Dielectric properties and point defect behavior of antimony oxide doped Ti deficient barium strontium titanate ceramics

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Abstract: The microstructures and dielectric properties of Sb2O3-doped Ti deficient barium strontium titanate ceramics prepared by solid state method were investigated with non-stoichiometric level and Sb2O3 content by SEM, XRD and LCR measure system. It is found that with the increase of Sb2O3 content by SEM, XRD and LCR measure system. It is found that with the increase of $\delta$, (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{1-x}$O$_{3-\delta}$ ceramics transform from single phase solid solutions with typical cubic perovskite structure to multiphase compounds while (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{1-x}$O$_{3-\delta}$ ceramics remain to be single-phase with the increasing Sb$_2$O$_3$ content. The distortion of the ABO$_3$ perovskite lattice caused by $V_{\text{II}}^\text{a}$ and $V_{\text{IV}}^\text{a}$ induces the drop of Curie temperature and the rise of relative dielectric constant in (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{1-x}$O$_{3-\delta}$ ceramics with increasing $\delta$ value. The orientation of $V_{\text{II}}^\text{a}$ elastic dipoles results in the domain-wall pinning and thus the reduction of the dielectric loss. With increasing Sb$_2$O$_3$ content, the relative dielectric constant, dielectric constant maximum and Curie temperature of (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{1-x}$O$_{3-\delta}$ ceramics decrease dramatically while the dielectric loss increases.

Key words: barium strontium titanate; defects; dielectric properties; non-stoichiometric ceramics

1 Introduction

Barium strontium titanate (Ba$_{1-x}$Sr$_x$TiO$_3$, BST) as a ferroelectric material with perovskite structure has drawn considerable attention in the microelectronic industries because of its outstanding properties such as adjustable phase transition temperature, high dielectric constant and low dielectric loss [1], which allows it to have a great potentiality for phase shifter, phased array antenna, resonator and capacitor applications. However, the conflict between the fine dielectric properties at room temperature and good dielectric temperature stability remains in the uniform BST ceramics [2]. In order to overcome the above mentioned drawback, the traditional doping method applied widely in electronic ceramics has been introduced into BST ceramics [3–5].

Due to the intermediate size and charge of trivalent ions compared with the Ba$^{2+}$, Sr$^{2+}$ and Ti$^{4+}$ ions, the aloivalent doping mechanism and the substitution preference of trivalent ions in BST ceramics as well as in BaTiO$_3$ ceramics have been debated for many years [6]. However, it is no doubt that the dielectric properties of perovskite BST ceramics are related to the doping mechanism and correspondingly the point defect behavior. In many cases, the doping mechanisms are not only dependent on the oxygen partial pressure ($p_{\text{O}_2}$) and sintering temperature/time but also the overall $n_a/n_B$ ratio [7]. Many literatures have been focused on the relationships between the point defect behavior and $n_a/n_B$ ratio in BaTiO$_3$ ceramics [8,9]. Also, some influences of $n_{\text{Ba}}/n_{\text{Ti}}$ ratio on the microstructures and dielectric properties in BST ceramics are gradually understood. DONG et al [2] concluded that adding excessive TiO$_2$ could remarkably inhibit grain growth, suppress and broaden the Curie peaks in compositionally inhomogeneous BST ceramics. SYAMAPRASAD et al [10] found that excess Ba led to high un-changed dielectric constant with a slight decrease of loss tangent in Ba$_{0.71}$Sr$_{0.29}$TiO$_3$ ceramics.

In our previous work, the dielectric properties of Sb$_2$O$_3$-doped stoichiometric BST ceramics such as (Ba$_{0.92}$Sr$_{0.08}$)$_2$Y$_{0.008}$TiO$_{3-\delta}$ ceramics ($n_{\text{Ba}}/n_{\text{Ti}}$=1) have been investigated and the Sb$_2$O$_3$ dopant showed extraordinary effects on the dielectric temperature stability improvement [11,12]. So, in this work, we report a
systematic study of the microstructure, point defect behavior and dielectric properties of Ti deficient 
(Ba0.75Sr0.25)Ti1−δO3−δ ceramics (n/δ>1) still taking the trivalent Sb3+ ions as dopant. The influences of δ value 
(namely the n/δ ratio) and doping content on point defect behavior and the dielectric properties in barium 
strontium titanate ceramics are discussed.

2 Experimental

The chemical compositions of the Sb2O3-doped Ti deficient barium strontium titanate specimens were given 
by the formula (Ba0.75Sr0.25)Ti1−δO3−δ+0.6%Sb2O3 (δ= 
0.002, 0.004, 0.006, 0.008) and (Ba0.75Sr0.25)Ti0.998O2.996+ 
δSb2O3 (x=0, 0.4%, 0.8%, 1.2%). High purity BaCO3 (>99.0%), SrCO3 (>99.0%) and TiO2 (>98.0%) 
powders used as starting raw materials were weighed according to the above compositions, ball-milled, dried and 
calced at 1080 °C for 2 h. The calcined powders were mixed with Sb2O3 (>99.0%), reground, dried and added with 
5% polyvinyl alcohol (PVA) as a binder for granulation. The mixture was sieved through 250 μm 
screen and then pressed into pellets of 10 mm in diameter and 2 mm in thickness under 250 MPa. 
Sintering was conducted in air at 1300~1320 °C for 2 h. For dielectric measurement, both the flat surfaces of the 
specimens were coated with BQ−5311 silver paste after ultrasonic bath cleaning and then fired at 800 °C for 
10 min.

The crystal structures of the specimens were confirmed by X-ray diffraction analysis (XRD, Rigaku 
D/max 2500v/pc) with Cu Kα radiation. The surface morphologies of the specimens were observed using the 
SEM (JSM−6480 ESEM). The capacitance quantity (C) and dissipation factor (D) were measured with 
LCR−8101G Automatic LCR Meter at 1 kHz. The relative dielectric constant (εr) and the loss tangent (tan δ) 
were calculated as follows:

\[
ε_r = \frac{14.4Ch}{d^2} 
\]

(1)

\[
\tan δ = \frac{fD}{1000} 
\]

(2)

where h is the thickness (cm), d is the diameter of the electrode (cm) and f is the test frequency (Hz). An 
amatic measuring system consisting of Automatic LCR Meter and THP-F-100 temperature control unit was 
used to record the capacitance quantity and dissipation factor from −20 °C to 50 °C at 1 kHz for measuring the 
temperature dependence of dielectric parameters.

3 Results and discussion

3.1 XRD and SEM analysis

The X-ray diffraction patterns of 0.6%Sb2O3-doped 
(Ba0.75Sr0.25)Ti1−δO3−δ bulk ceramics are shown in Fig. 1. 
With the increase of δ value, (Ba0.75Sr0.25)Ti1−δO3−δ+ 
0.6%Sb2O3 ceramics transform from single phase solid 
solutions with typical cubic perovskite structure to 
multiphase compounds. In other words, to maintain the 
ABO3 perovskite single phase structure, the δ value 
should be restricted to a very narrow range which is no 
more than 0.006 in present samples. Also, a slight shift of 
diffraction peaks to higher 2θ values with the increasing 
δ value was observed, especially for the (110), (200) and 
(211) peaks, which indicated that the unit cell volumes 
(Ba0.75Sr0.25)Ti1−δO3−δ ceramics decreased as the 
non-stoichiometric level of Ti ions in present ABO3 
perovskite structure increased. Similar phenomena have 
been previously reported in Ca substituted BST 
ceramics [13] and in our previous work for (La, Sb)- 
doped (Ba0.75Sr0.25)TiO3 ceramics [14]. Apparently, this 
shrinkage of unit cell volume is mainly attributed to the 
appearance of B-site vacancies V'B and oxygen 
vacancies VO in (Ba0.75Sr0.25)Ti1−δO3−δ ceramics which is 
revealed by the following point defect reaction equation:

\[
(Ba0.75Sr0.25)Ti1−δO3−δ → \]

\[
0.75Ba Ba + 0.25SrSt + (1−δ)TiTi +
(3−2δ)O O + δV'B + 2δVO 
\]

(3)

Fig. 1 XRD patterns for (Ba0.75Sr0.23)Ti1−δO3−δ+0.6%Sb2O3 
ceramics: (a) δ=0.002; (b) δ=0.006; (c) δ=0.008

The X-ray diffraction patterns of sintered Sb2O3- 
doped (Ba0.75Sr0.25)Ti0.998O2.996 bulk ceramics are shown 
in Fig. 2. All these polycrystals are single-phase 
compounds with perovskite structure, which implies that 
Sb3+ ions have incorporated into the lattice and thus 
maintain the perovskite structure of non-stoichiometric 
barium strontium titanate solid solution. The XRD 
profiles focusing on the (110) diffraction peaks are 
presented in Fig. 2(b). It shows that the diffraction 
peaks move towards lower 2θ values and then shift to 
higher 2θ values as the Sb2O3 doping content increases in

Fig. 2 XRD patterns for Sb$_2$O$_3$-doped (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{0.998}$O$_{2.996}$ ceramics with different Sb$_2$O$_3$ contents (1—0; 2—0.4%; 3—1.2%)

(Ba$_{0.75}$Sr$_{0.25}$)Ti$_{0.998}$O$_{2.996}$ ceramics, which reveals a variation of the unit cell volume for Sb$_2$O$_3$-doped (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{0.998}$O$_{2.996}$ ceramics. To be specific, with the increase of Sb$_2$O$_3$ content, the unit cell volume increases and then decreases slightly. In terms of size, the ionic radii of Ba$^{2+}$, Sr$^{2+}$ in 12 coordination and Ti$^{4+}$ in 6 coordination are 0.161, 0.144 and 0.061 nm, respectively. The radius of Sb$^{3+}$ ion in 6 coordination is 0.076 nm which is bigger than that of Ti$^{4+}$ ion but smaller than that of host A-site ion. Therefore, B-sites in the perovskite lattice are partially occupied by bigger Sb$^{3+}$ ions for present low Sb$_2$O$_3$ doping content samples, consequently causing the increase of the unit cell volume. While the above shrinkage of unit cell suggests that the substitution of Sb$^{3+}$ ions for the host A-site ions takes place in high Sb$_2$O$_3$ doping content samples. The substitution preference of Sb$^{3+}$ ions in present system is opposite to that in (Ba$_{0.992-x}$Sr$_x$Y$_{0.008}$)TiO$_{3.004}$ ceramics [11]. This difference of Sb$^{3+}$ substitution preference in perovskite lattice can be explained by the existence of B-site vacancies $V_{Ti}^{m}$ in non-stoichiometric (Ba$_{0.75}$Sr$_{0.25}$)-Ti$_{0.998}$O$_{2.996}$ ceramics as shown in Eq. (3). The incorporation of Sb$^{3+}$ ions into the lattice also brings about some kinds of point defects which turn out to be the main factors changing the dielectric characteristics of non-stoichiometric barium strontium titanate ceramics. In (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{0.998}$O$_{2.996}$ samples with low Sb$_2$O$_3$ doping concentration, Sb$^{3+}$ ions enter B-sites in the perovskite structure and serve as an acceptor dopant. The defect reaction is as follows:

$$\text{Sb}_2\text{O}_3 \rightarrow 2\text{Sb}^{2+}_\text{Ti} + V_{\text{Ti}}^{m} + 3\text{O}_\text{O}$$  \hspace{1cm} (4)

For high Sb$_2$O$_3$ doping concentration samples, Sb$^{3+}$ ions tend to occupy the A-sites and serve as a donor dopant. The defect reaction is as follows:

$$\text{Sb}_2\text{O}_3 \rightarrow 2\text{Sb}^{2+}_\text{A} + V_{\text{A}}^{m} + 3\text{O}_\text{O}$$  \hspace{1cm} (5)

Figure 3 shows the surface morphologies of 0.6%Sb$_2$O$_3$-doped Ti deficient (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{1-\delta}$O$_{3-2\delta}$ ceramics. And the surface morphologies of Sb$_2$O$_3$-doped (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{0.998}$O$_{2.996}$ ceramics are shown in Fig. 4. It appears that all samples exhibit dense microstructure and no abnormal grain growth is observed. There is no obvious change in the average grain size of
(Ba$_{0.75}$Sr$_{0.25}$)Ti$_{1-\delta}$O$_{3-2\delta}$ ceramics as the $\delta$ value increases, presenting that the non-stoichiometric level makes little contribution to refine the grain size. Distinguishingly, the average grain size of (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{0.998}$O$_{2.996}$ ceramics decreases dramatically after applying the Sb$_2$O$_3$ dopant while remains almost the same when gradually increasing the Sb$_2$O$_3$ content. And the grain size distribution of sintered ceramics can be refined by Sb$_2$O$_3$ addition.

### 3.2 Dielectric characteristics

Table 1 shows the relative dielectric constant and dielectric loss of 0.6% Sb$_2$O$_3$-doped (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{1-\delta}$O$_{3-2\delta}$ ceramics with different $\delta$ values at room temperature. It is obvious that all the non-stoichiometric (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{1-\delta}$O$_{3-2\delta}$ ceramics possess high relative dielectric constant (more than 4000) at room temperature. With the increase of $\delta$ value which is in the range of 0.002–0.006, the relative dielectric constant increases notably while the dielectric loss decreases considerably. This demonstrates that a proper non-stoichiometric level in (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{1-\delta}$O$_{3-2\delta}$ ceramics helps to improve the dielectric properties at room temperature. $n_{O^{2-}}/n_{Ti^{4+}}>1$ in BaTiO$_3$ has been demonstrated by HYATT et al [15] to reduce the loss tangent particularly in the paraelectric region above the Curie temperature. In our present (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{1-\delta}$O$_{3-2\delta}$ ceramics satisfying the condition of $(n_{O^{2-}}+n_{O^{2-}})/n_{Ti^{4+}}>1$, the dielectric loss is now proved to decrease with the increasing non-stoichiometric level, which is in accord with Hyatt’s results.

<table>
<thead>
<tr>
<th>$\delta$</th>
<th>$\varepsilon_{RT}$</th>
<th>tan $\delta_{RT}$</th>
<th>$T_C/\degree$</th>
<th>$\varepsilon_{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.002</td>
<td>4036</td>
<td>0.017</td>
<td>6.8</td>
<td>6041</td>
</tr>
<tr>
<td>0.004</td>
<td>4187</td>
<td>0.013</td>
<td>4.7</td>
<td>6504</td>
</tr>
<tr>
<td>0.006</td>
<td>4420</td>
<td>0.012</td>
<td>3.8</td>
<td>7007</td>
</tr>
<tr>
<td>0.008</td>
<td>4416</td>
<td>0.012</td>
<td>3.1</td>
<td>6694</td>
</tr>
</tbody>
</table>

Temperature dependence of relative dielectric constant and dielectric loss for 0.6% Sb$_2$O$_3$-doped (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{1-\delta}$O$_{3-2\delta}$ ceramics is shown in Fig. 5. The relative dielectric constant first increases, achieves a maximum remarked as $\varepsilon_{RT}^{max}$ and then decreases with increasing temperature. Contrarily, the dielectric loss decreases at the beginning, achieves a minimum and then increases with increasing temperature. The temperature corresponding to the relative dielectric constant maximum is taken as the Curie temperature $T_C$. It is obvious that the Curie temperature (see Table 1) decreases with increasing $\delta$ value.

![Fig. 4 SEM images of (Ba$_{0.75}$Sr$_{0.25}$)Ti$_{0.998}$O$_{2.996}$ ceramics with various Sb$_2$O$_3$ contents: (a) 0; (b) 0.4%; (c) 0.8%; (d) 1.2%](image-url)
value is, the lower the dielectric loss of (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{1-x}$O$_{3-2x}$ ceramics becomes. This phenomenon is related to the existing point defects as well. Oxygen vacancies $V_0^{**}$ residing at the corners of octahedra are well interconnected and therefore can be regarded as relatively mobile defects. The mobile defects migrate to domain boundaries. Orientation of the elastic dipoles caused by $V_0^{**}$ results in the domain-wall pinning and thus the reduction of the dielectric loss.

The relative dielectric constant and dielectric loss of (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{1-x}$O$_{3-2x}$ ceramics with different Sb$_2$O$_3$ doping contents at room temperature are shown in Table 2. It is clear that the relative dielectric constant of (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{0.998}$O$_{2.996}$ ceramics decreases dramatically with increasing Sb$_2$O$_3$ addition content. The substitution for $A/B$-site with any of the Sb$^{3+}$ ions leads to a shorter distance between the $B$-site ion and its nearest neighbors of the octahedron, so the movement of $B$-site ion is restricted, which weakens the spontaneous polarization of grain lattice, and consequently, the dielectric constant decreases with increasing Sb$_2$O$_3$ content macroscopically. The dielectric loss of (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{0.998}$O$_{2.996}$ ceramics increases with the increase of Sb$_2$O$_3$ content.

![Fig. 5 Temperature dependence of relative dielectric constant (a) and dielectric loss (b) for (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{1-x}$O$_{3-2x}$+0.6% Sb$_2$O$_3$ ceramics](image)

Table 2 Dielectric properties of Sb$_2$O$_3$-doped (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{0.998}$O$_{2.996}$ ceramics

<table>
<thead>
<tr>
<th>Sb$_2$O$_3$ content/%</th>
<th>$\varepsilon_r^{RT}$</th>
<th>$\tan\delta^{RT}$</th>
<th>$T_c/°C$</th>
<th>$\varepsilon_r^{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6514</td>
<td>0.0076</td>
<td>24.4</td>
<td>6526</td>
</tr>
<tr>
<td>0.4</td>
<td>5014</td>
<td>0.0078</td>
<td>16.6</td>
<td>5328</td>
</tr>
<tr>
<td>0.8</td>
<td>3013</td>
<td>0.0079</td>
<td>2</td>
<td>3550</td>
</tr>
<tr>
<td>1.2</td>
<td>2560</td>
<td>0.0082</td>
<td>$&lt;20$</td>
<td>-</td>
</tr>
</tbody>
</table>

Temperature dependence of relative dielectric constant and dielectric loss for Sb$_2$O$_3$-doped (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{0.998}$O$_{2.996}$ ceramics is shown in Fig. 6. It is obvious that the Curie temperature of Sb$_2$O$_3$-doped (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{0.998}$O$_{2.996}$ ceramics (see Table 2) shifts to lower value with increasing Sb$_2$O$_3$ doping content, which is attributed to the weakening of spontaneous polarization of the grain lattice caused by the substitution for host ion with any of the Sb$^{3+}$ ions as mentioned before. The charged vacancies caused by $A$-site /$B$-site substitution give rise to the local deformation of the perovskite unit cells, which also causes the reduction of Curie temperature. In the whole temperature range relative dielectric constants of Sb$_2$O$_3$-doped (Ba$_{0.75}$Sr$_{0.25}$)$_2$Ti$_{0.998}$O$_{2.996}$ ceramics are significantly suppressed as the Sb$_2$O$_3$ content increases. At high Sb$_2$O$_3$ doping contents (>0.8%), the curves become flat, which implies the high thermal stability of Sb$_2$O$_3$-doped non-stoichiometric barium strontium titanate ceramics. Particularly, the peak value remarked as $\varepsilon_r^{max}$ decreases with the increase of Sb$_2$O$_3$ content. The effects of Sb$_2$O$_3$ content on dielectric maximum are caused by the weakening of ferroelectricity, which is attributed to the replacing reaction of Sb$^{3+}$ ions for the host ions in perovskite lattice. As shown in Fig. 6(b) the dielectric loss decreases dramatically with the increasing temperature in low temperature range and reaches the
minimum at around 35 °C. Also, (Ba0.75Sr0.25)Ti0.998O2.996 ceramics with high Sb2O3 content exhibit better thermal stability of dielectric loss than that with low Sb2O3 content.

![Temperature dependence of relative dielectric constant (a) and dielectric loss (b) for Sb2O3-doped (Ba0.75Sr0.25)Ti0.998O2.996 ceramics](image)

### 4 Conclusions

1) (Ba0.75Sr0.25)Ti1−δO1−δ ceramics transform from single phase solid solutions with typical cubic perovskite structure to multiphase compounds with the increase of δ value while (Ba0.75Sr0.25)Ti0.998O2.996 ceramics remain to be single-phase solid solutions with the increasing Sb2O3 doping content.

2) The B-site vacancies \( V_{Ti}^{''} \) as well as oxygen vacancies \( V_{O}^{**} \) exist in (Ba0.75Sr0.25)Ti1−δO1−δ ceramics and the \( Sb^\prime = V_{Ti}^{''} / V_{O}^{**} \) complexes show in Sb2O3-doped (Ba0.75Sr0.25)Ti0.998O2.996 ceramics. Due to the existence of \( V_{Ti}^{''} \) in Ti deficient (Ba0.75Sr0.25)Ti0.998O2.996 ceramics, the substitution preference of Sb3+ ions is opposite to that in stoichiometric barium strontium titanate ceramics.

3) The distortion of the ABO3 perovskite structure caused by \( V_{Ti}^{''} \) and \( V_{O}^{**} \) facilitates the drop of Curie temperature and the rise of relative dielectric constant in (Ba0.75Sr0.25)Ti1−δO1−δ ceramics with increasing δ value.

The orientation of the elastic dipoles caused by \( V_{O}^{**} \) leads to the domain-wall pinning and thus the reduction of the dielectric loss. With increasing Sb2O3 content, the relative dielectric constant, dielectric constant maximum and Curie temperature of (Ba0.75Sr0.25)Ti0.998O2.996 ceramics decrease dramatically. Contrarily, the dielectric loss increases with the increasing Sb2O3 content because of the reduction of Ti4+ ion induced by Sb3+ ion substitution for host ion.

4) The average grain size and grain size distribution of (Ba0.75Sr0.25)Ti0.998O2.996 ceramics can be refined by Sb2O3 addition.

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### References


氧化锑掺杂贫 Ti 钛酸锶钡陶瓷的介电性能及缺陷行为

张 晨，凌志新，简 刚，陈方旭

摘 要：采用固相法制备 Sb_{2}O_{3} 掺杂的贫 Ti 钛酸锶钡陶瓷，通过 SEM、XRD 和 LCR 测试系统研究其显微结构及介电性能随非化学计量比及 Sb_{2}O_{3} 含量的变化。结果表明：随着 δ 值增大，(Ba_{0.75}Sr_{0.25})Ti_{1−δ}O_{3−2δ} 陶瓷由典型立方钙钛矿结构单相固溶体转变为多相化合物，而(Ba_{0.75}Sr_{0.25})Ti_{0.998}O_{2.996} 陶瓷随 Sb_{2}O_{3} 掺杂量增加始终为单相固溶体。由 V_Ti^{″} 及 O_{v}^{−} 引起的 ABO_{3} 型钙钛矿晶胞畸变导致(Ba_{0.75}Sr_{0.25})Ti_{1−δ}O_{3−2δ} 陶瓷随 δ 值增大居里温度降低且相对介电常数增高。弹性偶极子 O_{v}^{−} 的定向引起畴壁钉扎而导致其介电损耗降低。(Ba_{0.75}Sr_{0.25})Ti_{0.998}O_{2.996} 陶瓷的相对介电常数、介电常数最大值及居里温度均随着 Sb_{2}O_{3} 掺杂量增加显著降低而其介电损耗却随 Sb_{2}O_{3} 掺杂量的增加而增大。

关键词：钛酸锶钡；缺陷；介电性能；非化学计量陶瓷

(Edited by Xiang-qun LI)