

STRUCTURE AND MAGNETIC PROPERTIES OF PZT/CoCr HETEROSTRUCTURES

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Abstract. *The microstructure, crystallographic structure and magnetic properties of ferroelectric-ferromagnetic PZT/CoCr heterostructures have been investigated by using XRD, SEM and VSM. Upon applying an electric field, the in-plane magnetization of the heterostructures decreases at various bias magnetic fields. The change in magnetization and the magnetization reversed voltage were obtained. The results demonstrate that the change in magnetic anisotropy can be controlled by electric field via strain-mediated magnetoelectric coupling.*

Keywords: ferromagnetics, ferroelectrics, heterostructures.

I. INTRODUCTION

In recent years, there has been great interest in multiferroic materials as either single phase or as heterostructures [1, 2]. In these systems, thanks to the coupling existing between their magnetic and electric properties, one can control magnetic properties by an electric field through converse magneto-electric effect and vice versa. Such materials currently receive considerable interest for they open new perspectives in terms of memory devices [3–6]. In this work, we report on the study of microstructure, crystallographic structure and magnetic properties of PZT/CoCr heterostructures.

II. EXPERIMENTAL

In our study, micrometer-thick CoCr magnetic films were firstly deposited on $5 \times 5 \text{ mm}^2$ polyvinylidene fluoride (PVDF) substrates with different thickness using a RF magnetron sputtering. Next the PZT/CoCr heterostructures were formed by bonding CoCr ferromagnetic films and commercial piezoelectric PZT (APC-855, American Piezoceramics, longitudinal polarized). An Ag layer is made in contact with CoCr film as an electrode. The typical heterostructure size is $5 \times 5 \text{ mm}^2$. Microstructure of CoCr films was investigated by using an X-ray diffractometer

(XRD) D8 Advance with Cu K- α wavelength. Field emission scanning electron microscope (FE-SEM) S-4800 with accompanying elemental analysis technique, energy dispersive spectroscopy (EDS), was used to explore surface morphology and film composition. Room-temperature magnetic properties of PZT/CoCr heterostructures were studied in the magnetic field up to 2 kOe using a vibrating sample magnetometer (VSM) 7400. The applied electrical voltage ranged from -400 V to 400 V across the PZT substrate corresponding to electric field strength (E) of -8 kV/cm to +8 kV/cm.

III. RESULTS AND DISCUSSIONS

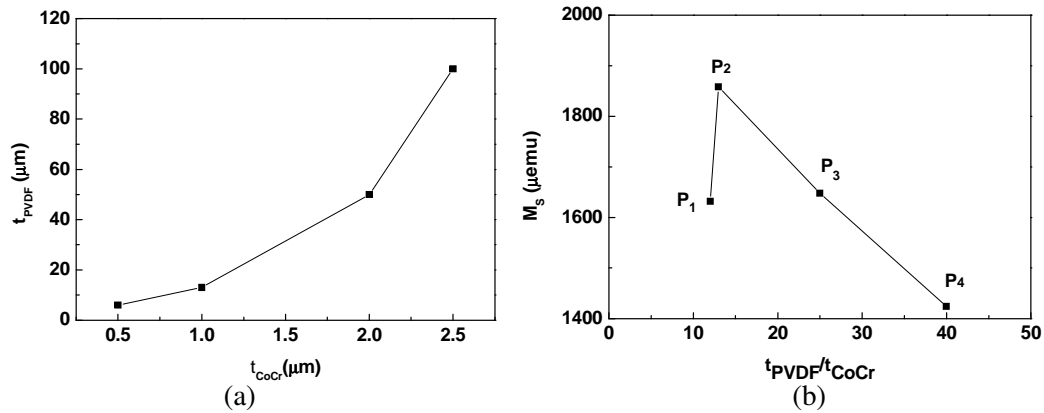


Fig. 1. (a) The thickness of CoCr ferromagnetic layer and PVDF substrate; (b) Dependence of saturation magnetization on the thickness ratio of PVDF/CoCr heterostructures

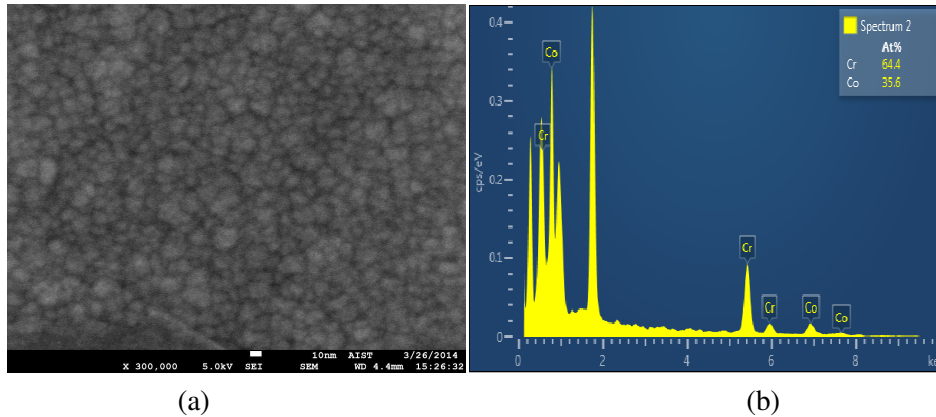


Fig. 2. (a) The SEM image and (b) the EDS pattern of CoCr film.

Fig. 1a presents the thicknesses of CoCr ferromagnetic layer and PVDF substrate in the studied samples. It notes that when increasing the thickness of PVDF substrate, the thickness of ferromagnetic layer also increases. We denoted these samples with the thickness ratio between the substrate and the film of $t_{PVDF}/t_{CoCr} = 12, 13, 25, 40$ as P₁, P₂, P₃ and P₄, respectively.

The FESEM image of a typical CoCr film is presented in Fig. 2a. The film surface is reasonable smooth, relatively dense and uniform microstructure with an average grain size of about 10 nm, reflected a good quality of deposited CoCr film. Moreover, from the EDS spectrum in Fig. 2b, one can observe the typical Cr and Co peaks, and the ratio of elements in the film and its composition of $\text{Co}_{35.6}\text{Cr}_{64.4}$ can be derived.

Fig. 3 shows the X-ray diffraction patterns of the CoCr films. For all samples, only (111) CoCr diffraction peak appeared around 26.2° . Generally this peak intensity increases with increasing the CoCr thickness and reached a maximum for sample P_3 (having the ferromagnetic layer thickness of $2.5 \mu\text{m}$). This (111) orientation is in agreement with the microstructure analysis which shows a random distribution of grains.

The magnetic hysteresis loops of CoCr films (not shown all here) indicate a planar ferromagnetic anisotropy. In Fig. 4 we represent the magnetic hysteresis loops of typical sample P_2 , measured at room temperature and at different directions between the applied magnetic field and the film plane $\alpha = 0^\circ, 45^\circ, 90^\circ$. The saturation magnetization M_S of all the samples is extracted and illustrated in Fig. 1b. It is noteworthy that M_S for sample P_2 is larger than that of others.

In order to investigate the magneto-electric property of the PZT/CoCr heterostructures, we measured the dependence of magnetization on the voltage applied across the PZT substrate at various bias magnetic fields H_{bias} from -2000 to 2000 Oe at $\alpha = 0^\circ$. In Fig. 5 we presents this $M(V)$ analyzed data for the typical sample P_2 . The results point out that the magnetization decrease when increasing applied voltage. The magnitude of ΔM is approximate $840 \mu\text{emu}$ for both -400 and $+400$ V voltages (ΔM is defined as $\Delta M = M(E) - M(0)$, where $M(E)$ is the magnetization under electric field and $M(0)$ is the magnetization under zero electric field). Besides, a reversible changes in magnetization under electric field are also observed at different voltage, denoted V_{rev} . V_{rev} is variable depending

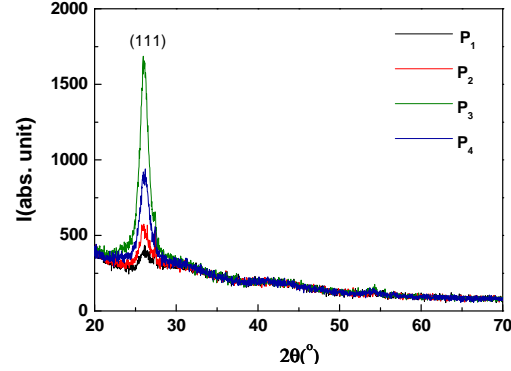


Fig. 3. XRD patterns of CoCr films

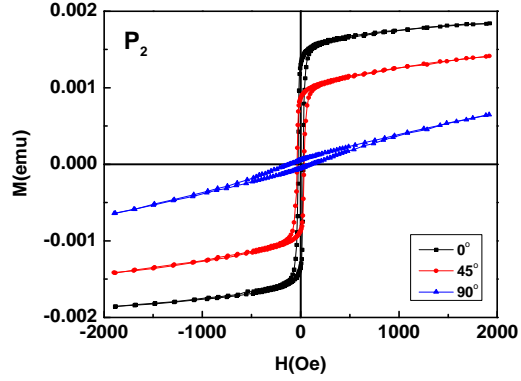


Fig. 4. The magnetic hysteresis loop measured under 0 V for the PZT/CoCr heterostructure

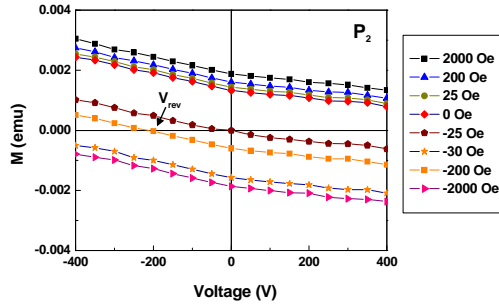


Fig. 5. Dependence of magnetization on applied voltage at various bias magnetic fields for sample P_2

on the external bias magnetic field. The control of magnetization by electric field can be understood by considering the electric field induced strain which results in the change in the magnetic anisotropy. We consider first the magneto-elastic energy which is given by $E_{me} \cos^2 \theta$ where θ is the directional cosine of the magnetization vector along the film normal [7]. The anisotropy constant associated with stress K_σ , expressed by formula $K_\sigma = \frac{3}{2} \lambda_{100} \sigma_{100}$, where λ_{100} is the in-plane magnetostriction coefficient of CoCr films and σ_{100} is the in-plane stress of CoCr films. In the PZT/CoCr heterostructures, CoCr films are under compressive, i.e., $\sigma_{100} < 0$, which results in $K_\sigma < 0$. The electric field applied along (001) direction leads to the elongation of the PZT substrate along c axis direction through the converse piezoelectric effect and thus resulting in an enhancement in the in-plane compression σ_{100} , leads to a decrease in K_σ . As a result, the in-plane magnetization decreases under electric field. This analysis of the results demonstrates that the electric field induced change in magnetic anisotropy via strain plays an important role in the interaction between magnetostrictive and piezoelectric phases in the heterostructures.

IV. CONCLUSIONS

The microstructure, crystallographic structure and magnetic properties of the PZT/CoCr heterostructures have been studied. The results show the good quality of CoCr ferromagnetic films and a highest change in magnetization ΔM of 840 μemu is obtained for the sample P₂. The magnetic properties can be controlled by an external electric field and this provides a possibility of application in electrically controlled memory devices.

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