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Magnetic Properties and Exchange Bias Effect of Cu and Cr doped Sm_2Co_{17} Alloy Film

Dashun Dong, Qingqing Fang*, Wenwen Wang, Jinjin Yang

School of Phys. & Mater. Sci., Anhui University, Hefei, 230039, China

*****Corresponding author: physfangqq@126.com

Abstract Cu and Cr-doped Sm_2Co_{17} films were synthesized using pulsed laser deposition method with the substrate of Si(100), and our results show that Cu and Cr incorporation can reduce the grain size and increase the coercivity of Cu and Cr-doped Sm_2Co_{17} films. Furthermore, incorporations of Cu and Cr will introduce a positive effect for the exchange bias of Cu and Cr-doped Sm_2Co_{17} films. The magnetic measurement of external magnetic field and zero-field-cooled (FC-ZFC) under the temperature ranging from 10K to 300 K prove that the critical value of FM-AFM transform is ~80 K in the Cu and Cr-doped Sm_2Co_{17} films, which showed that the exchange bias origins from the coupling competition between ferromagnetic phase and antiferromagnetic phase.

1. Introduction

Recently, rare earth based permanent-magnet materials have attracted broad attention due to their enormous applications in the fields of information technology, computer science and others [1,2,3]. Sm_2Co_{17} is a kind of high coercivity material acquiring the properties of high magnetocrystalline anisotropy, high Curie temperature, and excellent corrosion resistance and so on[4]. Later, many researchers have already prepared SmCo films relying on the physical or chemical method. Sayama et al.[5] synthesiezed SmCo films with perpendicular magnetic anisotropy on Cu underlayer by means of magnetron sputtering, and effects of Cu underlayer thickness on the structural and magnetic properties of SmCo films were measured. Some others pointed out that the structural and magnetic properties of SmCo films[6,7] strongly rely on the synthesized parameters. Zhang et al. reported that Ta buffer layer can be used to decrease the Cu surface roughness ,which enhanced the magnetic properties of SmCo films[8]. In this paper, Cr and Cu-doped Sm_2Co_{17} films on Cr buffer layer and Cu seed layer were synthesized using pulsed laser deposition (PLD). Results indicate that the incorporation of small amount of Cu and Cr can contribute to the growth of SmCo films and moderate Cr, which make the size of grain becomes smaller also enhance the coercivity of SmCo films. We also illustrate the magnetic exchange bias effect on Cu and Cr doped SmCo films.

2. Experiment

The $(Sm_2Co_{17}Cu_x)$/Cu/Cr (x=1.5, 2.5nm) films and $(Sm_2Co_{17}CuCr_y)$/Cu/Cr(y=1.6, 3.2nm) were synthesized on the Si(001) substrate using PLD. The purity of Sm, Cu, Cr and Co mental targets are 99.99%, and the base pressure was 2.0×10-4Pa. The film layer structure was $Sm_2Co_{17}Cu_x$ $(CuCr_y)$/Cu(100nm)/Cr(3nm)/Si(001). A 3-nm-thick Cr layer and 100-nm-thick Cu layer was a buffer layer and Cu seed layer, respectively. All samples were annealed at 680℃for 45 min, and the base pressure was 10-4 Pa. The surface morphology and structure of the films were measured by scanning electron microscopy (SEM) and X-ray diffraction (XRD), respectively. The hysteresis loops and temperature-depended magnetic properties of the films were measured using the Vibrating Sample Magnetometer(VSM) and Physical Property Measurement System(PPMS).

3. Results and discussion

The XRD patterns for Sm_2Co_{17}Cu(1.5nm)Cr_y/Cu(100nm)/Cr(3nm) films (A y=0; B y=1.6nm) indicate that the major structure is Sm_2Co_{17}. The SEM images of Sm_2Co_{17} Cu(1.5nm)Cr_y/Cu(100nm)/Cr(3nm) films (A y=0; B y=1.6nm) show that the grain size of pure Sm_2Co_{17} films is about 30 nm, and that of the Sm_2Co_{17} films mixed Cr(1.6 nm) is about 20 nm. This results indicate that incorporation of Cr not only refines the crystal grain, but also reduces its density. [9,10].

The hysteresis loops of $Sm_2Co_{17}Cu_x$/Cu(100nm)/Cr(3nm) films are shown in Fig. 1. The coercivity of Sm_2Co_{17} layer doped 2.5nm Cu(1636 Oe) is smaller than that of Sm_2Co_{17} layer doped 1.5 nm Cu(1731 Oe). Their SEM spectra are showed in Fig. 2. The surface of the sample doped 1.5 nm Cu SEM image is more smoother than that of the sample mixed 2.5 nm Cu, and their average grain size is about 50 nm and 200 nm, respectively. We suggested that the superabundant Cu was not helpful to the growth of the structure of the Sm_2Co_{17} films[11].

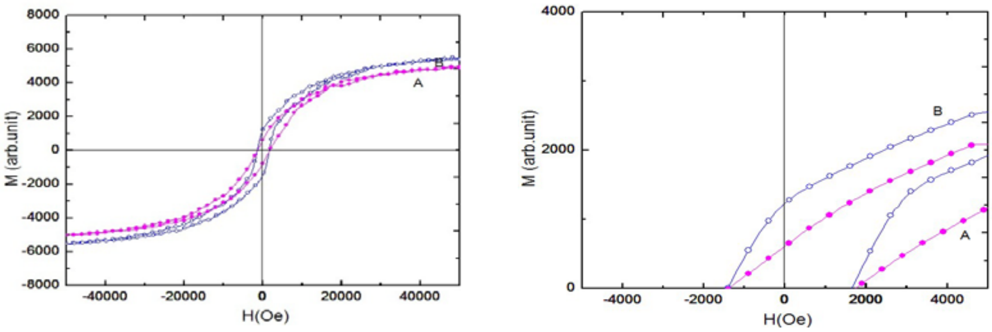
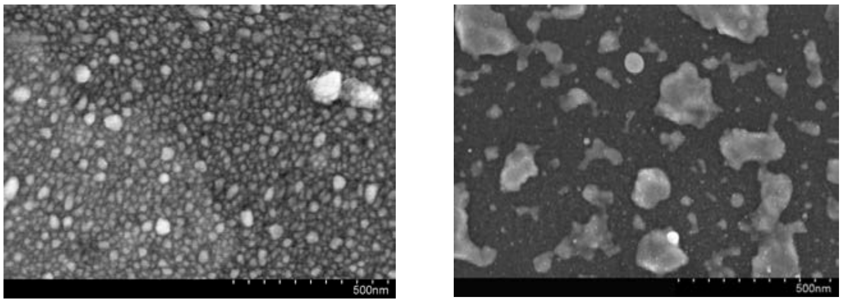


Fig. 1 Hysteresis loops of the $Sm_2Co_{17}Cu_x$/Cu(100nm)/Cr(3nm) films (x=1.5nm A; 2.5nm B).



(A) (B)

Figure 2 SEM images of the $Sm_2Co_{17}Cu_x$/Cu(100nm)/Cr(3nm) films (A, x=1.5nm; B, x=2.5nm)

Fig. 3 shows the hysteresis loops of the Sm_2Co_{17}Cu(1.5nm)Cr_y/Cu(100nm)/Cr(3nm) films (A, y=0 ; B, y=1.6nm ; C , y=3.2nm). The coercivity of SmCo layer doped 0 nm, 1.6 nm and 3.2 nm Cr are 1731 Oe, 2120 Oe and 2554 Oe, respectively. Fig. 4 gives the curve of the coercivity properties related to Cr content. It can be seen that the coercivity of Cr doped films is higher than that of the films without Cr incorporation.

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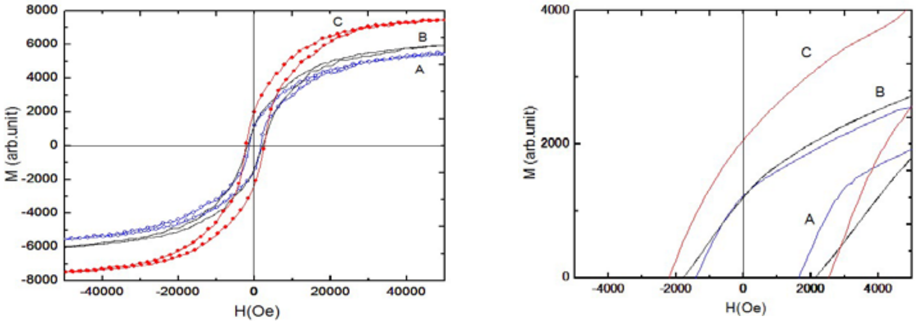


Fig. 3 Hysteresis loops of the $Sm_2Co_{17}Cu(1.5nm)Cr_y/Cu(100nm)/Cr(3nm)$ films (A, y=0 ; B, y=1.6nm ; C , y=3.2nm).

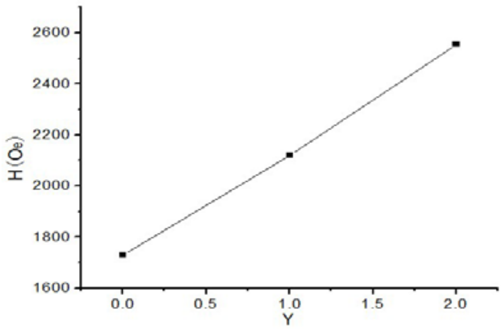
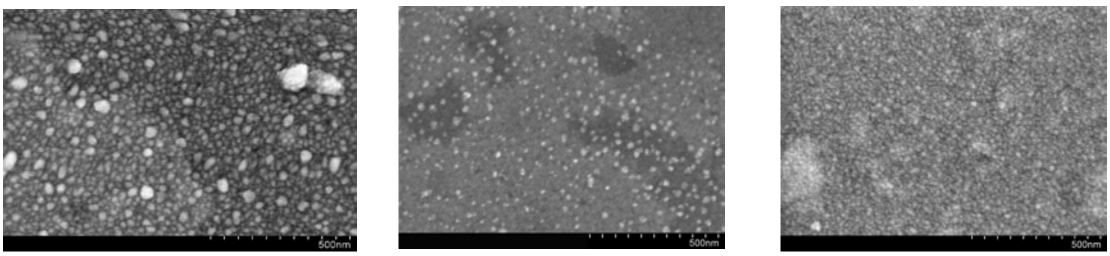


Figure 4 Dependence of the coercivity on Cr content for $Sm_2Co_{17}Cu(Cu1.5nm/Cr_y)$ /Cu(100nm)/Cr(3nm) films.

The SEM images of $Sm_2Co_{17}Cu(Cu\ 1.5nm)Cr_y/Cu(100nm)/Cr(3nm)$ (y=0 nm; 1.6 nm and 3.2 nm) are shown in Fig. 5. The grain sizes of the films doped Cr 0 nm, 1.6 nm and 3.2nm are about 10 nm, 16 nm, and 26 nm, respectively. This result indicates that doping Cr can contribute to reducing the surface roughness and grain sizes. The above studies suggested that opportune adjusting the content of Cr and Cu can optimize the magnetic properties and structure of Sm_2Co_{17} films[12,13,14].



(A) (B) (C)

Fig. 5 SEM images of the $Sm_2Co_{17}Cu(1.5nm)Cr_y/Cu(100nm)/Cr(3nm)$ films (y=0 A; 1.6nm B; 3.2nm C).

We also measure the hysteresis loops of $Sm_2Co_{17}Cu_x/Cu(100\ nm)/Cr(3nm)$ (x=1.5 and 2.5nm) films, we find that the both hysteresis loops shift to right direction, indicating that there is a positive exchange bias effect in this films. Researches showed that the exchange bias effect mainly resulted from the antiferromagnetic-ferromagnetic interactions and the coupling between the magnetic moment and external field in magnetic interface. Exchange bias effect is usually negative in a state of cool field when the ferromagnetic- antiferromagnetic interactions demonstrate ferromagnetic

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and vice versa. The appearance of positive exchange bias effect in Fig. 6 was attributed to the result of the competition between ferromagnetic phase (Sm_2Co_{17}) and anti-ferromagnetic phase (Cu) in the system [15,16,17].

4. Conclusion

In summary, $Sm_2Co_{17}Cu_x$/Cu/Cr(x=1.5nm,2.5nm) and Sm_2Co_{17}Cu(Cu=1.5nm)Cr_y/Cu(100nm) /Cr (3nm) (y=1.6nm,3.2nm) films are synthesized by pulsed laser deposition(PLD) method on the Si(100) substrate. The results indicated that doping moderate Cr could refine the grain as well as enhanced the coercivity, and that superfluous Cu would reduce the film density. Further study found that Cu and Cr dopant give rise to a positive exchange bias effect in Cu and Cr-doped Sm_2Co_{17} films. We suggested that the magnetic exchange bias effect was attributed to the interaction between antiferromagnetic state and ferromagnetic state in Cu and Cr-doped Sm2Co17 films and the intensity of exchange bias effect changed along with the competition between ferromagnetic phase (Sm_2Co_{17}) and antiferromagnetic phase (Cu,Cr) .

References

[1] Takei S, Shomura S, Morisako A, Matsumoto M, Haeiwa T 1997 *J. Appl. Phys.* **81** 4674.
[2] Liu J F, Chui T, Dimitrov D, Hadjipanayis G C 1998 *J. Appl. Phys*. **73** 3007.
[3] Neu V, Shaheen S A 1999 *J. Appl. Phys.* **86** 7006.
[4] Yan A, Bollero A, Müller K H, Gutfleisch O 2000 *J. Appl. Phys.* **91** 8825.
[5] Sayama J, Mizutani K 2006 *J. Magn. Magn. Mater*. **301** 271.
[6] Kato I, Takei S, Liu X X, and Morisako A 2006 *IEEE, Trans. Magn.*.**42** 2366.
[7] Sayama J, Miztutani K, Asahi T, Osaka T 2004 *Appl. Phys. Lett*. **85** 5640.
[8] Zhang L N, Chen J S, Ding J, et al. 2008 *J. Appl. Phys*. **103** 113908.
[9] Liu X H, Cui L Y, Zhou S X, et al. 2001 *Mater. Sci. Eng.* **304**, 1043.
[10] Andreescu R, O'Shea M J 2002 *J. Appl. Phys*. **91** 8183.
[11] Takei S, Morisako A, Matsumoto M 2004 *J. Magn. Magn. Mater.* **272** 1703.
[12] Ohtake M, Nukaga Y, Kirino F, *et al*, 2010 *J. Appl .Phys* **107** 09A706
[13] Zhao H B, Wang H, Liu X Q, *et al*. 2011 *J. Appl. Phys.***109** 07B715.
[14] Chen X, Hochstrat A, Borisov P, *et al*. 2006 *Appl. Phys. Lett.* **89** 202.
]15[Salaba E L, Rumplecker A, Kleitz F, *et al*. 2006 *Nano Lett.* **6** 2977.
[16] Nogues J, Schuller I K 1999 *J. Magn. Magn. Mater*, **192** 203.
[17] Zhou S M, Chien C L 2001 *Phys Rev B* **63**104.