

Effects of CrRu Underlayer and CrRu Capped Layer on the Microstructure and Magnetic Properties of FePt Films

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The magnetic properties and microstructure of CrRu/FePt bilayer and CrRu/FePt/CrRu trilayer deposited by dc magnetron sputtering on preheated natural-oxidized Si (100) wafer substrates were studied. It is found that both the in-plane coercivity ($H_{c//}$) and grain size of the FePt film increase with increasing the thickness of CrRu underlayer. The $H_{c//}$ value of the FePt film is further increased but the grain size is decreased as adding a CrRu capped layer on the FePt film. The granular $L1_0$ FePt nanoparticles with in-plane coercivity of 2300 Oe and isolated uniform size of 6.61 nm are achieved from the CrRu(15 nm)/FePt(25 nm)/CrRu(4 nm) film deposited at a low substrate temperature of 350 °C.

Index Terms—CrRu/FePt bilayer, CrRu/FePt/CrRu trilayer, in-plane coercivity, magnetron sputtering.

I. INTRODUCTION

THE $L1_0$ FePt nanoparticles are a candidate material for next generation high-density magnetic recording media due to its excellent environmental stability and ultra high magnetocrystalline anisotropy ($K_u \sim 7 \times 10^7$ erg/cm³). However, $L1_0$ FePt phase usually develops at a higher temperature around 600 °C [1], [2], which results in the FePt nanoparticle agglomerate and grain growth. Therefore, the ordering temperature of $L1_0$ FePt phase must be reduced for preventing grain growth. In addition, the medium noise which caused by the magnetic grain interactions have to be also solved [3], [4].

Previous studies had reported that the grain size and magnetic grain interactions could be reduced by addition of various materials such as Si₃N₄ [5] and AlN [6], but the addition of them would increase the ordering temperature of $L1_0$ FePt. It has been known that the ordering temperature could be reduced by introducing a underlayer due to the lattice misfit between FePt film and underlayer [7], [8]. On the other hand, the deposition of capped layer on the FePt film could reduce exchange coupling between FePt magnetic grains [9], [10]. In this work, we use CrRu underlayer and capped layer to prepare CrRu/FePt bilayer and CrRu/FePt/CrRu trilayer films, and investigate the effects of CrRu underlayer and CrRu capped layer on the grain size, saturation magnetization and coercivity of the FePt film.

II. EXPERIMENT

The CrRu underlayer thickness (t_{CrRu}) in the range of 10–100 nm, the FePt magnetic layer of 25 nm, and 4 nm CrRu capped layer are all deposited by dc magnetron sputtering at substrate temperature of 350 °C. The base pressure in the sputtering chamber is better than 5×10^{-7} Torr. The samples are cooled to room temperature under high vacuum in the sputtering chamber. The magnetic properties of the films are measured using a vibrating sample magnetometer (VSM) at room temperature. The microstructures of the films are investigated by a Philips Tecnai F30 field emission gun (FEG) transmission electron microscopy (TEM) and X-ray diffractometer (XRD) with Cu-K α radiation. The compositions of the films are determined by EDS, and they are Fe₅₅Pt₄₅ and Cr₉₀Ru₁₀ for the FePt and CrRu films, respectively.

III. RESULTS AND DISCUSSION

Fig. 1 shows the variations of $H_{c//}$ and grain size of FePt films with varying CrRu underlayer thickness. Previous study [11] had reported that the in-plane coercivity of single layer FePt film with thickness below 30 nm only had several hundreds Oe after annealing at a low-temperature of 350 °C. However, the $H_{c//}$ value can be increased to 1700 Oe by introducing a 10 nm CrRu underlayer under the 25 nm FePt film which deposited at 350 °C, as shown in Fig. 1. And $H_{c//}$ is enhanced significantly to 4000 Oe as t_{CrRu} is increased to 50 nm. When the t_{CrRu} is further increased to 100 nm, the $H_{c//}$ is further increased to 4280 Oe.

The $H_{c//}$ value of the FePt film increases as increasing t_{CrRu} from 10 to 100 nm may be owing to the following reasons:

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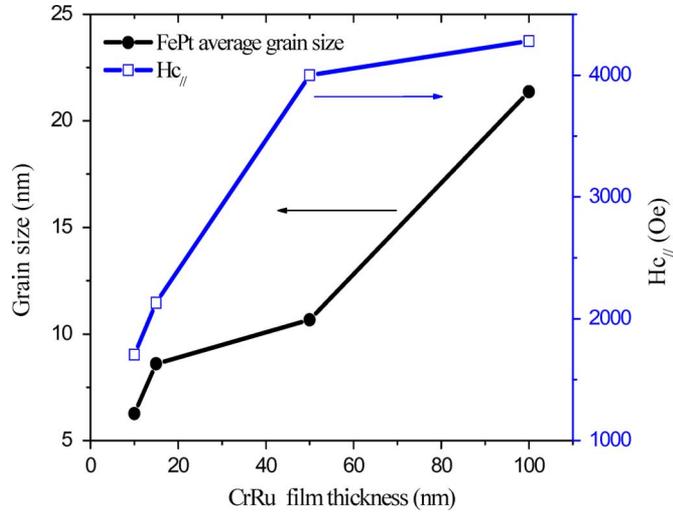


Fig. 1. The variations of $H_{c//}$ and grain size of the FePt film with CrRu underlayer thickness of the CrRu/FePt bilayer films which deposited at substrate temperature of 350 °C.

(I) For randomly orientated noninteracting particles, the dependence of coercivity (H_c) on the particle size (D) can be described as [12]

$$H_c = \frac{0.96 K_u}{M_s} \left[1 - \left(\frac{D_p}{D} \right)^{0.77} \right] \quad (1)$$

where M_s is the saturation magnetization. The minimal stable grain size (D_p) of FePt alloy is about 3 nm [13]. As shown in Fig. 1, the average grain size of FePt films increases from 6.3 to 21.3 nm as CrRu underlayer thickness increases from 10 to 100 nm. According to above equation, the increase in particle size leads the increase in coercivity. (II) Wong *et al.* [14] had reported that the degree of interfacial misfit is larger as the grain size in Cr/Co film is larger. Similarly, in our CrRu/FePt system, the average grain size of FePt films is increased as increasing t_{CrRu} from 10 to 100 nm that results in the increase in degree of interfacial misfit in the CrRu/FePt films, and the misfit defect in the FePt layer will be increased as the degree of interfacial misfit increases. This results that the transformation of soft γ -FePt to hard $L1_0$ FePt phase becomes easier. Therefore, the coercivity of FePt film is increased due to the degree of order of FePt layer is increased, i.e., increase the amount of $L1_0$ FePt phase in the FePt layer as the t_{CrRu} is increased from 10 to 100 nm.

Fig. 2 shows the M-H loops of (a) in-plane and (b) out-plane of the CrRu(15 nm)/FePt(25 nm) and CrRu(15 nm)/FePt(25 nm)/CrRu(4 nm) films. Comparing Fig. 2(a) with Fig. 2(b), we can see that both of the CrRu/FePt and CrRu/FePt/CrRu films have excellent in-plane magnetic anisotropy. This is due to that the lattice misfit between CrRu(002)[100] and FePt(200)[110] is about 6.6% which leads the $L1_0$ FePt(200) plane can epitaxially grow along the CrRu(002) underlayer.

The M_s value of FePt films decreases from 730 emu/cm^3 to 610 emu/cm^3 as 4 nm CrRu capped layer is added, as shown in Fig. 2(a). This may be due to the diffusion of Cr and Ru atoms from capped layer into FePt layer through grain boundary, and Cr or Ru atoms react partially with Fe or Pt atoms, which

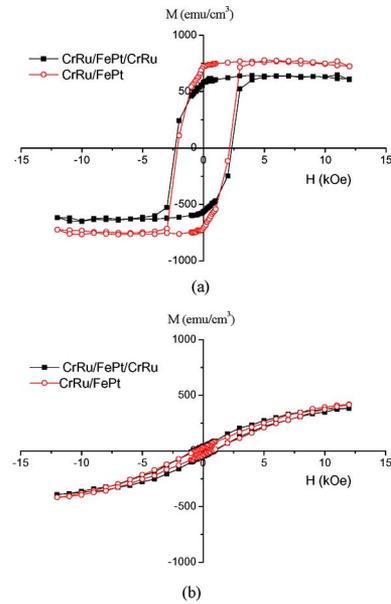


Fig. 2. The M-H loops of (a) in-plane (b) out-plane of the CrRu(15 nm)/FePt(25 nm) bilayer and CrRu(15 nm)/FePt(25 nm)/CrRu(4 nm) trilayer films which deposited at substrate temperature of 350 °C.

results in decrease of M_s value. On the other hand, most of the Cr and Ru atoms are distributed at grain boundary of FePt that will increase the grain boundary energy and decrease the energy barrier of the transformation of FePt from soft γ -FePt to hard $L1_0$ FePt phase. Therefore, adding CrRu capped layer on the FePt film will also enhance the degree of order of FePt layer. The decrease in M_s value of FePt layer as adding CrRu capped layer may be also ascribed the increase of $L1_0$ FePt phase content in the film, because the M_s value of $L1_0$ FePt phase is lower than that of γ -FePt phase[15]. Increase the amount of $L1_0$ FePt phase in the FePt layer will enhance coercivity of FePt film, and therefore the $H_{c//}$ value of FePt films increases from 2130 Oe to 2300 Oe when 4 nm CrRu capped layer is added, as shown in Fig. 2(a).

Fig. 3 are the TEM bright field images and grain size distribution of (a) CrRu(15 nm)/FePt(25 nm) and (b) CrRu(15 nm)/FePt(25 nm)/CrRu(4 nm) films which deposited at substrate temperature of 350 °C. It shows that the average grain size of the FePt film in CrRu(15 nm)/FePt(25 nm) bilayer is about 8.60 nm and the grain size distribution is large. When the 4 nm CrRu capped layer is added, the average grain size decreases to 6.61 nm and the film morphology shows narrow size distribution and the particles are isolated, as shown in Fig. 3(b). Several studies had shown that reduction of grain size and increasing the grain size uniformity would decrease the medium noise of thin film media [3], [16]. Therefore, the Cr and Ru atoms diffuse from capped layer into FePt layer can reduce grain growth and obtain isolated FePt particles with uniform size that is beneficial to reduce exchange coupling of the magnetic grains and decrease medium noise of FePt film.

IV. CONCLUSION

Both the $H_{c//}$ value and grain size of the FePt film are increased as a CrRu underlayer is introduced. Further adding a

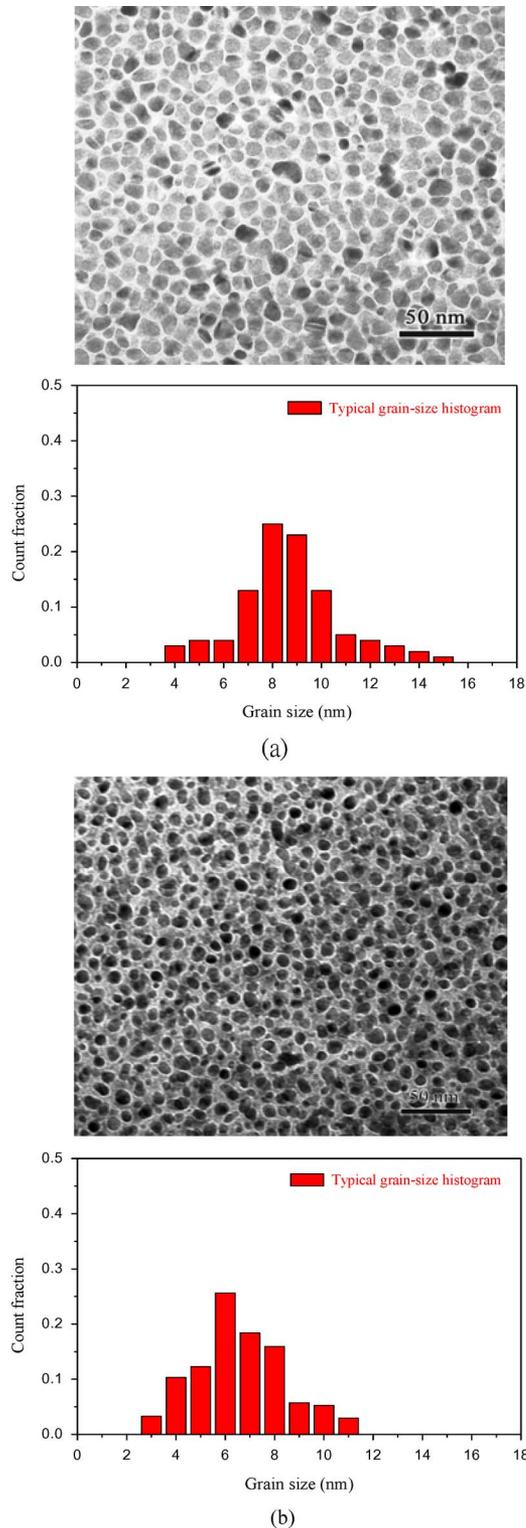


Fig. 3. The TEM bright field images and grain size distribution of (a) CrRu(15 nm)/FePt(25 nm) bilayer and (b) CrRu(15 nm)/FePt(25 nm)/CrRu(4 nm) trilayer films which deposited at substrate temperature of 350 °C.

CrRu capped layer onto FePt film, the isolated FePt grains with uniform grain size are obtained and the $H_{c//}$ of the FePt film is further increased, but the M_s value is decreased.

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