

# Sintering behavior and dielectric properties of $\text{SrB}_2\text{Si}_2\text{O}_8$ ceramics

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**Abstract** In this paper, the sintering behavior of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics based on the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  composition has been investigated. The influence of the BaO addition to the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics on the sintering behavior has been also examined. It shows that, due to the low-melting characteristics of the  $\text{SrO-B}_2\text{O}_3$  binary composition, the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics with peculiar dielectric properties can easily prepared by the introduction of  $\text{SiO}_2$  to the  $\text{SrO-B}_2\text{O}_3$  binary compositions at a sintering temperature of 950 °C. Additionally, the introduction of BaO to  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics has an obvious effect on the sintering behavior of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics. Also, the dielectric properties of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics are correlative to the phase compositions and the microstructures.

## 1 Introduction

Nowadays, low-temperature co-fired ceramics (LTCC) technologies have been attracting much attention because of the rapid growth of the wireless communication systems and microwave products in the consumer electronic market [1]. The low-temperature sintering technology is an important way to enable its advantageous utilization for today's packaging process in microelectronics and in microwave modules. Particularly, because the LTCC materials can be sintered at a temperature of below 1,000 °C, the embedded components and transmission lines can be made by using the highly conductive metals,

e.g. silver, copper, gold, with low conductor loss and low electrical resistance at high frequencies [1, 2]. So far, glass-ceramics and ceramic/glass composites have been widely researched for LTCC application due to their tailored physical properties and low sintering temperature [3]. The preparation of glass-ceramics is achieved by a devitrification of glass materials. Also, the ceramic/glass composites are usually fabricated by using glasses as a matrix and functional ceramic particles as filler, which is convenient to the property design of the composite materials. Because a liquid-phase sintering can supply various facilities for the achievement of the densification sintering [4], glass materials play an important role in the fabrication of LTCC materials. Nevertheless, the manufacture of most glass materials is usually a complex process including high-temperature melting, rapid cooling and crystallization. Its energy consumption is relatively high. Consequently, it should be considered by choosing more convenient methods to improve the preparation process to achieve an energy-saving LTCC preparation process. At present, there are some multiple oxide compositions with a melting temperature below 1,000 °C [5–10], such as  $\text{CaO-B}_2\text{O}_3\text{-SiO}_2$ ,  $\text{BaO-ZnO-SiO}_2\text{-B}_2\text{O}_3$ ,  $\text{BaO-B}_2\text{O}_3\text{-SiO}_2$ ,  $\text{Li}_2\text{O-MgO-P}_2\text{O}_5$ ,  $\text{ZnO-TeO}_2$  etc., which have the potential to develop single crystal phase ceramics, e.g.,  $\text{CaSiO}_3$ ,  $\text{Zn}_2\text{SiO}_4$ ,  $\text{BaSiO}_3$ ,  $\text{LiMgPO}_4$  and  $\text{Zn}_2\text{Te}_3\text{O}_8$ , etc., with peculiar physical properties and a low sintering temperature. The low-melting compositions can supply sufficient amounts of liquid phase for the crystal phase formations and the achievement of the densification sintering at relative low sintering temperature. In turn, dielectric and thermal properties of the low-temperature ceramics can be tailored in terms of these crystal phases.

In this work, a  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics with a low sintering temperature is researched as LTCC candidate materials, the

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$\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics based on  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  composition are fabricated by the introduction of a  $\text{SiO}_2$  component to a  $\text{SrO-B}_2\text{O}_3$  binary composition with low-melting characteristics. Presently, few researches have reported the luminescent properties of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  crystals used as a luminescence matrix [11, 12], but a very little research concerned on the sintering behaviors and the electric properties of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics. The objective of the work is to discuss the sintering behavior of the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics and its dielectric properties so that it can be developed for the possible application in the LTCC technologies.

## 2 Experimental

$\text{H}_3\text{BO}_3$ ,  $\text{SrCO}_3$ ,  $\text{H}_2\text{SiO}_3$  and  $\text{Ba(OH)}_2\cdot 8\text{H}_2\text{O}$  with purity higher than 99 % were used as the starting materials. According to the designed compositions listed in Table 1, the starting materials were weighed and milled with de-ionized water plus little ammonia for 7 h. The weight ratio of the water to solid was regulated to 2/1. Upon treatment, the slurries were dried at 80 °C. Subsequently, the powders with the particle size of 0.5–1.0  $\mu\text{m}$  were molded into green bodies under a compressive stress of 25 MPa. Finally, the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics specimens were obtained by continuously sintering the green bodies at 600 °C for 3 h and 950 °C for 2 h. The microstructures of the specimens were analyzed by using a color 3D laser microscope (KEYENCE, VK-9700, Japan), a X-ray powder diffraction patterns and a differential scanning calorimetry (NETZSCH STA449C, Germany, heating at a rate of 10 °C  $\text{min}^{-1}$ ), the X-ray powder diffraction patterns were recorded on a D/Max-III A machine (Rigaku Industrial Corporation, Japan) using  $\text{Cu K}\alpha$  Radiation (40 kV, 30 mA) with a scanning rate of 2°  $\text{min}^{-1}$ . Dielectric properties and quality value  $Q \times f$  at microwave frequencies were measured with a network analyzer (Model Agilent E363A, USA) by using Hakki-Coleman dielectric resonator method.

## 3 Results and discussion

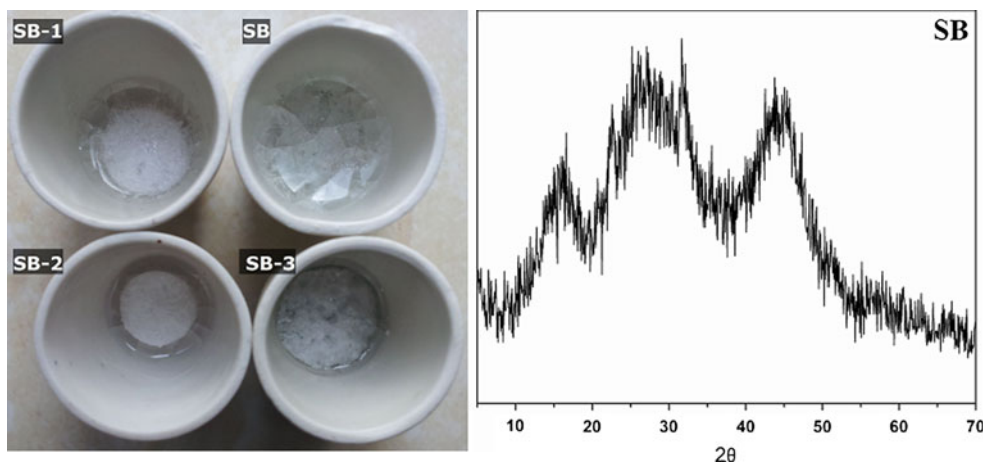
Sintering, especially a liquid-phase sintering is crucial to achieve a densification microstructure for LTCC materials. In addition, the densification sintering of ceramic materials also depend on sintering temperature, time as well as chemical and physical characteristics of starting materials such as particle size, chemical compositions, etc. Especially, the achievement of a low-temperature sintering for ceramics more mainly depends on the low-melting components existed in the ceramics materials. As well known

**Table 1** The chemical compositions of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics

| Name   | Compositions (mol)   |
|--------|--|
| SB     | $\text{SrO}\cdot 3\text{B}_2\text{O}_3$  |
| SB-1   | $\text{SrO}\cdot 2\text{B}_2\text{O}_3$  |
| SB-2   | $\text{SrO}\cdot 1.5\text{B}_2\text{O}_3\cdot 0.17\text{SiO}_2$                    |
| SB-3   | $\text{SrO}\cdot 1.5\text{B}_2\text{O}_3\cdot 0.33\text{SiO}_2$                    |
| SBS-1  | $\text{SrO}\cdot 1.5\text{B}_2\text{O}_3\cdot 1.5\text{SiO}_2$                     |
| SBS-2  | $\text{SrO}\cdot \text{B}_2\text{O}_3\cdot \text{SiO}_2$                           |
| SBS-3  | $\text{SrO}\cdot 1.3\text{B}_2\text{O}_3\cdot 1.7\text{SiO}_2$                     |
| SBS-4  | $\text{SrO}\cdot 0.7\text{B}_2\text{O}_3\cdot 1.7\text{SiO}_2$                     |
| SBS-5  | $\text{SrO}\cdot 1.5\text{B}_2\text{O}_3\cdot 2.3\text{SiO}_2$                     |
| SBS-6  | $\text{SrO}\cdot 1.1\text{B}_2\text{O}_3\cdot 2.0\text{SiO}_2$                     |
| SBSB-1 | $\text{SrO}\cdot 0.12\text{BaO}\cdot 1.8\text{B}_2\text{O}_3\cdot 2.8\text{SiO}_2$ |
| SBSB-2 | $\text{SrO}\cdot 0.1\text{BaO}\cdot 1.2\text{B}_2\text{O}_3\cdot 2.3\text{SiO}_2$  |
| SBSB-3 | $\text{SrO}\cdot 0.34\text{BaO}\cdot 2.3\text{B}_2\text{O}_3\cdot 3.5\text{SiO}_2$ |
| SBSB-4 | $\text{SrO}\cdot 1.4\text{BaO}\cdot 4.5\text{B}_2\text{O}_3\cdot 7\text{SiO}_2$    |
| SBSB-5 | $\text{SrO}\cdot 0.5\text{BaO}\cdot 1.9\text{B}_2\text{O}_3\cdot 3.5\text{SiO}_2$  |
| SBSB-6 | $\text{SrO}\cdot 1.7\text{BaO}\cdot 3.8\text{B}_2\text{O}_3\cdot 7\text{SiO}_2$    |

from the phase diagram of a  $\text{SrO-B}_2\text{O}_3$  binary system [13], the liquid phase of the  $\text{SrO-B}_2\text{O}_3$  composition can be formed at least 950 °C whereas the low-temperature liquid phase zone is corresponded to the  $\text{SrO-B}_2\text{O}_3$  composition with a 60–80 mol%  $\text{B}_2\text{O}_3$  content, which consequently guarantee the low-temperature preparation of the  $\text{SrO-B}_2\text{O}_3$  melts. However, the  $\text{SrO-B}_2\text{O}_3$  melts can not completely contribute crucial advantages for physical properties such as thermal and dielectric properties. Therefore, the introduction of other oxides, e.g.,  $\text{SiO}_2$ , to the  $\text{SrO-B}_2\text{O}_3$  compositions is expected to obtain the functional mineral phase and consequently achieve the fabrication of the low-temperature sintering ceramics with peculiar physical properties. Especially, the preparation process of the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics is based on an aqueous suspension route, and by the means of a chemical combination, hydrated borate compounds with a low-melting temperature and precursor compounds of the functional mineral phases can be formed from the suspension solutions of  $\text{H}_3\text{BO}_3$ ,  $\text{H}_2\text{SiO}_3$  and  $\text{SrCO}_3$ , which consequently can provide more possibilities for the fabrication of the low temperature sintering ceramics with peculiar physical properties.

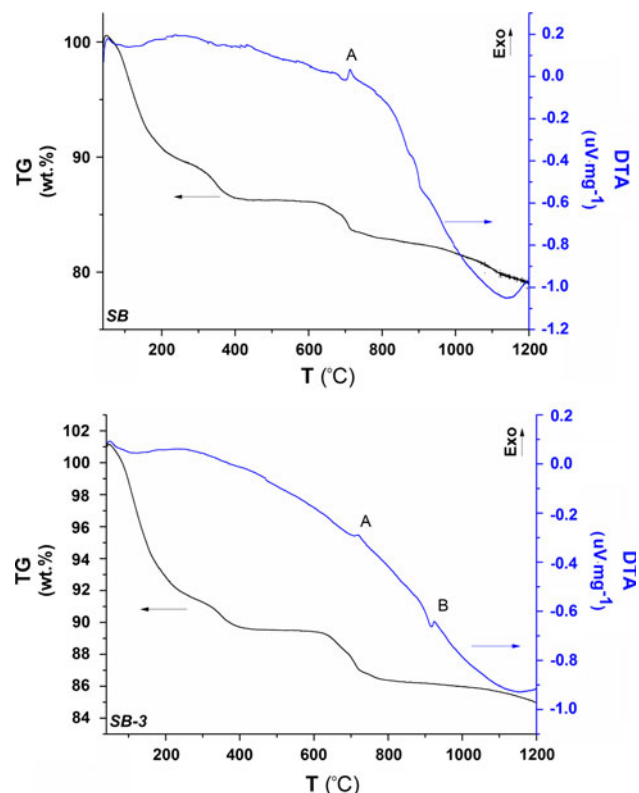
As shown in Fig. 1, the specimen SB with a  $\text{SrO}\cdot 3\text{B}_2\text{O}_3$  composition have been basically transformed into a glassy form by a sintering processing for 2 h at 950 °C, indicating that a feasible  $\text{SrO-B}_2\text{O}_3$  binary composition possess a low-melting characteristics. In comparison with the specimen SB, the specimen SB-1 with a  $\text{SrO}\cdot 2\text{B}_2\text{O}_3$  composition also shows a melting form but it is not be transformed completely into a glassy form. It means that the  $\text{B}_2\text{O}_3$  content have an obvious effect on the melting characteristics of the  $\text{SrO-B}_2\text{O}_3$



**Fig. 1** The pictures of the SrO–B<sub>2</sub>O<sub>3</sub> ceramics and the SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> ceramics sintered at 950 °C

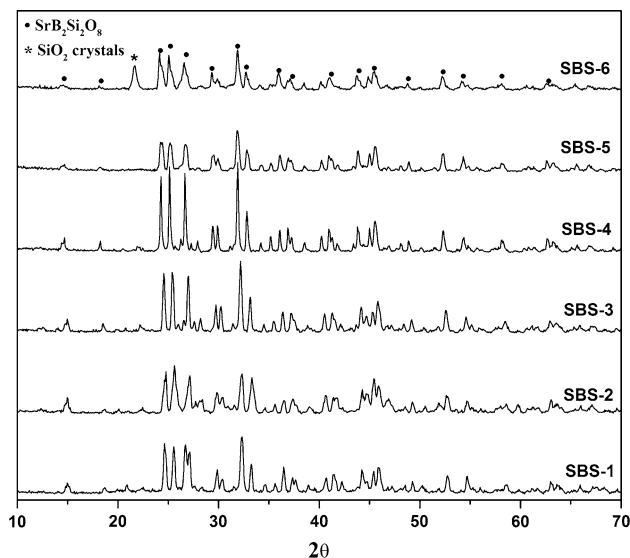
composition, the result is in agreement with the SrO–B<sub>2</sub>O<sub>3</sub> binary phase diagram. On the other hand, the introduction of SiO<sub>2</sub> to the SrO–B<sub>2</sub>O<sub>3</sub> composition do not obviously change the melting characteristics of the SrO–B<sub>2</sub>O<sub>3</sub> composition but the sintering behavior of the SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> melts seems to be changed by a feasible increase of the SiO<sub>2</sub> content. As shown in Fig. 2, it is estimated that strontium borate compounds (crystallization peak, A) have been formed at about

700 °C and subsequently the compound crystals are gradually melted due to a elevating temperature and finally transformed into a glassy form. The melting characteristics depending on temperature for the specimen SB is similar to that for the specimen SB-3. It is speculated that the melting characteristics of the two specimens should be correlative to the strontium borate compounds existed in the slurries. As a result, it means that the B<sub>2</sub>O<sub>3</sub> content can be avaiably decreased as the increase of the SiO<sub>2</sub> content in the SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> compositions and consequently achieve the low-temperature preparation of the SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> ceramics. In addition, as shown in DTA cure of the specimen SB-3, it is also found that, besides the peak A at about 700 °C, another crystallization peak (marker B) are appeared at about 930 °C. It indicates that the rational introduction of SiO<sub>2</sub> to the SrO–B<sub>2</sub>O<sub>3</sub> composition can cause a formation of new crystal phases and more possibly obtain the low-temperature sintering SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> ceramics. According to the results, several SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> ceramic specimens have been prepared by a sintering process at 950 °C and the XRD patterns are represented in Fig. 3.



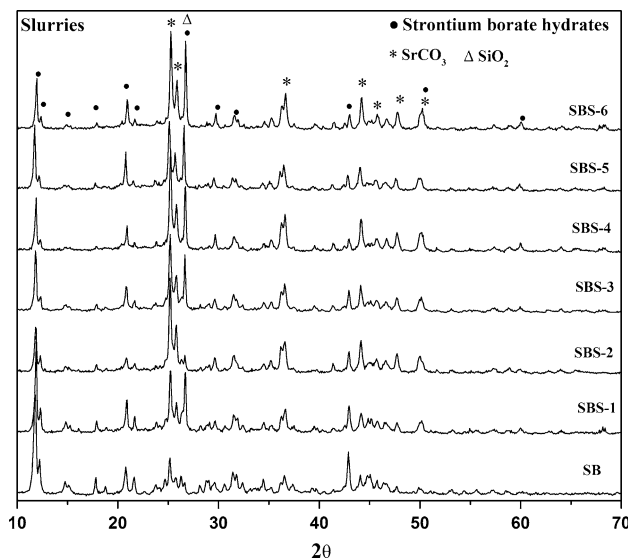
**Fig. 2** The DTA–TG curves of the slurries for the specimen SB and SB-3

As shown in Fig. 3, the major mineral phase of the SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> ceramic specimens is a SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> crystal phase and SiO<sub>2</sub> crystal phases are also appeared in the XRD pattern of the specimen SBS-6. It indicates that the SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> crystal phase can be formed easily from the SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> ceramic specimens via the present process. The formation of SiO<sub>2</sub> crystals should be owing to the crystallization of the SiO<sub>2</sub> residual polymer molecules during sintering, since the specimen SBS-6 has a relatively high SiO<sub>2</sub> content. In fact, the formation of the mineral phases in the SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> ceramics and its sintering behavior are more mainly decided by the compounds existed in its slurries. Figure 4 represents the XRD patterns of the SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> ceramic slurries. It shows that the SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> ceramic slurries mainly contain strontium borate hydrates and a small quantity of



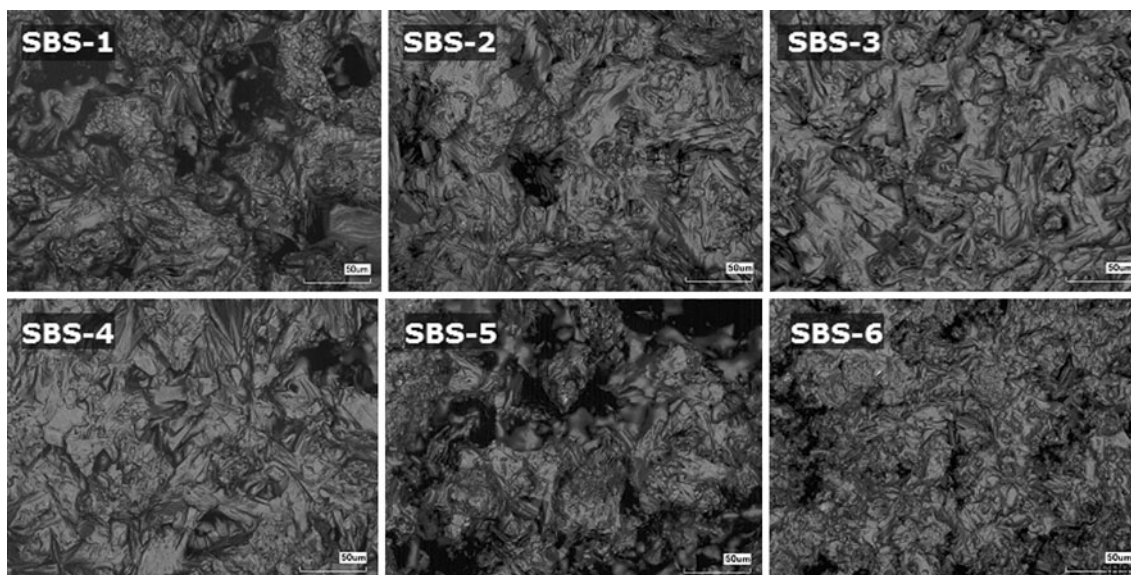
**Fig. 3** The XRD patterns of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics

residual starting materials or polymer molecules. It is estimated that the strontium borate hydrates with a low-melting characteristics can supply a liquid-phase sintering aid for the achievement of the densification microstructures of the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics during sintering, and at the same time cause the available dissolution of the  $\text{SiO}_2$  polymer molecules to a  $\text{SrO-B}_2\text{O}_3$  liquid phase to form the  $\text{SrB}_2\text{Si}_2\text{O}_8$  crystal phase. So the existence of the strontium borate hydrates in the slurries is crucial to the fabrication of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics. In the case of the microstructures, Fig. 5 gives the photomicrographs of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics; it indicates that, after be sintered at  $950^\circ\text{C}$ , the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics possess the dense microstructures besides the specimens SBS-1 and SBS-5, whose microstructures are porous. The formation of the porous microstructures is usually attributed to the absence of a liquid phase in ceramic materials, since the pores can not be filled completely with an enough liquid phase during sintering. In addition, an over sintering can also results in the porous microstructures due to an occurrence of an excessive amounts of liquid phases during sintering. Therefore, the microstructures of the specimens SBS-1 and SBS-5 should be more possibly correlative to their chemical compositions such as  $\text{B}_2\text{O}_3$  or  $\text{SiO}_2$  content, since the high  $\text{B}_2\text{O}_3$  content can increase amounts of a liquid phase but the high  $\text{SiO}_2$  can decrease it as a result of a crystallization of  $\text{SiO}_2$  polymer molecules. In addition, the microstructures and the densities are also further influenced by some correlative factors such as crystallization and an existence of residual glassy phases. The further research needs a more detailed investigation on the relationship between the chemical composition and the amounts of a liquid phase in the future works.



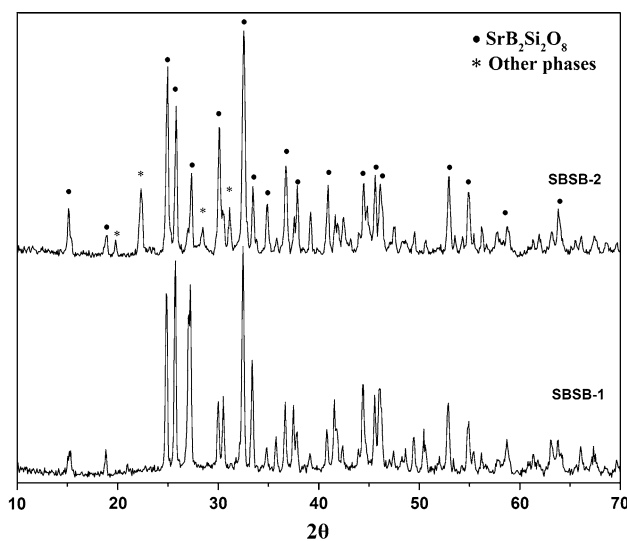
**Fig. 4** The XRD patterns of the slurries for the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics

On the other hand, the sintering behavior of the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics can be also influenced by the introduction of  $\text{BaO}$  to the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  composition. As known from the phase diagram of the binary system  $\text{BaO-B}_2\text{O}_3$  [14], the onset of a liquid phase in the binary system  $\text{BaO-B}_2\text{O}_3$  can be observed at least  $869^\circ\text{C}$ , it means that the eutectic temperature of the binary system  $\text{BaO-B}_2\text{O}_3$  is lower than that of the binary system  $\text{SrO-B}_2\text{O}_3$ . So the introduction of  $\text{BaO}$  to the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics is expected to improve the sintering behavior so as to cause a good densification sintering for the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics. Figure 6 gives the XRD patterns of the specimens SBSB-1 and SBSB-2, which are prepared by a replace of 5 wt%  $\text{BaO}$  for the  $\text{SrO}$  in the specimens SBS-5 and SBS-6, respectively, and a sintering process for 2 h at  $950^\circ\text{C}$ . As shown in Fig. 6, the major mineral phases of the specimens SBSB-1 and SBSB-2 are a  $\text{SrB}_2\text{Si}_2\text{O}_8$  crystal phase and little other mineral phases, e.g.,  $\text{SiO}_2$  crystal phases. It indicates that the feasible replace of  $\text{BaO}$  for the  $\text{SrO}$  in the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics can not obviously change the phase composition of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics. But the effect of the  $\text{BaO}$  introduction on the microstructures is greatly distinct. As shown in Fig. 7, the photomicrograph of the specimen SBSB-1 shows a good crystallization of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  crystals due to the existence of a sufficient liquid phase, whereas the photomicrographs of the specimen SBSB-2 also exhibit weak microstructures as a result of the absence of a liquid phase that are possibly attributed to a high  $\text{SiO}_2$  content in the composition. As shown In Fig. 8, it is found that, besides  $\text{SrCO}_3$  compound and  $\text{SiO}_2$  polymer molecules, the slurries of the specimens SBSB-1 and SBSB-2 contain only little barium borates hydrates. The appearance of the barium



**Fig. 5** The photomicrographs of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics

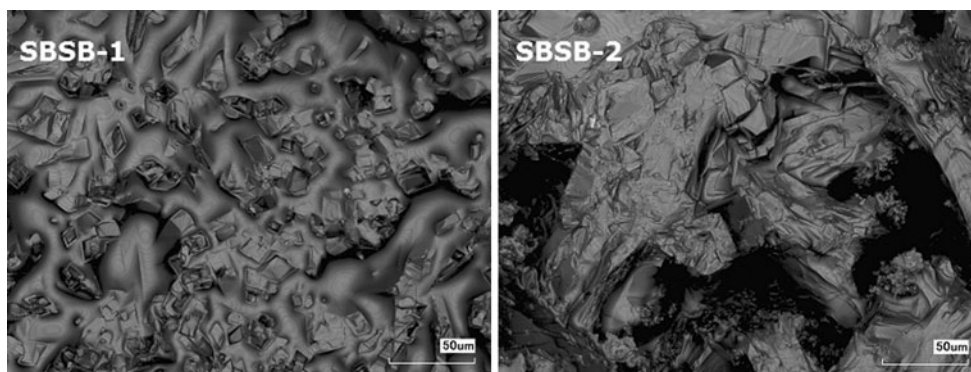
borates hydrates in the slurries of the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics should be relative to the complicated exchange of Ba and Sr ions in the aqueous suspension. It implies that the chemical-bond preference of the  $\text{B}_2\text{O}_3$  polymer molecules is more tending to Ba ion rather than Sr ion, thus it can hinder the formation of strontium borate hydrates in the slurries of the specimens SBSB-1 and SBSB-2. Furthermore, as the compounds with low-melting characteristics [8], the appearance of the barium borates hydrates in the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics can further cause more liquid phase during sintering and at a certain extent facilitate the densification sintering of the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics. But as presented in Figs. 9, 10, with the BaO replace for the SrO in the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics, it does not only change the mineral phase composition of the  $\text{SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics but also result in a weak sintering behavior such as an over sintering phenomenon. In Fig. 10, the picture of the  $\text{BaO-SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics specimens SBSB-3, 4, 5, 6 have obviously shown that an over-sintering phenomenon have been shown on the pictures of these specimens with high BaO and  $\text{B}_2\text{O}_3$  content. Moreover, the specimens SBSB-3, 4, 5, 6 sintered at 850 and 900 °C, respectively looks totally like similar with the specimens sintered at 950 °C. It indicates that the high  $\text{BaO-B}_2\text{O}_3$  components in the ceramics can hinder the achievement of a densification sintering due to an over sintering. It is estimated that the occurrence of the over-sintering phenomenon should be attributed to the existence of the excessive liquid phases in the ceramics. Similarly, it also more easily causes a crystallization of the  $\text{SiO}_2$  polymer molecules and finally forms  $\text{SiO}_2$  crystals. Consequently, the weak sintering behavior is unbeneficial to achieve a good microstructures and dielectric properties. The regulation of the BaO and  $\text{B}_2\text{O}_3$  content in the composition of the



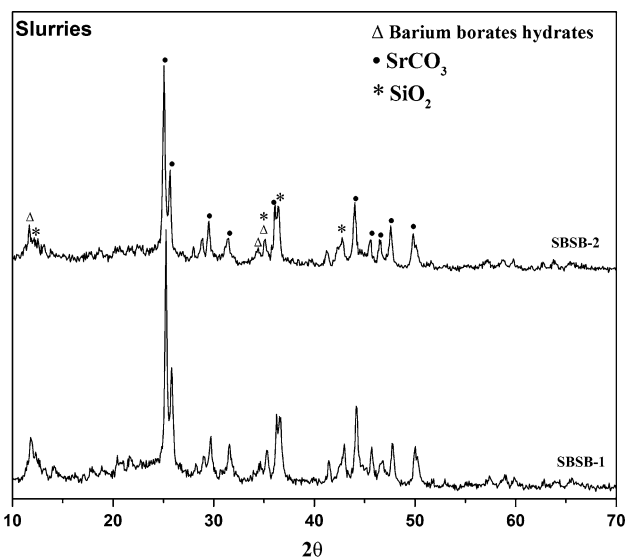
**Fig. 6** The XRD patterns of the specimens SBSB-1 and SBSB-2

$\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics is equally important to achieve a single  $\text{SrB}_2\text{Si}_2\text{O}_8$  crystal phase and a good sintering behavior.

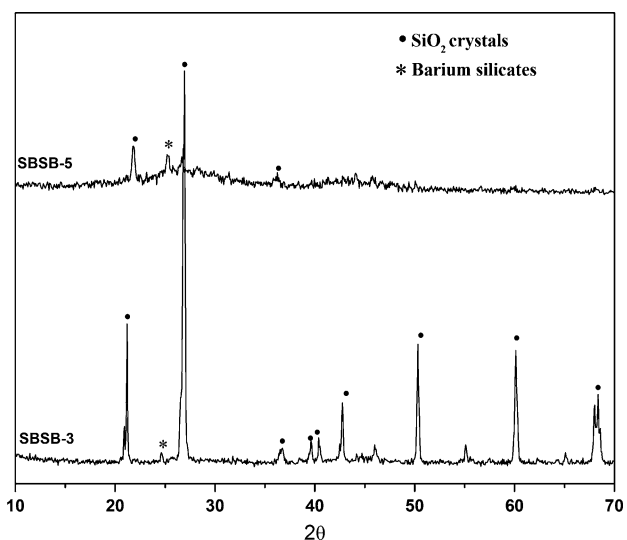
Generally, our investigations have indicated that the  $\text{SrO-B}_2\text{O}_3$  composition with low-melting characteristics can play an important role in the fabrication of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics. The  $\text{SrO-B}_2\text{O}_3$  composition, as a liquid phase, in the ceramics can availably drive the various particles and polymer molecular dispersing and combining with each other to form the mineral phases with thermodynamic stability during sintering. On the basis of the classical theory of the liquid phase sintering [15], the sintering behavior of the low-temperature sintering ceramics can be understood as the mechanism that, by a liquid phase flow, the phase formation and the occurrence



**Fig. 7** The photomicrographs of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics with an addition of a BaO component



**Fig. 8** The XRD patterns of the slurries for the specimens SBSB-1 and SBSB-2



**Fig. 9** The XRD patterns of the specimens SBSB-3 and SBSB-5



**Fig. 10** The pictures of the  $\text{BaO-SrO-B}_2\text{O}_3\text{-SiO}_2$  ceramics sintered at  $950^\circ\text{C}$

of the densification were achieved along with crystal particle dispersing, rearrangement, solution-precipitation and solid-stat sintering.

As far as the dielectric properties of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics is concerned, the  $Q \times f$  value and the dielectric constant and loss of the specimens are listed in Table 2. It shows that the dielectric constants of the  $\text{SrB}_2\text{Si}_2\text{O}_8$  ceramics have the values of about 4 and the dielectric losses are in a range of  $10^{-3}$ – $10^{-4}$ . Because of the porous microstructures, the dielectric properties of the specimens SBS-1, SBS-5 and SBSB-2 are relatively weaker than that of other specimens. In addition, an amount of the residual glassy phases in the specimen SBSB-1, which originated from the excessive liquid phases existed in the ceramics during sintering, should be responsible for its relative low dielectric constant. Also, it is found that the specimen SBS-4, whose chemical composition contains a reasonable  $\text{B}_2\text{O}_3$

**Table 2** The dielectric properties of the SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> ceramics

| Name   | Test frequency (GHz) | $\epsilon_r$ | $\tan\alpha$ (%) | $Q \times f$ (GHz) | Density (g cm <sup>-3</sup> ) |
|--------|----------------------|--------------|------------------|--------------------|-------------------------------|
| SBS-1  | 14                   | 3.8          | 0.1              | 11,015             | 2.97                          |
| SBS-2  | 12                   | 4.3          | 0.1              | 14,651             | 2.93                          |
| SBS-3  | 12                   | 4.2          | 0.08             | 9,525              | 2.87                          |
| SBS-4  | 13                   | 4.2          | 0.13             | 20,617             | 3.20                          |
| SBS-5  | 12                   | 3.3          | 0.09             | 12,894             | 2.63                          |
| SBS-6  | 12                   | 4.3          | 0.12             | 10,131             | 2.69                          |
| SBSB-1 | 12                   | 3.2          | 0.17             | 7,045              | 2.16                          |
| SBSB-2 | 13                   | 2.8          | 0.28             | 14,603             | 3.06                          |

content and is closed the composition of a nature mineral, pekovite [16], obtain a good sintering behavior and a high  $Q \times f$  value. As well known, SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> is an alkaline borosilicate mineral with a Pekovite (Danburite) crystal structure. At present, most of alkaline borosilicate minerals have been widely researched for the applications in the immobilization on high-level radioactive wastes and photo luminescent materials. Moreover, the alkaline borosilicate minerals are widely used to fabricate LTCC materials such as SrO-, CaO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> glass–ceramics, for the application in microwave devices and electronic packaging. However, until recently, a very little literature has reported the dielectric properties of the SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> ceramics based on SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> composition. More importantly, the preparation method of the single crystal phase ceramics is advantageous to develop an energy-saving process for the preparation of LTCC materials, since it does not need an additional glass manufacture process.

#### 4 Conclusions

The present work is to discuss the sintering behavior of the SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> ceramics based on SrO–B<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub> composition, which are prepared by an aqueous solid-state process at a sintering temperature of 950 °C. It indicates that the SrO–B<sub>2</sub>O<sub>3</sub> composition with low-melting characteristics can play an important role in the liquid-phase sintering of the SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> ceramics. The phase formation and the achievement of the densification sintering are relative to the existence of a strontium borate hydrates in the ceramic slurries. At the same time, we realized that there are two obvious effects on the densification sintering of the SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> ceramics, on the one hand, the existence of the BaO and B<sub>2</sub>O<sub>3</sub> components in the SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> ceramics can offer more possibilities to set a proper sintering behavior but on the other hand, the sintering behavior and the

physical properties can be also deteriorated due to a high BaO, B<sub>2</sub>O<sub>3</sub> or SiO<sub>2</sub> content in the composition. The SrB<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> ceramics possess a dielectric constant of about 4 and its loss can be lowered up to 10<sup>-4</sup>.

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