Science of Sintering, 51 (2019) 295-307

doi:https://doi.org/10.2298/SOS1903295Z

UDK: 546.824: 622.785

Enhanced Sintering and Nonlinear Dielectric Properties of Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ Ceramics With a Small Amount of Lithium Additive

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Abstract: The powders with the nominal compositions of Ba$_{0.6}$Sr$_{0.4}$TiO$_3$+$x$ wt.% Li$_2$CO$_3$ ($x=0$ and $x=1.0$) were synthesized by a citrate precursor method. The sintering behavior, structure and dielectric properties of the ceramic specimens were investigated. Compared with the lithium-free specimen ($x=0$), the lithium-added specimen ($x=1.0$) showed appreciably enhanced sintering properties, achieving a relative density of 96.0% after sintering at 900 °C. The origin of the liquid-phase was explained. The effects of the liquid-phase on the densification progress of the lithium-added specimen in different sintering stages were elucidated. The lithium addition was found to be beneficial to the nonlinear dielectric properties. The ceramic specimen with $x=1.0$ exhibited a figure-of-merit of 106 under a bias electric field of 20 kV/cm, higher by ~60% than the value (67) for the specimen with $x=0$.

Keywords: Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ ceramics; Li$_2$CO$_3$ additive; Sintering; Nonlinear dielectric properties.

1. Introduction

The perovskite (ABO$_3$) ferroelectrics based on barium strontium titanate (Ba$_{1-x}$Sr$_x$TiO$_3$, BST) system exhibit strong dielectric nonlinearity under bias electric field. Such bias electric field-dependent effect is relevant to the basic physics of the polar dielectrics [1]. Moreover, the strong dielectric nonlinearity makes BST a promising candidate material for tunable microwave devices used in mobile communication technology [2]. The dielectric nonlinearity of BST has been the subject of extensive research because of the scientific and technological significance [2-4].

Multilayer low-temperature co-fired ceramic (LTCC) process has been the state-of-the-art technology for fabricating electroceramic components used in mobile communication systems. LTCC technology allows fabrication of laminated modules composed of an identical functional material or diverse functional layers together with the internal electrodes via an one-step sintering process at a low temperature (e.g. ~900 °C) [5, 6]. Unfortunately, BST

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dielectrics suffer from high sintering temperatures (e.g., ~1400 °C), incompatible with LTCC technology. Therefore, it is imperative to lower the sintering temperature of BST dielectrics in view of their realization in tunable microwave devices.

Sintering of BaTiO₃-based dielectrics, including BST, is an intriguing topic of practical importance [7, 8]. A variety of strategies have been employed to lower the sintering temperature of BST ceramics, such as adopting highly sinter-active BST powders synthesized by wet chemical routes as the starting powders [9, 10], preparing the ceramics using novel sintering techniques [11, 12] and adding sintering aids [13-22]. Among these strategies, adding sintering aids is the most convenient and commonly-used method. BST ceramics could be densified at sintering temperatures between 950 to 1250 °C by adding glass frits [13-15] or low melting-point oxides [16-18], hinging on the nature and amount of added species. In contrast, lithium additives are more effective in enhancing the sintering properties of BST ceramics. For example, adding small amounts of Li₂CO₃ (1-5 wt%) into BST could lower the sintering temperature down to ~900 °C [19-22]. The low-temperature densification of Li₂CO₃-added BST ceramics suggests the presence of a liquid-phase during the sintering. The sinterability, crystal structure, microstructure and dielectric properties of BST ceramics added with varying amounts of Li₂CO₃ have been investigated [19, 21]. Nonetheless, the mechanism for the low-temperature densification of Li₂CO₃-added BST ceramics has not been fully explained. Several essential issues remain to be addressed, as to what the origin of the liquid-phase is and how the liquid-phase contributes to the densification progress.

Ba₀.₆Sr₀.₄TiO₃ is a desirable dielectric material for the tunable device utilization [2-4]. In this work, the sintering behavior, structure and dielectric properties of Li₂CO₃-added Ba₀.₆Sr₀.₄TiO₃ ceramics were investigated in comparison with Ba₀.₆Sr₀.₄TiO₃ ceramics. For avoiding the formation of undesired impurity phase and resulting degradation of dielectric properties [19, 21], the nominal amount of Li₂CO₃ added into Ba₀.₆Sr₀.₄TiO₃ was limited to 1.0 wt.%. The emphasis of this work is focused on understanding the sintering behavior of the lithium-added specimens. Meanwhile, the effects of the lithium addition on the structure and dielectric properties were examined.

2. Materials and Experimental Procedures

Reagent-grade Ba(NO₃)₂, Sr(NO₃)₂, LiNO₃, tetrabutyl titanate and citric acid (Sinopharm Chemical Reagent Co., Ltd.) were used as the starting materials. The powders with the nominal compositions of Ba₀.₆Sr₀.₄TiO₃+x wt.% Li₂CO₃ (x=0 and 1.0) were synthesized using a citrate precursor method. The synthetic procedure was identical to that described in our earlier paper [9]. In this work, the mole ratio of citric acid to the total metal cation content was 1.5 and the powders were calcined at 650 °C. The calcined powders were uniaxially compacted into rectangular bars (5 mm×4 mm×30 mm) and discs (13 mm in diameter and 1 mm in thickness). The dilatometric analysis was performed based on the compacted bars using a Netzsch DIL 402C dilatometer at a heating rate of 5 °C/min in air. The compacted discs were sintered in air to produce ceramic specimens. The sintering temperatures of the ceramic specimens were determined by referring to the result of the dilatometric analysis. The lithium-free (x=0) and lithium-added (x=1.0) specimens were sintered at temperatures between 1200 to 1300 °C for 2 h and 700 to 950 °C for 6 h, respectively.

Thermogravimetry-differential scanning calorimetry (TG-DSC) analysis of the citrate precursors and calcined powders was performed in air using a Netzsch STA 449C simultaneous thermal analyzer at heating rates of 5 and 2 °C/min, respectively. The phase purity of the calcined powders and crystal structure of the ceramic specimens were examined by X-ray diffraction (XRD) technique using a Philips X’pert PBO X-ray diffractometer with Cu Kα radiation. The crystallographic parameters of the ceramic specimens were determined
based their XRD data using the MDI Jade 6.0 software. The particle morphology of the calcined powders and microstructure of the ceramic specimens were observed using a Jeol JSM-5610LV scanning electron microscope (SEM). The ceramic specimens used for SEM observation were polished and thermally etched. The average particle sizes of the powders and average grain sizes of the ceramic specimens were estimated by image analysis using the Image-pro Plus image analysis software. Infrared spectra of the calcined powders were recorded using a Fourier transform infrared (FT-IR) spectrometer (Nexus) in the range of 400-1600 cm\(^{-1}\). Raman spectra of the ceramic specimens were recorded using a Renishaw INVIA Raman spectrometer in backscattering geometry with excitation at 632.8 nm.

The bulk density of the ceramic specimens was measured using the Archimedes method with ethyl alcohol as the medium. The relative density was calculated with respect to the theoretical density of Ba\(_{0.6}\)Sr\(_{0.4}\)TiO\(_3\) determined by XRD analysis. The ceramic specimens were polished and painted with silver electrodes on both surfaces to measure their dielectric properties. The temperature dependence of the dielectric constant (\(\varepsilon_r\)) and loss (tan\(\delta\)) was measured using a TH2828 precision LCR meter (20 Hz to 1 MHz) and a JYT-800L environmental chamber (C4 controller) between -60 and 120 °C. The dielectric properties under bias electric field were measured at room temperature using a TH2818 automatic component analyzer at 10 kHz.

3. Results and Discussion

3.1. Characterization of the synthesized powders

Fig. 1 shows the TG-DSC curves of the citrate precursors. The two citrate precursors underwent similar physiochemical changes upon pyrolysis. The weight losses taking place in several steps were related to the decomposition and combustion of the citrate precursors. The evident exothermic peaks at \(~450\) °C were caused by the burning of residual carbon species. It was noticed that a shoulder occurred at temperatures from 350 to 400 °C in the DSC curve of the precursor with \(x=1.0\) (Fig. 1b), which was absent for the precursor with \(x=0\) (Fig. 1a). This phenomenon is attributed to the conversion of lithium species present in the precursor with \(x=1.0\) to Li\(_2\)CO\(_3\) via a reaction with CO\(_2\) released from the pyrolysis of the precursor [23, 24].

![Fig. 1. TG-DSC curves of the citrate precursors with (a) x=0 and (b) x=1.0.](image)

Fig. 2 shows the SEM images of the calcined powders. The two powders had similar particle morphology, consisting of fine and uniform particles (~100 nm). Fig. 3 shows the XRD patterns of the calcined powders after exposure in the ambient atmosphere for different times. The two as-calcined powders showed a perovskite structure. The absence of Li\(_2\)CO\(_3\) phase for the powder with \(x=1.0\) is due to the low amount of the additive (1.0 wt%). A minor
Impurity phase was detected for the two powders after exposure for three weeks (Figs. 3a and c), which is assignable to (Ba, Sr)CO$_3$ [9, 13]. Figs. 3b and d clearly illustrates the presence of the impurity phase. This result is reminiscent of surface carbonation of the powders in the ambient atmosphere [25, 26].

![Fig. 2. SEM images of the calcined powders with (a) x=0 and (b) x=1.0.](image)

![Fig. 3. XRD patterns the calcined powders after exposure in the ambient atmosphere for different times. The sections a and b show the XRD patterns of the powder with x=0 in the 2θ ranges of 10-80° and 20-27°, respectively. The sections c and d show the XRD patterns of the powder with x=1.0 in the two 2θ ranges, respectively.](image)

Fig. 4a shows the FT-IR spectra of the powder with x=0 after exposure in the ambient atmosphere for different times. The as-calcined powder showed a strong absorption band at ~542 cm$^{-1}$ together with two weak bands at ~860 cm$^{-1}$ and ~1440 cm$^{-1}$, respectively. The strong band is ascribed to the vibration of Ti-O in Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ perovskite, while the two weak bands are assigned to carbonate groups adsorbed on the surface [25-27]. The two weak bands evolved to be visible with increasing the exposure time, while the strong absorption band remained unchanged. The powder with x=1.0 displayed an analogous spectral evolution (Fig. 4b).
The results of the XRD and FT-IR investigations suggest that the two powders were contaminated with a small amount of (Ba,Sr)CO₃ in the ambient atmosphere. This behavior is believed to arise from a reaction of the A-site constituents (i.e. Ba²⁺ and Sr²⁺) on the surface with CO₂ in the surrounding atmosphere [25, 26]. Such surface reaction appears to be conceivable given the chemical affinity between the A-site constituents (alkaline) and CO₂ (acid). It is plausible that the amount of the resulting (Ba,Sr)CO₃ should hinge on the exposure time in the ambient atmosphere. The absence of (Ba,Sr)CO₃ for the powders being exposed for less than three weeks (Fig. 3) is presumably due to its low amount. Considering this factor, all specimens (powders or ceramics) investigated in the following sections were prepared from the powders after exposure for one week.

Fig. 4. FT-IR spectra of the calcined powders with (a) x=0 and (b) x=1.0 after exposure in the ambient atmosphere for different times.

Fig. 5 shows the TG-DSC curves of the powders. No significant physicochemical change could be found for the powder with x=0 (Fig. 5a). A broad endothermic peak at ~600 °C and an exothermic peak at ~915 °C could be seen for the powder with x=1.0 (Fig. 5b). The peak temperature of the endothermic behavior (~600 °C) is much lower than the melting point (723 °C) of Li₂CO₃ [28]. Given the presence of the (Ba,Sr)CO₃ phase, the endothermic behavior is assumed to be caused by eutectic melting of the (Ba,Sr)CO₃ and Li₂CO₃ [29]. The broadening of the endothermic peak can be attributed to the small amounts of the two minor phases in the lithium-added powder. The exothermic behavior (~915 °C) corresponds to a dissolution-precipitation process [30]. More discussion will be made on this process in section 3.2.2.

Fig. 5. TG-DSC curves of the calcined powders with (a) x=0 and (b) x=1.0.
3.2. Sintering behavior and structure of the ceramic specimens
3.2.1. Microstructural evolution with sintering temperature

Fig. 6 shows the dilatometric curves of the compacted bars. Compared with the lithium-free specimen (x=0), the shrinkage behavior of the lithium-added specimen (x=1.0) was obviously facilitated, being initiated after ~745 °C, reaching the maximum rate at ~815 °C and coming to be saturated after ~975 °C. This result suggests that the lithium-added ceramic specimens should exhibit enhanced sintering properties.

Fig. 7 shows the relative densities of the ceramic specimens as a function of sintering temperature. The relative density of the ceramic specimen with x=0 reached the maximum value (94.6%) when sintering at 1260 °C (Fig. 7a). SEM observation indicated that the average grain size of this specimen was ~0.5 μm (the inset in Fig. 7a). By contrast, the sinterability of the specimen with x=1.0 was appreciably enhanced (Fig. 7b). For example, the specimen sintered at 900 °C achieved a high relative density of 96.0%. Considering the similar particle morphology of the two powders (Fig. 2), the enhanced sinterability of the specimen with x=1.0 should be related to the lithium addition.

Fig. 8 shows the SEM images of the ceramic specimens with x=1.0 sintered at different temperatures. The specimens sintered at temperatures between 700 to 800 °C displayed porous microstructures composed of fine grains (Figs. 8a-c). The grain growth and densification progress evolved to be substantial with further elevating the sintering temperature (Figs. 8d-f). The average grain sizes of the specimens were determined by image analysis. The results are shown in the inset of Fig. 7b. The average grain sizes were essentially unvaried (~0.3 μm) in the sintering temperature range from 700 to 800 °C and then evidently increased with elevating the sintering temperature from 850 to 950 °C. This result infers different sintering mechanisms in these two temperature ranges.

The lithium-free specimen (x=0) sintered at 1260 °C and lithium-added specimen (x=1.0) sintered at 900 °C showed the similar relative densities (around 95%) and average grain sizes (around 0.5 μm). In the following sections (3.2.2 and 3.3), these two ceramics
were employed for investigating the effect of the lithium addition on the crystal structure and dielectric properties.

**Fig. 7.** Relative densities of the ceramic specimens with (a) \( x=0 \) and (b) \( x=1.0 \) as a function of sintering temperature. The inset in the section a shows the SEM image of the lithium-free specimen \( (x=0) \) sintered at 1260 °C. The inset in the section b shows the average grain sizes of the lithium-added specimens \( (x=1.0) \) sintered at different temperatures.

**Fig. 8.** SEM images of the ceramic specimens with \( x=1.0 \) sintered at (a) 700 °C, (b) 750 °C, (c) 800 °C, (d) 850 °C, (e) 900 °C and (f) 950 °C.

### 3.2.2. Crystal structure change with the lithium addition

Fig. 9 shows the XRD patterns of the ceramic specimens. A cubic perovskite structure was identified for the two specimens, with no impurity phase being found within the detection limit of XRD technique. The XRD peaks for the specimen with \( x=1.0 \) slightly shifted towards lower diffraction angle directions relative to the specimen with \( x=0 \). As an example to illustrate this trend, the inset shows the XRD patterns in the \( 2\theta \) range of 45-47°, corresponding to the reflection of (200) crystallographic plane in cubic perovskite structure. The lithium addition led to a shift of the (200) peak to lower diffraction angle direction by \( \sim 0.02 \) °. Accordingly, the lattice constant \( a \) was increased from 3.9684 Å at \( x=0 \) to 3.9711 Å at \( x=1.0 \). The peak shift behavior can be attributed to the incorporation of \( \text{Li}^+ \) into the octahedral cages of \( \text{Ba}_{0.6}\text{Sr}_{0.4}\text{TiO}_3 \) perovskite [31, 32]. \( \text{Li}^+ \) has a larger ionic radius (0.76 Å,
six-fold coordination) than Ti$^{4+}$ (0.605 Å, six-fold coordination) [33]. The lithium incorporation leads to an enlargement of the unit-cell in dimension, thus accounting for the peak shift behavior [32].

![Fig. 9. XRD patterns of the ceramic specimens with x=0 and x=1.0, respectively. The inset shows the XRD patterns in the 2θ range of 45-47°.](image)

Fig. 9. XRD patterns of the ceramic specimens with x=0 and x=1.0, respectively. The inset shows the XRD patterns in the 2θ range of 45-47°.

Fig. 10 shows the Raman spectroscopy of the two ceramic specimens. Eight active response modes were detected for the specimen with x=0. The ascriptions of these response modes were determined by referring to the literature results for BST perovskites [34, 35]. It has been demonstrated that Raman response is inactive in nature for a cubic BaTiO$_3$-based perovskite [35, 36]. The active responses of the specimen with x=0 can be assigned to the presence of local polar distortions embedded in the cubic structure of the specimen at room temperature [36, 37].

![Fig. 10. Raman spectra of the ceramic specimens with x=0 and x=1.0, respectively.](image)

Fig. 10. Raman spectra of the ceramic specimens with x=0 and x=1.0, respectively.

While the Raman response modes of the specimen with x=1.0 was similar to the specimen with x=0, the intensities of these responses were obviously weakened. Especially, the E(TO$_2$) and A$_1$(LO$_3$) modes, occurring for the specimen with x=0 at ~298 cm$^{-1}$ and ~740 cm$^{-1}$, respectively, were absent for the specimen with x=1.0. These two response modes are specific to tetragonal BaTiO$_3$-based perovskites [38]. Hence it can be suggested that the local polar distortions embedded in the cubic perovskite structure became faded with the lithium addition. Aside from this, the lithium addition resulted in an obvious alteration of the intensity ratio between the A$_1$(TO$_3$) (~520 cm$^{-1}$) and E(TO$_3$) (~570 cm$^{-1}$) modes. These two modes
correspond to the O-Ti-O vibrations along $a$ axis and $ab$ plane, respectively [39]. The alteration of the intensity ratio between the two modes can be related to the incorporation of Li$^+$ into the octahedral cages, affecting the O-Ti-O phonon vibrations as a result.

### 3.2.3 Mechanism for the low-temperature densification of the lithium-added specimen

On the basis of the investigations performed so far, a tentative scenario is proposed to interpret the low-temperature densification of the lithium-added specimen. By and large, the low-temperature densification behavior can be linked to a liquid-phase sintering mechanism. The liquid-phase was originated from the eutectic melting of the (Ba,Sr)CO$_3$ and Li$_2$CO$_3$ (Fig. 5b). The presence of the liquid-phase is presumed to be responsible for the initiation of the shrinkage at $\sim$745 °C for the compacted bars (Fig. 6a) and the fast increase of the relative density with elevating the sintering temperature from 700 to 750 °C for the ceramic specimens (Fig. 7b).

The relative densities of the lithium-added specimens were increased with elevating the sintering temperature from 72.5% at 700 °C to 83.0% and 84.1% at 750 and 800 °C, respectively (Fig. 7b). The average grain sizes, on the other hand, were basically unchanged in the sintering temperature range from 700 to 800 °C ($\sim$0.3 μm, the inset in Fig. 7b). These results indicate that the sintering behavior in this temperature range was governed by a grain rearrangement process facilitated by the liquid-phase [40], leading to a compact grain arrangement whereas incapable of inducing a substantial grain growth.

Further elevating the sintering temperature resulted in accelerated grain growth and densification progress (Fig. 8). The relative densities of the specimens sintered at 900 and 950 °C attained 96.0 and 97.5 % (Fig. 7b), while their average grain sizes were increased to 0.47 and 0.75 μm, respectively (the inset in Fig. 7b). As can be noticed, the accelerated microstructural evolution took place concurrent with a dissolution-precipitation process (Fig. 5b). The dissolution-precipitation process refers to the dissolution of partial Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ into the liquid-phase and subsequent precipitation of various constituents in the liquid-phase onto the grains, followed by the incorporation of these constituents (e.g. lithium) into the perovskite structure (Figs. 9 and 10). Such an occurrence is favorable for mass transport and grain growth during sintering, which is critical for achieving a satisfactory level of densification. In view of this, the dissolution-precipitation process is proposed to account for the high relative densities of the specimens sintered at 900 and 950 °C, respectively.

### 3.3. Dielectric properties of the ceramics specimens

Fig. 11 shows the temperature dependence of the dielectric constant ($\varepsilon_r$) and loss (tanδ) at different frequencies for the ceramic specimens. A diffuse phase-transition (DPT) behavior was observed for the specimen with x=0, consistent with literature result [41]. While the specimen with x=1.0 showed similar dielectric behavior, its dielectric constant peaks were somewhat broadened relative to the specimen with x=0. This change can be related to the incorporation of Li$^+$ into the lattice (Figs. 9 and 10), leading to increased compositional inhomogeneity on the micro-scale.

The temperature where a dielectric constant maximum occurred (T_m) was around 0 °C for the specimen with x=0 (Fig. 11a), agreeing with the literature value (272 K) for Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ ceramics [41]. The lithium addition did not alter the T_m value (Fig. 11b), notwithstanding the incorporation of Li$^+$ into the octahedral site. This phenomenon can be understood with respect to two converse effects associated with the lithium incorporation. The ferroelectricity of Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ is inherently related to a long-range coupling between the ferroelectrically active [TiO$_6$] octahedrons [42]. With a larger ionic radius than Ti$^{4+}$, the incorporation of Li$^+$ serves to enlarge the dimension of the octahedrons and thus allows a larger displacement of Ti$^{4+}$ ions away from their centrosymmetrical position. This effect
favors an increase of $T_m$ value. On the other hand, the lithium incorporation and concomitant formation of oxygen vacancies in the lattice [31, 32] deteriorate the coupling between the $[\text{TiO}_6]$ octahedrons and thereby temperature stability of the ferroelectricity. The $T_m$ value of the specimen with $x=1.0$, unaltered relative to the specimen with $x=0$, is assumed to be the result of a compromise between the two factors.

![Fig. 11. Temperature dependence of the dielectric constant ($\varepsilon_r$) and loss ($\tan\delta$) at different frequencies for the ceramic specimens with (a) $x=0$ and (b) $x=1.0$.](image)

Fig. 12 shows the nonlinear dielectric properties of the ceramic specimens. The tunability was calculated as the percentage of dielectric constant change under applied bias electric field. The figure-of-merit (FOM) was defined as the ratio between the tunability and the dielectric loss measured under zero bias filed. The specimens with $x=0$ and $x=1.0$ exhibited the dielectric constants of 3010 and 3280 under zero bias filed, together with the losses of 0.48 and 0.32 %, respectively. Considering the similar grain sizes (around 0.5 μm) and identical $T_m$ value (Fig. 11) of the two specimens, the slightly increased dielectric
constant and the decreased dielectric loss of the specimen with $x=1.0$ are intuitively attributed to its somewhat higher densification degree (96.0%).

The dielectric nonlinearity of the two specimens was characterized by the decline of the dielectric constants and losses with increasing bias electric field in magnitude (Figs. 12a and b). The two specimens exhibited similar tunability values under 20 kV/cm (32 and 34 %, Fig. 12c), whereas the corresponding FOM values (67 and 106, Fig. 12d) were quite different. The larger FOM value (106) of the specimen with $x=1.0$ is mainly attributed to its lower dielectric loss (0.32 %). This FOM value rivals the literature result (~91) determined under the same conditions (10 kHz and 20 kV/cm) for Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ ceramics prepared by the conventional solid-state method [43]. Representing a subtle balance between tunability and dielectric dissipation, FOM serves as the criterion for appraising the overall properties of a nonlinear dielectric material [41]. In terms of this criterion, the lithium addition is beneficial to the nonlinear dielectric properties of Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ ceramics.

Adding a glass frit or a low melting-point oxide additive into BST usually gave rise to a dilemma in property changes, i.e. enhancing the sintering properties at the expense of more or less sacrificing the dielectric properties [14, 16, 19]. Unlike this situation, the addition of a small amount Li$_2$CO$_3$ into Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ ceramics yielded a simultaneous enhancement of the two properties in this work. It is thus suggested that the method used in this work may be applied to BST dielectric ceramics with other compositions.

4. Conclusion

The 1.0 wt.% Li$_2$CO$_3$-added Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ ceramics prepared by the citrate precursor method demonstrated a simultaneous enhancement of sintering and nonlinear dielectric properties. The lithium species introduced into the citrate precursor was converted to Li$_2$CO$_3$ during the synthetic process of the powder. The synthesized powder was contaminated with a small amount of (Ba,Sr)CO$_3$ on the surface in the ambient atmosphere. The lithium-added specimen attained a relative density of 96.0 % when sintering at 900 °C. The low-temperature densification behavior was related to a liquid sintering mechanism. The origin of the liquid-phase was explained in terms of the eutectic melting of the (Ba,Sr)CO$_3$ and Li$_2$CO$_3$. The liquid-phase facilitated the grain rearrangement during early-stage sintering and promoted the grain growth via a dissolution-precipitation process during final-stage sintering. The FOM (106) of the lithium-added specimen sintered at 900 °C was increased by ~60 % relative to the value (67) for the lithium-free specimen prepared by the citrate method. The method used in this work may be applied to other BST dielectric ceramics and derivatives of this solid solution system.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Nos. 51072146 and 51872047) and Technology Research Project of Hubei Provincial Department of Education (No. B2016277).

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Садржај: Прахови састава Ba$_{0.6}$Sr$_{0.4}$TiO$_3$+x wt.% Li$_2$CO$_3$ (x=0 и x=1.0) су синтетисани цитратном прекурсорском методом. Испитивани су синтеровање, структура и диелектрична својства синтерованих узорака. У поређењу са узорцима без литијума (x=0), узорци са литијумом (x=1.0) показују побољшана својства након синтеровања, достигнући релативну густину од 96.0 % након синтеровања на 900 °C. Побољшана својства су повезана са механизmom течно-фазног синтеровања. Објашњен је и утицај течне фазе на згушњавање узорака са литијумом. Нађено је да додатак литијума има позитиван утицај на нелинеарна диелектрична својства.

Кључне речи: Ba$_{0.6}$Sr$_{0.4}$TiO$_3$ керамика; Li$_2$CO$_3$ адитив; синтеровање; нелинеарна диелектрична својства.

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