

Enhanced piezoelectric properties and excellent thermal stabilities of cobalt-modified Aurivillius-type calcium bismuth titanate ($\text{CaBi}_4\text{Ti}_4\text{O}_{15}$)



Tian-Long Zhao^a, Chun-Ming Wang^{a,*}, Chun-Lei Wang^a, Yi-Ming Wang^a, Shuxiang Dong^b

^a School of Physics, State Key Laboratory of Crystal Materials, Shandong University, Jinan 250100, People's Republic of China

^b Department of Materials Science and Engineering, College of Engineering, Peking University, Beijing 100871, People's Republic of China

ARTICLE INFO

Article history:

Received 4 March 2015

Received in revised form 8 July 2015

Accepted 19 August 2015

Available online 29 August 2015

Keywords:

Piezoelectric ceramics

Bismuth layer-structured ferroelectrics (BLSFs)

High temperature applications

Calcium bismuth titanate ($\text{CaBi}_4\text{Ti}_4\text{O}_{15}$)

ABSTRACT

Bismuth layer-structured ferroelectric (BLSF) calcium bismuth titanate ($\text{CaBi}_4\text{Ti}_4\text{O}_{15}$, CBT) piezoelectric ceramics with 0.0–1.0 wt.% cobalt oxide (Co_2O_3) have been prepared via a conventional solid-state reaction method. Microstructural morphology and electrical properties of cobalt oxide-modified CBT ceramics were investigated in detail. X-ray powder diffraction (XRPD) analysis revealed that the cobalt oxide-modified CBT ceramics have a pure four-layer Aurivillius-type structure. The piezoelectric properties of CBT ceramics were significantly enhanced by cobalt oxide modifications. The piezoelectric coefficient d_{33} and Curie temperature T_c of 0.2 wt.% cobalt oxide-modified CBT ceramics (CBT-Co4) are 14 pC/N and 782 °C, respectively. The DC resistivity and thermal depoling behavior at elevated temperature indicated that the CBT-Co4 ceramics exhibit good thermal stability, demonstrating that the CBT-Co4 ceramics are potential materials for high temperature piezoelectric applications.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

The Aurivillius family of bismuth layer-structured ferroelectric (BLSF) ceramics encompasses many promising materials of potential use in sensing technology of piezoelectric devices under high temperature, such as filters, sensors, and oscillators [1,2]. Structurally, the general formula of BLSFs is $(\text{Bi}_2\text{O}_2)^{2+}(\text{A}_{m-1}\text{B}_m\text{O}_{3m+1})^{2-}$, where A is a mono-, di- or trivalent element (or their combination) suited to dodecahedral coordination; B is a transition element suited to octahedral coordination; m is an integer which represents the number of BO_6 octahedra in $(\text{A}_{m-1}\text{B}_m\text{O}_{3m+1})^{2-}$ between the $(\text{Bi}_2\text{O}_2)^{2+}$ layers, usually in the range of 1–5 [3–5]. Electrically, the piezoelectric properties of BLSFs are strongly dependent on the value of m and the pseudo-perovskite blocks between the $(\text{Bi}_2\text{O}_2)^{2+}$ layers as well as the chemical elements in the A and B sites. The BLSFs present relatively low dielectric constant, low aging rate, strong anisotropic electromechanical coupling factors and low temperature coefficient of resonant frequency [6,7]. These features, together with their high Curie temperature (T_c), make

BLSFs attractive in high temperature and high frequency piezoelectric sensor applications. However, the piezoelectric activity (d_{33}) in BLSFs ceramics is found to be still relatively low [8–16], because of the difficulty in the poling process of the BLSFs ceramics which requires relatively high electric field due to the high coercive fields (E_c) and the two-dimensional orientation restriction of the rotation of the spontaneous polarization (P_s) in the BLSFs ceramics [17].

Calcium bismuth titanate, $\text{CaBi}_4\text{Ti}_4\text{O}_{15}$ (CBT), a member of Aurivillius-type materials with $m=4$, is characterized by its high Curie temperature ($T_c \sim 780^\circ\text{C}$) and low dielectric loss, showing potential applications for high temperature piezoelectric sensor. However, the prototype CBT ceramics are greatly difficult to be poled and exhibit very low piezoelectric activities ($d_{33} \sim 7 \text{ pC/N}$), as well as high conductivity at elevated temperature [18]. To overcome these shortcomings, many efforts have been paid to improve the ferroelectric and piezoelectric of CBT ceramics, including A-site [19–21], B-site modification [22,23], grain orientation techniques [24], etc. In these studies, A-site substitution is more effective than B-site substitution because the cations in B-site have the similar in size and hardly make a major contribution to the polarization process. Consequently, most reports on enhancing the ferroelectric and piezoelectric properties of CBT ceramics are concentrated on A-site rather than B-site modification. However, A-site modification usually leads to a drop of T_c , whereas the advantage of

* Corresponding author. Tel.: +86 138 6914 4988; fax: +86 531 88377031.
E-mail address: wangcm@sdu.edu.cn (C.-M. Wang).

high T_c to Aurivillius compounds is not sacrificed by B-site modification. In addition, B-site cations are located at the center of oxygen octahedra, any slight change in the radius of a B-site cation may also play a major structural role in the polarization process, and B-site modification usually decreases the high-temperature conductivity. It has been reported that the modification by acceptor manganese is an effective way to improve the piezoelectric properties and decrease the high-temperature conductivity of CBT ceramics [22]. Recently, a remarkable increase in the piezoelectric properties was reported for cobalt-doped $\text{Na}_{0.5}\text{Bi}_{4.5}\text{Ti}_4\text{O}_{15}$ piezoelectric ceramics [25]. Since CBT ceramics have the similar crystalline structure with the $\text{Na}_{0.5}\text{Bi}_{4.5}\text{Ti}_4\text{O}_{15}$ ceramics, one can expect that acceptor cobalt modification could also improve the piezoelectricity and electrical resistivity of CBT ceramics. In this paper, the effects of the cobalt oxide modification on the dielectric, ferroelectric and piezoelectric properties of CBT ceramics are studied.

2. Experimental procedure

The Aurivillius-type CBT ceramic samples with cobalt modification were prepared by conventional solid state reaction method. The analytical grades CaCO_3 (99.8%), Bi_2O_3 (99.8%), and TiO_2 (99.9%) were selected as raw materials (all the raw materials are from Sinopharm Chemical Reagent Co., Ltd, China) and weighed according to the stoichiometric proportion compositions of $\text{CaBi}_4\text{Ti}_4\text{O}_{15}$. The mixed oxide were ball milled using ZrO_2 balls in ethanol medium for 12 h, then the milled powders were burned at 800°C for 3 h. Cobalt was added in the form of Co_2O_3 (99%) to the mixture according to the following compositions: $\text{CBT} + x \text{ wt.}\% \text{Co}_2\text{O}_3$, (where $x=0, 0.1, 0.2, 0.3, 0.4, 0.5$, and 1.0 , abbreviated as CBT, CBT-Co2, CBT-Co4, CBT-Co6, CBT-Co8, CBT-Co10 and CBT-Co20, respectively). After ball milled again, the mixture was dried, ground, and granulated with polyvinyl alcohol (PVA) binder. The granulated powder was pressed into pellets with 15 mm in diameter and 2.0 mm in thickness at a pressure of 120 MPa. These disks were sintered at $1100\text{--}1150^\circ\text{C}$ for 3 h by the ordinarily fired method and then cooled down to room temperature freely. Some of them were polished to a thickness of about 0.8 mm.

The phase structure of the sintered samples was analyzed by X-ray powder diffraction (named XRPD) technology with $\text{Cu K}\alpha_1$ radiation (D8 Advance, Bruker AXS GmbH). The surface microstructure of the sintered ceramics was observed by scanning electron microscopy (SEM, S-4800, Hitachi, Tokyo, Japan). Samples for electrical measurements were polished parallel and electroded with silver paste on both surfaces of the polished samples, and then fired at 570°C for 20 min. Samples were poled in silicone oil under a DC electric field of 10 kV/mm at 180°C for 20 min. The piezoelectric coefficient d_{33} was measured using a quasi-static d_{33} meter (YE2730A, Institute of Acoustics, Beijing, China). The dielectric properties of these ceramics were measured using an Agilent 4294A impedance analyzer according to IEEE standards. The electric-field driven strains were measured using a standard ferroelectric test system (TF Analyzer 2000 FE-Module). Temperature dependence of DC resistivity was measured using a Digit Multimeter of a 2-Wire Resistance Measurement (Model 34410A 6.5, Agilent) at heating rates of $2^\circ\text{C}/\text{min}$ with the heating system refitted from the sintering furnace. The polarization hysteresis and the field induced strain curve were measured by the system (aixACCT TF Analyzer 1000, aixACCT, Aachen, Germany) with a high voltage amplifier (TREK 610E, 10 kV, TREK, Medina, NY). The dielectric spectrum measurements were performed with a 4294A impedance analyzer (Agilent) as a function of temperature. Thermal annealing experiments were conducted by holding the poled samples at specific temperatures for 1 h. Finally, the thermal annealed samples were cooled to room temperature, and d_{33} was subsequently measured.

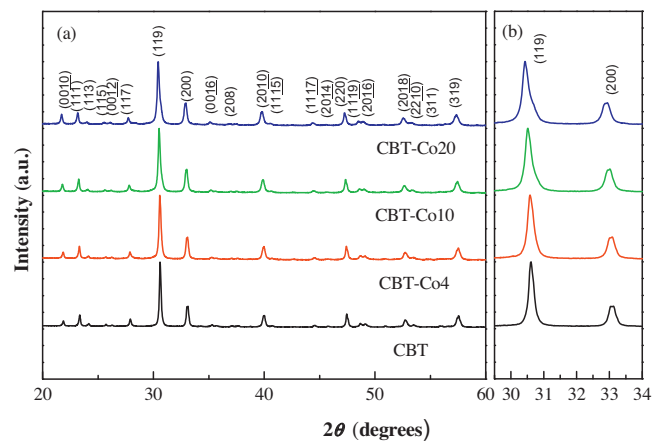


Fig. 1. (a) Room temperature X-ray diffraction patterns of the CBT-based piezoelectric ceramic powder sintered at 1100°C . From bottom to top: CBT, CBT-Co4, CBT-Co10, and CBT-Co20. (b) The variation trend of the selected peak (119) and (200), from bottom to top: CBT, CBT-Co4, CBT-Co10, and CBT-Co20.

3. Results and discussion

Fig. 1(a) presents the XRPD patterns of the cobalt oxide-modified CBT piezoelectric ceramic powder sintered at 1100°C , from bottom to top: CBT, CBT-Co4, CBT-Co10, and CBT-Co20, respectively. It can be seen that the highest intensity of diffraction peak locates at the (119) peak for all XRPD patterns, which is consistent with the fact that the most intense reflections of BLSFs are all of the type of $(112m + 1)$ [26,27]. All the diffraction patterns are in agreement with the diffraction data for the CBT, and no secondary phase has been detected, indicating that the cobalt oxide modification does not change the crystal structure of CBT ceramics. Furthermore, from the selected peak (119) and (200) shown in Fig. 1(b), it can be obviously seen that the diffraction peak shifts slightly toward lower angles with the increasing of x , indicating that the introduction of Co ions into the CBT materials results in slight crystal distortion.

Based on the XRPD patterns, the lattice parameters (a , b , and c) are determined and shown in Fig. 2. It can be clearly seen that the lattice parameters increase linearly with the increasing of Co content. It has been reported that the Co ions exist in the solid solutions as Co^{2+} during the sintered temperature range from 1080 to 1120°C [28]. In this work, the cobalt oxide-modified CBT ceramic samples are sintered at 1100°C , so the Co ions will also be in the

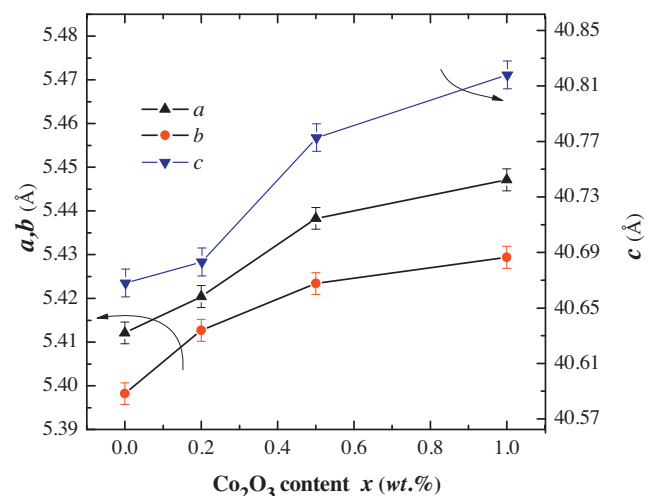


Fig. 2. Lattice parameters as a function of Co_2O_3 content x .

Download English Version:

<https://daneshyari.com/en/article/1528498>

Download Persian Version:

<https://daneshyari.com/article/1528498>

[Daneshyari.com](https://daneshyari.com)