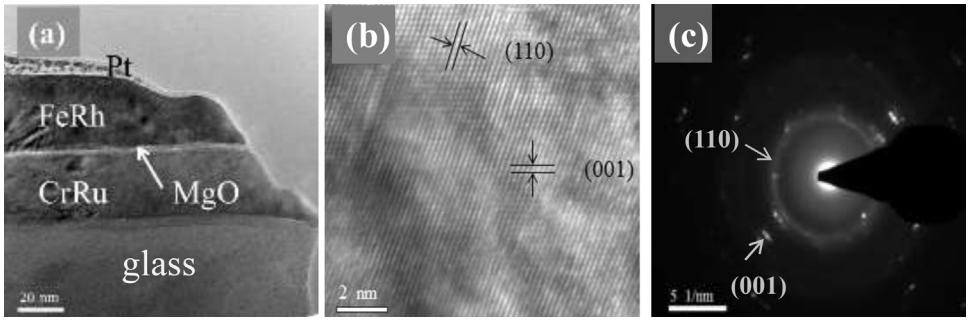

Fig. 2. Typical TEM images of the TiO_2-doped FeRh thin film. (a) A cross-sectional view of the sample. (b) HRTEM image of typical cross-section of the FeRh-TiO_2/MgO/CrRu/glass multi-layer film. (c) SAED of the FeRh-TiO_2/MgO/CrRu/glass thin film.

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