Perpendicular Magnetic Anisotropy in Flexible Barium Hexaferrite/muscovite Heterostructure

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Abstract

As the development of magnetic storage devices becomes more important, perpendicular magnetic anisotropy (PMA) materials have attracted numerous attention increasingly. Meanwhile, applications of functional flexible devices are of great importance nowadays. Therefore, a flexible storage system with PMA property will be in a high demand in the future. Barium hexaferrite ($BaFe_{12}O_{19}$, BaM) is a promising PMA material on this flexible system due to its moderately large magnetocrystalline anisotropy, high Curie temperature, as well as excellent chemical stability and corrosion resistance. As for flexible substrate, muscovite mica is selected due to high flexibility within few microns in thickness, high thermal and chemical stability. In this study, we fabricate $BaFe_{12}O_{19}$(BaM)/muscovite heterostructure with PMA property via pulsed laser deposition. The particular PMA property was precisely analyzed by vibrating sample magnetometer (VSM), magnetic force microscopy (MFM), and x-ray absorption spectroscopy (XAS). In order to quantify the PMA property of the system, a calculation of intrinsic magnetic anisotropy energy was implemented, which is around 3.58M erg/cm^3. Furthermore, a series of bending tests was carried out, showing robust PMA property against severe mechanical bending. These results demonstrate that BaM/muscovite heterostructure with PMA property has potential application in flexible magnetic storage devices and actuator.

keywords：perpendicular magnetic anisotropy, muscovite mica, magnetic storage devices, actuator

Introduction

In the past decades, perpendicular magnetic anisotropy (PMA) materials play an important role in the realm of magnetic storage or recording devices. Compared to the traditional longitudinal recording, perpendicular magnetic recording (PMR) can highly increase the storage density. [1] As the demand of the flexible electronics and spintronics gets higher, it is crucial to integrate device with flexibility. With a fairly large magnetocrystalline anisotropy, high Curie temperature, and excellent resistance to corrosion, Barium hexaferrite ($BaFe_{12}O_{19}$, BaM) was selected to be deposited on flexible muscovite substrate. BaM/muscovite heterostructure reaches both PMA property and flexibility, which is a suitable candidate for potential magnetic storage devices and actuator.

Experiment method

The epitaxial BaM thin film was deposited on muscovite substrate using pulsed laser deposition. The pressure was carefully controlled at 400 mtorr. During the deposition of 54000 pulse counts, the muscovite substrate was heated up to 800°C.

Results and discussion

Structural analysis

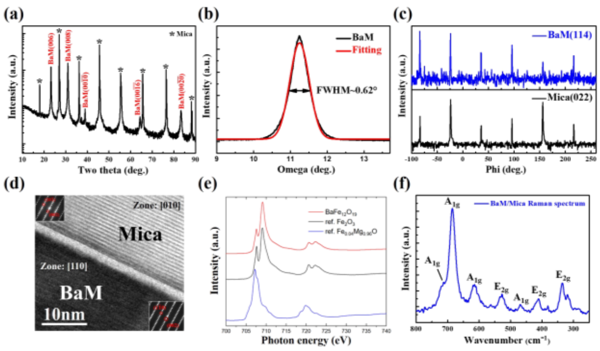

Fig. 1 XRD, TEM, XAS and Raman of BaM/muscovite

The BaM/muscovite heterostructure has been carefully examined by x-ray diffraction. Fig. 1a shows that (001)-oriented BaM film is grown on (001)-oriented muscovite substrate in out-of-plane direction. This result reaches our expectation because [001] direction is the easy magnetization of BaM, which may result in the PMA property of the system. The FWHM of BaM(006) peak is around 0.62º, which indicates a desirable crystallinity of BaM film in Fig. 1b. Furthermore, the phi scan in Fig. 1c confirms the epitaxial relationship between BaM film and muscovite substrate. The accurate alignment between muscovite(022) and BaM(114) peak at every 60º interval indicates the in-plane epitaxial relationship as BaM[110]//Mica[010]. In order to recognize the interface and orientation of BaM film and muscovite substrate, transmission electron microscopy was performed in Fig. 1d. The interface is not sharp enough; however, the orientation is consistent with 2θ scan and phi scan results. From x-ray absorption spectroscopy result in Fig. 1e, it shows that the valence state of Fe ions in BaM film is 3+ due to the absence of Fe^{2+} peak ($Fe_{0.04}Mg_{0.96}O$ is served as Fe^{2+} reference). To investigate the crystal symmetry and structure of BaM/muscovite, a Raman spectrum was employed in Fig. 1f. According to J. Kreisel et al. [2] study, a structure of Z(YY)$\bar{Z}$ BaM was confirmed. Also, the strongest Raman mode at 684cm^{-1}(A_{1g}) can be allocated to the motions of the FeO_5 bipyramidal group.

VSM and MFM analysis

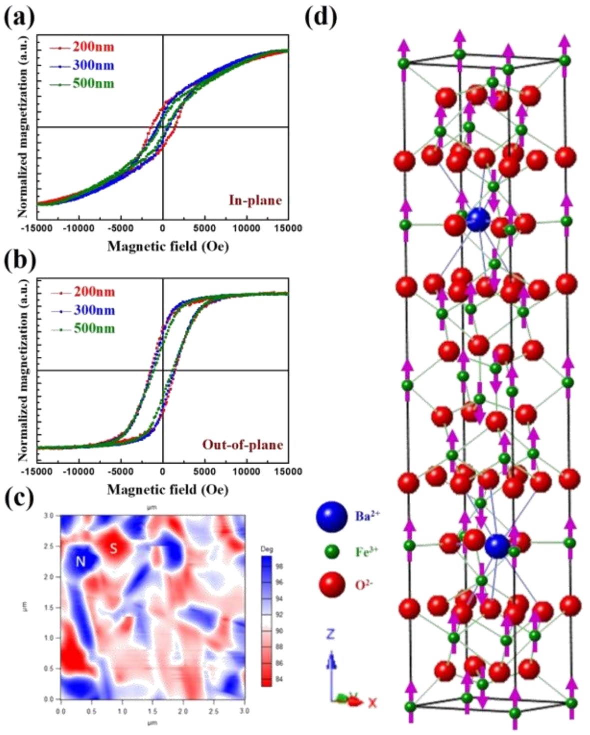

Fig. 2 In-plane, out-of-plane hysteresis loops, MFM and magnetic structure of BaM

To demonstrate the PMA property of BaM/muscovite heterostructure, vibrating sample magnetometer (VSM) was employed. From Fig. 2a and 2b, the PMA property was confirmed. Also, the hard magnetization tends to lie on in-plane direction when the thickness of BaM thin film increases from 200nm to 500nm. However, there is a little change on MH loop in out-of-plane direction when the thickness increases. Moreover, the phenomena of perpendicular magnetic moment was evidently noted by magnetic force microscopy (MFM) in Fig. 2c. A schematic of BaM magnetic structure along c-axis was exhibited in Fig. 2d. Overall, the net magnetization per formula unit is 20μB.

XAS and XMCD analysis

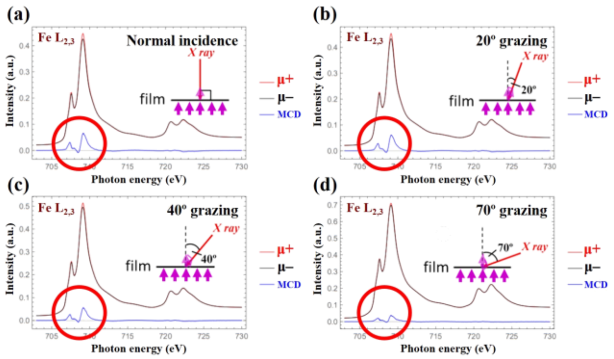

Fig. 3 XAS and XMCD measurement under different grazing angle

The PMA property of BaM/muscovite heterostructure was further investigated by XAS-XMCD. The grazing angle of x-ray is getting larger from Fig. 3a to Fig. 3d. Correspondingly, the signal of XMCD is getting smaller. Because the signal of XMCD ($\vec{M}$) is proportional to (μ^+ - μ^-) of XAS, it is clarified that most magnetic moment orientation of Fe ions in BaM film is perpendicular to the film.

Bending tests

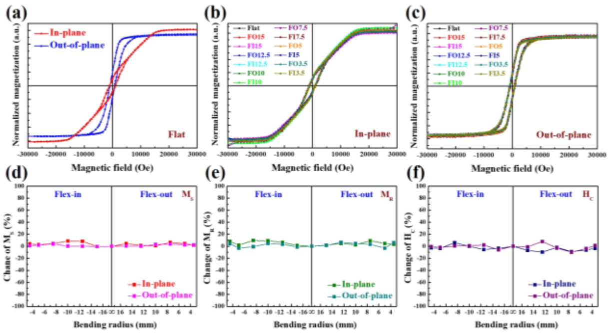

Fig. 4 Hysteresis loops under various bending radius

In order to exhibit the potential application of BaM/muscovite heterostructure, bending tests were carried out in Fig. 4. The bending radii were chosen from infinity (flat) to 3.5 millimeter with flex-in and flex-out modes. The macroscopic hysteresis loops were illustrated in Fig. 4a, 4b, and 4c. Through prudent sort-out, we discover that the change of saturation magnetization, remanence magnetization, and coercivity are all within 10% under bending. These results show that BaM/muscovite heterostructure can retain its initial PMA property under external mechanical bending, which paves the way to flexible magnetic storage devices and actuator.

Conclusions

In summary, we have epitaxially fabricated BaM film on muscovite substrate. This study has provided a flexible system with PMA property, which can bear high temperature, corrosion and mechanical bending. This unique property was carefully analyzed by VSM, MFM and XAS-XMCD. The design of this BaM/muscovite heterostructure could be a solution to flexible storage devices and actuator in the future.

Acknowledgements

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References

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