Tunable multiferroic properties of cerium doped bismuth ferrite

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DOI 10.17586/2220-8054-2019-10-3-255-265

Multiferroic Bi1−xCexFeO3 (x = 0.05, 0.1, 0.15, 0.2) nanoparticles were prepared using an auto-combustion method. The effect of cerium substitution on the crystal structure, electrical and magnetic properties of BiFeO3 (Bismuth Ferrite) was studied. X-raydiffraction spectra revealed that Ce substitution increases the lattice parameters. The average particle size estimated from TEM images is less than 50 nanometers. According to the magnetic hysteresis loops, it was found that the enhanced magnetization which results from increasing Ce concentration is attributed to the nanoparticle size and enhanced ferroelectric polarization. The magnetization and ferroelectric polarization were found to exhibit an exotic mutual relationship. The samples were found to exhibit relaxation of dielectric polarization. This rare combination of Ce doped BiFeO3 by auto-combustion method has not been reported before.

Keywords: Multiferroic, nano particles, X-ray diffraction, ferroelectric, ferromagnetic.

Received: 9 March 2019
Revised: 24 May 2019

1. Introduction

One of the reasons for fabricating novel materials for attaining rich functionality is to unite different physical properties in single material. Magnetic and Ferroelectric materials are enduring subject of study and have led to notable progress in the development of technology to date. These apparently distinct phenomena can coexist in certain unusual substances, termed as multiferroics which are of key importance, both from research as well as technological perspective.

Multiferroic materials exhibit the phenomena of ferroelectricity (FE), ferromagnetism (FM) and ferroelasticity simultaneously in their singlephase [1–3]. Although the possibility of coupling or interaction between ferromagnetic and ferroelectric order parameters is known for quite long time, its existence and practical applications were realized only after the discovery of multiferroicity in BiFeO3.

Bismuth ferrite is found to be one such material which demonstrate a coupling between magnetic and ferroelectric order, having Curie temperature \(T_C \approx 1100 \degree K\) and antiferromagnetic temperature \(T_N \approx 640 \degree K\) [4, 5]. Bismuth ferrite possesses G-type antiferromagnetic ordering because of its complex cycloidal spin structure with a wavelength of 62 nm with [110] spiral direction and (110) spin rotation plane [6]. However BiFeO3 suffers from several major issues like phase defects such as oxygen vacancies and impurity, high leakage current, spiral spin structure, large difference in transition temperature \(\left( T_C \& T_N \right)\). The leakage current a rises in BiFeO3 due to its nonstoichiometry. This is particular lybecause of the difficulty in obtaining stoichiometric singlephase BiFeO3 materials. In order to reduce leakage current density efforts have been made by using different fabrication methods. Several techniques have also been recently adopted to eliminate secondary phases and oxygen vacancies [7–11]. Particle size also plays a vital role in controlling the structural and magnetic properties of BiFeO3 [12]. The authors [13] described the necessity to lower the sintering time during the increase in synthesis temperature to confine the formed BiFeO3 crystals within the nanosize range. The current trend is to avoid brute force methods in order to have a better control of stoichiometry, structure, and phase purity of metal oxides. The authors [14]reported cerium-substituted BiFeO3 powders using hydrothermal method revealed the lattice contraction and decrease of grain size. Synthesis of Ce substituted BiFeO3 nanoflakes [15] using sol-gel method has resulted in enhancement of electrical properties. The combustion or fire synthesis is quite simple, fast, and economical. It is possible to control the particle size of solid combustion product to nano-range by using suitable fuels that control the nature of combustion. Urea is documented as an ideal fuel for the combustion synthesis of high temperature oxides [16]. In this work, auto combustion method was used for synthesis as it has not been reported for the synthesis of Ce doped BiFeO3 and urea was chosen as the fuel, which act as a self-catalyst and generates heat as its melting point is very low, which further helps in increasing the reactivity of the samples yielding a good result as compared to solid state process.

Attempts to improve the electrical properties have been made by doping it with rare earth elements such as lanthanum (La), samarium(Sm), gadolinium (Gd) and dysprosium (Dy) etc. [17, 18]. Efforts have also been made to
overcome these issues by using transition metals [19] into BiFeO$_3$, also modifying material by including solid solution of BiFeO$_3$ with BaTiO$_3$ etc. [20, 21]. Difficulties also prevail in the practical realization of BiFeO$_3$, resulting from weak ferromagnetism exhibited by BiFeO$_3$, as the spiral spin modulation, superimposed on G-type antiferromagnetic spin ordering [22, 23], cancels out any possible net magnetization. One means for suppressing spiral spin modulation in BiFeO$_3$ is the chemical substitution in the A-sublattice [24–29]. Diamagnetic substitution at A-site in BiFeO$_3$ has been shown to enhance the net magnetization of parent material because of the kind of diamagnetic dopant element [30, 31].

In the present work, we have incorporated the compositional variations which have permitted the attainment of improved multiferroic properties. Cerium was chosen to substitute at A-site of BiFeO$_3$ because the ionic radius of Ce$^{3+}$ is comparable with that of Bi$^{3+}$. The electronic configuration of Ce$^{3+}$ also causes hybridization resulting in formation of Ce–O bond [32] leading to a noncentrosymmetrically distorted structure and a suppressed spiral spin structure, probably improving the ferroelectric and magnetic properties. The partial substitution of Bi$^{3+}$ ions by rare earth ions are reported to improve multiferroic properties of BiFeO$_3$ [33–37].

2. Experimental

The samples with the composition Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15, 0.2$) were prepared by an auto combustion method using urea as a fuel. The prime basis of auto combustion method depends on the proficiency of high exothermic reactions to be self-sustaining and, therefore, energetically efficient. The exothermic reaction is initiated at the ignition temperature, and generate heat which is displayed in a maximum or combustion temperature ($T_{comb}$), which can volatilize low boiling point impurities, and therefore result in purer products than those produced by more conventional techniques. The precursor materials used for the synthesis of Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15, 0.2$) by the auto combustion route were analytical reagent grade bismuth nitrate pentahydrate (Bi(NO$_3$)$_3$·5H$_2$O), ferric nitrate nonahydrate (Fe(NO$_3$)$_3$·9H$_2$O), Cerium(III) nitratehexahydrate (Ce(NO$_3$)$_3$·6H$_2$O) with a purity of more than 99 %. Analytical grade urea in a powder form with purity more than 99 % was used as fuel in the synthesis of the Bi$_{1-x}$Ce$_x$FeO$_3$ powder. Appropriate quantities of materials were weighed in microbalance according to the stoichiometry to obtain (0.05, 0.1, 0.15, 0.2) trivalent Ce$^{3+}$ dopant concentrations to replace trivalent Bi$^{3+}$. Stoichiometry of these doxmixtures for combustion is calculated based on the total oxidizing and reducing valencies of oxidizer and fuel. So that the equivalent oxidizer to fuel ratio becomes unity which results in release of maximum heat [38, 39]:

$$0.8\text{Bi(NO}_3\text{)}_3 \cdot 5\text{H}_2\text{O} + \text{Fe(NO}_3\text{)}_3 \cdot 9\text{H}_2\text{O} + 0.2\text{Ce(NO}_3\text{)}_3 \cdot 6\text{H}_2\text{O} + 5\text{CH}_4\text{N}_2\text{O}$$

$$\rightarrow \text{Bi}_{0.8}\text{Ce}_{0.2}\text{FeO}_3(s) + 8\text{N}_2(g) + 24\text{H}_2\text{O(l)} + 5\text{CO}_2(g).$$

According to propellant chemistry, the valencies of the elements carbon, hydrogen, nitrogen and oxygen are +4, +1, 0 and −2 respectively. The valency of nitrogen is taken as zero because of its conversion to molecular nitrogen during combustion. The valencies of metal depend upon metal ions in that compound. The valencies of the metals bismuth, iron and cerium are +3, +3 and +3 respectively. Thus, amixture of (Bi(NO$_3$)$_3$·5H$_2$O), (Fe(NO$_3$)$_3$·9H$_2$O), Ce(NO$_3$)$_3$·6H$_2$O and urea in an appropriate molar proportion were thoroughly mixed by grinding using agate mortar and pestle to form a homogeneous mixture. This homogeneous mixture was then poured into a crucible and was introduced into a 500 °C preheated muffle furnace, which under goes self-propagating, gas producing combustion reaction to yield voluminous metal oxide in less than 5 minutes, which is a porous and foamy product [40]. The porous powder was ground in a mortar and pestle to obtain a fine powder. The ground powder was again placed into the furnace for sintering at 400 °C for 3 hours.

The samples were then characterized by using various techniques. X-ray powder diffraction data was collected using an XPERT-PRO diffractometer with CuKα radiation ($\lambda = 0.15456$ nm) at step of 0.02 in the range $2\theta = 200$ to 800. The magnetic properties were measured by a vibrating sample magnetometer (Lakeshore VSM 7410) at room temperature. Dielectric measurements were performed on an impedance analyzer (WeynKerr6500B) for which the sintered samples were mechanically pressed inh ydraulc press and an Ag paste was applied to both sides of the polished pellets. Ferroelectric hysteresis loops were studied by a P–E loop tracer.

3. Result and discussion

Room temperature powder x-ray diffraction was then carried out on Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15, 0.2$). Rhombohedral perovskite structure is retained even after substituting Ce$^{3+}$ ions for Bi$^{3+}$ in BiFeO$_3$. The profile fit for the Rietveld refinement of Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15, 0.2$) samples are shown in Fig.1(a,b,c,d) respectively. Ce doping causes the peaks to shift toward lower $2\theta$ value this indicates that Ce is getting substituted in the BiFeO$_3$ lattice.
The lattice parameters are found to increase with Ce doping because ionic radii of Ce\(^{3+}\) (radius = 1.01 Å) is more than that of Bi\(^{3+}\) (radius = 1.03 Å) ion [41]. The crystallite sizes of all the samples \(\text{Bi}_{1-x}\text{Ce}_x\text{FeO}_3\) \((x = 0.05, 0.1, 0.15, 0.2)\) were found to be 16 nm, 19 nm, 22 nm and 27 nm respectively obtained by considering the most intense diffraction peak in the pattern using Scherer’s formula.

The stimulated XRD patterns of sample coincide well with the measured XRD pattern with generally small \(R\)-values as illustrated in Table 1. The lattice parameters and other refined parameter are also tabulated in Table 1.

SEM micrograph of Ce doped samples exhibits fine-grained structure with sharp grain boundaries with almost uniform diameter as shown in Fig. 2. The micrographs of the samples showed relatively greater homogeneity in the microstructure. Also the grain size of the samples decreases with increasing cerium in BiFeO\(_3\) which is a clear indication of incorporation of cerium into BiFeO\(_3\).

Typical TEM images of \(\text{Bi}_{1-x}\text{Ce}_x\text{FeO}_3\) \((x = 0.05, 0.1, 0.15, 0.2)\) samples prepared by the auto combustion method is shown in Fig. 3 respectively.

The average particle size estimated from TEM images for \(\text{Bi}_{1-x}\text{Ce}_x\text{FeO}_3\) \((x = 0.05, 0.1, 0.15, 0.2)\) were found to be 15 nm, 20 nm, 24 nm and 27 nm respectively, which is in accordance with XRD analysis. The particles are well connected with each other and are found to be approximate lysphericalin shape. The average particle size is found to decrease with Ce doping. Thus we can conclude that the substitution of Bismuth by rare-earth in multiferroic material BiFeO\(_3\)is accompanied by a significant decrease in particle size [42].

FIG. 1. The fit for the Rietveld refined profile for the Bi\(_{0.95}\text{Ce}_{0.05}\text{FeO}_3\) (a); Bi\(_{0.9}\text{Ce}_{0.1}\text{FeO}_3\) (b); Bi\(_{0.85}\text{Ce}_{0.15}\text{FeO}_3\) (c) and Bi\(_{0.8}\text{Ce}_{0.2}\text{FeO}_3\) (d) samples.
TABLE 1. Details of Rietveld refined XRD parameters for Bi$_{1-x}$Ce$_x$FeO$_3$

| Parameters | Bi$_{0.95}$Ce$_{0.05}$FeO$_3$ | Bi$_{0.9}$Ce$_{0.1}$FeO$_3$ | Bi$_{0.85}$Ce$_{0.15}$FeO$_3$ | Bi$_{0.8}$Ce$_{0.2}$FeO$_3$ |
|------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| 2θ range (deg.) | 20° to 80° | 20° to 80° | 20° to 80° | 20° to 80° |
| Step size (deg.) | 0.02 | 0.02 | 0.02 | 0.02 |
| Wavelength | 1.5406 Å | 1.5406 Å | 1.5406 Å | 1.5406 Å |
| Space group | R3c | R3c | R3c | R3c |
| a (Å) | 5.587 Å | 5.613 Å | 5.643 Å | 5.659 Å |
| b (Å) | 5.587 Å | 5.613 Å | 5.643 Å | 5.659 Å |
| c (Å) | 13.876 Å | 13.902 Å | 13.932 Å | 13.948 Å |
| Volume (Å$^3$) | 375.09 Å$^3$ | 379.3 Å$^3$ | 384.19 Å$^3$ | 386.82 Å$^3$ |
| $R_F$ | 1.7 | 2.1 | 2.5 | 2.8 |
| $R_{Bragg}$ | 2.95 | 2.8 | 2.6 | 2.35 |
| $R_{wp}$ | 16 | 15.6 | 14.5 | 13.0 |
| $R_{exp}$ | 13.8 | 14.0 | 15.6 | 17.6 |
| $R_p$ | 12.4 | 13.5 | 14.4 | 15.4 |
| $\chi^2$ | 1.924 | 1.804 | 1.423 | 1.34 |

Thermal analysis of Bi$_{1-x}$Ce$_x$FeO$_3$ (x = 0.05, 0.1, 0.15, 0.2) samples sintered at 400 °C has been carried out with DTA (600 – 900 °C) to study the transition temperatures. DTA results for temperature range (800 – 900 °C) are shown in Fig. 4. For Bi$_{1-x}$Ce$_x$FeO$_3$ respectively. A peak is observed for all the samples. Kaczmarek et al. [43] have attributed the peak observed in DTA near 830 °C to ferroelectric phase transition (Curie temperature, $T_C$) of bulk BiFeO$_3$. This clear endothermic peak is of chief interest here. The peak is shifted towards higher temperature with increase in Ce concentration. This increase in $T_C$ can be due to the decrease in pressure with increase in the cell volume. In BaTiO$_3$, the various transition temperatures shift down on compression [44]. Similarly, lowering of ferroelectric transition temperature is observed when doped with smaller atoms [45].

The room temperature magnetic hysteresis loops for Bi$_{1-x}$Ce$_x$FeO$_3$ (x = 0.05, 0.1, 0.15, 0.2) samples are shown in Fig. 5 recorded at 300 K. It is noted that saturation is achieved in all the samples for an applied field of <10 KOe.
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All the samples exhibited ferromagnetic ordering at room temperature. Owing to finite size the nanoparticles usually show unusual magnetic behaviors distinct from that of their bulk counterparts. In antiferromagnetic nanoparticles, due to the large surface to volume ratio, the contribution of uncompensated spins at the surface becomes higher.

Néel [46–48] proposed that the finite magnetic moment of nanoparticles of antiferromagnetic materials is due to the presence of the uncompenated spin at the surface of the particles. Apart from uncompensated spins at the surface, canting of spins in antiferromagnetic sublattices also plays an important role in the magnetic properties of the nanostructures [49,50]. Ce doping could have increased the canting angle, which in turn has resulted in enhanced magnetic properties. Another reason for the observed ferromagnetism is the suppression of spirals pin structure characteristic of BiFeO$_3$. When the particle size is on the order of or < 62 nm, this spiral spin structure changes so as to result in enhancement in magnetic properties. The variation of magnetic parameters and crystallite size is tabulated in Table 2. It is clear that Ce doping has strengthened the magnetic properties of BiFeO$_3$ significantly.

Figure 6 shows P–E hysteresis loops for the Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15, 0.2$) as a function of electric field. Ferroelectric parameters at room temperature for Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15, 0.2$) samples are given in Table 3. All samples show typical ferroelectric behavior. According to Wang et al. [51], the ferroelectricity of the BiFeO$_3$ samples originated from the displacements of Bi with respect to the FeO$_6$ cages along the (111) plane. Experimental results suggested that partial doping of Ce ions in BiFeO$_3$ acts as donor in oxygen octahedron and force the reduction of oxygen vacancies by restricting the formation of Fe$^{3+}$ to Fe$^{2+}$ ions, resulting in a great suppression of leakage current.

It is found that remanent polarization is found to increase with an increase in crystallite size. As the grain boundary is a low permittivity region, it has weak ferroelectricity. Therefore, polarization of grain boundary may be little or

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**Fig. 3.** TEM images of Bi$_{1-x}$Ce$_x$FeO$_3$ nanoparticles (a) $x = 0.05$; (b) $x = 0.1$; (c) $x = 0.15$ and (d) $x = 0.2$

**Fig. 4.** DTA curve of Bi$_{1-x}$Ce$_x$FeO$_3$ sintered at 400 °C
FIG. 5. The M–H plot of Bi$_{1-x}$Ce$_x$FeO$_3$ (x = 0.05, 0.1, 0.15, 0.2) at 300 K.

TABLE 2. Details of Magnetic Parameters at Room Temperature for Bi$_{1-x}$Ce$_x$FeO$_3$ samples

| Sample         | Remanent Magnetization (emu/g) | Saturation Magnetization (emu/g) | Crystallite Size (nm) |
|----------------|--------------------------------|---------------------------------|-----------------------|
| Bi$_{0.95}$Ce$_{0.05}$FeO$_3$ | 0.5               | 1.48                           | 16                    |
| Bi$_{0.9}$Ce$_{0.1}$FeO$_3$   | 0.7               | 1.89                           | 19                    |
| Bi$_{0.85}$Ce$_{0.15}$FeO$_3$ | 1.3               | 2.71                           | 22                    |
| Bi$_{0.8}$Ce$_{0.2}$FeO$_3$   | 1.6               | 3.38                           | 27                    |

FIG. 6. Ferroelectric hysteresis loop of Bi$_{1-x}$Ce$_x$FeO$_3$ (x = 0.05, 0.1, 0.15, 0.2) at 50 Hz.
attributed to the suppression of oxygen vacancies due to the substitution of Ce. Consequently, the remanent polarization increases as the crystallite size increases [52]. Also the remanent polarization depolarization field and polarization decreases. The number of grain boundary increases as crystallite size decreases. and depletion layer on grain surface can be formed. That results in polarization discontinuity on grain surface to form even nonexistent. On the other hand, space charges in grain boundary exclude polarization charge on grain surface properties.

It has been observed that $\varepsilon$ dominates and dipoles are unable to follow the field reversal in such a small interval of time at higher frequencies. This type of anomaly near the Néel temperature has also been predicted by several studies [53–58]. Here, the peaks disappearing magnetic order as compared to electric order and attests to magneto-electric coupling in the samples. It can be concluded from the present work that auto-combustion synthesis technique can be an advantageous method to prepare single phase cerium-doped BiFeO$_3$. The XRD pattern showed rhombohedrally distorted perovskite structure for cerium-doped BiFeO$_3$. The crystallite size is found to increase with increasing cerium concentration. Magnetization is found to increase considerably in all doped samples due to canting of spins and particle size less than 62 nm, which is less than the periodicity of BiFeO$_3$. Also cerium-doped BiFeO$_3$ sample shows fairly good ferroelectric behavior with increased remanent polarization with increasing crystallite size. Increasing the cerium concentration is found to reduce the Néel temperature, which is observed from the temperature dependant dielectric

### Table 3: Details of Ferroelectric Parameters at Room Temperature for Bi$_{1-x}$Ce$_x$FeO$_3$ samples

| Sample            | Electric field, $E_c$ (KV/cm) | Remnant polarization $P_r$ ($\mu$C/cm$^2$) | Crystallite Size (nm) |
|-------------------|-------------------------------|------------------------------------------|-----------------------|
| Bi$_{0.95}$Ce$_{0.05}$FeO$_3$ | 25                            | 3.08                                     | 16                    |
| Bi$_{0.9}$Ce$_{0.1}$FeO$_3$    | 38                            | 4.21                                     | 19                    |
| Bi$_{0.85}$Ce$_{0.15}$FeO$_3$  | 46                            | 5.02                                     | 22                    |
| Bi$_{0.8}$Ce$_{0.2}$FeO$_3$    | 63                            | 6.8                                      | 27                    |

The measured temperature dependence of dielectric constant $\varepsilon$ and loss for Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15$ and $0.2$) samples at 100 Hz frequency are shown in Fig. 7(a,b), respectively. The peak in the dielectric constant is attributed to a transformation from the antiferromagnetic order to the paramagnetic order, indicating an effect of disappearing magnetic order as compared to electric order and attests to magneto-electric coupling in the samples. This type of anomaly near the Néel temperature has also been predicted by several studies [53–58]. Here, the peaks show a diffuse nature. The substitution of cerium shifts the dielectric peak to low temperature region and a diffuse dielectric peak results. The peak shift may be attributed to the slightly larger ionic radii of Ce$^{3+}$ which replaces Bi$^{3+}$ due to which tolerance factor decreases which in turn reduces the Néel temperature. Another significant result is peak broadening with increased cerium concentration.

Figure 7(b) shows the variation in dielectric loss $\tan\delta$ for Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15, 0.2$) samples. Further as noted in the dielectric constant, anomalies are observed at 390, 380, 374 and 352 $^\circ$C for $x = 0.05, 0.1, 0.15$ & 0.2 respectively. In addition, the peaks in dielectric constant $\varepsilon$ and dielectric loss $\tan\delta$ shifted towards a lower temperature with increased Ce$^{3+}$ substitution, which indicates a decrease in the antiferromagnetic ordering temperature upon Ce$^{3+}$ substitution.

Frequency (100 Hz – 1 MHz) dependence of real part of dielectric constant $\varepsilon'$ and loss for the Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15, 0.2$) samples at 300 K is shown in Fig. 8(a,b) respectively. For all samples, the $\varepsilon'$ decreases with the increase in frequency and is consistent with combined response of orientational relaxation of dipoles and conduction of charge carriers. It may be attributable to the fact that the intra well hopping probability of charge carriers dominates and dipoles are unable to follow the field reversal in such a small interval of time at higher frequencies. It has been observed that $\varepsilon'$ is increasing with substitution of Ce. Variation in $\tan\delta$ with frequency at 300 K for Bi$_{1-x}$Ce$_x$FeO$_3$ ($x = 0.05, 0.1, 0.15, 0.2$) samples is shown in Fig. 8(a,b).

It is evident that $\tan\delta$ also decreases with an increase in frequency. The increase in the dielectric constant may be attributed to the suppression of oxygen vacancies due to the substitution of Ce$^{3+}$ at Bi$^{3+}$ site. Since the substitution of Ce at Bi site is ascribed to compensation of the volatile Bi component in BiFeO$_3$, which causes reduction in the oxygen vacancies, which could have been generated to compensate the positive charge deficiency caused by the volatilization of Bi [59,60]. As a result, the number of oxygen vacancies decrease, therefore Bi$_{0.8}$Ce$_{0.2}$FeO$_3$ has the highest $\varepsilon$ value among all the Ce doped compositions.

### 4. Conclusions

It can be concluded from the present work that auto-combustion synthesis technique can be an advantageous method to prepare single phase cerium-doped BiFeO$_3$. The XRD pattern showed rhombohedrally distorted perovskite structure for cerium-doped BiFeO$_3$. The crystallite size is found to increase with increasing cerium concentration. Magnetization is found to increase considerably in all doped samples due to canting of spins and particle size less than 62 nm, which is less than the periodicity of BiFeO$_3$. Also cerium-doped BiFeO$_3$ sample shows fairly good ferroelectric behavior with increased remanent polarization with increasing crystallite size. Increasing the cerium concentration is found to reduce the Néel temperature, which is observed from the temperature dependant dielectric
anomaly. This dielectric anomaly observed in all the samples is a signature of magneto-electric coupling. Dielectric constant also shows strong frequency dependence for all the samples, indicating the usual dielectric dispersion. It is anticipated that appropriate doping at A Site of BiFeO₃ can enhance the intrinsic magnets and ferroelectric properties as well as generating novel functionalities.
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