CHAPTER 6

Conclusions

6.1 Conclusions

In this study, the novel BCZT powder, BCZT-*x*Bi and BCZT-*x*Bi-*y*PMNT ceramics when x = 0.005, 0.01, 0.02 and 0.1 mole fraction and y = 1, 3 and 5 weight fraction were successfully fabricated by a sol-gel auto combustion method and conventional sintering techniques. Physical properties, structure, phase characterization, microstructure, dielectric properties, ferroelectric properties and electrostrictive properties of these ceramic systems were carried out. Based on experimental observation, the conclusion was presented in the following details:

(1) Pure BCZT powder was obtained by using the solution with pH 7 and calcined at 900°C for 2h with a step of heating/cooling rate of 5°C/min.

(2) BCZT ceramic with a high relative density (~98%) was obtained by sintering at 1450°C for 2 h with a step of heating rate/cooling rate of 5°C/min. The optimized BCZT-*0.02*Bi ceramic could be achieved when sintered at 1200°C for 2h with a step of heating rate/cooling rate of 5°C/min.

(3) BCZT and BCZT-*x*Bi possessed the tetragonal phase with space group P4mm while BCZT-*x*Bi-*y*PMNT ceramics changed from tetragonal to mixed phases between tetragonal and rhombohedral.

(4) BCZT and BCZT-*x*Bi presented homogeneous grain. The good bonding was observed for 1wt% and 3wt% of PMNT addition, while 5wt% presented crack between PMNT and BCZT-*0.02*Bi area.

(5) The enhancement of grain size in BCZT system was a main factor for improving dielectric properties and electrostrictive properties. The relaxor behavior was increased with increasing grain size. The good dielectric properties were observed in BCZT-*0.02*Bi ceramic. BCZT-*x*Bi-*y*PMNT system significantly enhanced dielectric properties, relaxor

Table 6.1 Comparisons of dielectric properties of this study and PMN and PZN relaxor based materials of previous studies

Relaxor material	**ε_r measured at 25°C (1 kHz)**	**T_{max} (°C) (1 kHz)**	***tan δ* (1 kHz)**	**Reference**
BCZT ceramics	2300	104	0.125	M.A. Rafig et al.[48]
BCZT ceramics	3060	93	-	W. Lui et al.[15]
BCZT ceramics	4500	85	0.009	P. Wang et al. [16]
NPO	15-100	-	0.001	[99]
X7R	2000-4000	-	0.035	[99]
Y5V	>16000	-	0.090	[99]
Z5U	7000	-	-	[99]
BCZT	5700	0	0.002	This study
BCZT-*0.02*Bi	1690	-32	0.0018	This study
BCZT-*0.02*Bi-3PMNT	2582	-4	0.0016	This study

behavior, and shifting of the maximum temperature toward to the high temperature of BCZT-*0.02*Bi ceramic.

(6) All samples showed a linear P-E loop at room temperature. However, at low enough temperature, the opening of P-E loop indicated the presence of relaxor behavior which was also confirmed by the modified Curie-Weiss law, Quadratic law and Vogel-Fulcher law, respectively.

(7) Dielectric properties are shown in Table 6.1. It can be seen that dielectric constant and dielectric loss measured at 25°C at a frequency of 1 kHz of the BCZT-based ceramics is comparable to that observed of BCZT ceramics of previous studies and the multilayer ceramic capacitors for commercial. Although maximum dielectric constant temperature of BCZT-based ceramics is lower than that of the previous one, its dielectric constant and dielectric loss, however, are higher. It can be generally concluded that BCZT and BCZT-*0.02*Bi-3PMNT ceramics are suitable for an application of multilayer ceramic capacitor.

6.2 Suggestion for future work

In order to increase value of this work, several observations from the experiments have not yet been completely explained. Therefore, suggestions of future work are given as follows,

(1) To understand more on relaxor ferroelectric properties of BCZT-based ceramics, i.e. impedance as a function of temperature, a Cole-Cole and Kohlraush-Williams-Watts (KWW) functions should be investigated.

(2) In order to understand of Bi addition in BCZT-based ceramics on electrical properties, the synchrotron characterization should be carried out.

(3) Due to the ceramics with good dielectric properties were achieved in this study, a prototype of capacitor device should be established and its efficiency under actual application should be tested.