Preparation and Electrical Characterization of Bi$_{1-x}$Nd$_x$FeO$_3$ ($x=0.0$ and $0.05$) Ceramics

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Abstract. The solid state reaction method has been implemented for the preparation of multiferroic Bi$_{1-x}$Nd$_x$FeO$_3$ ($x=0.0$ and $0.05$) ceramics. The constituent oxides were mixed and calcined at 873 K and then sintered at 1123 K. The X-Ray Diffraction technique has been used to analyze the structure of prepared ceramics at room temperature (RT). Frequency and temperature dependent dielectric properties have been measured. The DC conductivity of these compounds has also been measured from RT to 603 K. The activation energies ($E_a$) are 1.84 eV and 2.02 eV for pure and Nd doped compounds which has been calculated from the Arrhenius relation $\sigma = \sigma_0 \exp (-E_a/RT)$.

Keywords: Multiferroic, Ceramic, X-ray diffractation, Dielectric, Conductivity.

1. Introduction
The ceramics which possesses ferroelectric, ferromagnetic and ferroelastic in same phase at room temperature is known as multiferroic/multifunctional. Bismuth ferrite (BiFeO$_3$) is such a ceramic which shows multiferroic characteristic [1]. Due to this unique characteristic of BiFeO$_3$, it is an interesting material for using in memory storage devices and other electronic applications [2-5]. BiFeO$_3$ is a member of perovskite (ABO$_3$) types compound family which exhibit ferroelectric Curie temperature ($T_C$) and anti-ferromagnetic Neel temperature ($T_N$) at 1103 K and 643 K respectively [5]. When this compound is calcined at high temperature, the leakage current phenomenon produces which is the important hitch of this material for implementing it in different technological devices. The change in volatilization and valances by Bismuth (Bi$^{4+}$) and Iron (Fe$^{3+}$) ions respectively during the calcination process at high temperature are the root cause to generate the leakage current phenomena in this compound [3, 5]. Also, due to the low dielectric constant and high electrical conductivity restricts its electrical characteristics hence there is a hindrance to obtain the saturated hysteresis loop for this compound. [4]. In order to overcome all these problems, researchers study their interactive characteristics to make them useful in electronic devices by doping with different rare earth elements on Bi-site and Mn, Zn, Co, Sc etc. on Fe-site of this compound [5-8]. For further checking we have doped Nd on Bi-site of BiFeO$_3$ and studied its structural and electrical properties.

2. Materials and Methods
Bismuth Neodymium Ferrite, Bi$_{1-x}$Nd$_x$FeO$_3$ ($x=0.0$ and $0.05$), ceramics have been prepared at high-temperature using the solid state reaction method. The stoichiometric amount of desired oxides has been mixed and ground together under liquid medium (acetone) in an agate-mortar. The Oxide mixtures of both pristine and doped compounds have been heated for 2 to 6 hours at 873 K in the Muffle furnace. After this, the mixture of these compounds was compressed in hydraulic press to form the pellet. The sintering of these pellets has been done at 1123 K for 10 minutes. The X-ray Diffraction data have been collected from X-ray Diffractometer (Rigaku) in the 20 range from 20° to 80° with step size of 0.02°. To measure the electrical properties of both compounds, the pellets were electroded with the silver paint. The LCR Hi-tester (Hioki 3532-50) was used for the measurement of dielectric...
constant as a function of frequency and temperature. The dc conductivity has also been measured using two probe methods from RT to 623K.

3. Results and Discussion

3.1 Structural Properties

The X-ray Diffraction patterns of prepared ferrite compounds, Bi$_{1-x}$Nd$_x$FeO$_3$ (x= 0.0 and 0.05), have been analyzed which confirmed the R3c Space Group of rhombohedral Structure and is shown in Figure 1. The X-ray data of pristine compound are well matching with JCPDS file No. 71-2494. The pristine compound doesn’t show any impurity peak whereas the minor impurity peaks are present in the doped compound. The magnified XRD pattern of both compounds is shown in the inset of Figure 1. From the inset figure, it is evident that the most prominent peaks for both the compounds are at same Bragg position of 30.94°.

![Figure 1. XRD patterns of Bi$_{1-x}$Nd$_x$FeO$_3$ (x= 0.0 and 0.05) along with magnified XRD patterns in the range of 30°-32° (in the inset of graph) at RT.](image)

3.2 Electrical Properties

The dielectric constant ($\varepsilon'$) and dissipation factor ($\varepsilon''$) of both pure and doped compounds (Figure 2 and 3) indicates that $\varepsilon'$ and $\varepsilon''$ decreases rapidly due to space charge contribution at low frequencies, but at higher frequencies they become frequency independent. The temperature variation of the dielectric constant ($\varepsilon'$) at the frequency of 1MHz for both pure and doped compounds is shown in Figure 4. It is observed from the graph that the $\varepsilon'$ show increasing trend with increase of temperature. The dielectric constant also shows fluctuating behavior.

Figure 5 shows the variation of log $\sigma_{dc}$ versus 1000/T curve. The Arrhenius relation $\sigma = \sigma_0 \exp (-E_a/K\Theta)$ has been implemented for the analysis of conductivity ($\sigma_{dc}$) under dc field in the temperature range of 303K-603K. From the Figure 5, it is observed that the conductivity increases with the increase of temperature in the case of pure compound. When Bi-site is substituted with low concentration of Nd (x= 0.05), the conductivity shows same trend as the pure compound but slight decreased magnitude as shown in the figure. The activation energies ($E_a$) calculated for pure and doped compounds are 1.84 eV and 2.02 eV respectively in the measured temperature range.
4. Conclusion

Bi$_{1-x}$Nd$_x$FeO$_3$ ($x = 0.0$ & $0.05$) ceramics have been prepared by conventional ceramic processing technique. Both the compounds show rhombohedral structure with space group R3c. The substitution of Nd atom on A-site is responsible to decrease the electrical conductivity of BiFeO$_3$ which is due to the minimized volatilization of Bi$^{3+}$ ions.

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