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Phase evolution and piezoelectric properties of SnO_2 doped KNN based piezoceramics

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ABSTRACT

The present research focuses on the electrical properties of lead-free piezoceramics $(0.985\text{-}x)(K_{0.485}Na_{0.485}Li_{0.03})(Nb_{0.96}Sb_{0.04})O_3\text{-}0.015(Bi_{0.5}Na_{0.5})ZrO_3\text{-}xSnO_2$ (KNNLS-BNZ-$xSnO_2$, $x = 0.003$, 0.006, 0.009, 0.012, and 0.015). This study examines the influence of varying SnO_2 doping levels on the microstructure and piezoelectric properties of the ceramics. All the ceramics prepared demonstrate pure perovskite structure without any secondary phases. The Rietveld refinement analysis of XRD data reveals the existence of multiphase evolution around room temperature. The tetragonality (c/a) and cell volume of the ceramics tend to rise with an increase in Sn^{4+} content, potentially leading to improved ferroelectric characteristics. The optimum values obtained were Curie temperature (T_c) = 395 °C, remnant polarization (P_r) = 21.07 μC/cm^2, piezoelectric coefficient (d_{33})=357 pC/N, piezoelectric voltage constant (g_{33}) = 24 × 10^{-3} Vm/N, and figure of merit (FOM_{off}) = 10.34 pm^2/N, corresponding to the ceramic doped with $x = 0.012$ SnO_2. The findings indicate that an optimal amount of Sn^{4+} in the host composition KNNLS-BNZ improves piezoelectric properties by constructing an R-O-T phase boundary near room temperature. This study suggests that the ceramic with $x = 0.012$ SnO_2 exhibits a favorably high T_c coupled with an exceptional energy harvesting capability, making it a suitable candidate for energy harvesting applications.

1. Introduction

Piezoelectric materials comprise a significant category of smart materials that plays a crucial role in electromechanical devices, including piezoelectric actuators, sensors, ultrasonic medical imaging devices, structural health monitoring systems, and piezoelectric energy harvesting units. These materials possess the ability to convert mechanical energy into electrical energy or vice versa [1–3]. Piezoelectric energy harvesting devices are gaining importance due to the rise in the demand for nonconventional power sources in the past two decades [4]. The harvesting of energy from surrounding sources with a view to negate the necessity for batteries or increase their lifespan has emerged as a prominent area of interest among researchers [5]. Piezoelectric harvesting systems offer a sustainable power supply that requires very little maintenance and replacement [6].

Commercially utilized piezoelectric ceramics are primarily $Pb(Zr_{1-x}Ti_x)O_3$ (PZT)-based materials, which offer outstanding piezoelectric performance, and their preparation method is well established [7–10]. However, several countries have implemented restrictive laws and regulations against the use of these materials as they contain significant amount of toxic element 'lead' which causes severe harm to human health and environment. The EU enacted the "WEEE" and "ROHS" Acts 2006, with the aim of limiting the production and consumption of lead-containing piezoelectric materials and devices [11,12]. As a result, lead-free piezoelectric ceramics have gained importance in the field of electromechanical technology [11–13]. Among the lead-free alternatives, KNN-based piezoelectric ceramics have attracted enormous attention owing to their lower sintering temperature, relatively high electrical characteristics and significantly high Curie temperature (T_c). Ever since their development, KNN-based ceramics have been finding

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