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Study of asymmetric charge writing on $Pb(Zr,Ti)O_3$ thin films by Kelvin probe force microscopy

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Abstract

Polycrystalline $Pb(Zr_{0.55}Ti_{0.45})O_3$ thin film was deposited on $Pt/Ti/SiO_2/Si(1\ 0\ 0)$ by radio-frequency-magnetron sputtering method, and the writing of charge bits on the surface of PZT thin film was studied by Kelvin probe force microscopy. It is found that the surface potential of the negative charge bits are higher than those of the corresponding positive ones. When ferroelectric polarization switching occurs, the potential difference becomes even more remarkable. A qualitative model was proposed to explain the origin of the asymmetric charge writing. It is demonstrated that the internal field in the interface layer, which is near the ferroelectric/electrode interface in ferroelectric film, is likely to be the cause for the occurrence of this phenomenon.

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Keywords: Kelvin probe force microscopy; Asymmetric charge writing; PZT thin film; Internal field

1. Introduction

Scanning probe microscopy (SPM) has been widely utilized to characterize the nanoscale devices and materials for data storage during last decades. Various kinds of recording bits based on SPM have been proposed, such as thermomechanical bits on polymer surface [1], charge trapping bits on nitride-oxide-silicon system [2], and polarization bits on ferroelectric films [3,4]. Recently, the research on high-density storage ferroelectric thin films, including current imaging [5], piezoelectric detection [6–8], and domain reversal [9], have attracted much attention due to their prospective application in non-volatile storage devices. One of interesting issues is the charge writing based on Kelvin probe force microscopy (KPFM). Chen et al. [10] studied the evolution of surface potential and domain after polarization. Son et al. showed the polarization writing effect on SBT, PZT, and $BiMnO_3$ thin films [11,12]. However, some reality problems keep unsolved and hamper the application of ferroelectric thin films in the microelectronics industry. In this paper, we report on the study of the charge writing on the surface of polycrystalline $Pb(Zr,Ti)O_3$ thin film by KPFM. The asymmetric charge writing which define as the preference of negative charge bits is observed in the writing voltages range from -10 to 10 V. The origin of the asymmetric charge writing is also discussed.

2. Experiments

The 270-nm-thick $Pb(Zr_{0.55}Ti_{0.45})O_3$ film was deposited onto $Pt/Ti/SiO_2/Si(1\ 0\ 0)$ by radio-frequency-magnetron sputtering for 2000 s using ULVAC system. After the deposition, post-rapid thermal annealing was performed at 650 °C for 1 min. The crystalline structure of the film was determined by X-ray diffraction (XRD) using Bede D1 diffractometer.

The charge writing was achieved by applying a bias voltage between KPFM tip and bottom Pt electrode of the sample. The conductive tip was grounded and the bias was applied to the sample surface at selected point. The widths of all writing pulses are 1 s. The surface potentials of pre-written bits were measured by scanning probe microscopy (SPA300, Seiko). Rhodium coated silicon tip (force constant of ~3 N/m and resonance frequency of ~28 kHz) was used. In the potential measurements, twice scan is completely carried out. The first line scan gives the line information of topography, the second

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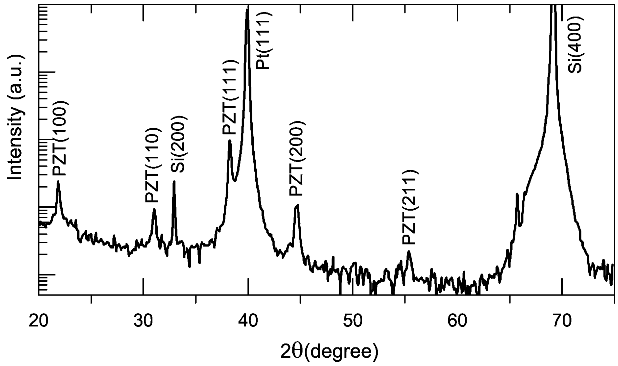

Fig. 1. X-ray θ–2θ diffraction pattern of $Pb(Zr,Ti)O_3$ thin film.

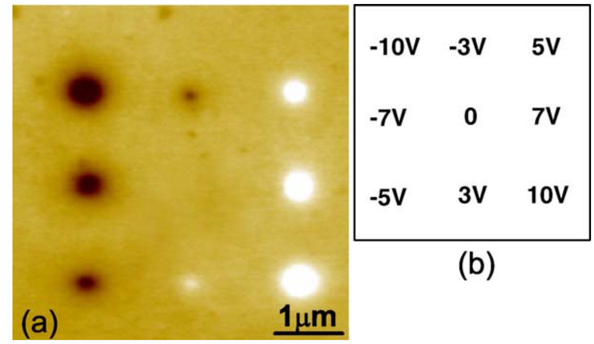

Fig. 2. The surface potential image of PZT thin film written by various bias voltages (a). The 3×3 matrix of writing bits and the corresponding voltages (b).

line scan tracks the trace of the first scan and the surface potential is measured by amplitude nullify method. In this method, feedback is applied to change the magnitude of the dc voltage so that the electric force between tip and sample vanishes when the voltage of tip is equal to the surface potential, thus the surface potential image can be obtained. The details of the principle of potential measurement can be found elsewhere [13]. All the experiments were carried out in atmosphere.

3. Results

Fig. 1 shows the XRD pattern of our PZT thin film. A typical perovskite phase with no detectable pyrochlore phase is observed. The PZT film is highly (1 1 1)-oriented, indicating that the out-of-plane polarization could be relatively strong for a rhombohedral PZT film.

Fig. 2(a) shows the potential image of PZT film after the charge writing of 3×3 arrays, the corresponding writing

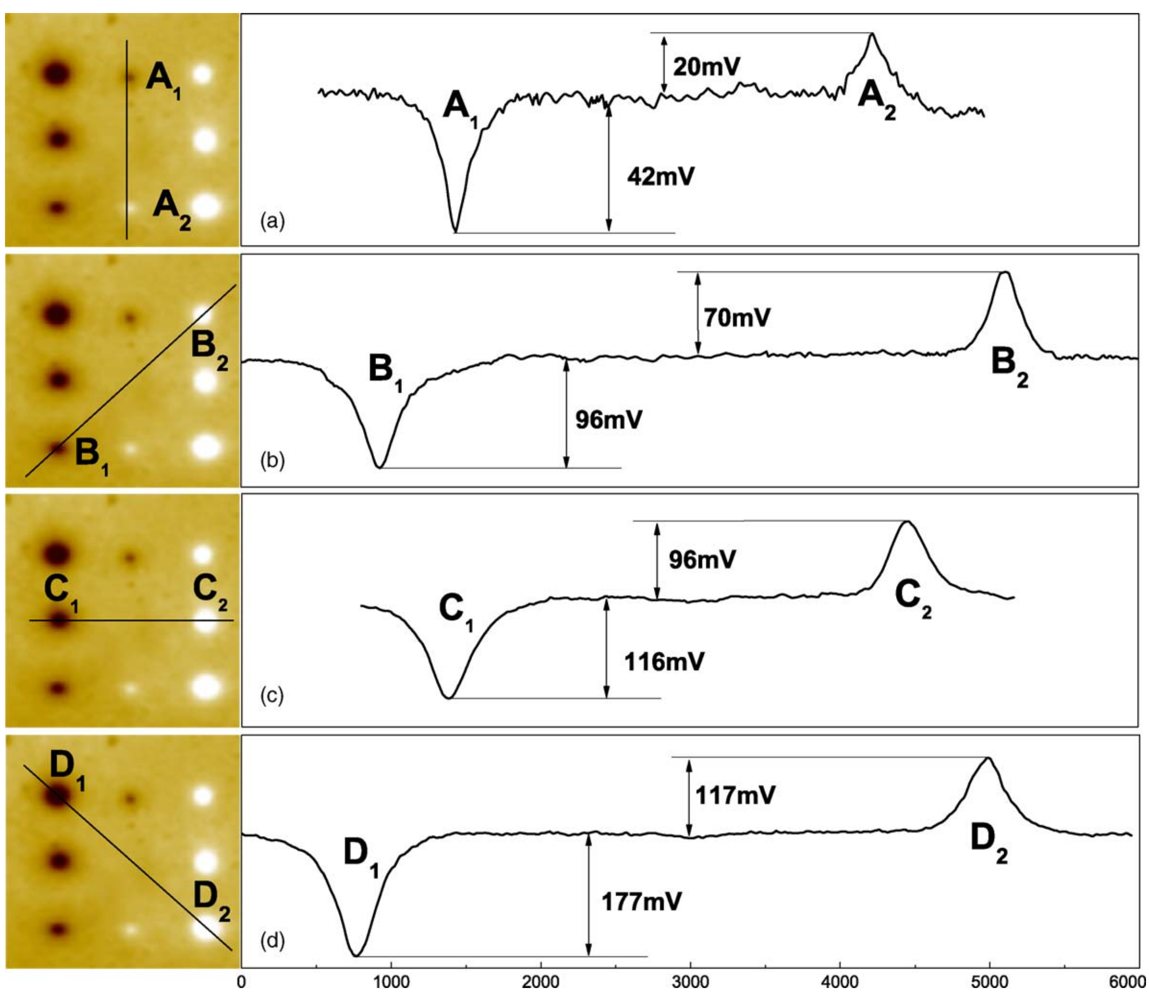

Fig. 3. The potential profiles of the KPFM image of writing bits; (a)–(d) are the line profiles of the charge bits written by the biases of −3/3, −5/5, −7/7, and −10/10 V. All the bit potential amplitude induced by negative biases are larger than those by positive biases, and the potential difference are about 22, 26, 20 and 60 mV, respectively.