NANOSCALE DOMAIN SWITCHINGS OF $Bi_{3.15}Dy_{0.85}Ti_3O_{12}$ THIN FILM AT THE SIMULTANEOUS APPLICATION OF POLARIZING VOLTAGE AND LOADING FORCE

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Summary The nanoscale domain switchings of $Bi_{3.15}Dy_{0.85}Ti_3O_{12}$ thin film were investigated by piezoresponse force microscopy at the different DC polarizing voltages, loading forces and simultaneous both of them. Especially, both of 90°and 180°domain switchings were observed at the simultaneously applied fields of polarizing voltage (+10V) and loading forces (100 and 200 nN). The different formation mechanisms are also discussed.

INTRODUCTION

Piezoresponse force microscopy (PFM) has become a standard method to study on ferroelectric phenomena, such as the domain dynamics and switching, fatigue, and phase transition in ferroelectric thin film materials [1]. Most of the devices (such as actuators and transducers) based on ferroelectric films operate under different external fields (electric, stress or thermal fields), which often acts an important role in the domain wall and domain switching evolution to affect the ferroelectric properties of ferroelectric thin film [2]. Therefore further work is needed for improved understanding of the nature of the complex domain structure and domain switching behavior in polarizable ferroelectric thin films under different external fields. A few experimental attempts have been reported on the nanoscale domain switching observation of ferroelectric thin films under the polarizing voltage[3] or loading force [4]induced by the PFM tip. However, to date, there is a little study of the direct observation on nanoscale domain switching induced by the PFM tip under the simultaneously applied fields of polarizing voltage and loading force, and the evolution mechanism never be understood completely.

EXPERIMENTAL DETAILS

A commercial PFM (Digital Instruments Nanoscope) equipped with diamond coated cantilever was used to obtain the topographic and piezo-phase images. It is worth mentioning that the tip apex radius and the spring constant are determined as 10 nm and 11.8 N/m for the weak change in the film's microstructure and nanoscale scan area [5]. The three typical applied fields were respectively designed as the single polarizing voltage, the single loading force, and the applied fields of polarizing voltage and loading force to apply on the $Bi_{3.15}Dy_{0.85}Ti_3O_{12}$ (BDT) thin film by PFM, in order that the domain evolution including nucleation, coalescence and growth can be obtained. At first, the PFM tip was used to apply DC bias 0 V, -12 V and +12 V on the film surface within the scan area of 600×600 nm^2. Secondly, the different loading forces 0, 150 and 300 nN were performed on the film surface within 800×800 nm^2. Finally, the loading forces 100 and 200 nN combining DC bias +10 V were applied on the film surface within 800×800 nm^2.

RESULTS AND DISCUSSION

The topography and piezoelectric phase image of the original state, the piezoelectric phase images under the DC voltages −12 V and +12 V are given in Figs. 1(a)-(d), respectively. In Fig. 1(a), the crack-free thin film exhibits a smooth and homogeneous microstructure with few intergranular porosities. The selected five grains of "1", "2", "3" "4" and "5" are marked by the white loops and the corresponding phase images are shown in Fig. 1(b). The multicolor contrasts within the grains indicate that the BDT thin film is polydomain state with polycrytal structure. From Fig. 1(c), it is easy to see that the white color contrasts in four grains "1", "2", "3" and "4" partly turn to black or grey at the polarizing voltage -12 V. For positive DC voltage +12 V, the black or grey contrasts of four grains in Fig. 1(c) become obviously white shown in Fig.1 (d). Both of the changes of color contrasts means that the polarization direction of the original domains are all reversed parallel to the external polarizing electric field, namely the 180°domain switching.

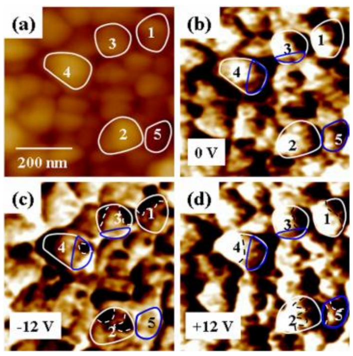

Fig. 1 The topographic image of the area of 600×600 nm^2 (a), the piezo-phase images with the polarizing voltages at 0V (b), −12V (c), and +12V (d).

The topographic image, phase image of the original state and the piezo-phase images at the different loading forces 150 nN and 300 nN are illustrated in

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Figs. 2(a)-(d), respectively. There are mainly three types of domain switching after applying different loading forces according to the change of color contrasts. From the Figs. 2(a), the sizes of grains marked by “1”, “2”, “3”, “4”,“5” and “6” are exhibited to show the different domain switchings. During the switching process shown in Figs. 2(b)-(d), it can be seen that the original white regions of some grains, such as grains “1”, “2” and “3”, tend to become grey gradually with the increase of loading forces from 150 nN to 300 nN, while some dark regions in the grains “4” and “5” tend to become grey. The change from white or black color contrasts to the grey means that the polarization vectors were reversed from perpendicular to parallel direction, namely, ±90 °-domain tend to become 0 °-domain with the increase of applied loading forces. The insets at the bottom right corner of Figs. 3(b)-(d) illustrate the three types of polarization vectors rotation within the grains underneath the tip. The observed domains switching may be due to the combined action of compressive mechanical and shearing stresses.

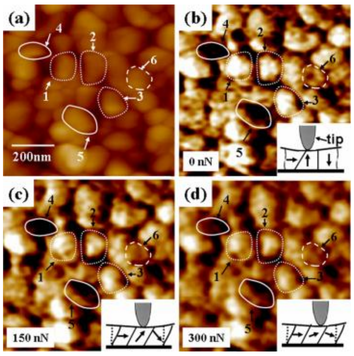

Fig. 2 At free voltage, the topographic image of the area of 800×800 nm^2 (a), the piezo-phase images with the different loading forces applied by the PFM tip of 0 nN (b), 150 nN (c), and 300 nN (d).

The topography, piezoelectric phase image of the original state, the piezoelectric phase images applied by both DC voltage +10 V and loading force 100 nN, +10 V and 200 nN are given in Figs. 3(a)-(d), respectively. The typical five grains “1”, “2”, “3”, “4” and “5” are chosen in Figs. 3(a). As seen from Fig. 3(b) to Fig. 3(c), the regions of the grains “1”, “2” and “3” partly turn from dark to white color contrast. The white color contrast in grain “4” becomes grey while unchanged in grain “5”. These changes of the color contrasts indicate that 180 ° and 90 ° domain switching occur. According to the previous discussion [6], the 180 ° domain switching is induced by the polarizing voltage. However, there are mainly two interpretations about the 90 ° domain switching [7]. Firstly, it maybe induced by the loading force as same as discussed in Fig. 3. Secondly, the external electric field should have a component parallel to the film surface outside of the tip-sample contact area which may induce 90 ° domain switching from ±90 °-domains to 0 °-domains [10]. In order to prove that the domain switchings come from the force-voltage coupling, a lager loading force of 200 nN is applied and the piezo-phase image is given in Fig. 3(d). From Fig. 3(d), we can observe that the white color contrast in grain “5” become grey. That is to say, a new 90 ° domain switching from +90 °-domains to 0 °-domains occurs. So we think loading force plays the role in 90 ° domain switching. The 180 ° domain switching was not observed during this process, which may owing to the suppression of large external electric field and loading force to the reversed domain switching.

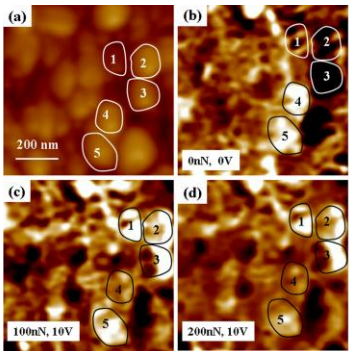

Fig. 3 The topographic image of the area of 800×800 nm^2(a), the piezo-phase images without the loading force and polarizing voltage (b), at both the loading force of 100 nN and a polarizing voltage of +10 V (c) at both the loading force of 200 nN and a polarizing voltage of +10 V.

CONCLUSIONS

The domain switchings in BDT thin film were investigated by PFM at the different DC polarizing voltages, loading forces and simultaneous both of them, respectively. At first 180 °domain switchings were observed when the polarizing DC voltages were applied. Secondly, according to the noticeable color contrasts change of piezo-phase images, it can be observed that ±90 °-domains tend to become 0 °-domains with the increase of applied loading forces. The domains rotation was interpreted by deformation of the grain which may be induced by the combined action of the compressive and shearing stresses exerted by PFM tip. Finally, for the existence of both loading force and polarizing voltage, the domain switchings from the force-voltage coupling effect were observed. The 90 ° domain switching induced by loading force was proved by increasing the force to 200 nN. These observations demonstrate the possibility of using PFM as a nanoscale tool for imaging phase transitions under mechanical stress and external electric fields.

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