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Structural. infrared. magnetic and ferroelectric properties of $Sr_{0.5}Ba_{0.5}Ti_{1-x}Fe_xO_3$ nanoceramics: Modifications via trivalent Fe ion doping

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Highlights

- Successful preparation of Fe^{3+} doped $Sr_{0.5}Ba_{0.5}TiO_3$ (SBT) nanoceramics by sol-gel auto combustion technique.
- It's structural, morphological, infrared, and multiferroic properties were studied.
- Pure SBT sample shows cubic structure whereas Fe doped SBT samples transformed in a tetragonal phase.
- Magnetic and ferroelectric properties strongly influenced by Fe ion doping.
- Co-existence of magnetic & ferroelectric properties makes it potential candidate for multiferroic device applications.

Abstract

The work reveals the structural, infrared and multiferroic (viz. magnetic, ferroelectric) properties of sol-gel auto burning incorporated $Sr_{0.5}Ba_{0.5}Ti_{1-x}Fe_xO_3$ (0.00≤x≤0.25 in step of 0.05) perovskite structured nanoceramics. The XRD analysis demonstrates the phase change from cubic to tetragonal structure due to Fe doping. The functional groups of prepared samples were dictated by Fourier transform infrared (FT-IR) spectroscopy. The scanning and transmission electron microscopy were utilized for surface morphological studies. The compositional stoichiometry of the prepared samples was determined by energy dispersive spectrum (EDS) system. The P-E and vibrating sample magnetometer (VSM) techniques were utilized to portray the multiferroic properties of prepared samples. The ferromagnetic and ferroelectric investigation of prepared samples uncovers, the hysteresis loop is firmly impacted by Fe ion doping by production of oxygen vacancies. The doping of magnetic Fe^{3+} ions in host $Sr_{0.5}Ba_{0.5}TiO_3$ nanoparticles modified and improved the structural, infrared and multiferroic properties enormously.

Introduction

Multiferroic properties of perovskite (ABO_3) structured materials are broadly utilized in logical and mechanical applications in the last several years [1,2]. The perovskite materials have a few critical properties viz. ferro-electric, multi-ferroic, piezo-electric, magneto-caloric and optical, dielectric and ferro-magnetic properties etc [[3], [4], [5], [6], [7], [8]]. Hence, these astounding electronic properties of perovskite organized materials make it practical for structuring the advanced electronic gadgets. These days, multiferroic is a present and an intriguing theme for the gadgets and numerous different enterprises because of its critical properties and applications. The perovskite material Strontium barium titanate (SBT) ceramics have been generally utilized in hardware, stockpiling and memory gadgets [[9], [10], [11]]. It has application in powerful arbitrary access memory, clay capacitors, in the sensor as pyroelectric sensors, concoction sensors, biosensors, microwave gadgets, infrared locators and optoelectronic applications [[12], [13], [14], [15], [16], [17]]. SBT has generally utilized in microelectronic mechanical framework applications due to their ferroelectric attributes [18]. SBT has generally utilized in microelectronic mechanical framework applications due to their ferroelectric attributes [11]. Substitution of accepter (Fe, Ni and Co) dopants at the B site of SBT perovskite type material without changing the A site focus will drives the creation of vacancies and lattice defects [19,20].

For the most part, the preparation strategies, sintering temperature influences the structural, spectroscopic, infrared, electromagnetic and a few different properties [21]. The various sorts of techniques were found in earlier reports for synthesis of perovskite ceramic, for example, solid state reaction, hydrothermal techniques, wet synthetic strategies and so forth [22,23]. Be that as it may, wet chemical synthesis technique (sol-gel auto burning) is increasingly profitable because of necessity of moderate temperature as well as effective accomplishment of the desired physical, electronic and magnetic properties. Because of the high resistivity and low energy loss (eddy current), nanometre size ferroelectric perovskite got considerably more significance in research network [24]. These significant properties of ferroelectric perovskite materials are practical for the mechanical application over a wide scope of frequencies. The ferroelectric and magnetic properties of nano perovskite materials are rely on crystallite size, distribution of particle sizes and interplanner spacings and these properties can be changed by synthesis techniques [25,26]. Sol-gel auto ignition has as of late turned into an extremely well known strategy because of a basic procedure, low sintering temperature, less time and low vitality utilization than other conventional techniques [27,28]. In this way, the sol-gel technique is utilized to improve properties with greater homogeneity and constricted particle distribution [29]. The sol-gel strategy is profoundly swayed on structural, electrical and magnetic properties in perovskite materials [[30], [31], [32], [33]].

Ferromagnetic material iron (Fe) has variable oxidation resistance at room temperature [34]. Subsequently, substitution of Fe at Ti site of the SBT framework might be positive to initiate an intriguing mix of ferroelectric and magnetic properties at the same time. There are very few reports available on combination of Fe doped SBT materials and these reports are just cantered around structural, dielectric and micro-structural properties [35]. Nevertheless, not many reports are available on the ferroelectric and magnetic properties of Fe doped SBT nanoceramics incorporated by means of wet synthetic techniques. Along these lines, it is interesting to pursue the endeavours expounding the ferroelectric and ferromagnetic properties of SBT materials by doping trivalent magnetic Fe ions.

In the previous studies, the more reports are available on the impact of Fe^{3+} content on the physicochemical properties of individual $BaTiO_3$ (BTO) or $SrTiO_3$ (STO) nano-ceramics [36]. In comparison with this, the impact of Fe^{3+} content on the combination of both the BTO and STO with equi-amount Ba^{2+} and Sr^{2+} content is less focused by the researchers. Ayad et al. (2015) [9] reported the structural and dielectric parameters of the Fe^{3+} content doped SBT nano-ceramics up to a doping level of 0.1. The obtained nano-ceramics showed the superior dielectric parameters and lowered losses which make them a strong contender in capacitance applications. Xie et al. (2018) [37] have focused their studies on the Fe^{3+} doped SBT in thin film form with a minimal doping level of 0.015. Notable enrichment in the dielectric parameters was observed by them which are accountable for storage devices. Kaur et al. [38] (2014) studied the structural and UV–Vis absorbance properties of SBT (with Ba=0.7 and Sr=0.3) nano-ceramics up to a minimal doping level of 0.20. Jacob et al. (2015) [39] investigated the dielectric and impedance parameters of the Fe^{3+} incorporated SBT ceramics. The Fe^{3+} incorporation resulted in the noteworthy changes in impotence analysis of SBT. Saeed et al. (2015) [40] undertaken the studies related to the magneto-structural properties of SBT nano-ceramics doped with Fe^{3+} up to a doping level of 20%. The considerable improvement in the remanence ratio of obtained SBT shows its suitability in Memory-chip applications. Although, these report shows the promising outcomes of Fe^{3+} inserted SBT nano-ceramics but they are limited to the structural, magnetic and dielectric parameters and constrained towards the Fe doping level of 0.2 only. Also, the multiferroic analysis of these nano systems is not properly investigated in the literature. In addition, the sol-gel self ignition route was rarely employed for the nanoscale synthesis of Fe^{3+} incorporated SBT samples. This motivated us to do systematic investigations on the influence of Fe^{3+} incorporation (up to Fe doping level of 0.25) on the structure, morphology, infrared and multiferroic parameters of sol-gel synthesized SBT nano-ceramics.

In perspective on the above certainty, the aim of the present work is to synthesize Fe doped barium-strontium titanate nanoceramics ($Sr_{0.5}Ba_{0.5}Ti_{1-x}Fe_xO_3$, 0.00≤x≤0.25 in step of 0.05) by utilizing sol-gel auto burning technique and to examine the modifications in structural, morphological, infrared and multiferroic properties of $Sr_{0.5}Ba_{0.5}TiO_3$ framework by trivalent Fe ion doping.

Section snippets

Synthesis of $Sr_{0.5}Ba_{0.5}Ti_{1-x}Fe_xO_3$ nanoceramics

All synthetic substances were utilized as it is gotten with no further filtration in test. Analytical (AR) grade barium nitrate hexahydrate (Ba $(NO_3)_2{\cdot}6H_2O$), Strontium nitrate hexahydrate (Sr $(NO_3)_2$ $6H_2O$), tetra butyl titanate (Ti $(OC_4H_9)_4$), citric acid ($C_6H_8O_7$), ferric nitrate (Fe $(NO_3)_2{\cdot}9H_2O$), ethanol (C_2H_5–OH) and ammonium hydroxide (NH_4OH) provided by Merck with ~99% purity. The pure ($Sr_{0.5}Ba_{0.5}TiO_3$) and doped BST ($Sr_{0.5}Ba_{0.5}Ti_{1-x}Fe_xO_3$, 0.00≤x≤0.25 in step of 0.05) nanopowders was…

Thermal analysis (TG-DTA)

The thermal characterizations of pure SBT ($Sr_{0.5}Ba_{0.5}TiO_3$) sample synthesized by the sol-gel auto-combustion method was carried out using thermogravimetric and differential thermal analysis (TG-DTA) up to 1000°C at steady heating rate of 5°C/min in air atmosphere. Fig. 2 shows the DTA and TGA curves of the SBT sample. The TGA curve evidently shows that there is an overall weight loss of 27% from room temperature to 1000°C temperature range. TGA curve as visible in Fig. 2 shows a linear…

Conclusions

The $Sr_{0.5}Ba_{0.5}Ti_{1-x}Fe_xO_3$ nanoceramics were successfully synthesized using the sol-gel auto combustion technique. The pure SBT sample shows cubic structure whereas Fe doped SBT samples transformed in a tetragonal phase as confirmed by the XRD study. The average crystallite size varies in the range of 17 nm–19 nm. XRD analysis also confirmed the perovskite structure of prepared nanoceramics with space group *Pm3m*. The micro-structural studies were investigated through FE-SEM and TEM technique…

Author’s contribution

Study conception and design: **K. M. Jadhav, A. A. Pandit**, Acquisition of data: **Dhananjay N. Bhoyar, Sandeep B. Somvanshi, Prashant B. Kharat**, Analysis and interpretation of data: **Dhananjay N. Bhoyar, Sandeep B. Somvanshi, Prashant B. Kharat, K. M. Jadhav**, Drafting of manuscript: **Dhananjay N. Bhoyar, Sandeep B. Somvanshi, Prashant B. Kharat, A. A. Pandit, K. M. Jadhav**, Critical revision: **Dhananjay N. Bhoyar, Sandeep B. Somvanshi, K. M. Jadhav**.…

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Declaration of competing interest

There are no conflicts of interest.…

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