Structural evolution and electrical characteristics of Sn-doped Ba$_{0.8}$Sr$_{0.2}$TiO$_3$ ceramics

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ABSTRACT

(Ba$_{0.8}$Sr$_{0.2}$)(Ti$_{1−x}$Sn$_x$)O$_3$ (BSTS) perovskite structure ferroelectric ceramics with different compositions ($x$=0; 0.03; 0.05; 0.07; 0.10 and 0.20) were synthesized by a conventional high temperature solid-state reaction. X-ray diffraction (XRD) study allowed the identification of a pure solid solution with average tetragonal symmetry for $x≤0.05$ and cubic for $x=0.07$ at room temperature (RT). Especially, for the composition $x=0.05$, a coexistence of tetragonal (P4mm) with dominating fraction close to 88.84% and cubic (Pm3m) (11.16%) phases was determined in powder by Rietveld refinement. The local structures of the BSTS samples were studied by Raman spectroscopy, which shows a small fraction of rhombohedral phases for Sn-rich compositions ($x=0.05$) at RT. Dielectric analysis show a diffuse phase transition for $x=0.05$, the dielectric permittivity become three time better than that of pure (Ba$_{0.8}$Sr$_{0.2}$)TiO$_3$ and when $x=0.20$, the material change from normal ferroelectric to a typical relaxor ferroelectric. Macroscopic Polarization-field loops measured at RT illustrate a decreasing of the polarization at the maximum field of 3 kV/mm from 14.31 to 1.35 µC/cm$^2$ confirming XRD and dielectric studies.

1. Introduction

Ferroelectrics materials are characterized by adaptable spontaneous polarization. Depending on the composition, they can exhibit excellent dielectric and piezoelectric properties, and high electrocaloric effect [1–4]. Due to their non toxicity, BaTiO$_3$ (BT) -based ceramics obtained by A and/or B sites isovalent substitutions still one of the more extensively studied perovskite (ABO$_3$) ferroelectric systems.

Barium strontium titanate (Ba, Sr)TiO$_3$ (BST) represents one of the most favorable ferroelectric largely used in engineering applications such as multilayer ceramic capacitors, transducers, tunable microwave, dynamic and non-volatile random access memories [5–10]. The main interest is to have high dielectric permittivity combined with small losses and controllable Curie Temperature $T_C$ by adjusting the mole fraction of Ba$^{2+}$/Sr$^{2+}$. With increasing the strontium content, the phase transition temperatures $T_C$ decreases linearly and all phase transitions typical of BT compound (rhombohedral (R) – orthorhombic (O) – tetragonal (T) – cubic (C)) are observed until 80% of Sr$^{2+}$ concentration [11]. In particular, (Ba$_{0.8}$Sr$_{0.2}$) TiO$_3$ (BST0.2) show a noncentrosymmetric tetragonal structure at RT with a sharp phase transition at $T_C=60$ °C [12].

On the other hand, investigation of the effects of the substitution of Ti$^{4+}$ by Sn$^{4+}$ on the structural and dielectric properties of BT compounds are reported in the literature [13–16]. In fact, it is observed that the phase transition of Ba(Ti, Sn)O$_3$ (BTS) becomes diffuse as displayed by significant deviation from the Curie–Weiss and exhibit a relaxor behavior for large tin content ($x=0.20$) [17]. Thus, broadening of the peak of the dielectric permittivity in a wide working temperature range is accompanied by enhancement of its level, and both being useful for applications. Currently, few works in the literature have reported on the effect of the substitution of Ti$^{4+}$ by Sn$^{4+}$ ions in the BST lattice [18,19]. As a consequence, it is reported in this paper the influence of Sn doping on structural, dielectric and ferroelectric properties of BST0.20 material. (Ba$_{0.8}$Sr$_{0.2}$)(Ti$_{1−x}$Sn$_x$)O$_3$ with $x=0$; 0.03; 0.05; 0.07; 0.10 and 0.20 were prepared by the solid-state technique. These ceramics were structurally characterized by XRD and Raman spectroscopy. The other properties were investigated through the complex dielectric permittivity and macroscopic P (E) loops measurements.

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2. Experimental procedure

Stoichiometric Ba_{0.8}Sr_{0.2} (Ti_{1-x}Sn_{x}) O_3 with (x=0, 0.03; 0.05, 0.07, 0.10, 0.20) were synthesized by the conventional mixed oxide way using BaCO_3 (> 99%), SrCO_3 (> 99%), TiO_2 (> 99%) and SnO_2 (> 99%) high purity raw materials. The powders were weighed, milled in an agate mortar with alcohol and calcined at 1150 °C for 12 h in air. After calcination, 5% wt of polyvinyl alcohol (PVA) was added to the calcined powders as a binder, and the mixture was desiccated at 70 °C for 1 h. Pellets were cut into the size of 8 mm in diameter and 10 mm in thickness, burned out up to 600 °C to remove PVA, sintered at 1400–1450 °C depending to Sn content for 3 h in the air and then they were slowly cooled at the normal cooling rate of the furnace.

XRD analysis was performed to identify the phases in the synthesized powders. The XRD data were recorded at RT on a Philips diffractometer using Cu Kα radiation. The diffraction measurements were done from 10° to 80° 2θ, with a scan step increment of 0.02°.

Being X-ray diffraction sensitive to the long-range ordering (average symmetry), Raman spectroscopy was performed on all samples over a wide temperature range to supply information about the local symmetry (short-range ordering) and the possible phase superposition (coexistence). All the spectra were obtained by way of a Raman spectrometer (HORIBA Jobin-Yvon Labram, HRT 4600 h 800) using the He–Ne laser excitation line of 632.8 nm (1.96 eV) focused on the investigated point of sample surface allowing the laser beam spot width to be 2 μm. The spectra were collected in normal and side-view backscattering geometry using a furrier-cooled Charged Coupled Device (CCD) camera. Temperature-dependent Raman experiments were performed with a Linkam TP94.

The dielectric constant change of various specimens according to the temperature and Sn contents was measured using Solartron SI-1255 frequency response analyzer and 1296 dielectric interface. Measurements below RT were carried out with an optistat DN Oxford cryostat and an Oxford ITC503 temperature controller. BSTS ceramic disks were electroded with Ag pastes. Polarization versus electric fields. The working frequency was fixed to 1 Hz.

3. Results and discussion

3.1. Phases investigation

XRD patterns of BSTS for x=0, 0.03, 0.05, 0.07, 0.10 and 0.20 recorded at RT are shown in Fig. 1a. The diffraction patterns were refined using the Fullprof software in pattern matching mode [20]. All the ceramics possess typical BT perovskite structure without parasitic peaks. This demonstrated that the solid state reaction was completed and homogeneous. The partial replacement of Ti^{4+} (ionic radius 0.605 Å) by Sn^{4+} (ionic radius 0.690 Å) induces a shift of the main reflections toward lower 2θ values with the increase of Sn content (Fig. 1b), that prove the total incorporation of Sn into the perovskite lattice. The recorded patterns indicate that an increase of the Sn content in the BST0.2 material result in a structural T to C transition. The values of lattice parameters a and c, the unit-cell volume and a decrease of ferroelectric to paraelectric phase transition temperature $T_c$.

The unit-cell parameters and cell volume for BSTS ceramics with x=0–0.20.

Table 1

<table>
<thead>
<tr>
<th>X</th>
<th>Unit-cell parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a (Å)</td>
</tr>
<tr>
<td>0</td>
<td>3.9806</td>
</tr>
<tr>
<td>0.03</td>
<td>3.9863</td>
</tr>
<tr>
<td>0.05</td>
<td>3.9914</td>
</tr>
<tr>
<td>0.07</td>
<td>3.9711</td>
</tr>
<tr>
<td>0.10</td>
<td>3.9952</td>
</tr>
<tr>
<td>0.20</td>
<td>4.0078</td>
</tr>
</tbody>
</table>
perature was determined based on the dielectric data presented in the next section: \( T_C = 25 \text{°C} \). It is found then, for \( x = 0.05 \), a mixture consisting of a predominant T phase (88.84\%) and a C phase (11.16\%) with \( \text{Pm} 3\text{m} \) symmetry. This is characteristic of second order phase transition for which the ferroelectric phase transition occurs in a broader temperature range. Then, the isovalent substitution of \( \text{Ti}^{4+} \) by \( \text{Sn}^{4+} \) ions shifts the first order character of BSTO.2 [25] towards a second order one, as reported previously by Yusuda et al. for BTS ceramics [26].

3.2. Raman spectroscopy study

The spectrum of pure BT was used as the starting point for any interpretation of Raman response in BT-based solid solutions. In the paraelectric C phase of BT with 5 atoms per primitive cell, there are 12 optic degrees of freedom that convert according to the triply degenerate irreducible representations of the \( \text{O}_h \) point group: \( \Gamma_{\text{opt}} = 3F_1u + F_{2u} \). The \( F_{1u} \) modes are only infrared active while \( F_{2u} \) is the so-called silent mode, since it is neither infrared nor Raman active. In the T ferroelectric phase (space group \( \text{Cm} 3 \)), \( F_{1u} \) mode splits into \( A_1 + E \) modes, while the \( F_{2u} \) splits into \( B_1 + E \) modes. The factor group analysis predicts \( 3A_1 \) (xx, yy, zz)+\( 4E \) (xz, yz)+\( B_1 \) (xx, yy) phonons. The \( A_1 \) and \( E \) modes are both Raman and infrared active, while the \( B_1 \) mode is only Raman active. Long-range electrostatic forces associated with lattice ionicity split the \( E \) and \( A_1 \) modes into transverse (TO) and longitudinal (LO) components. When transition changes from T to O (Amm2), optical vibrations belong to \( A_1, A_2, B_1 \) and \( B_2 \) symmetry. The lowest O to R (\( \text{R} m3 \)) phase transition, results in \( 3A_1 + A_2 + 4E \) modes, where \( A_1 \) and \( E \) modes are Raman active [27].

RT depolarized Raman spectra of \( \text{Ba}_{0.8}\text{Sr}_{0.2} \text{(Ti}_{1-x} \text{Sn}_{x})\text{O}_3 \) for various \( x \) values are plotted in Fig. 3. For \( x = 0 \), the Raman spectrum exhibits all the features inherent in the T BT crystal as reported previously by Kuo et al. [28]. For \( x = 0.05 \), the presence of an interference effect at \( 180 \text{ cm}^{-1} \), which occurs only in the T phase [29], the sharp “silent” mode at \( 309 \text{ cm}^{-1} \) related to the \( B_1 \), \( E \) (TO, LO) phonon modes and the mode at \( 749 \text{ cm}^{-1} \) due to the \( A_1 \), \( E \) (LO) is a signature of a long range T symmetry [30,31]. By increasing the Sn content, a progressive damping of all modes until their complete disappearance for \( x = 0.20 \) establishes a ferroelectric–paraelectric crossover. Then, it is obvious that for higher Sn content \( x \geq 0.07 \), the material is in a C paraelectric state. Two broad bands centered at \( 235 \) and \( 532 \text{ cm}^{-1} \) are assigned to the \( A_1 \) (TO) phonon mode. They persisted also in the C phase which is related to the presence of short-range cationic distortions that induce polar nano-regions (PNRs) in the structures [32].

The R phase is characterized specially by sharpening and splitting of the Raman modes that occur at low wavenumbers (\( \leq 200 \text{ cm}^{-1} \)) [33]. Therefore, the onset of sharp dip at \( 125 \text{ cm}^{-1} \) in the Raman spectra for Sn-rich compounds (\( x = 0.05-0.20 \)) confirms the presence of R-BT structure with small fractions at RT in these compounds. This can be interpreted by the disorder of Sn element introduced in the structure of BSTO.2, that is to say the effect of NPRs which still present above the temperature transition \( T_C \). Furthermore, since Zr substitution effect is similar to Sn one in the BT, the peak at \( 125 \text{ cm}^{-1} \), for high Sn concentrations (\( x > 0.05 \)), can be assigned to a normal mode involving Sn ions motion against the polar \( \text{TiO}_6 \) octahedra as reported by Farhi et al. for \( \text{Ba(Ti, Zr)}\text{O}_3 \) material [29]. The Raman spectrum of the O phase is very similar to that of the T phase but with much weaker intensity, that’s why it appear a sharp peak near \( 489 \text{ cm}^{-1} \) that not present in general in the spectral signature of T BT.

In order to support this affirmation found at RT and to verify the results of the dielectric measurements presented in the next section, the evolution with temperature of the Raman spectra have been collected for compositions with \( x = 0 \), \( 0.05 \), and \( 0.10 \). The results of this analysis are plotted in Figs. 4–6 respectively. Undoped BSTO.2 presents qualitatively a Raman spectra similar to BT one (Fig. 4). All the successive phase transitions (R-O, O-T and T-C) are occurred with variations in the temperatures. The presence of sharp peaks at \( 125 \), \( 178 \), and \( 495 \text{ cm}^{-1} \) at low temperatures indicate that the material acquire R structure. The transition to the O phase observed at \( T = 120 \text{°C} \) is marking by the damping of the low frequencies peaks. Decreasing temperature to \( T = 20 \text{°C} \), the peak at \( 125 \text{ cm}^{-1} \) completely disappears, and the material now is in T phase. Transition to the paraelectric phase is observed at \( T_C = 60 \text{°C} \) by the abrupt disappearance of the ferroelectric-associated modes at \( 306 \text{ cm}^{-1} \) and \( 730 \text{ cm}^{-1} \) with the interference feature at \( 180 \text{ cm}^{-1} \). However, two modes at \( 216 \) and \( 531 \text{ cm}^{-1} \) persist above \( T_C \), indicating the presence of a local short range polar order in the C phase. These results are in agreement with dielectric analysis presented in next section.

A different spectrum is obtained with Sn substitution. It is clear that increasing of Sn content in BSTO.2 faded the temperature of ferroelectric-paraelectric transition, again with persistence of short-range order at higher temperature (T > \( T_C \)). For \( x = 0.05 \) (Fig. 5), the transition to the C phase is occurred at \( T_C = 25 \text{°C} \). In the range of 25 °C to 5 °C, spectra are dominated by typical T features. Cooling to \( \sim 15 \text{°C} \), a weak band at \( 472 \text{ cm}^{-1} \), appeared, signifying transformation into the O phase with a local persistence of T distortions. Below \( \sim 15 \text{°C} \), spectra can be illustrated by sequences of peaks belonging to both O and R phases. In

![Fig. 3. Room temperature Raman spectra of BSTS ceramics, x=0-0.20.](image1)

![Fig. 4. Raman spectra of Ba_{0.8}Sr_{0.2}TiO_3 in dependence of temperature.](image2)
fact, the characteristic mode of O phase at 472 cm\(^{-1}\) is not sharp and the modes below 200 cm\(^{-1}\) gradually appear and become more obvious with decreasing temperature. Particularly, the weak dip at 125 cm\(^{-1}\) recorded for BSTS with 0.05 \(\leq x \leq 0.20\) at RT comes out in low symmetry of \((\text{Ba}_{0.8}\text{Sr}_{0.2})\text{(Ti}_{0.95}\text{Sn}_{0.05})\text{O}_3\).

Similar results are obtained for the composition with \(x=0.10\). At low temperatures, coexistence between R and O structures can be postulated, although the Sn-related normal mode at 125 cm\(^{-1}\) becomes more marked than in composition with \(x=0.05\). Loss of long-range ferroelectricity takes places at around 0 °C, revealing that the material is already in its paraelectric C state at RT, as depicted also from Fig. 6. The most remarkable observation is the persistence of the dip at 125 cm\(^{-1}\) until RT for higher Sn compositions (\(x=0.05\)–0.20). It is clear that with increasing \(x\text{(Sn)}\), this feature becomes stronger. Farhi et al. reported the same results for Zr substitution in BT. Going into details; this dip could be considered as a signature of a R local ordering around Zr ions [29]. Therefore, in regards to Raman results at RT (Fig. 3), it can be concluded from structural changes that gradual substitution of Sn for Ti in BSTS ceramics yields a phase transition from a T for \(x=0\)–0.05 materials to a locally distorted C structure with coexistence of low-ordered R symmetry for compositions with \(x=0.05\)–0.20 at RT.

### 3.3. Dielectric and macroscopic ferroelectric properties

Real and imaginary parts of permittivity versus temperature of BSTS ceramics with different Sn contents measured at the frequency \(f=1\) kHz are shown in Figs. 7 and 8, respectively. All the three dielectric anomalies which are known to subsist in BT (R-O, O-T and T-C) are detectable for samples with \(x<0.10\) and they gradually meet together in a broad ferroelectric–paraelectric phase transition for \(x \geq 0.10\). Table 2 illustrates the critical temperatures, the Curie–Weiss tempera-

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Table 2: Summary of some physical parameters of the BSTS ceramics with \(x=0\)–0.20.

<table>
<thead>
<tr>
<th>Composition</th>
<th>(x=0)</th>
<th>(x=0.03)</th>
<th>(x=0.05)</th>
<th>(x=0.07)</th>
<th>(x=0.10)</th>
<th>(x=0.20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{O-T}) (°C)</td>
<td>123</td>
<td>47</td>
<td>27</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(T_{O-C}) (°C)</td>
<td>23</td>
<td>6</td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(T_C) (°C)</td>
<td>61</td>
<td>41</td>
<td>25</td>
<td>13</td>
<td>7</td>
<td>–93</td>
</tr>
<tr>
<td>(T_{O} ) (°C)</td>
<td>56</td>
<td>37</td>
<td>32</td>
<td>24</td>
<td>11</td>
<td>–47</td>
</tr>
<tr>
<td>(t'\text{max} )</td>
<td>9178</td>
<td>10,057</td>
<td>15,325</td>
<td>16,887</td>
<td>24,114</td>
<td>18,097</td>
</tr>
<tr>
<td>(t') (RT)</td>
<td>2567</td>
<td>5605</td>
<td>15,325</td>
<td>10,446</td>
<td>5605</td>
<td>1394</td>
</tr>
<tr>
<td>tan(δ) (RT)</td>
<td>0.0289</td>
<td>0.0485</td>
<td>0.0275</td>
<td>0.0696</td>
<td>0.0306</td>
<td>0.0008</td>
</tr>
<tr>
<td>(\eta)</td>
<td>1.24</td>
<td>1.42</td>
<td>1.48</td>
<td>1.61</td>
<td>1.72</td>
<td>1.96</td>
</tr>
<tr>
<td>(S) (°C)</td>
<td>20.8</td>
<td>19.88</td>
<td>18</td>
<td>19</td>
<td>22.7</td>
<td>37.71</td>
</tr>
</tbody>
</table>
atures $T_C$ determined by a linear fit of the inverse of dielectric permittivity in the C phase and the maximum values of permittivities at 1 kHz (at $T_C$ and RT).

In fact, $T_C$ decreases with increasing Sn$^{4+}$ dopants while the other two transitions temperatures (R-O and O-T) increases to higher temperatures in agreement with the pinching effect [34]. Pinching effect is complete when the three phase transition temperatures coexist and it corresponds to a specific tin concentration with the largest value of dielectric permittivity. It is found a very high value of maximum dielectric permittivity for $x=0.10$ with is three times greater than pure BST0.2 one ($\varepsilon'_\text{max}=24,114$). Shi et al. explain why the dielectric properties are enhanced with the Sn substitution in BT. They observed that, as the chemical distribution of Sn in the material is inhomogeneous, the formed PNRs in the matrix of BT contain the smaller Sn concentration [35]. Then, they expand under the stress of the matrix because their smaller lattice constant, which allow larger off-center displacements between Ti and Oxygen octahedra [35]. Therefore, permittivities values are greatly reinforced [35].

For $x=0.07$, the pinching effect is not complete though only one transition is observed in its real part of the dielectric permittivity (Fig. 7). It is evident from the inset in Fig. 8 that small anomalies persisted in its imaginary part of permittivity.

Sn addition on B sites increases the RT permittivity values from 2500 for pure BST0.20 to 15,300 for $x=0.05$ and then decreases to 1400 for $x=0.20$. Due to the proximity of its $T_C$ ($T_C=25 \degree C$), the highest temperature variation of permittivity around RT is observed for $x=0.05$.

In order to evaluate the nature of the dielectric response, the evolution of the $\varepsilon'/\varepsilon_r$ at 1 kHz of all compounds with the fitting to Curie law equation ($\varepsilon' = \frac{C}{T} + \varepsilon_r$) in paraelectric state is presented in the Fig. 9, where $T_0$ is the Curie–Weiss temperature and $C$ is the Curie–Weiss constant. Based on Landau’s theory of phase transition, the transition is of first order for $x=0.05$ and close to second order for $x=0.05$, as shown in the inset of Fig. 9. For a second order transition, a crystal structure undergoes a continuous change over a temperature interval with two competing phases (ordered and disordered) in the vicinity of $T_C$. Since the proximity of its critical temperature $T_C$ to RT, the sample with $x=0.05$ presented a T-C coexistence which confirms clearly XRD results. Indeed, we can’t deduce the order of the transition for $x=0.07$ of BSTS compounds because $T_C < T_0$ (Table 2). However, a diffuse phase transition can be induced by creating a disorder in B site [36,37]. Thus, the permittivity peak of BSTS gradually broadens with increasing Sn content, indicating that the transitions are more diffuse. Furthermore, a relaxor state is established for the composition with $x=0.20$ in which the temperature of permittivity peak $T_m$ depends on frequency.

Therefore, to characterize the degree of diffuseness, the normalized real part of permittivity ($\varepsilon'_r/\varepsilon '_\text{max}$) at the frequency 1 kHz as a function of ($T–T_m$) is plotted in Fig. 10 for all BSTS compounds. The extent of the diffusivity is presented by the area under each curve. It can be noticed that the sharpness of the peaks is reduced regularly with increasing x(Sn). C. Lei et al. set use the width of the peak at 2/3 of the maximum to better describe this behavior [17]. They introduced two parameters, W2/3M-H and W2/3M-L (Fig. 9), defined as the difference between $T_m$ and the temperature where $\varepsilon'_r = \frac{\varepsilon'_\text{max}}{2}$ from the high (H) temperature and the low (L) temperature sides of the peak, respectively. The evolutions of both parameters versus $x$ are plotted in the inset of Fig. 10. For $x=0$ to 0.10, W2/3M-H is almost stable, while W2/3M-L increases gradually with increasing $x$, and both parameters have the highest values for the sample with $x=0.20$, confirming his relaxor behavior. Similarly to BaTiO3–BaSnO3 system [13], increment of Sn content in BST0.2 solid solution promotes a gradual diffusiveness of the phase transition and exhibit relaxor behavior for large x.

To more describe the diffuse phase transition in BSTS ceramics and calculate some characteristic parameters, we use the empirical equation derived from the Curie–Weiss law and proposed by Santos and Eiras [38]:

$$\varepsilon'_r = \frac{\varepsilon'_\text{max}}{(T–T_m)^\delta} + 1$$

(1)

With the fitting parameters $\delta$ and $\eta$ are frequency independent. $\delta$ give information about the interval of temperature extension of the diffuseness and $\eta$ indicates the character of the phase transition. $\eta=1$ describe a classic ferroelectric phase transition while when $\eta=1$, we have a complete diffuse phase transition feature of relaxor behavior. Intermediate values of $\eta$ between 1 and 2 describe an incomplete diffuse phase transition. By a linear fit of the experimental curves of dielectric permittivities in the region of frequency dispersion with Eq. (1), $\delta$ and $\eta$ values are computed and cited in Table 2 for all the BSTS samples. We noted that both of $\delta$ and $\eta$ increases with the increasing of tin doping content ($\delta$ from 20.8 to 37.71 °C and $\eta$ from 1.24 to 1.96 for $x=0$ to $x=0.20$ respectively). This result confirms that Sn substitution in BSTS solid solution induces a diffuse phase transition and a relaxor behavior for large $x=0.20$.

The polarization cycles of BSTS ceramics with different tin concentration were recorded at RT and 1 Hz frequency (see Fig. 11) to explore ferroelectric properties. The studied samples showed narrow hysteresis cycles with a suitable symmetrical shape and reproducible field responses. As the Sn doping increases, the remanent polarization

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**Fig. 9.** Thermal variation of $1/\varepsilon'_r$ at 10 kHz BSTS ceramics, $x=0$–0.20 (symbols: experimental data; solid line, the fitting to the Curie–Weiss law).

**Fig. 10.** Normalized dielectric permittivity of BSTS ceramics at 1 kHz.
at the maximum field of 3 kV/mm decreases from 14.31 to 1.35 μC/cm². Also, the coercive field is in the range of 0.13 kV/mm for the undoped sample and close to zero for x=0.2. The hysteretic nature of the P(E) curves is reduced with increasing sloping and tends to have linear field dependence. This confirms that the compositions with x=0.07, 0.10 and 0.20 have a paraelectric state at RT far from its Tc or Tc(Tm=13.7 °C and ~93 °C respectively). Moreover, for x=0.05, as Tc is equal to RT, the area of his cycle is reduced in comparison to compositions with x=0 and x=0.03, but still nonlinear affirming the proportion of T and C phases (88.84% and 11.16% respectively). These results are in good agreement with XRD and dielectric data.

4. Conclusion

Pure Barium strontium strontium titanate (Ba0.8Sr0.2TixO3; Ti:Sn) ceramics as a function of Sn substitution were prepared using the conventional solid-state reaction.

Fig. 11. Macroscopic hysteresis loops for BSTS ceramics with x=0–0.20 at room temperature.

References