PIEZOELECTRIC AND ELECTROSTRICTIVE DISPLACEMENTS OF (1-*x*)$Na_{0.5}Bi_{0.5}TiO_3$-*x*$K_{0.5}Bi_{0.5}TiO_3$ THIN FILMS UNDER THE BIPOLAR DRIVING FILED

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Summary Under the bipolar driving field, the piezoelectric displacements and electrostrictive displacements were measured by using scanning probe microscope and phenomenological approach, and they are about 874, 578, 380, 440 pm and 1080, 810, 460, 410 pm for NBT-KBT100*x* thin films with *x*=0.15, 0.18, 0.20, 0.25, respectively. The improved electrostrictive performance could make NBT-based thin film a promising candidate to the design and application of servo transducers and micropositioning devices.

INTRODUCTION

NBT-KBT100*x* thin films, as one kind of relaxor, were only reported on ferroelectric, dielectric, piezoelectric properties and morphotropic phase boundary (MPB) at *x*=0.15 [1, 2], but never be involved in the electrostriction performance of NBT-KBT100*x* thin films. The electrostrictive strain is generally far below 0.1% for the most materials with a very small electrostriction coefficient, however it is practically useful owing to its high level of 0.1% for some ferroelectric relaxors with the electrostriction coefficient value of ~10^{-2} m^4/C^2. Mechanical applications range from stacked actuators, through inchworms, microangle-adjusting devices, and oil pressure servo valves [3]. The electrostrictive performance is very important for determining the electromechanical strain of microactuators and sensitivity of microsensors, nevertheless based on phenomenological approach relatively few reports for such second-order electromechanical effect in typical NBT-KBT*x* thin films are available in the literatures. In this study, the piezoelectric displacements D_3^* and electrostrictive displacements D_3 of NBT-KBT100*x* films were investigated by using scanning probe microscope (SPM) and phenomenological approach. It is expected that the present research may offer useful guideline to the design and application of servo transducers and micropositioning devices based on NBT-KBT*x* thin films.

EXPERIMENTAL

The NBT-KBT*x* thin films with *x*=0.15, 0.18, 0.20, 0.25 fabricated on LNO/Ti/SiO_2/Si(100) by MOD method were annealed at 700 °C. Under the bipolar driving filed of 250 kV/cm, the ferroelectric and dielectric properties were measured by ferroelectric tester (Precision Workstation, Radiant Technologies, USA) and semiconductor characterization system (4200, Keithley, USA) at the frequency of 1 kHz and 30 kHz, and the piezoelectric property was measured by commercially available SPM (SPI4000&SPA300HV, Seiko, Japan) equipped with a conductive Rh-coated silicon cantilever (SI-DF3, Seiko, Japan) with a spring constant of 1.9 N/m, a resonant frequency of 28 kHz, and an integrated tip of about 10 nm in diameter. The electrostrictive effect can be expressed in terms of polarization, it is known that the S_3 follows the theoretically derived quadratic relation [4]

$$S_3 = Q_{33} P_3^2 \tag{1}$$

where Q_{33} is electrostriction coefficient. In the field-biased state the Q_{33} still plays an important role in determining values of the piezoelectric coefficients, then Q_{33} of the relaxor can be expressed as the following equation [5]

$$Q_{33} = d_{33}^{\text{eff}} \big/ 2\varepsilon_0 \varepsilon P_3 \tag{2}$$

ε_{33} is the absolute permittivity. One can substitute the ε_{33} and modified equation of converse piezoelectric effect [6] into the simultaneous equations Eqs. (1) and (2), then the D_3 can be rewritten

$$D_3 = (D_3^* - D_I^*) \big/ 2\varepsilon\varepsilon_0 (E - E_I) \tag{3}$$

where ε_0 is the vacuum permittivity. As for D_3^*-electric field (D_3^* - E) curve, E is applied electric field for each point, while D_I^* and E_I are D_3^* and E for the intersection.

RESULTS AND DISCUSSION

The D_3^* - E and the D_3 - E hysteresis loops under the bipolar driving field of 250 kV/cm are respectively depicted in Figs. 1(a)-(d) for NBT-KBT100*x* thin films with *x*=0.15, 0.18, 0.20, 0.25. From the D_3^* - E curves the maximum D_3^*

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are respectively 874, 578, 380 and 440 pm, and the maximum values of d_{33}^{eff} can be calculated as 104, 64, 57, 48 pm/V by the modified equation of converse piezoelectric effect [6] for NBT-KBT100*x* with *x*=0.15, 0.18, 0.20, 0.25 thin films, respectively. For the ten piezoelectric measurements, the statistical average D_3^* values are 812, 620, 570 and 422 pm for NBT-KBT100*x* thin films with *x*=0.15, 0.18, 0.20, 0.25, respectively. As a NBT-based relaxor ferroelectric material, the present NBT-KBT thin film at a composition around *x*=0.15 near the MPB [1] , and it may be attributed to the following reasons for the high piezoelectric properties of NBT-KBT15 thin film. At first, it is quite easy for an electric field to tilt the polar vector of domain, and this gives rise to very strong piezoelectric activity [7]. Secondly, NBT-KBT15 thin film possess an increase in the number of possible spontaneous polarization direction, which may result in large coupling factors and excellent piezoelectric properties [8].

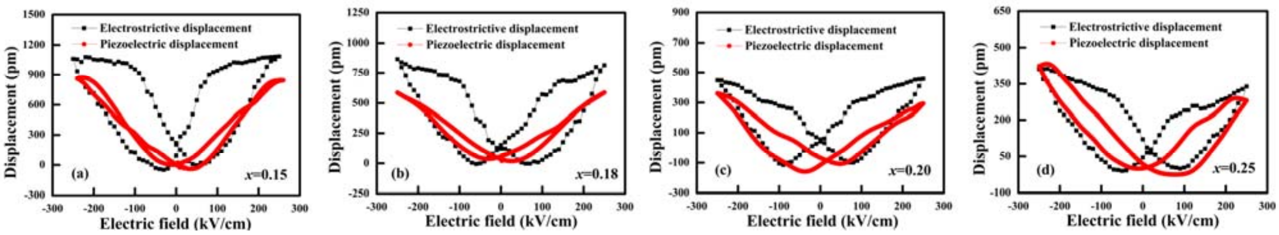

Fig 1. Electrostrictive and piezoelectric displacements of NBT-KBT100*x* thin films with the different potassium.

The D_3 can be determined according to Eq. (3), and the maximum D_3 are respectively 1080, 810, 460, 410 pm under the bipolar driving field of 250 kV/cm for NBT-KBT thin films with *x*=0.15, 0.18, 0.20 and 0.25. The average of Q_{33} determined by Eq. (2) are about 0.025, 0.022, 0.021 and 0.020 m^4/C^2 of NBT-KBT100*x* thin films with *x*=0.15, 0.18, 0.20 and 0.25, respectively. The Q_{33} of NBT-KBT100*x* thin films have the same high order of magnitude for (1-*x*)$PbMg_{1/3}Nb_{1/3}O_3$-*x*$PbTiO_3$ (PMN-*x*PT) relaxor ferroelectric thin films [5]. Comparing with the D_3^* and D_3, the D_3 of NBT-KBT100*x* thin films are lager than D_3^* at compositions *x*=0.15, 0.18, 0.20, and they are in agreement with the previous report, which the electrostrictive effect may dominate over the piezoelectric effect in a high bipolar driving field [9]. The enhanced D_3^* can be explained by the equivalent energy for the coexistence of rhombohedral and tetragonal phases, and they can be transformed each other in poling process [10]. The improved electrostrictive performance could make NBT-based thin film a promising candidate to the design and application of servo transducers and micropositioning devices.

CONCLUSIONS

NBT-KBT100*x* thin films with *x*=0.15, 0.18, 0.20, 0.25 were fabricated on LNO/Ti/SiO_2/Si(100) substrates by MOD. Under the bipolar driving field of 250 kV/cm, the maximum D_3^* and D_3 are about 874, 578, 380 and 440 pm and 1080, 810, 540, 410 pm. Comparing with the D_3^* and D_3, the D_3 of NBT-KBT100*x* thin films make a great contribution to electric-field induced displacements. The enhanced D_3^* can be explained by the equivalent energy for the coexistence of rhombohedral and tetragonal phases, and they can be transformed each other in poling process. The improved electrostrictive performance could make NBT-based thin film a promising candidate to the design and application of servo transducers and micropositioning devices.

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