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Composition induced structure evolution and large strain response in ternary Bi_{0.5}Na_{0.5}TiO₃-Bi_{0.5}K_{0.5}TiO₃-SrTiO₃ solid solution

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A ternary perovskite lead-free solid solution $Bi_{0.5}Na_{0.5}TiO_3$ - $Bi_{0.5}K_{0.5}TiO_3$ - $SrTiO_3$ was designed and fabricated using a conventional fabrication process. The temperature and composition dependence of the ferroelectric, dielectric, piezoelectric, and electromechanical properties were systematically investigated, and a schematic phase diagram was established. The introduction of the $SrTiO_3$ was found to induce a structure evolution from the ferroelectric rhombohedra to ergodic relaxor pseudocubic phases. At a critical composition with $SrTiO_3$ of 0.15, large strain level of ~0.25% was obtained under a moderate field of 4.4 kV/mm at 0.1 Hz and the normalized strain reached up to 585 pm/V. Through the combination of the X-ray diffraction results with the piezoresponse force microscopy analysis, the composition induced structure evolution process and intrinsic mechanism responsible for the large strain response were discussed. The large strain level also makes the system quite promising for application to "on-off" actuators. © 2013 AIP Publishing LLC. [http://dx.doi.org/10.1063/1.4825122]

I. INTRODUCTION

Lead-free ferroelectric and piezoelectric materials are attracting significant attention due to their potential as "environmentally friendly" alternatives to traditional Pb(Zr, Ti)O₃ (PZT) family.^{1,2} Bi_{0.5}Na_{0.5}TiO₃ (BNT), as one of the most promising candidate, has attracted continuous attention during the past decade. Two typical BNT-based solid solutions, BNT-BaTiO₃ (BNT-BT) and BNT-Bi_{0.5}K_{0.5}TiO₃ (BNT-BKT), were designed and enhanced electromechanical performance was obtained around the morphotropic phase boundary (MPB) similarly as in the PZT system.^{3,4} Nevertheless, even though some improvements have been achieved and a few ultrasonic devices with acceptable performance were demonstrated, the overall piezoelectric properties of the lead-free counterparts were still inferior to the lead-based one.⁵ How to further improve the piezoelectric response is not only scientifically interesting but also technologically important for piezoelectric device applications.

It is well known that the maximum achievable strain level along with the normalized strain is one of the most important parameters for actuator application. Recent work on BNT-based solid solution showed that large strain response can be induced under high electric field. A large strain level up to 0.45% under an electric field of 8 kV/mm was obtained in a ternary system BNT-BT-K_{0.5}Na_{0.5}NbO₃ (BNT-BT-KNN) proposed by Rödel's group in 2007.⁶ Similar strain behavior was also observed in the follow-up investigations.^{7–9} In this work, we developed a ternary solid solution based on binary BNT-BKT system through introducing paraelectric SrTiO₃. A large strain level of ~0.25% was obtained under a moderate

field of 4.4 kV/mm at 0.1 Hz around a critical composition between ferroelectric rhombohedra and relaxor pseudocubic phases. The structure, ferroelectric, dielectric, and piezoelectric properties were systematically studied and a schematic phase diagram was established. The slow-scanning X-ray diffraction (XRD) and the piezoresponse force microscopy (PFM) were performed to reveal the composition induced structure evolution and discuss the origins for the large strain response.

II. EXPERIMENT

 $(0.88-x)Bi_{0.5}Na_{0.5}TiO_3-0.12Bi_{0.5}K_{0.5}TiO_3-xSrTiO_3$ (BNKST, BNKSTx) ceramics with x from 0 to 0.15 were prepared by a conventional solid state fabrication process. The starting materials were weighed according to the stoichiometric formula and ball milled in ethanol. The dried slurries were calcined at 850 °C and then ball milled again. The dried powders were subsequently pressed into green disks and sintered at 1200 °C. Silver paste was coated and fired at 650 °C. The specimens for measurement of piezoelectric properties were poled in silicone oil bath with a dc field of 3–4 kV/mm for 15 min. All the electrical measurements were performed after ageing for at least 24 h.

The crystal structures of the sintered ceramics were characterized by X-ray diffractometry (D8 Focus, Germany) using unpoled crushed samples. Dielectric constant and loss of the ceramics were measured using an automatic acquisition system with an impedance analyzer (Agilent HP4294A, Santa Clara, CA) in the temperature range of 25–400 °C under 100 Hz–100 kHz. The piezoelectric constant d_{33} of the poled samples was measured using a Berlincourt d_{33} meter at 55 Hz. The ferroelectric hysteresis loops and strain curves were measured in silicon oil with a Sawyer-Tower circuit

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along with a laser interferometer (TF2000, Aixacct, Aachen, Germany).

III. RESULTS AND DISCUSSION

Fig. 1(a) shows the XRD patterns for the sintered BNKST ceramics. All the compositions exhibited pure single-phase perovskite structure with no secondary phases observed. The XRD with the 2θ in the range of $38^{\circ}-48^{\circ}$ (corresponding to the (111) and (200) which are the characteristic peaks for the rhombohedral and tetragonal phases) was performed under a slow scanning rate of 0.0026° to give an insight into the phase structure as shown in Fig. 1(b). The introduction of the SrTiO₃ caused the crystal lattice distortion and shifted the diffraction peaks leftwards due to larger ionic radius of Sr^{2+} than the Bi³⁺ or Na⁺. For BNKST*x* with x smaller than 0.08, obvious peak splitting can be observed for the peak (111), indicating the ferroelectric rhombohedra phase at room temperature. The further increasing of the SrTiO₃ weakened the rhombohedral distortion 90- α and induced the formation of the pseudocubic or cubic phase characterized by the single (111) and (200) peaks. Here, it can be noticed that for BNKST with x > 0.10 slightly rhombohedral or tetragonal distortion could not be excluded using our XRD due to the resolution limitation. Piezoelectric and



FIG. 1. XRD patterns for the sintered BNKSTx ceramics with the 2θ in the range of (a) $20^{\circ}-70^{\circ}$, (b) $38^{\circ}-48^{\circ}$.

electromechanical response can still be detected for BNKST with *x* of 0.10–0.15 (quite weak piezoelectric response for BNKST0.15). Similar composition-induced pseudocubic structure has also been observed in previous solid solutions with large strain response such as BNT-BT, BNT-BT-KNN, Bi_{0.5}Na_{0.5}TiO₃-Ba(Al_{1/2}Sb_{1/2})O₃, and Bi_{0.5}Na_{0.5}TiO₃-BaTiO₃-SrTiO₃ (BNBST) systems.^{6–8,10,11} In addition, the sintered BNKST*x* ceramics with *x* from 0 to 0.15 have a density range of 5.84–5.96 g/cm³, which is all more than 97% of the corresponding theoretical one, indicating dense microstructure for all the compositions.

Figs. 2 and 3 illustrate the temperature, frequency, and composition dependence of the dielectric constant $(\varepsilon_{33}^T/\varepsilon_0)$ and loss $(\tan \delta)$ for unpoled and poled BNKSTx with x of 0.08, 0.10, 0.13, and 0.15 under 100 Hz-100 kHz. From all the curves, broad dielectric constant peak could be well observed indicating a diffused phase transition behavior, which should be correlated with the multiple complexes in the A-site (such as Bi³⁺, Na¹⁺, K⁺, Sr²⁺, etc.) of perovskite compounds. For the unpoled ceramics shown in Fig. 2, relaxor characteristics with strong frequency dispersion could be observed from the ambient temperature to the temperature around the dielectric shoulder. After poled, in addition to the permittivity-maximum temperature $T_{\rm m}$, depolarization temperature $T_{\rm d}$ can be generally determined from the loss peak as indicated by the arrows in Fig. 3. Compared to the unpoled ceramics, frequency dispersion decreased substantially in poled ones with x < 0.15 below $T_{\rm d}$, indicating the formation of the ferroelectric long-range order with macrodomain structure under the electric field. For BNKST0.15, due to the T_d was shifted to below room temperature, the external poling field could not set up the long-range ferroelectric order and obvious frequency dispersion remained at room temperature. Furthermore, it should be noticed that obvious relaxor characteristics still remained between the $T_{\rm d}$ and the temperature around the dielectric shoulder in the poled BNKST ceramics, indicating a different structure nature. Both the T_m and T_d decreased with x increasing and the corresponding relaxor region also shifted downwards. Some investigations proposed that the antiferroelectric phase was dominant for the relaxor region based on the observation of the double hysteresis loop.¹² Actually, the BNT-based system has a quite complicated compositionand temperature-induced phase transition process and the intrinsic nature for this relaxor region is still controversial.¹³ In order to give a quantitative analysis of the relaxation degree, an empirical formula was utilized as follows:

$$ln(1/\varepsilon - 1/\varepsilon_{\rm m}) + \ln C = \gamma ln(T - T_{\rm m}), \tag{1}$$

where *C* is a material related constant, ε and $\varepsilon_{\rm m}$ correspond to the dielectric constant $\varepsilon_{33}^T/\varepsilon_0$ and the maximum dielectric constant, respectively, and γ is the degree of diffuseness with the value varies in the range from 1 for a normal ferroelectric to 2 for an ideal relaxor ferroelectric.¹⁴ The corresponding value of γ can be obtained from the plot of $ln(1/\varepsilon - 1/\varepsilon_{\rm m})$ vs. $ln(T-T_{\rm m})$ as shown in Fig. 4. It can be seen that the γ of BNKST with *x* of 0.08, 0.1, 0.13, and 0.15 were in the range of 1.84–1.99, indicating relaxor characteristics.



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FIG. 2. Temperature dependence of the dielectric constant $\varepsilon_{33}^T/\varepsilon_0$ and loss tan δ of the unpoled BNKST*x* ceramics with *x* of 0.08, 0.10, 0.13, and 0.15 from 25 °C to 400 °C under the frequency of 100 Hz to 100 kHz.

Fig. 5 shows three representative room-temperature ferroelectric *P*-*E* loops, polarization current density *J*-*E* curves, and electric-field-induced bipolar and unipolar *S*-*E* curves of BNKST0.08, BNKST0.10, and BNKST0.15, respectively. Typical rectangular loop can be observed for the rhombohedral BNKST0.08 with the remnant polarization P_r and coercive field E_c of ~30 μ C/cm² and ~3 kV/mm, respectively. One sharp polarization current peak (denoted as *P*1) ascribed to the typical ferroelectric domain switching could be observed when the applied field reached E_c . The corresponding bipolar strain curve (Fig. 5(b)) exhibited typical butterfly shape ascribed to the ferroelectric domain and domain wall motions. Quasi-linear unipolar strain response with little hysteresis could be simultaneously observed with the normalized strain $S_{\text{max}}/E_{\text{max}}$ (determined from the unipolar strain response under 0.1 Hz) of ~273 pm/V. With the *x* increased to 0.10, even though the BNKST began to exhibit a pseudocubic structure from XRD in Fig. 1(b), typical ferroelectric and strain response can still be observed, indicating the ferroelectric nature only with the E_c shifted to lower field direction. At the moment, the best quasi-static low-field piezoelectric properties were obtained in the BNKST0.10 with d_{33} up to 205 pC/N, electromechanical coupling coefficient k_p of 0.36, and k_t of 0.47. Such results were also comparable to the traditional "hard" PZT ceramics. With *x* further increased to 0.15, obviously pinched *P*-*E* loop can be observed along with an additional polarization current peak (denoted as *P2*). The E_c corresponding to *P*1 was further shifted to lower field



FIG. 3. Temperature dependence of the dielectric constant $\varepsilon_{33}^T/\varepsilon_0$ and loss tan δ of the poled BNKST*x* ceramics with *x* of 0.08, 0.10, 0.13, and 0.15 from 25 °C to 400 °C under the frequency of 100 Hz to 100 kHz.



FIG. 4. A plot of $ln(1/\epsilon - 1/\epsilon_m)$ vs. $ln(T-T_m)$ for BNKST ceramics.

direction and the P2 exhibited a composition independent behavior, suggesting a different physical nature from P1, which was also observed in BNBST system.^{7,15} From Figs. 5(h) and 5(i), the bipolar S-E curve exhibited deformed butterfly shape with the negative strain close to zero. Large strain level of ~0.25% was obtained during the first cycle under a moderate field of 4.4 kV/mm at 0.1 Hz with the S_{max}/E_{max} as high as 585 pm/V. Apart from the remnant strain of ~0.05%, a large reversible strain level of 0.20% could be obtained with the S_{max}/E_{max} of ~480 pm/V as shown in Fig. 5(i). These values were entirely comparable to the recently reported BNT-BT-KNN and BNBST systems.^{6,7} The large electric-field-induced strain would be of great interest in "on-off" actuators.

Based on the above structural analysis and electrical properties, a schematic phase diagram for the poled BNKST solid solution was constructed shown in Figs. 6(a) and 6(b) along with the composition dependence (x from 0 to 0.15shown here) of the ferroelectric, piezoelectric, and electromechanical properties in Figs. 6(c) and 6(d). With the composition x increasing from 0 to 0.15, a critical composition between the ferroelectric long-range-order (rhombohedral) and relaxor (ergodic) pseudocubic phases was proposed at x around 0.15. The corresponding d_{33} increased slightly first from 133 pC/N to 204 pC/N for x < 0.13 then followed a sharp reduction to ~ 9 pC/N with the x increasing to 0.15. The corresponding unipolar reversible strain increased to a maximum value up to $\sim 0.2\%$ at critical composition x of 0.15 with normalized strain $S_{\text{max}}/E_{\text{max}}$ up to 480 pm/V. Meanwhile, the radial electromechanical coupling coefficient $k_{\rm p}$ also first increased to a maximum of 0.36 and decreased rapidly. The k_p for poled BNKST0.15 could not be detected at all because the relaxor (ergodic) pseudocubic was dominant at the moment. The corresponding composition dependence of maximum polarization $P_{\rm m}$, remnant polarization $P_{\rm r}$, and coercive field E_c was shown in Fig. 6(d). At around the critical composition x of 0.15, a sharp decrease in the remnant polarization $P_{\rm r}$ and $E_{\rm c}$ was also observed.

In order to explore the structural reason responsible for the large strain response, PFM, as one of the most powerful nanoscale imaging techniques, was utilized in present work.



FIG. 5. The room-temperature ferroelectric *P-E* loops, polarization current density *J-E* curves, and electric-field-induced *S-E* curves of BNKST0.08, BNKST0.10, and BNKST0.15.



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FIG. 6. The schematic phase diagram for BNBST system and compositiondependent piezoelectric and ferroelectric properties at room temperature.

The surface and domain morphology for the BNKST*x* ceramics was carried out using an atomic force microscope (AFM) mode ((SPA400, Seiko, Japan)). An ac modulating voltage of 4 V at 5.7 kHz was applied to the bottom electrode of the samples and the tip was electrically grounded. Two representative PFM topologies and domain images of BNKST0.10 (Figs. 7(a) and 7(b)) and BNKST0.15 (Figs. 7(c) and 7(d)) were shown. In the piezoresponse images (Figs. 7(b) and 7(d)), dark contrast areas represented domains with downward polarization orientation, while bright contrast represented the opposite case. For BNKST0.10, the contrast was obvious and most of the grain exhibited multidomain states with mixed dark/bright color. In comparison, the BNKST0.15 exhibited quite weak contrast except for a small fraction of



FIG. 7. The topography and piezoresponse images for two representative compositions BNKST0.10 ((a) and (b)) and BNKST0.15 ((c) and (d)).

dark areas around the grain boundary. The introduction of $SrTiO_3$ was found to induce a transformation from typical ferroelectric domain structure to near "non-ferroelectric" state.

Regarding the structural origins for the recently reported BNT-based solid solutions with high strain response under external electric field, Zhang et al. ascribed it to a fieldinduced antiferroelectric (AFE) to ferroelectric (FE) phase transition along with the domain switching contribution.⁶ However, for an AFE-FE phase transition, a volume change should be always accompanied. Jo et al. excluded this assumption through simultaneously monitoring the longitudinal and transverse strain.¹⁶ Hussain et al. considered the high strain originated from the coexistence of the ferroelectric and non-polar phases at room temperature.⁹ Highresolution instruments were also adopted to give an insight into the structural origins. In situ transmission electron microscopy (TEM) study indicated there was no ferroelectric domain in the fresh samples, while reversible lamella domain structure could be induced under external electric field, which also agree with our present PFM results.¹⁷ The X-ray neutron diffraction study indicated after applying the electric field, the BNT-BT-KNN solid solution underwent a phase transition from near-cubic tetragonal (evidenced by the presence of the superlattice reflection from oxygen octahedral tilting) to rhombohedral phase at local scale.¹⁸ As a matter of fact, the BNT-based solid solution has complicated structures. Take the BNT-BT, for example, up to present more than five phase diagram has been proposed and some issues still remain uncertain.^{12,13,19–22} Recent high-resolution X-ray diffraction study even proposed that the well-studied BNT had a monoclinic structure with space group Cc instead of rhombohedral R3c.²³

Here, combined with recently reported TEM,¹⁷ X-ray neutron diffraction results,¹⁸ Raman data,²¹ and our XRD, domain structures, and dielectric spectrum, we consider that the present BNKST with large strain level (such as BNKST0.15) should be regarded as a relaxor ferroelectric state (macroscopically cubic, while non-cubic at nanoscale) at ambient

temperature, which can be summarized and characterized by these features: (a) Cubic structure from the XRD; (b) Noncubic at local scale by high-resolution *in situ* measurement; (c) No visible ferroelectric domain in the fresh samples, however, could be reversibly induced under external field; (d) Relaxor characteristic from the dielectric spectrum for unpoled and poled samples around the ambient temperature; (e) Pinched room-temperature ferroelectric hysteresis loop with little remnant polarization and coercive field; (f) quite weak low-field macroscopic piezoelectric properties and large strain with considerable hysteresis could be induced under external electric field. Actually, it needed to be supplemented that in our present work, a few ferroelectric domain was still visible in BNKST0.15 and further slightly increase in the SrTiO₃ can entirely diminished visible domain structure as expected. The reversible large strain response in BNKST0.15 was suggested to be originated from electric field induced phase transition from the ergodic relaxor pseudocubic state to ferroelectric rhombohedral phase. After field removal, the ergodic relaxor can bring the system back to its original state so as to realize large reversible strain response.

IV. CONCLUSION

In summary, a ternary solid solution BNKST was designed and fabricated, and a schematic phase diagram was established. A critical composition between the relaxor pseudocubic and ferroelectric rhombohedral was induced through introducing SrTiO₃ and a large reversible normalized strain S_{max}/E_{max} up to 585 pm/V was obtained. The high strain level was suggested to be originated from the composition induced structure evolution from the ergodic relaxor state to ferroelectric phase under external electric field. The proposed BNKST system shows great potential in environmentally friendly "on-off" actuators.

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- ¹J. Rödel, W. Jo, T. P. K. Seifert, E. M. Anton, T. Granzow, and D. Damjanovic, J. Am. Ceram. Soc. **92**, 1153 (2009).
- ²Y. Saito, H. Takao, T. Tani, T. Nonoyama, K. Takatori, T. Homma, T. Nagaya, and M. Nakamura, Nature 432, 84 (2004).
- ³T. Takenaka, H. Nagata, and Y. Hiruma, Jpn. J. Appl. Phys., Part 1 47, 3787 (2008).
- ⁴Y. Hiruma, K. Yoshii, H. Nagata, and T. Takenaka, J. Appl. Phys. **103**, 084121 (2008).
- ⁵W. F. Liu and X. B. Ren, Phys. Rev. Lett. **103**, 257602 (2009).
- ⁶S. T. Zhang, A. B. Kounga, E. Aulbach, H. Ehrenberg, and J. Rödel, Appl. Phys. Lett. **91**, 112906 (2007).
- ⁷F. F. Wang, M. Xu, Y. X. Tang, T. Wang, W. Z. Shi, and C. M. Leung, J. Am. Ceram. Soc. **95**, 1955 (2012).
- ⁸Y. Hiruma, H. Nagata, and T. Takenaka, Appl. Phys. Lett. **95**, 052903 (2009).
- ⁹A. Hussain, C. W. Ahn, J. S. Lee, A. Ullah, and I. W. Kim, Sens. Actuators, A 158, 84 (2010).
- ¹⁰J. E. Daniels, W. Jo, J. Rödel, and J. L. Jones, Appl. Phys. Lett. 95, 032904 (2009).
- ¹¹W. Jo, J. E. Daniels, J. L. Jones, X. Tan, P. A. Thomas, D. Damjanovic, and J. Rödel, J. Appl. Phys. **109**, 014110 (2011).
- ¹²T. Takenaka, K. Maruyama, and K. Sakata, Jpn. J. Appl. Phys., Part 1 30, 2236 (1991).
- ¹³W. Jo and J. Rödel, Appl. Phys. Lett. **99**, 042901 (2011).
- ¹⁴K. Uchino and S. Nomura, Ferroelectr., Lett. Sect. 44, 55 (1982).
 ¹⁵F. F. Wang, M. Xu, C. M. Leung, Y. X. Tang, T. Wang, X. M. Chen, and
- W. Z. Shi, J. Mater. Sci. 47, 282 (2012). ¹⁶W. Jo, T. Granzow, E. Aulbach, J. Rodel, and D. Damjanovic, J. Appl.
- Phys. **105**, 094102 (2009).
- ¹⁷J. Kling, X. Tan, W. Jo, H.-J. Kleebe, H. Fuess, and J. Rödel, J. Am. Ceram. Soc. **93**, 2452 (2010).
- ¹⁸M. Hinterstein, M. Knapp, M. Hölzel, W. Jo, A. Cervellino, H. Ehrenberg, and H. Fuess, J. Appl. Cryst. 43, 1314 (2010).
- ¹⁹Y. Hiruma, Y. Watanabe, H. Nagata, and T. Takenaka, Key Eng. Mater. 350, 93 (2007).
- ²⁰C. Ma, X. Tan, E. Dul'kin, and M. Roth, J. Appl. Phys. **108**, 104105 (2010).
- ²¹B. Wylie-Van Eerd, D. Damjanovic, N. Klein, N. Setter, and J. Trodahl, Phys. Rev. B 82, 104112 (2010).
- ²²J. Yao, L. Yan, W. Ge, L. Luo, J. Li, and D. Viehland, Phys. Rev. B 83, 054107 (2011).
- ²³E. Aksel, J. S. Forrester, J. L. Jones, P. A. Thomas, K. Page, and M. R. Suchomel, Appl. Phys. Lett. 98, 152901 (2011).

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