Synthesis and Characterizations of Substituted Ceramic Multiferroics

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By

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Chapter 7: Conclusions and Future scope

7.1 Conclusions

Bismuth ferrite ($BiFeO_3$) is the most promising lead-free material among other multifunctional ceramics because of its ferroelectric and ferromagnetic coupling above room temperature. The doping with the A site enhances ferroelectric response, doping at the B site minimizes the problem associated with leakage current, and doping of the ABO_3 system refines both the dielectric and magnetic properties of the pure $BiFeO_3$ ceramic. The doping of Sm at the Bi site of $BiFeO_3$, i.e., $Bi_{0.9}Sm_{0.1}FeO_3$ (BSFO), ceramic up to a fixed level of 0.1 provides an overall enhancement of dielectric constant, remanent magnetization, and remanent polarization values and lowers the dielectric losses. The effect of various doping on different properties, *viz.*, structural, optical, magnetic, dielectric, and I-V characterizations on BSFO, are studied. The BSFO ceramics are synthesized by the solid-state method. Within this objective of the study, the following important outcome can be drawn:

- ❖ The polycrystalline samples of $(Bi_{0.9-x}Gd_xSm_{0.1})FeO_3$ (x = 0.0, 0.025, 0.050, 0.075, and 0.1) are prepared using a solid-state ceramic route. The X-ray diffraction studies suggest the phase transformation from pure rhombohedral to pseudocubic up to $x \geq 0.05$ due to attaining the solubility limit of $BiFeO_3$. The lattice parameters are observed to decrease for $x \leq 0.05$. The SEM study reveals that the grains are of hexagonal shape, and grain sizes are obtained in the range of ~1.9 -2.5 μm. The increase in grain size up to x = 0.05 confirms the solubility limit up to x = 0.05. The dielectric constant is increased 14 times of BSFO samples below the MPB. The remanent magnetization is increased linearly with the concentration of Gd substitution in BSFO. The formation of the garnet phase has significantly altered the polarization by 3.56 times and magnetization by 2.16 times. The resulting increments in magnetization make the material a promising candidate for advanced electronic applications.

- ❖ The perovskite-based ceramic samples of $(Bi_{0.9}Sm_{0.1})(Fe_{1-x}Mg_x)O_3$ (x =0.0, 0.025, 0.050, 0.075, and 0.1) are prepared using high energy ball milling. The X-ray diffraction data reveals that the major phase is rhombohedral up to $x \geq 0.075$. Field emission scanning electron back-scattered micrographs reveal irregular shapes and some abnormally grown grains. The average grain sizes are obtained in the range of ~ 0.5-3.0 µm. The magnetic moment is increased up to x = 0.050. The leakage current and oxygen vacancies are minimum. The grain boundary is limited, and ohmic conductions are dominated in almost all samples. The leakage current is reduced by seven orders of magnitude for $(Bi_{0.9}Sm_{0.1})(Fe_{0.95}Mg_{0.05})O_3$ ceramic than the pure BSFO. The leakage current value is $3.64\times10^{-7,}$ comparatively lower than reported thin films (8.89×10^{-7} A/cm^2) and comparable with samples prepared using the rapid sintering method (2.1×10^{-7} A/cm^2). The grain boundary limited conduction, and ohmic conductions are dominated in almost all samples. The present work provides an easily accessible way of enhancing ferroelectric properties and significantly suppressing leakage current within bulk $BiFeO_3$ system to withstand large remnant polarization. The as-prepared material can be a good choice for various applications such as non-volatile ferroelectric random-access memory, magnetic data storage, and other electron device applications.
- ❖ Lead free solid solution of $\{(1-x)\,(Bi_{0.9}Sm_{0.1})FeO_3 - (x)\,Ba(Zr_{0.15}Ti_{0.85})O_3\}$ (BSFO − BZT) (x =0.0, 0.1, 0.15, 0.2, 0.25, 0.5) are prepared using solid-state reaction method.

The structural analysis confirms that BSFO retains its rhombohedral symmetry (*R3c* space group) up to the x = 0.025; further addition of BZT changes the crystal symmetry to tetragonal with *P4mm* space group. The dielectric measurements reveal the presence of several anomalies with increasing temperature; all these dielectric anomalies are explained within four segments of the temperature range. The temperature and frequency-dependent impedance analysis confirm the existence of NTCR (a reverse trend with resistance and temperature) for all samples. The leakage current behavior for all these samples is investigated using both approaches; space charge limited conduction (SCLC) for bulk and Schottky emission (SE) for interface limited conduction. The conduction behavior for the pure BSFO sample is found to be dominated by ohmic conduction, while the grain boundary limited conduction dominates the BZT doped samples. The {0.80 $(Bi_{0.9}Sm_{0.1})FeO_3$ – 0.20 $Ba(Zr_{0.15}Ti_{0.85})O_3$} sample is found to have the least value for leakage current among all the prepared samples. The sample x = 0.15 satisfies both parameters; it achieves the largest dielectric constant and a moderate leakage current density value (1.2×10-9 A/cm^2), which is lower than pure BSFO. The study also states the existence of morphotropic phase boundary at x = 0.15 for the BSFO−BZT system. It may provide its best candidacy to fabricate stable photovoltaic, multilayer actuators, and ferroelectric memory devices.

7.2 Future scope

As far as the material application is concerned, the following work objective can be taken for further advancements and growth of the multiferroic materials:

- To explore the mechanism of sintering for different sintering aids
- Sintering kinetics can be studied to understand the effect of microstructure. It has been observed that the microstructure plays a key role in affecting the materials' electro-magnetic properties.
- Raman analysis can be provided for a deep understanding of the optical behavior of the doped ceramics.
- Fabrication and characterization of thin-film using modified BFSO ceramics for ferroelectric memory devices.