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Short communication

Microwave dielectric properties of new $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics

Cheng-Hsing Hsu *, Chia-Hao Chang

Department of Electrical Engineering, National United University, No. 1, Lien-Da, Kung-Ching Li, Miao-Li 36003, Taiwan

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Abstract

In this study, the microwave dielectric properties and microstructures of $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics prepared by conventional solid-state route were examined. The dielectric constant values (ε_r) saturated at 7.7–8.5. The $Q \times f$ values of 6400–6700 GHz were obtained when the sintering temperatures were in the range of 1450–1540 °C. The temperature coefficient of the resonant frequency τ_f was not sensitive to the sintering temperature. The ε_r value of 8.5, $Q \times f$ value of 6700 GHz, and τ_f value of −44 ppm/°C were obtained for $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics sintered at 1540 °C.

Keywords: C. Dielectric properties; Ceramics; $(Ca_{0.8}Sr_{0.2})SnO_3$

1. Introduction

The dielectric properties of ceramic materials are of interest in dielectric resonator applications. The main focus of research is to search for materials with a high-quality factor ($Q \times f$), high dielectric constant (ε_r), and zero temperature coefficient of resonant frequency (τ_f) for use as dielectric resonators and microwave device substrates. High dielectric constant materials can effectively reduce the size of resonators, and the inverse of the dielectric loss must be high to achieve prominent frequency selectivity and stability in microwave transmitter components. Moreover, a small temperature coefficient of the resonant frequency is needed to ensure the stability of the microwave components at different working temperatures. Several compounds, such as $(Zr,Sn)TiO_4$, $Mg(Zr,Ti)O_3$, and $(Mg,Ca)TiO_3$ have therefore been developed [1–3].

The $CaTiO_3$ ceramic has been reported to have good microwave dielectric properties and has been of great interest as a potential dielectric resonator for microwave applications [4]. Appropriate substitutions in the A site of the $(Ca,Sr)TiO_3$ ceramic family to form a solid solution have been investigated to achieve a high dielectric constant, which allows such compounds to adapt to higher frequency applications [5]. As $(Ca_{0.8}Sr_{0.2})TiO_3$ has ε_r of 181, $Q \times f$ of 8300 (GHz), and τ_f of +991 ppm/°C, it is one of the $(Ca,Sr)TiO_3$ compositions that has been determined to have the potential to be used as resonators in microwave applications [5]. On the other hand, to further investigate the influence of equivalent-charge substitutions for B sites on $(CaSr)TiO_3$, we used Sn^{4+} to substitute Ti^{4+} to form $(Ca_{0.8}Sr_{0.2})SnO_3$, due to the fact that the ionic radii of Sn^{4+} (0.69 nm) and Ti^{4+} (0.605 nm) are similar. In this study, $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics, using start powders of $CaCO_3$, $SrCO_3$, and SnO_2, were synthesized by solid-state method, and the microwave dielectric properties and the microstructures of $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics were also investigated.

2. Experimental procedures

A sample of $(Ca_{0.8}Sr_{0.2})SnO_3$ mixed according to the desired stoichiometry was synthesized by conventional solid-state method from individual high-purity oxide powders (>99.9%): $CaCO_3$, $SrCO_3$, and SnO_2. The powders were ground in distilled water for 12 h in a ball mill with agent balls. All mixtures were dried, forced through a 200-mesh sieve, and calcined at 1250 °C for 4 h. The calcined reagent was ground into a fine powder for 12 h. The fine powder, together with the organic binder, was pressed into pellets with dimensions of 11 mm diameter and 5 mm thickness under a pressure of 2000 kg/cm^2. These pellets were sintered at temperatures of 1450–1540 °C for 4 h in air. Both the heating and cooling rates were set at 10 °C/min. On other hand, the X-ray diffraction (XRD, Siemens D5000) data of powder and bulk samples were

* Corresponding author. Tel.: +886 37 381401; fax: +886 37 327887.
E-mail address: hsuch@nuu.edu.tw (C.-H. Hsu).

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collected using Cu Kα radiation and a graphite monochromator in the 2θ range of 20–60°. The microstructural observations and analysis of sintered surface were performed using a scanning electron microscopy (SEM, Philips XL-40FEG). The density of the sintered specimens, as a function of sintering temperature, was measured by the liquid Archimedes method using distilled water as the liquid. The ε_r and $Q \times f$ values at microwave frequencies were measured using the Hakki–Coleman dielectric resonator method, as modified and improved by Courtney [6,7]. The dielectric resonator was positioned between two brass plates to form a cavity-like structure. The test cavity was placed over a thermostat and the temperature range used was +25 °C to +80 °C.

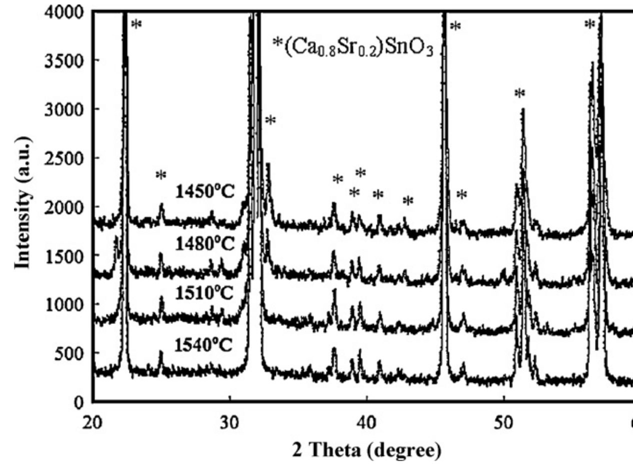

Fig. 1. X-ray diffraction patterns of the $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics at different sintering temperatures.

3. Results and discussions

Fig. 1 shows the XRD patterns of the $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics at different sintering temperatures. It was observed that $(Ca_{0.8}Sr_{0.2})SnO_3$ indexed orthorhombic $Ccm2_1$. Similar XRD patterns were detected for the $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics with various sintering temperatures. The second phase was not observed at different sintering temperatures, because detection of a minor phase by XRD is extremely difficult. In addition, identical XRD patterns were observed for the ceramics irrespective of the sintering temperature. The surface microstructural photographs of $(Ca_{0.8}Sr_{0.2})SnO_3$ sintered at 1450–1540 °C are presented in Fig. 2. The porosity decreased with increasing sintering temperature owing to grain growth. However, grain growth was observed for $(Ca_{0.8}Sr_{0.2})SnO_3$ specimen at higher sintering temperatures. These factors may directly affect the microwave dielectric properties of the $(Ca_{0.8}Sr_{0.2})SnO_3$ samples.

The plot of bulk density and dielectric constant of the $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics versus the sintering temperature is illustrated in Fig. 3. The density increased with increasing sintering temperature. This was because such a high sintering temperature would cause grain growth, resulting in an increase in density. The increase in density may directly affect the

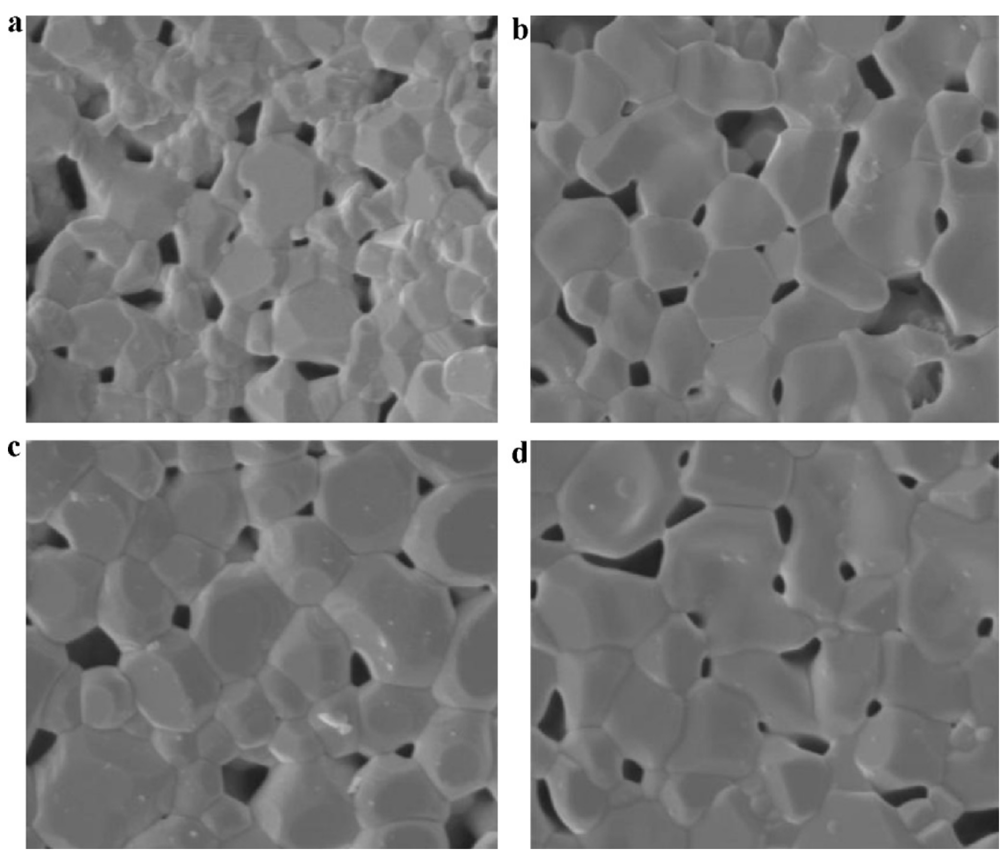

Fig. 2. SEM photographs of $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics at different sintering temperatures: (a) 1450 °C; (b) 1480 °C; (c) 1510 °C; (d) 1540 °C.

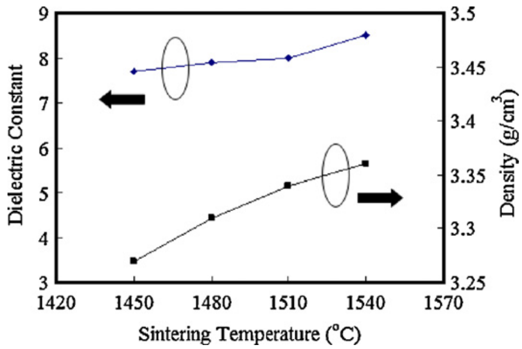

Fig. 3. Dependence of sintering condition of $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics on density and dielectric constant.

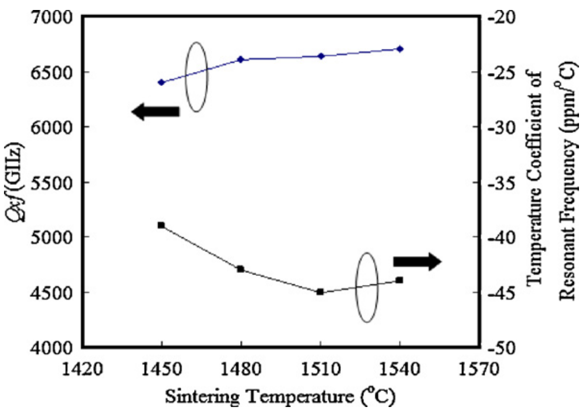

Fig. 4. Dependence of sintering condition of $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics on quality factor ($Q \times f$) and the temperature coefficient of resonant frequency (τ_f).

microwave dielectric properties. In addition, the dielectric constant of the $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics may also act as a function of its sintering temperature. The dielectric constant revealed the same trend with the density – higher density signifies lower porosity that results in higher ε_r value, and it increased with the increase in sintering temperature. In this experiment, a maximum dielectric constant of 8.5 was obtained for $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics sintered at 1540 °C.

The $Q \times f$ value of the $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics as a function of its sintering temperature and time is illustrated in Fig. 4. The $Q \times f$ value increased from 6400 to 6700 GHz as the sintering temperature increased from 1450 to 1540 °C. Many factors are believed to affect the microwave dielectric loss and can be divided into two categories: intrinsic loss and extrinsic loss [8]. Intrinsic losses are mainly caused by lattice vibration modes, while extrinsic losses are dominated by a second phase, oxygen vacancies, grain sizes, and densification or porosity. Density also plays an important role in controlling the dielectric loss and this has been shown for other microwave dielectric materials. As the variation of the $Q \times f$ value was found to be with the density, the degradation of the $Q \times f$ value was attributed to a decrease in density. As the $Q \times f$ value revealed the same trend with the density, it implies that the variation of $Q \times f$ value was dominated by the change in density. Moreover, uniform grain morphology and lower porosity resulted in less dielectric loss, which also benefitted the $Q \times f$ value of the ceramics. On the other hand, Fig. 4 also shows τ_f of the $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics as a function of its sintering temperature. τ_f is well known to be related to the composition and secondary phase of a material. As the composition remained unchanged and no secondary phase was detected, no significant change in the τ_f value was observed as expected. The τ_f value varied from -39 to -44 ppm/°C at various sintering temperatures. At 1540 °C, a τ_f value of -44 ppm/°C was noted for $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics.

4. Conclusion

In this study, the microwave dielectric properties of $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics were investigated. When compared with the previous reports, a significant improvement in the dielectric properties has been accomplished. Microwave dielectric properties ($\varepsilon_r \sim 8.5$, $Q \times f \sim 6700$ at 14 GHz, and $\tau_f \sim -44$ ppm/°C) could be obtained for $(Ca_{0.8}Sr_{0.2})SnO_3$ sintered at 1540 °C. Thus, the new $(Ca_{0.8}Sr_{0.2})SnO_3$ ceramics could be employed in microwave devices.

Acknowledgment

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