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Effect of interfacial diffusion on microstructure and properties of FePt/B_4C multifunctional multilayer composite films

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Abstract

FePt/B_4C multilayer composite films were prepared by magnetron sputtering and subsequent annealing in vacuum. By changing Fe layer thickness of $[Fe/Pt]_6/B_4C$ films, optimal magnetic property (8.8 kOe and remanence squareness is about 1.0) is got in $[Fe(5.25\ nm)/Pt(3.75\ nm)]_6/B_4C$ sample whose composition is Fe rich and near stoichiometric ratio. The characterizations of microstructure demonstrate that the diffusion of B and C atoms into FePt layer depends strongly on B_4C interlayer thickness. When B_4C interlayer thickness of $[Fe(2.625\ nm)/Pt(3.75\ nm)/Fe(2.625\ nm)/B_4C]_6$ films is bigger than 3 nm, stable value of grain size (6–6.5 nm), coercivity (6–7 kOe) and hardness (16–20 GPa) is observed. Finally, the multifunctional single FePt/B_4C composite film may find its way to substitute traditional three-layer structure commonly used in present data storage technology.

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Keywords: Magnetron sputtering; Vacuum annealing; Multifunction; Multilayer composite film; Magnetic recording

1. Introduction

The current thin film medium for magnetic recording applications usually employs three-layer structure [1], i.e. a magnetic layer covered by additional protection layers and then suitable lubricants. $L1_0$-ordered FePt films maybe used as a magnetic layer due to their high magnetization (1100 emu/cm^3) and large anisotropy ($K_u > 5 \times 10^7$ erg/cm^3) [2]. Then protection layer and lubricant layer were added which has well mechanical properties and lubricant properties. However, the grain size of pure FePt films is usually large and exchange coupling between the neighboring grains cannot be weakened effectively. FePt/nonmagnetic-layer (C [3–5], B_2O_3 [6,7], Ag [8,9], NiAl [10], MgO [11,12], Al_2O_3 [13], FeMn [14], Mn [15], and Cu [16,17] layers) multilayers structure has been demonstrated to be effective in satisfying the requirement of small particle size and reduced exchange coupling. These works have focused on three main aspects currently employed for the FePt/nonmagnetic-layer multilayers structure: (1) the change of ordering degree on nonmagnetic-layer thickness [3,4,6–8,10]; (2) the influence of nonmagnetic-layer thickness on microstructure and magnetic properties [5,11,12]; (3) the systematic investigation of exchange bias and the magnetic anisotropy [14,15].

Nevertheless, interfacial diffusion will occur during the composite film growth and post-annealing process. The role of diffusion on the microstructure and properties of the film remains unclear. In this study, we focus our research on FePt/B_4C multilayer film investigating the influence of diffusion on the microstructure and properties. B_4C is chosen as a promising matrix candidate due to its good thermal stability and intrinsic high hardness, which is the third hardest material after diamond and cubic boron nitride at room temperature. Moreover, the B_4C surface can be easily oxidized to boron oxide, which naturally absorbs water vapor in the air and forms boric acid, which is an excellent solid lubricant [18]. Therefore, the FePt/B_4C film can integrate multiple functions, namely satisfactory mechanical, tribological and magnetic properties required for

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ultra high-density magnetic recording. This not only simplifies the deposition process, but also improves the recording density by reducing the head–media distance. Furthermore, the study can result in further understanding of the evolution of various properties as a function of B_4C interlayer thickness and structure of FePt magnetic layer.

2. Experimental

The [FePt/B_4C x nm$]_6$ multilayer precursors with x ranging from 1 to 7 nm were deposited by magnetron sputtering on Si (1 0 0) substrates. Three 2.5-in. targets (B_4C 99.5%, Fe 99.9%, Pt 99.9%, Kurt J. Company) were used as the source material, and the multilayer thin films were deposited by rotating the substrate to the three targets successively. To optimized stoichiometric ratio of Fe/Pt, the thickness of Fe layer varied from 2.25 to 6.75 nm when Pt layer thickness is fixed to 3.75 nm. Then the B_4C interlayer is introduced and 5.25 nm Fe layer is divided two to ensure the reaction between Fe layer and Pt layer of [Fe(2.625 nm)/Pt(3.75 nm)/Fe(2.625 nm)/$B_4C]_6$ samples is enough. In order to protect FePt layer from oxidation, 6 nm B_4C top layers are deposited subsequently. During the deposition, no substrate heating was applied. Then the as-deposited films were annealed in vacuum ($\sim 10^{-4}$ Pa) at 500 °C for 30 min.

The composition and thickness of the films were determined by X-ray photoelectron spectroscopy [(XPS), PHI, Quantum 2000]. The crystallinity and microstructure of the films was characterized by *x*-ray diffraction [(XRD), Bruker D5] with Cu Kα radiation and transmission electron microscope [(TEM), Tecnai G2 FEG]. The dark field images were taken by a high-angle annular dark-field (HAADF) detector. Both energy dispersive X-ray spectrometer (EDS, EDX) and electron energy loss spectrometer (EELS, GIF) attached to the same microscope were used to obtain the compositional scanning profiles of the multilayer films. Room-temperature magnetic characteristics were carried out by vibrating sample magnetometer (VSM, Oxford instruments). The magnetic domain structures were investigated by magnetic force microscopy (MFM). MFM imaging were performed using the tapping and lift modes under ambient conditions, using a Nanoscope III scanning probe microscope with a vertically magnetized hard Co-alloy-coated silicon tip. The hardness and elastic modulus were measured using a Hysitron nanoindentor.

3. Results and discussion

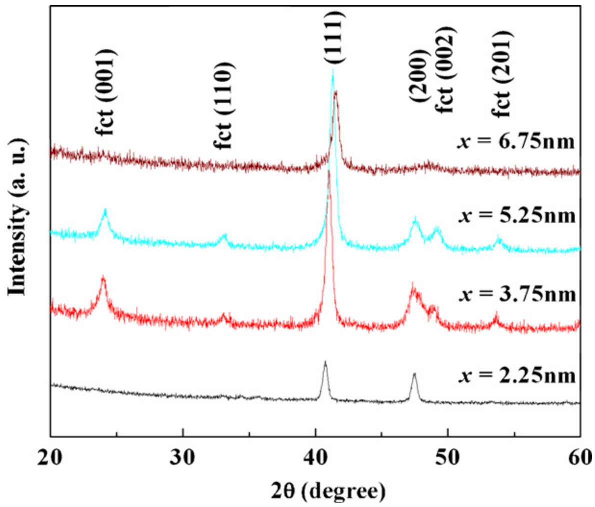

Fig. 1. XRD patterns of the [Fe(x nm)/Pt(3.75 nm)$]_6$/B_4C films annealed at 500 °C for 30 min with different Fe layer thickness.

It is known that two kinds of phases, namely face centered-cubic (fcc) and face-centered-tetragonal (fct) phases exist in FePt alloy while only the fct phase has a larger K_u value. Fig. 1 gives the XRD patterns of the [Fe(x nm)/Pt(3.75 nm)$]_6$/B_4C films annealed at 500 °C for 30 min with different Fe layer thickness. As can be seen, the phase transformation of FePt grains changes with the Fe layer thickness. When Fe layer thickness is 2.25 nm, the (1 1 1) and (2 0 0) FePt peaks emerge. In the [Fe(3.75 nm)/Pt(3.75 nm)$]_6$/B_4C sample, fct (0 0 1) (1 1 0) (2 0 1) peaks, the splitting of (2 0 0) peak and the emergency of superlattice (0 0 2) peak are observed. The result indicates the existence of fct FePt phase when the thickness of Fe layer is the same as that of Pt layer. With increasing the thickness of Fe layer to 5.25 nm, superlattice (0 0 2) peak becomes stronger from fcc (2 0 0) peak. The result implies more complete phase transformation. Further increasing Fe layer thickness to 6.75 nm, only obvious (1 1 1) peak can be observed. So we can conclude that excess Pt atoms in FePt/B_4C films impede the phase transformation of FePt grains. At the same time, the positions of all peaks shift to a higher angle with increasing Fe layer thickness. It indicates that Fe sites of FePt grains are partly replaced by Pt atoms with decreasing Fe composition.

Shown in Fig. 2 are in-plane magnetic hysteresis loops measured at 300 K for [Fe(x nm)/Pt(3.75 nm)$]_6$/B_4C films annealed at 500 °C for 30 min. Clearly, coercivity (H_c) has a strong dependence on Fe layer thickness. The coercivity is found to increase firstly and then to decrease with increasing Fe layer thickness. At the same time, satisfactory coercivity (8.8 kOe) and good remanence squareness (about 1.0) is got in [Fe(5.25 nm)/Pt(3.75 nm)$]_6$/B_4C sample compared to the Pt

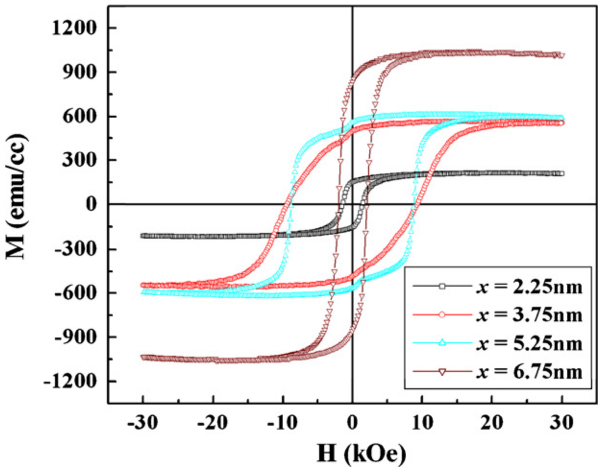

Fig. 2. In-plane magnetic hysteresis loops of [Fe(x nm)/Pt(3.75 nm)$]_6$/B_4C films annealed at 500 °C for 30 min with different Fe layer thickness.