ARTICLE IN PRESS

Ceramics International xxx (xxxx) xxx

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

High energy storage performance of (1-x)(0.96$K_{0.48}Na_{0.52}NbO_3$-0.04$BaZrO_3$)-$x$$Bi_{5/6}In_{0.5}Sn_{0.5}O_3$ ceramics via a combined strategy of fine grains and multiphase regulation

Long Yang [a,b], Yuanyuan Wang [a,*], Alexander Korotkevich [c], Lei Cao [a,b,**], Minmin Mao [a], Xueqing Yu [a], Bing Liu [a], Matjaz Spreitzer [d], Mikhail P. Kuz'min [e], Kaixin Song [a,***]

[a] College of Electronic Information and Engineering, Hangzhou Dianzi University, Hangzhou, 310018, China
[b] Key Laboratory of Micro-nano Sensing and IoT of Wenzhou, Wenzhou Institute of Hangzhou Dianzi University, Wenzhou, 325038, China
[c] Belarusian State University of Informatics and Radioelectronics, 6 P.Brovki street, 220013, Minsk, Belarus
[d] Advanced Materials Department, Jozef Stefan Institute, Ljubljana, 1000, Slovenia
[e] Department of Non-ferrous Metals, Irkutsk National Research Technical University, 83 Lermontov St, Irkutsk, Russia

ARTICLE INFO

Handling Editor: Dr P. Vincenzini

Keywords:
Dielectric ceramics
Energy storage performance
Multiphase regulation
Grain refinement

ABSTRACT

Dielectric ceramics have been the subject of considerable interest due to their high-power density. Nevertheless, the primary impediments to their practical implementation are the low energy storage density and efficiency. In this study, 0.96$K_{0.48}Na_{0.52}NbO_3$-0.04$BaZrO_3$(KNNBZ) ceramics doped with different ratios of $Bi_{5/6}In_{0.5}Sn_{0.5}O_3$(BIS) were prepared. The KNNBZ-0.15BIS ceramics exhibited superior energy storage performance, with a recoverable energy storage density of 4.16 J/cm^3, a breakdown strength of 550 kV/cm, and an energy storage efficiency of 88.4 %. The substitution of ions with different radii and valence states for equivalent sites (A or B sites) in the ceramic results in the coexistence of rhombohedral phase, orthorhombic phase, tetragonal phase, and cubic phase, as well as the emergence of polyphase polar nanoregions. This lattice distortion and chemical disorder lead to the formation of small-sized polar nanoregions and an elongated *P-E* loop. Concurrently, the elevated resistivity and ultra-fine grain of the ceramics markedly enhance the breakdown strength. This study employs a strategy of multiphase regulation and grain refinement to demonstrate the potential of KNNBZ-xBIS ceramics as candidate materials for lead-free energy storage ceramics.

1. Introduction

The progress of high energy density capacitors has appealed to significant attention from the scientific and engineering communities, driven by the growing demand for electric vehicles, pulsed power systems and medical devices. Dielectric ceramics represent a significant class of functional materials, and are the most commonly utilized materials in the construction of energy storage capacitors [1–5]. Electric energy in dielectric capacitors is stored and released through electrostatic polarization and depolarization under loading and unloading electric fields. Consequently, in comparison with alternative energy storage techniques, dielectric capacitors exhibit a rapid charging and discharging capability, coupled with a high power density [6,7]. Nevertheless, the energy density remains significantly lower than that of chemical batteries, limiting their broader usage in electronic devices that demand miniaturization and integration[8–12]. In general, the energy storage density (W), recoverable energy storage density (W_{rec}), and energy storage efficiency (η) of dielectric capacitors can be got using the Eqs [13]:

$$W = \int_0^{P_{max}} EdP \tag{1}$$

$$W_{rec} = \int_{P_r}^{P_{max}} EdP \tag{2}$$

* Corresponding author.
** Corresponding author. College of Electronic Information and Engineering, Hangzhou Dianzi University, Hangzhou, 310018, China.
*** Corresponding author.
E-mail addresses: wangyuanyuan6140@163.com (Y. Wang), LeiC@hdu.edu.cn (L. Cao), kxsong@hdu.edu.cn (K. Song).

https://doi.org/10.1016/j.ceramint.2025.05.310
Received 13 February 2025; Received in revised form 16 May 2025; Accepted 21 May 2025
Available online 21 May 2025

Please cite this article as: Long Yang et al., *Ceramics International*, https://doi.org/10.1016/j.ceramint.2025.05.310