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An investigation of modified Dielectric material for wireless communication applications

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Abstract:
BSZT40NF has been doped with rare earth oxides (Erbium, Holmium and Samarium) in an attempt to understand the effect on the reliability of the dielectric material for multilayer capacitor and tunable microwave applications. The morphology of the samples used was characterized using scanning electron microscopy (SEM) used to confirm the presence of each rare earth ions. It is suggested that incorporation of rare earth ions into the BSZT40NF is as a result of ionic radius, resulting in varying grain growth and tunable properties. The change in reliability and tunable properties of the capacitor and microwave devices can be attributed to overall distribution of rare earth oxides and their occupation site within the BSZT40NF dielectric.
Term Index: BSZT40NF, rare earth ions, SEM, Tunable properties.

I Introduction:

After successful investigation of P-E characterization and tunable properties of $(Ba_{0.6}Sr_{0.4})(Zr_{1-x}Ti_x)O_3$(x=0.4, 0.5 & 0.65) (BSZT) dielectric ceramics in our previous studies [1], the research of same compound with other rare earth ions doped is necessary in order to understand better amongst all substituted BSZT's for capacitor and microwave applications.

Barium Titanate (BT) ferroelectric exhibiting high dielectric nonlinearity has become one of the promising materials to realize the potential applications for tunable capacitors and microwave devices [2]. Barium strontium titanate (BST) is another vital material which has significant performance in the microwave frequency range, because of its large dielectric constant (εr) and high dielectric tunability at room temperature has been frequently used in the tunable filters [3]. Barium zirconate titanate (BZT), as an important member of the BT-based ferroelectric materials family, has received extensive attention due to its eminent dielectric performance. BZT ceramics present high voltage resistance characteristics because Zr4+ is chemically more stable than Ti4+ [4-6]. Barium strontium zirconate titanate (BSZT) has the advantages of both additives Sr and Zr [7-8]. $(Ba_{0.6}Sr_{0.4})(Zr_{0.6}Ti_{0.4})O_3$-$Nb_2O_5$-$Fe_2O_3$ (BSZT40NF) The Nb_2O_5 is a donor dopant, which resulted in the lattice distortion and increased the tetragonality, and Fe_2O_3 is an acceptor dopant, which led to the high density of oxygen vacancy and promoted crystal grain growth of BSZT ceramics [9].

Tunable dielectric materials are characterized by two prime parameters: 1) Tunability (η) and 2) Loss Tangent (Tan δ).Tunability of the material is the ratio of difference in ε at zero-electric field (E_o) and ε at a particular E to the ε at zero-electric field, at a given temperature and is expressed as [10].

$$\eta = \left(\frac{\varepsilon(E_0) - \varepsilon(E)}{\varepsilon(E_0)}\right) X100$$

Dielectric materials with high tunability, low dielectric loss, and moderate dielectric constant are desired for tunable microwave applications. High dielectric constant leads to high tunability. In order to obtain high value of dielectric constant it is necessary to establish high density, homogeneous and fine-grained microstructure as well as uniform distribution of dopants and additives [11-12]. For high dielectric constant and low loss many researchers were used rare earth elements (La, Gd, Nd, Sm, Ho, Pr and Er) as a doping material in BT and BZT [13-14].

In this paper, we report the tunable characteristics of Er, Ho and Sm doped BSZTNF solid solution, with nominal stoichiometry $(Ba_{0.6}Sr_{0.4})(Zr_{0.6}Ti_{0.4})O_3$-$Nb_2O_5$-$Fe_2O_3$ (BSZT40NF) and compare the tunable characteristics of Er, Ho and Sm doped BSZT40NF solid solution. The main objective of present work is to understand the effect of rare earth ion (Er, Ho and Sm) on the tunable properties of BSZT40NF ceramics toward developing capacitor and microwave device.

II Experiment

Polycrystalline Ceramic samples were prepared by conventional solid state reaction method from weighed amounts of Barium carbonate

($BaCO_3$),Strontium carbonate ($SrCO_3$), Zirconium oxide (ZrO_2), Titanium oxide (TiO_2), Niobium oxide (Nb_2O_5), Iron oxide (Fe_2O_3) and RE-oxide (Er_2O_3, HO_2O_3, Sm_2O_3) (all Hi Media, India, purity 99.99%). The starting materials were ground for 4hours and calcined at 1000^0C for 12hours. They were further ground for 2hours and subjected for pre-sintering at 1000^0C. This product obtained was again ground for 2hours and pressed into circular shaped disc pellets (diameter 10mm and thickness 1-2mm) using 5% PVA as a binding agent. Pellets were sintered at 1000^0C for 8hrs. For good electrical contacts, a silver paste is applied on both sides of pellet. X-ray diffraction technique was used to describe crystallographic structure, chemical composition, and physical properties of materials. SEM (JSM / 8048 / SM, JEOL, Japan) is used to determine the average crystallite size and to understand the surface morphology. Tunability was measured by measuring the dielectric constant of the sample under an applied electric field using a voltage source (TREK 610, Trek, Inc.) and a high voltage blocking circuit, which effectively separates the *LCR* meter from the voltage (10kV/cm) applied to the sample.

III Result and Discussion:

The room temperature X-ray diffraction (XRD) pattern of BSZT40NFE, BSZT40NFH and BSZT40NFS ceramics are shown in Fig.1. The reflection peaks' corresponding to 2θ-values were indexed on a cubic system along with pyrochloric phase of Er, Ho and Sm. On the basis of least squares' fitting between observed and calculated inter-planar distance (d), we found that, the pattern of BSZT40NFE, BSZT40NFH and BSZT40NFS reflects the formation of single phase perovskite. The lattice parameters and cell volume of BPZT10 and BPZT20 are given in Table 1. Peak broadening is originated from variations in lattice spacing, caused by lattice strain. These salient features are clearly evidenced in the present set of compounds.

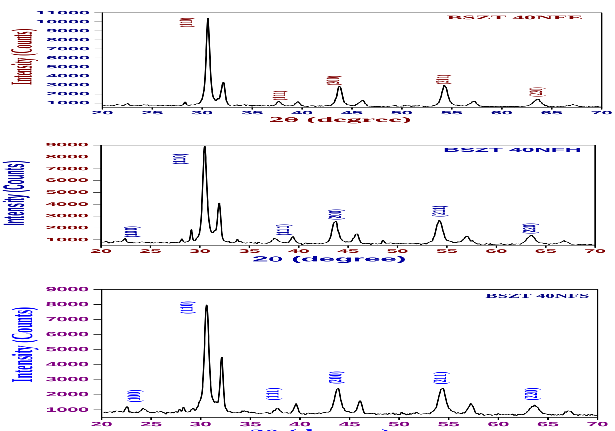

Figure 1: X-ray diffraction pattern of BSZT40NFE, BSZT40NFH and BSZT40NFS

Fig. 2 illustrates the SEM micrographs of BSZT40NF doped with rare earth ion (Er,Ho and Sm) ceramics. All the compounds showed porous and non-uniformly distributed grains due to the characteristic of matter transport mechanism between the grains during the sintering process. At initial stages of solid state reaction, the carbonates and oxides were well mixed and thoroughly grinded in order to reduce the powder particle sizes. The heat promoted slow kinetics of inter-diffusion in the contact points between the particles with irregular morphologies. This diffusion resulted into irregular shaped grains due to an elastic deformation caused by the surface energy reduction in the contact interface by its orientation and mobility [15, 16]. The average grain sizes of the samples are given in Table 1.

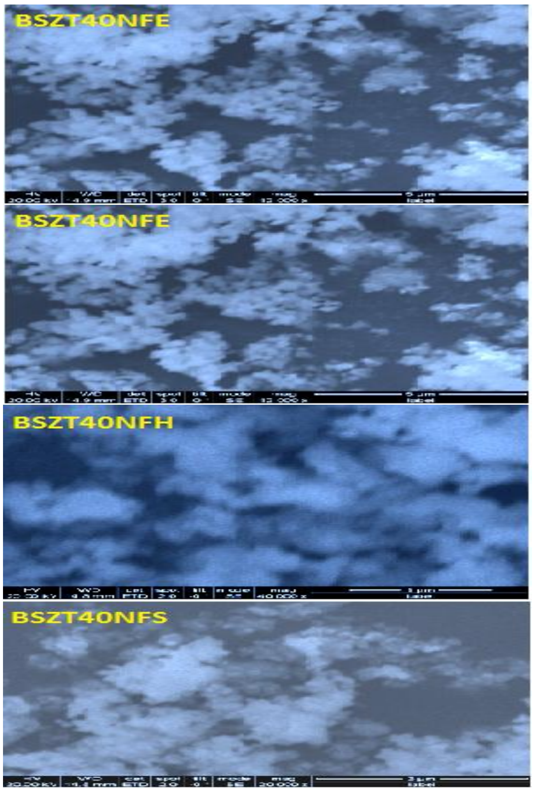

Figure 2: SEM Micrograph of BSZT40NFE, BSZT40NFH and BSZT40NFS

The tunable properties of BSZT40NFE, BSZT40NFH and BSZT40NFS if shown in figure 3. It is observed that for all the samples the maximum value of ε is obtained closer to the T_c. High η values are commonly associated with maximum value of ε values. Tunability (η) values are shown in table 1 for BSZT and modified BSZT ceramics.

Table 1: Structural and Tunable properties of BSZT40NFE,BSZT40NFH and BSZT40NFS

Sample code	Lattice parameters (Å)		(c/a)	Cell Volu-me (Å)^3	Particl e size (nm)	X-ray density (gm/cm^3)	Grain size (µm)	η (%) E=1.5 KV/cm
	a (± 0.005)	c (± 0.008)						
BSZT40NFE	4.129	4.125	1.000	70.34	2.35	24.72	0.81	85.8
BSZT40NFH	4.133	4.173	1.009	71.31	2.63	24.27	0.83	91.4
BSZT40NFS	4.133	4.146	1.003	70.84	2.57	23.74	0.82	88.51

The highest η =91.4% for BSZT40NFH ceramic as compared to BSZT40NFE and BSZT40NFS.
The material with high η and low ε is suitable for tunable µw application devices such as electronically tunable mixers, delay lines, filters, capacitors, resonators and phase shifters etc [17,18]. As compared to all the doped BSZT40NF ceramics it is found that tunability will be less for BSZT40NFE and BSZT40NFS this because of grain size. The reduction of the grain size is the cause for the ε reduction in the pure BT. However, in the BSZT system; the local paraelectric phase could also contribute to the reduction of the ε and hence tunability [19].

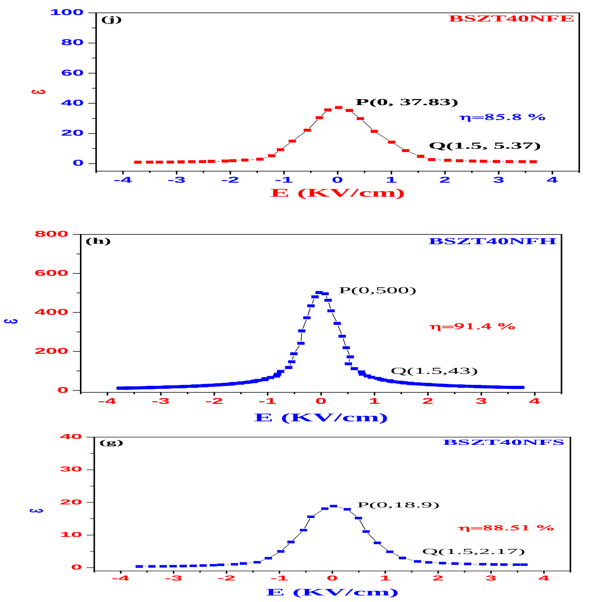

Figure 3: Tunable properties of BSZT40NFE,BSZT40NFH and BSZT40NFS

IV Conclusion

BSZT40NF has been doped with rare earth oxides (Erbium, Holmium and Samarium) is synthesized and morphology of the samples shows single Perovskite structure and the large grain size is found for the Ho doped BSZT40NF ceramics as compared to the Er and Sm doped rare earth elements. The large grain size leads to high permittivity and hence high tunability of about 91% such compounds are useful for multilayer capacitors and microwave device applications.

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