Temperature dependent capacitance of a ferroelectric ceramic

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Abstract

BCZT ceramic compositions ($Ba_{0.85}Ca_{0.15}$)($Zr_{0.10}Ti_{0.90}$)O_3) were synthesized by using solid state reaction method. The ingredients were ball milled and calcined at 1300°C for 4hrs. Sintering was carried out at 1500 °C for 8hrs. XRD and Raman measurements on the calcined powder reveal the phase pure synthesis of the BCZT composition with coexistence of rhombohedral, orthorhombic, and tetragonal phases. The microstructure of BCZT ceramics was examined on the unpolished surface of as-sintered ceramic using a scanning electron microscope (SEM) and the average grain size is ~37.61mm ±10.99mm. Room temperature coercive field E_C of BCZT ceramic, are +Ec ~ 3.13 kV/cm and-E_C ~ -3.11 kV/cm and remnant polarization (P_r) +P_r ~ 8.85 µC/cm² and -P_r ~ -8.63 µC/cm² respectively. The capacitance of the ceramic sample was measured across different frequencies using a lock-in amplifier with a low voltage AC signal excitation, ensuring an improved signal-to-noise ratio. The dielectric properties of the material are analyzed over different frequencies and temperature to understand the impact of thermal variations on its capacitance. The results reveal a strong dependence of capacitance on frequency and temperature, attributed to phase transitions within the ferroelectric material. The use of a lock-in amplifier enabled the detection of subtle variations in capacitance that would otherwise be obscured by different types of noises. These findings provide valuable understanding into the thermal stability of lead-free ferroelectric ceramics, contributing to their potential application as capacitors, sensors, and energy storage devices. The study also demonstrates the effectiveness of lock-in amplification techniques in probing weak signals with high sensitivity and a way to measure capacitance of any capacitor with accuracy.

Introduction

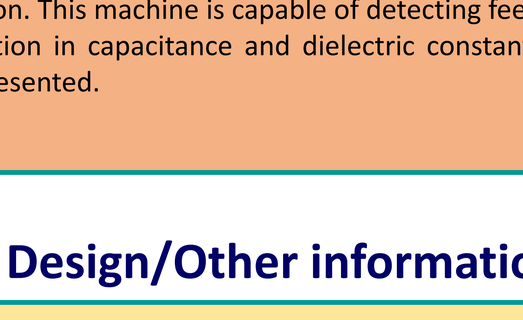
Lead-based piezoelectric ceramics have dominated the commercial piezoelectric device market for many years due to their superior piezoelectric capabilities[1]. However, these materials utilise lead oxide, which is restricted in many countries due to its hazardous nature. Liu and Ren[2] reported high piezoelectric response (d33>600pC/N) in the **BCZT ceramics** system at par with lead-based piezoelectric materials. However, such a high piezoelectric charge constant is difficult to accomplish and can be influenced by different processing techniques, sintering and poling conditions[3]. The present study shows the effect of sintering temperature and time on the microstructure and ferroelectric properties of BCZT ceramics. The electrical characterization of the ceramic is done by a Lock- in-amplifier, which works on the principle of phase-sensitive detection. This machine is capable of detecting feeble signals buried in noise. The variation in capacitance and dielectric constant with frequency of the ceramic is presented.

Design/Other information

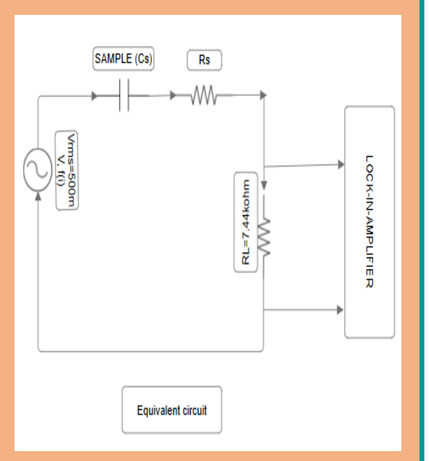
A real capacitor has an ESR, i.e. Equivalent series resistor, which affects its capacitance. To measure the ESR associated with the ceramic, the technique of impedance analysis of a circuit has been used and after calculations it was found out that using the following relations we can measure the ESR of the capacitor and thereafter find the capacitance of the capacitor which is connected with a series load resistor as :

$$Z = RL + Rs + 1/j\omega Cs$$
$$Rs = RL\{[1/(A(1+\tan^2\varphi))]-1\}$$
$$\tan\varphi = 1/\omega Cs(RL+Rs)$$

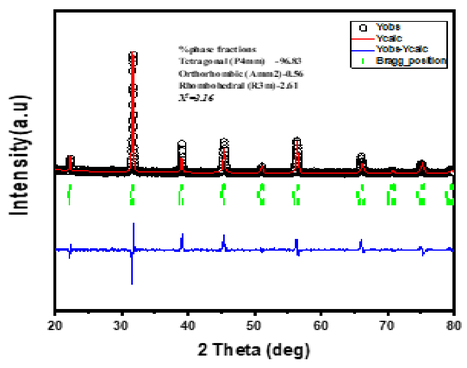
The principle of phase-sensitive detection is used in a Lock-in-amplifier to detect the output signal. The output signal is weak and buried in noise and with the help of a Lock-in-amplifier, a steady signal was measured including the phase difference

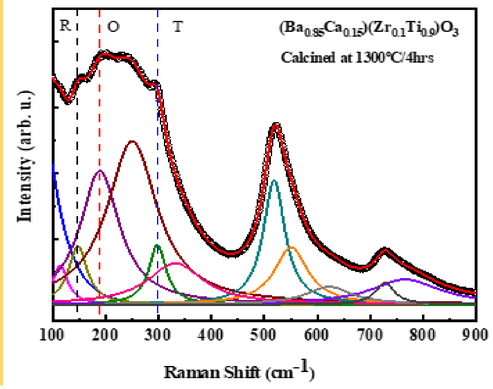


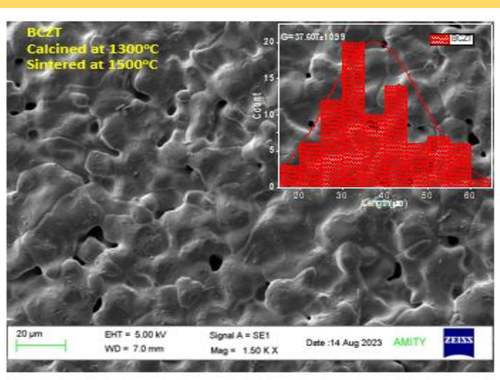
Set up

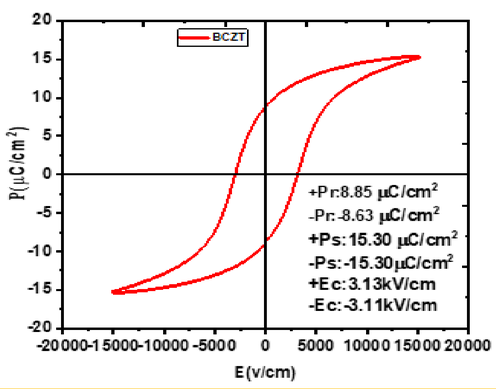


Results









Frequency dependence table*

Frequency (Hz)	Capacitance (in F)	K (Dielectric Constant)
10	1.5452 e-09	2609.7
100	1.4382 e-09	2429.1
1000	1.4113 e-09	2383.6
10000	1.4908 e-09	2517.8
100000	1.8425 e-09	3111.8

Conclusions

Rietveld refinement of the XRD data confirmed the coexistence of orthorhombic, tetragonal and rhombohedral phases which has also been confirmed by the Raman Spectroscopy exhibiting the Raman modes corresponding to these phases. The grain size of BCZT ceramics synthesized with different calcination and sintering temperature and time reveals that the grain size increases with increasing in sintering temperature and time. The measurements using the lock-in-amplifier were found to agree with the theoretical knowledge, making it a useful device for the detection of very low signals that are buried in noise. A large value of remnant polarization and coercive field makes the material useful for piezoelectric applications.

References

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4. SR860 Lock-in-amplifier Manual.

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