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Dependence of magnetic characteristics on sputtering-power and substrate-temperature in amorphous $Tb_{40}(FeCoV)_{60}$ films

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ABSTRACT

The amorphous $Tb_{40}(Fe_{49}Co_{49}V_2)_{60}$ films were deposited at different sputtering powers and substrate temperatures. The microstructural and magnetic characteristics were investigated by means of field emission scan electron microscope, magnetic force microscope and vibrating sample magnetometer. Our results show that with increasing sputtering power, out-of-plane coercivity decreases monotonically while saturation magnetization has a maximum value of 231 kA/m for the sample prepared at 50 W. The as-deposited alloy films are amorphous, whereas the coercivity and saturation magnetization are strongly dependent on the substrate temperature. An out-of-plane hysteresis loop with coercivity below 22 mT and saturation magnetization over 290 kA/m is obtained combining dc power and substrate temperature. The dominant mechanism of room temperature coercivity appears to be domain wall pinning, rather than nucleation under all conditions measured. The variation of saturation magnetization is similar to that of perpendicular magnetic anisotropy with either sputtering power or substrate temperature according to the difference of magnetic domain structure.

1. Introduction

Amorphous TbFeCo alloy films are considered to be potential materials used in microactuator devices [1–3]. Plenty of researches focus on reducing the necessary driving magnetic fields. Recently, a large effort has been made to fabricate TbFeCo films with enlarged low-field susceptibilities, reduced coercivity and controlled orientation of easy axis by many methods such as e-beam co-evaporation, molecular-beam epitaxy and plasma process [4–7]. Among them, magnetron sputtering is a relatively simple, effective and practical method whose process parameters that were experimentally proved to be valuable for optimization of TbFeCo films, including sputtering power [8] and substrate temperature [9]. It has been found that the increase in sputtering power could increase the Ar-ion energies during sputtering, resulting in a large rearrangement of atoms [10], and it is also strongly dependent on the substrate temperature [11]. Thus, the rearrangement of sputtering atoms can be adjusted by sputtering power and substrate temperature, which could help form magnetic domain and improve magnetic properties.

In this work, the dependence of microstructures and magnetic properties on sputtering power and substrate temperature in $Tb_{40}(FeCoV)_{60}$ films has been investigated. It was found that both the power of about 50 W and substrate temperature of about 150 °C are approximately optimum deposition conditions for magnetic softness and the underlying mechanism is discussed.

2. Experimental

The $Tb_{40}(FeCoV)_{60}$ films were dc magnetron cosputtered from a multiple target arrangement with a pure Tb target and a composite $Fe_{49}Co_{49}V_2$ target (America: Hiperco50, Russia: 50KΦ, China: 1J22, curie temperature $T_c \approx 980$ °C and saturation flux density $B_s \approx 2.4$ T) onto Si (100) substrates by an MP700 sputtering system. The base pressure and working argon pressure in the vacuum chamber were 3×10^{-4} Pa and 0.6 Pa, respectively. The power (P_w) for $Fe_{49}Co_{49}V_2$ target varied from 43 W to 64 W while that for Tb target was correspondingly adjusted to ensure an approximate 1:1.5 atomic ratio of Tb:(Fe+Co). The substrate temperature (T_s) varied from room temperature to 300 °C, which was controlled by a heater installed behind the substrate holder. No XRD peak of $Tb_{40}(FeCoV)_{60}$ films is found for the sample prepared at substrate temperature below 300 °C, indicating the films are amorphous as shown in Fig. 1. For the sample deposited

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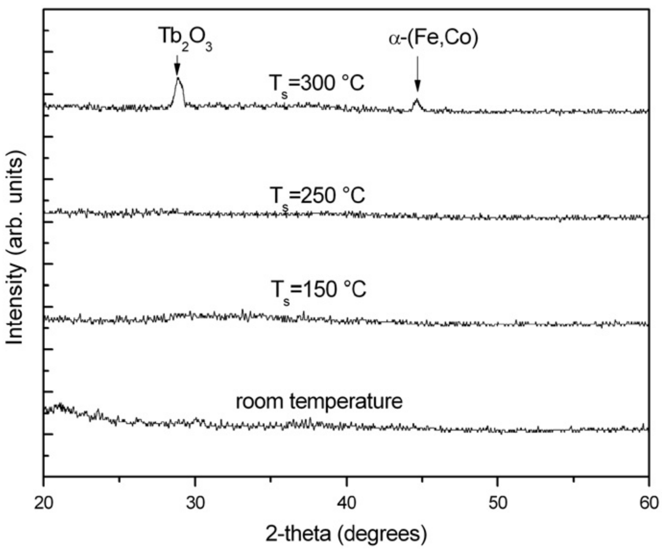

Fig. 1. XRD patterns of the $Tb_{40}(FeCoV)_{60}$ films deposited at varied substrate temperatures.

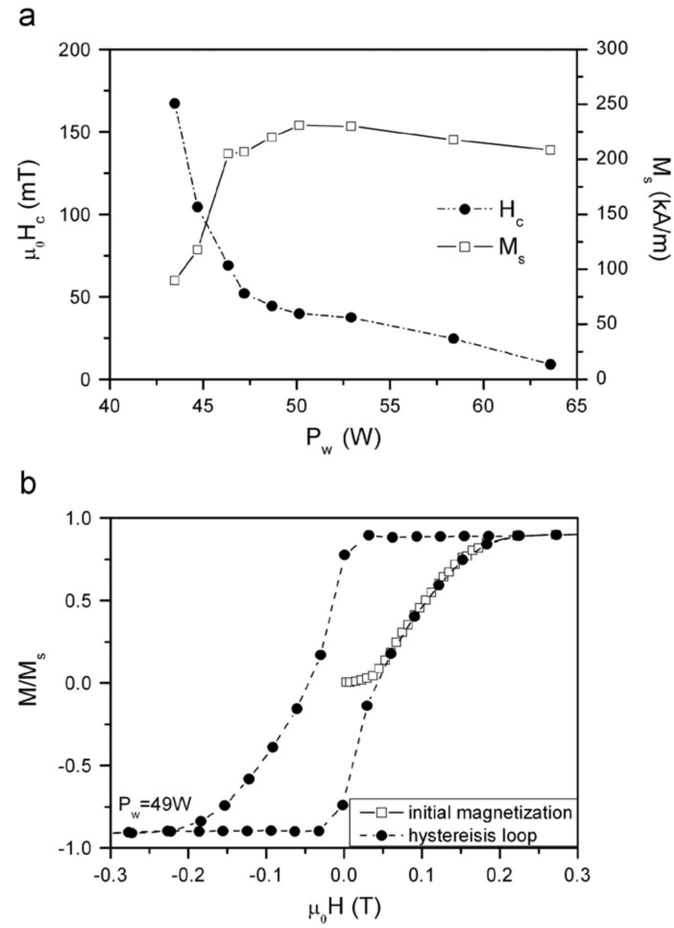

Fig. 2. (a) Variation of out-of-plane coercivity μ_0H_c and saturation magnetization M_s with dc power P_w. (b) Initial magnetization curve and magnetic hysteresis loop.

at 300 °C, a weak peak of Tb oxide in the-deposited sample is possibly due to the slight oxidation during deposition.

The film thickness measured mechanically using a stylus profiler (Dektak 6M) was about 120 nm without any coating. The composition was determined by energy-dispersive X-ray (EDX) with a Hitachi S-530 SEM. The magnetic domain structure was explored by a Nanoscope IIIa-D3000 magnetic force microscope in tapping/lift modes (MFM). The microstructure investigation was performed using a JSM 6700F field emission scan electron microscope (FEM). The magnetic measurement was carried out on a Lakeshore 7404 vibrating sample magnetometer (VSM) with a maximum field up to 1.45 T at room temperature.

3. Results and discussion

3.1. Sputtering power dependence of magnetic properties

Out-of-plane coercivity (μ_0H_c) and saturation magnetization (M_s) as functions of the sputtering power (P_w) are shown in Fig. 2(a). As the power increases, the coercivity shows a monotonous decreasing trend. The saturation magnetization rapidly increases with increasing power, to a maximum of 231 kA/m at P_w=50 W and then slightly decreases with further increasing P_w. A representative of initial magnetization curve and the magnetic hysteresis loop for the sample prepared at 49 W is intuitively shown in Fig. 2(b), which indicates that the as-deposited samples are demagnetized and have well-defined perpendicular magnetization. If the coercivity were nucleation limited, the magnetic domains in the demagnetized state would allow the initial magnetization to rise at applied fields smaller than the coercive field found in the magnetic hysteresis loop. For all samples, however, the rise of magnetization revealed in the initial magnetization curve indicates that the coercivity is limited by domain wall pinning rather than nucleation, which is consistent with other experimental results [12].

As shown in Fig. 2(a) the saturation magnetization rapidly increases with increasing power up to 50 W, which can result from the decrease in free volume due to the increase of bonding strength between adatoms. Besides, the dependence of saturation magnetization on power would likely be associated with the variability of pair order anisotropy (POA). According to the literature [10], the POA, described as a statistical preference for like atom pairs along the in-plane direction and unlike atom pairs perpendicular to the film plane, was shown to correlate strongly with perpendicular magnetic anisotropy (PMA). During sputtering, one ion/neutral energy within the range of threshold energies is expected to produce the most selective resputtering events, which leads to the largest POA and thus to the strongest PMA. When sputtering power is high, an argon ion/neutral incident at the film surface would sputter a surface adatom without a selective character because its energy is in excess of the upper limit of threshold energies. Correspondingly, when sputtering power is low, the energy transmitted via an elastic collision to the adatom is insufficient to overcome the surface work function and no resputtering takes place because the argon/neutral energy is less than the lower limit of threshold energies. Thus, a large POA and a strong PMA can be obtained by sputtering at an appropriate P_w. This is also confirmed by the MFM patterns ($10 \times 10\ \mu m^2$), as shown in Fig. 3. A distinct black–bright contrast strip domain structure is observed for the sample prepared at 50 W, indicating a strong PMA. For other powers, the black–bright contrast is gradually degraded as shown in Fig. 3(a), especially, at the power of 43 W. Therefore, when the power is closed to optimum value, the increase in the amount of anisotropic atom pairs in film normal direction induced by maximum selective resputtering strengthens PMA, and thus increases saturation magnetization.

The coercivity may be related to the homogeneity and compactness of the samples. With the decrease in power as it is below 50 W, the decrease in bombardment energy of incident atoms causes the decrease in compactness and the increase in