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Electric Field-Induced Changes in the Ferroelastic Behavior of $(Na_{1/2}Bi_{1/2})TiO_3$-$BaTiO_3$

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Abstract

In this study, the macroscopic mechanical behavior was characterized for poled and unpoled polycrystalline $(1-x)(Na_{1/2}Bi_{1/2})TiO_3$-$x$$BaTiO_3$ (NBT-*x*BT) for compositions across the morphotropic phase boundary (MPB). Due to a field-induced ferroelectric phase transformation, NBT-*x*BT compositions near the MPB (x = 6 – 7 mol%) showed a significant decrease in the coercive stress for electrically poled samples. The apparent difference in mechanical behavior is suggested to be due to an irreversible electric-field-induced transformation to long-range ferroelectric order in the poled samples. The results indicate a significant difference in the critical stresses for the relaxor-ferroelectric transition and ferroelastic domain wall motion, which can have important effects on applications for lead-free ferroelectrics. To further illustrate this, a method was developed to electrically depole NBT-*x*BT at room temperature, resulting in an unpoled NBT-*x*BT material with long-range ferroelectric order. Mechanical testing revealed analogous macroscopic ferroelastic behavior to the poled samples, despite the lack of a piezoelectric response.

Keywords: Electrical depoling; Ferroelastic Properties; Dielectric, Properties; Lead-Free

1. Introduction

Piezoelectric materials have been implemented in various engineered structures and devices for their electromechanical coupling. Current transducer applications, such as sensors and actuators, are primarily based on the lead zirconate titanate ($Pb(Zr_{1-x}Ti_x)O_3$, PZT) system [1–3]. However, over the last few decades, regulations on the restriction of the use of hazardous substances in electronic devices [2,4] has led to intensive research efforts to identify lead-free piezoelectric alternatives[5]. The candidates with the most potential are based on $BaTiO_3$ (BT) [6,7], $K_xNa_{1-x}NbO_3$ (KNN) [8], and $Na_{1/2}Bi_{1/2}TiO_3$ (NBT)[9]. From these promising candidate systems, NBT-based materials have displayed the largest unipolar strain response [10–14], making them potentially useful for actuator applications.

Among the various NBT-based compositions, solid solutions of $(1\text{-}x)Na_{1/2}Bi_{1/2}TiO_3$-$x$$BaTiO_3$ (NBT-*x*BT) and related pseudo-ternary compositions, such as $(1\text{-}x\text{-}y)Na_{1/2}Bi_{1/2}TiO_3$-$x$$BaTiO_3$-$y$$K_{0.5}Na_{0.5}NbO_3$ (NBT-*x*BT-*y*KNN), have been the most widely investigated [5]. This is due to the excellent large field strain response observed near the morphotropic phase boundary (MPB) that separates the ferroelectric rhombohedral ($R3c$) and ferroelectric tetragonal ($P4mm$) phases at a BT content of approximately 6 − 7 mol% at room temperature [10,15–17]. Like the lead-containing counterpart PZT, NBT-*x*BT materials show their largest electromechanical response at the MPB, with piezoelectric coefficients d_{33} of about 150 pC/N. In comparison to PZT, however, the enhanced large field electromechanical behavior/response is understood to be due to an electric field-induced