Diffuse and relaxor phase transitions of Ba$_{0.95}$Bi$_{0.05}$Ti$_{1-x}$Fe$_x$O$_3$ ceramics at x=0.00 to 1.00 of Fe content, prepared by solid state method.

GOUITAA Najwa*, LAMCHARFI Taj-dine, ABDI Farid, ECHATOUFI Nor-Said and AMARASS Mustapha.

Signals, Systems and Components Laboratory (LSSC), Electrical Engineering Department, University Sidi Mohamed Ben Abdellah USMBA, FST. Fez, Imouzzer Road B.P. 2202, Morocco.

author’s e-mail address: najwa.gouitaa@gmail.com

Abstract:

The dielectric properties of iron and bismuth co-substituted BaTiO$_3$ ceramic with the formula: Ba$_{0.95}$Bi$_{0.05}$Ti$_{1-x}$Fe$_x$O$_3$ (BBTF$_x$) for x=0.00 to 1.00, synthesis with solid state route, were characterized. The results of dielectric permittivity dependence of temperature show three dielectric phase transitions from a rhombohedral ferroelectric to orthorhombic ferroelectric (T$_{R0}$) than to a tetragonal ferroelectric phase (at T$_{0,T}$), and finally to cubic paraelectric at the Curie temperature (T$_C$). Calculating the relaxation parameters of ΔT$_{relax}$ and the dispersion factor Δε’$_{max}$ / ε’$_{max}$, we have found that all the ceramics present a relaxation and a dispersion phenomenon. And the phase transition T$_{0,T}$ for x = 0.00 has the highest value of ΔT$_{relax}$ while the dispersion factor has the highest value for the phase transition T$_m$ at x = 0.60. The diffuseness parameter γ refined from Uchino law showed a diffuse phase transition for all the ceramics. While γ has a value close to 1 for T$_{R0}$ for x = 0.00, which indicate a standard Curie-Weiss law. The dielectric evolution as function of frequency shows a resonance behavior for x=0.00 of Fe content while for the other ceramics we obtained a classical ferroelectric behavior.

Keywords:

Dielectric, BaTiO$_3$, phase transition, relaxation, dispersion, diffuse, resonance.

I. Introduction

For electronic industry, the BaTiO$_3$ based material has been widely used and has an important role in the applications of actuators, sensors, resonators, ultrasonic transducers, bolometers, solid state refrigeration and other capacitive applications [1-3]. The basic properties of ferroelectric ceramics based capacitors are the high dielectric constant, low dielectric loss, and high hysteresis free strain near room temperature over the wide frequencies. The dielectric and ferroelectric properties of BT-based can be modified by a large variety of substitutions possible at Ba-site or Ti-site independently or simultaneously. In order to improve their dielectric and ferroelectric properties these substituents can be isovalent or heterovalent ions. Effects of isovalent substitutions such as Pb$^{2+}$, Ca$^{2+}$ or Sr$^{2+}$ for Ba-site and Zr$^{4+}$, Hf$^{4+}$ or Mn$^{2+}$ for Ti$^{4+}$-site on microstructure, dielectric properties of BT-based ceramics have already been investigated [4-6]. Whereas the rare-earth substitution of heterovalent ions such as Dy$^{3+}$, Tb$^{3+}$, Eu$^{3+}$, Nd$^{3+}$, Gd$^{3+}$, Yb$^{3+}$, Sm$^{3+}$, Er$^{3+}$, Ho$^{3+}$, Sb$^{3+}$, Sc$^{3+}$, La$^{3+}$, Nb$^{4+}$, Bi$^{3+}$ for Band Ti-site cause charge imbalance and creation of vacancies on A sites or B sites [7-12].

BiFeO$_3$-ABO$_3$ systems have attracted great attention as a means to rise structural stability and sinterability [13,14]. Processing of BiFeO$_3$ with other perovskite structured materials, such as BaTiO$_3$, would prevent the formation of secondary phases [15,16] and have excellent ferroelectric properties (T$_C$= 120 °C).
Recently, several researchers reported multiferroic perovskite ceramics which have antiferromagnetic – ferroelectric and antiferromagnetic /weak ferromagnetic ferroelectric systems [17,18]. As a typical ferroelectric-magnetic material, the BiFeO₃ has been a member of rare earth perovskite family having semi-conducting characteristics at room temperature with abnormal dielectric constant and loss which can be a useful substitution for BT. As there are few extensive reports on the simultaneous substitution of Bi³⁺ and Fe³⁺ in BaTiO₃. Therefore, we have studied the structural and multiphase phase transitions of Ba₀.₉₅Bi₀.₅Ti₁₋ₓFeₓO₃ ceramics for x=0.00 to 1.00, in our previous work [19]. We have found a coexistence of three phases which are tetragonal, hexagonal and pseudo-cubic in a large marge of concentration of Fe (from x=0.40 to 0.80). And The results of dielectric properties show three dielectric relaxation phase transitions from a rhombohedral ferroelectric to orthorhombic ferroelectric (T₃) then to a tetragonal ferroelectric phase (at T₄) and finally to cubic paraelectric at the Curie temperature (T₃). The present paper, is focusing on the detailed study of these phase transitions by identifying a relaxation and diffuseness parameters to describe these phase transitions by identifying a relaxation and diffuseness parameters to describe these phase transitions.

II. Experimental

The Ba₀.₉₅Bi₀.₅Ti₁₋ₓFeₓO₃ (BBTFₓ) ceramics for x=0.00 to 1.00 were prepared by the conventional solid-state method using oxides of BaCO₃, Bi₂O₃, TiO₂ and Fe₂O₃ with high-purity of 99%, 99%, 99% and 97% respectively and from Sigma-Aldrich provider. The doping site of Fe and Bi ions in BaTiO₃ was weighted by stoichiometric proportions of raw materials according to the reaction:

\[
0.95 \text{BaCO}_3 + \frac{1}{2} 0.05 \text{Bi}_2\text{O}_3 + \frac{1}{2} x \text{Fe}_2\text{O}_3 + (1- \frac{0.05}{4} - x) \text{Ti}_2\text{O}_3 \rightarrow \text{Ba}_{0.95}\text{Bi}_{0.05}\text{Ti}_{1-0.05/4-x}\text{Fe}_x\text{O}_{3+x/2} + \text{CO}_2
\]

The starting powders were weighted in stoichiometric proportion and ground for 30 min after that milled under acetone for 4h. The obtained powders were dried at 80°C for 24h. The dried powders were mixed using agate mortar for 30 min and then de-carbonated and pre-reacted by calcining in alumina at 1100°C for 4h. After calcination, the powders were mixed for 30 min.

The calcined powders were pressed into pellets, after adding few drops of 1 wt% Polyvinyl Alcohol (PVA) as a binder, and sintered in air at 1200°C for 6h. The dielectric properties as function of frequency and temperature were studied with Agilent E4980A (20Hz-2MHz).

III. Results and discussion

1. Dielectric properties as function of temperature

The figure.1 shows the evolution of the dielectric permittivity, as a function of temperature from the room temperature to 600°C and at different frequencies (from 5 KHz to 2 MHz), for BBTFₓ samples (x = 0.00, 0.20, 0.40, 0.60, 0.80 and 1.00). The spectra show three dielectric anomalies at different temperatures. Based on our previous work. The first maximum at low temperature 150°C, corresponds to a phase transition from the ferroelectric rhombohedral phase to the ferroelectric orthorhombic phase Tᵣₒ. The second maximum at intermediate temperatures (~500°C) corresponds to a phase transition from the ferroelectric orthorhombic phase to the ferroelectric tetragonal phase Tᵣₜ. While the third maximum at high temperatures (~ 600°C) corresponds to a phase transition from the tetragonal ferroelectric phase to the cubic paraelectric phase Tₘ.

These three phase transitions show a dielectric relaxation phenomenon in all these ceramics and a diffuse behavior.

1.1. Relaxation phenomenon

In order to describe the relaxation behavior of the phase transitions, three regions are distinguished: region I corresponding to the first phase transition Tᵣₒ, region II in which the second peak persists Tᵣₜ and region III for high temperatures where the paraelectric-ferroelectric phase transition Tₘ takes place.

The adjustment parameters and the characteristics of the relaxer phenomenon for the three phase transitions are summarized in the table. I, with:

ΔTₘₑₓₗ is the relaxation parameter at Tₘ and it is defined by:

\[\Delta T_{relax} (°C) = T_m (100 \text{ KHz}) - T_m (5 \text{ KHz})\]
And $\Delta \varepsilon'_{r,\text{max}} / \varepsilon'_{r,\text{max}}$ dispersion factor defined by:

$$\Delta \varepsilon'_{r,\text{max}} / \varepsilon'_{r,\text{max}} = \frac{\varepsilon'_{r}(5 \text{ KHz}) - \varepsilon'_{r}(100 \text{ KHz})}{\varepsilon'_{r}(5 \text{ KHz})}$$

The values of these parameters are grouped in table 1. We note that the values of $\Delta T_{\text{relax}}$ increase with the increase in the Fe level for the first phase transition $T_{R-O}$ and decrease with the increase in Fe for the other two phase transitions $T_{O-T}$ and $T_m$. The phase transition $T_{O-T}$ for $x = 0.00$ has the highest value of $\Delta T_{\text{relax}}$. While the dispersion factor has the highest value for the phase transition $T_m$ at $x = 0.60$.

**Table 1.** Parameters value of the relaxer phenomenon $\Delta T_{\text{relax}}$ and $\Delta \varepsilon'_{r,\text{max}} / \varepsilon'_{r,\text{max}}$ for the three phase transitions.

| Phase transition | x  | $\Delta T_{\text{relax}}$ (°C) | $\Delta \varepsilon'_{r,\text{max}} / \varepsilon'_{r,\text{max}}$ |
|------------------|----|-------------------------------|---------------------------------|
| $T_{R-O}$        | 0.00 | 3                             | 0.16                            |
|                  | 0.20 | 7                             | 0.18                            |
|                  | 0.40 | 5                             | 0.73                            |
|                  | 0.60 | 9                             | 0.5                             |
|                  | 0.80 | 17                            | 0.37                            |
|                  | 1.00 | 26                            | 0.7                             |
| $T_{O-T}$        | 0.00 | 56                            | 0.67                            |
|                  | 0.20 | 30                            | 0.056                           |
|                  | 0.40 | 17                            | 0.51                            |
|                  | 0.60 | 21                            | 0.6                             |
|                  | 0.80 | 3                             | 0.64                            |
|                  | 1.00 | 8                             | 0.55                            |
| $T_m$            | 0.00 | ----                          | ----                            |
|                  | 0.20 | 10                            | 0.52                            |
|                  | 0.40 | 9                             | 0.63                            |
|                  | 0.60 | 4                             | 0.86                            |
|                  | 0.80 | 7                             | 0.60                            |
|                  | 1.00 | 7                             | 0.72                            |

Joby E. Joy et al. [20] reported that the dielectric properties of the perovskite oxides of formula $\text{Ba}_3\text{M}^{III}\text{TiM}^{V}\text{O}_9$ for $\text{M}^{III} = \text{Fe, Ga, Y and Lu}$, $\text{M}^{V} = \text{Nb, Ta and Sb}$ showed a relaxer-like behavior only for the $\text{M}^{III} = \text{Fe}$ oxides, whereas all the other oxides showed a classical dielectric behavior. In our case, the relaxation is also present for $\text{BBTO}$ not substituted by Fe ion, which suggests that this phenomenon is due to the presence of $\text{Bi}^{3+}$ in the $\text{Ba}^{2+}$ site corresponding to $\text{M}^{III}$. However, the BT material doped with Fe at 0.20, although it does not correspond to an $\text{M}^{V}$ ion, the material is a relaxer which indicates that the combination of the two substitutions (Bi and Fe) favors the relaxer phenomenon. The co-substitution of these two ions ($\text{Bi}^{3+}$ and $\text{Fe}^{3+}$) promotes the relaxer character.
On the other hand, it has been suggested that the defects such as oxygen vacancies are responsible for dielectric relaxation in the high temperature region. The existence of oxygen vacancies is characteristic of BaTiO$_3$ ferroelectric ceramics prepared by high temperature sintering. In BaTiO$_3$, oxygen vacancies with n-type carriers are generated by the following reaction:

$$\text{O}_\text{o} \leftrightarrow \text{V} \bar{O}^\ddagger + 2 e^- + \frac{1}{2} \text{O}_2(g)$$

The electrons released in this reaction can be sensed by the Fe$^{3+}$ ions to form Fe$^{2+}$ ions:

$$\text{Fe}^{3+} + e^- \leftrightarrow \text{Fe}^{2+}$$

Where O$_o$ is the oxygen ion in the oxygen lattice site, with a neutral charge, V$\bar{O}^\ddagger$ denotes the oxygen gap in the BaTiO$_3$ lattice with an effective charge of +2 according to the Kräger-Vink notation. The change in ionization can be written by the formula:

$$\text{V}\bar{O}^\ddagger + e^- \leftrightarrow \text{V}\bar{O}$$

With: V$\bar{O}$ denotes the oxygen gap in the BaTiO$_3$ with an effective charge of +1.

The oxygen vacancies V$\bar{O}$ and V$\bar{O}$ would be attracted by the negatively charged impurity center Fe$_{\text{Ti}}^{'\text{+}}$ (Fe ion in a Ti lattice site, with -1 charge -Fe$^{3+}$) Fe$_{\text{Ti}}^{'\text{+}}$ (Fe ion in a Ti lattice site, with -2 charge -Fe$^{2+}$) creating the defective complexes [21] according to the formula:

$$\text{Fe}^{'\text{Ti}}_-- \text{V}\bar{O} \text{ et } \text{Fe}^{'\text{Ti}}_-- \text{V}\bar{O}$$

The coexistence of Fe$^{3+}$ and Fe$^{2+}$ causes an electron jump between the Fe$^{3+}$ and Fe$^{2+}$ ions, with the oxygen vacancies acting as a bridge between them. In addition, it can lead to increased values of electrical conductivity, dielectric losses, and space charge build-up at grain boundaries [22].

For all these compounds, a relaxer behavior was detected. Thus, the replacement of Ti$^{4+}$ by Fe$^{3+}$ and of Ba$^{2+}$ by Bi$^{3+}$ have the effect of promoting the relaxation behavior for the three transition temperatures with values which vary according to the rate of Fe$^{3+}$ substitution.
1.2. Diffuse character

1.2.1. Curie-Weiss law

The normal ferroelectrics are characterized by a steep phase transition, at $T_C$, from the polar to the non-polar phase, reflected by the discontinuity of $\varepsilon_r$ above $T_C$. The transition temperature $T_C$ is independent of the frequency and the paraelectric behavior of a normal ferroelectric is described by the Curie-Weiss law:

$$\varepsilon'_r = \frac{C}{T-T_0}$$

Where $C$ denotes the Curie Weiss constant and $T_0$ the Curie Weiss temperature.

To study this type of behavior (ferroelectric with diffuse phase transition), we have plotted the curves of $1/\varepsilon'_r$ as a function of temperature for the three phase transitions as it is shown in the figures. These curves can be divided into three regions: the first region represents the ferroelectric behavior up to the transition of $T_m$, the second region close to the transition indicates a diffuse transition from $T_m$ to the temperature $T_{cw}$ and the third region, above $T_{cw}$, represents the linear behavior of $1/\varepsilon'_r$ as a function of temperature according to the Curie Weiss diagram. The Curie Weiss temperature $T_0$ is obtained by extrapolating the third region to the temperature axis. And the factors $\Omega$ and $C$ represent respectively the inverse of the slope $s$ of the line $1/\varepsilon'_r(T)$. These different constants are listed in the table. The values of the ratio $\Omega / C$ obtained are close to the $-2$ value for the $T_{E-O}$, $T_{O-T}$ transitions at $x = 0.20$, $x = 0.00$ and for $T_m$ at $x = 0.20$ and $0.80$, which corresponds to an ideal transition second order at these doping rates and close to -8 for the transition $T_m$ at $x = 0.40$, $0.60$ and $1.00$ which corresponds to a first order transition [23,24]. While for the other substitution rates the ratio $\Omega / C$ is very far from -2 and -8 because the phase transitions at these substitution rates are very diffuse, which limits the application of the Curie-Weiss law.

The parameter $\Delta T_m$, is used to indicate the degree of deviation from the Curie Weiss law and it is defined as follows:

$$\Delta T_m = T_{CW} - T_m$$

Where $T_{CW}$ denotes the temperature at which the permittivity begins to deviate from Curie Weiss law and $T_m$ represents the temperature of the minimum of $1/\varepsilon'_r$.

The values of this parameter (Table. 2) are all different from zero. So, we have a deviation from the Curie Weiss behavior for all the ceramics, which has been qualified for a short-range association between the nanopolar domains [25]. In addition, the deviation from the Curie Weiss law at some temperatures range above $T_m$ is one of the most features of ferroelectric relaxers [26].
Figure. 2 Evolution of $1/\varepsilon_r'$ as function temperature at 5 kHz for $T_{R,0}$ phase transition for BBTF$_x$ at $x=$ a. 0.00, b.0.20, c.0.40, d.0.60, e.0.80 and f.1.00.

Figure. 3 Evolution of $1/\varepsilon_r'$ as function temperature at 5 kHz for $T_{O,T}$ phase transition for BBTF$_x$ at $x=$ a. 0.00, b.0.20, c.0.40, d.0.60, e.0.80 and f.1.00.
Figure 4 Evolution of $1/\epsilon'$ as function temperature at 5 kHz for $T_m$ phase transition for BBTF$_x$ at x= a. 0.20, b.0.40, c.0.60, d.0.80 and e.1.00.

Table 2. Curie Weiss parameters for the three phase transitions.

| Phase transition | x   | $\Delta T_m$ (°C) | C $(10^5 °C)$ | $\Omega$ $(10^5 °C)$ | $\Omega/C$ |
|------------------|-----|-------------------|--------------|---------------------|-----------|
|                  | 0.00| 13                | 4.3          | -0.45               | -0.10     |
| $T_{R-O}$        | 0.20| 27                | 1            | -1.7                | -1.7      |
|                  | 0.40| 24                | 7.2          | -1.42               | -0.2      |
|                  | 0.60| 6                 | 25           | -10                 | -0.4      |
|                  | 0.80| 13                | 13.3         | -1.5                | -0.11     |
|                  | 1.00| 5                 | 5            | -0.74               | -0.15     |
|                  | 0.00| ---               | ---          | ---                 | ---       |
| $T_{O-T}$        | 0.20| 18                | 1.01         | -0.13               | -0.13     |
|                  | 0.40| 19                | 5            | -4.27               | -0.85     |
|                  | 0.60| 17                | 10.3         | -2.30               | -0.22     |
|                  | 0.80| 15                | 7.35         | -2.32               | -0.32     |
|                  | 1.00| 6                 | 1.1          | -0.74               | -0.67     |
|                  | 0.00| ----              | ----         | --                  | --        |
|                  | 0.20| 16                | 4.5          | -5.5                | -1.22     |
|                  | 0.40| 6                 | 0.1          | -1                  | -10       |
1.2.2. **Uchino law**

Figures 5, 6 and 7 illustrate the ferroelectric behavior of BBTF<sub>x</sub> compounds (for x = 0.00 to 1.00) according to the modified Uchino law [27], in a straight line form the equation:

\[ \ln \left[ \frac{\varepsilon'_{r,\text{max}}/\varepsilon'_r - 1}{2} \right] = \gamma \ln (T - T_m) - \delta \ln \delta \]

With: δ Gaussian diffusion factor (K) and γ indicate the character of the transition: γ = 1 for an ideal Curie transition, γ = 2 for the relaxer behavior.

Linear relationships are observed in the plot of \( \ln \left[ \frac{(\varepsilon'_{r,\text{max}}/\varepsilon'_r - 1)}{2} \right] \) versus \( \ln (T - T_m) \) at 5 kHz of frequency for the three regions. By fitting the experimental data to the Uchino equation, the values of γ and δ are deduced and are presented in the table. 3. We note that for some ceramics and phase transition, the values of γ are in the range 1.35 to 1.90, which corresponds to an incomplete diffuse phase transition. The diffusivity γ has a value close to 1 for T<sub>R,0</sub> at x = 0.00 (BBTO not co-substituted) which indicate a standard Curie-Weiss law. While for other ceramics at x = 0.20 and 1.00 for T<sub>O,T</sub> as well as at x = 0.00 and 0.80 for T<sub>m</sub>, Uchino's law is no longer applicable because the Curie temperature distribution at these doping rates does not follow the Gaussian distribution as it was described by Smolenski [28].

The diffuse phase transition behavior of these samples can be explained by the presence of micro-heterogeneities in these materials due to the thermochemical diffusion controlled by solid state reactions. The micro-heterogeneities are due to the random occupation of B and A sites by different ions. Such a heterogeneous distribution of cations leads to different states of polarization and therefore to different relaxation times in different regions [29].

On the other hand, basing on the values of the diffusion factor δ, it can be seen that when the Fe level increases this factor varies irregularly for all the phase transitions.

| T<sub>m</sub> | 0.60 | 0.80 | 1.00 |
|-------------|------|------|------|
| 5           | 1.04 | 0.5  | 0.95 |
| -11.76      | -1.02| -8   | -842 |
Figure 5. Ln \([((\varepsilon_{r,\text{max}}/\varepsilon_\ell) - 1)] \) versus Ln (T-Tm) at 5 kHz for T_R-O phase transition for BBTF_x ceramics at x = 0.00 to 1.00.

Figure 6. Ln \([((\varepsilon_{r,\text{max}}/\varepsilon_\ell) - 1)] \) versus Ln (T-Tm) at 5 kHz for T_O-T phase transition for BBTF_x ceramics at x = 0.00, 0.40, 0.60 and 0.80.
Figure. 7. Ln \([(\varepsilon'_r/\varepsilon'_r, \text{max}) \cdot (T-T_m)]\) versus Ln (T-T_m) at 5 kHz for T_m phase transition for BBTF_x ceramics at x= 0.20, 0.40, 0.60 and 1.00.

Tableau. 3. \(\gamma\) and \(\delta\) values for the tree phase transitions at different Fe contents.

| Phase transition | \(T_{R-O}\) | \(T_{O-T}\) | \(T_m\) |
|------------------|-------------|-------------|---------|
| Fe content       | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 0.0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |
| \(\gamma\)       | 1.1 | 1.49 | 1.84 | >2 | 1.89 | >2 | 1.82 | --- | 1.51 | 1.01 | 1.90 | --- | 1.08 | 1.35 | >2 | --- | >2 |
| \(\delta\)       | 33.1 | 164 | 40.44 | 30 | 90 | 36.6 | 181 | --- | 84.8 | 20.9 | 10.7 | --- | 324 | 20.3 | 10.7 | --- | 8.5 |

2. Dielectric properties as function of frequency

The figure. 8 shows the dielectric constant at different temperatures as a function of frequency of all ceramics in the frequency range from 20 Hz to 2 MHz. For the BT substituted at 0.05 of Bi (x = 0.00), the permittivity curves show a resonance phenomenon and the peak shifts towards low frequencies, for temperatures below 160 °C, then towards high frequencies beyond this temperature. This resonance phenomenon is no longer visible for temperatures above 220 °C.

While the BBTF_x ceramics with x = 0.20 to 1.00, show a classical ferroelectric behavior. In fact, the values of the dielectric constant decrease rapidly with increasing frequency and become almost independent of frequency. This decrease in the dielectric constant with the increase in frequency can be explained by the phenomenon of dipole relaxation due to the contribution of interfacial polarization of the Maxwell - Wagner type [30]. The dipoles with large effective masses (eg oxygen vacancies) may follow the applied field at low frequency and does not follow it at higher frequencies.

The figure. 9 shows the variation of dielectric loss (tan \(\delta\)) as a function of frequency at different temperatures. The curves of x = 0.00 (figure. 9.a) show that the dielectric loss decreases with the frequency for the low frequencies then becomes almost constant and then reaches a maximum for the temperatures of 160 °C and 220 °C. These maxima corresponding to the resonance frequencies of \(\varepsilon'_r\) which move towards the high frequencies and decrease in intensity with the increase of the temperature then they are no longer observable for the other temperatures and this is in relation with the phenomenon of resonance which is no longer observed because we exceed the frequency range of the device.

For BBTO ceramics substituted with Fe for x = 0.20 to 1.00, the dielectric losses have the same evolution. In fact, the latter decrease rapidly at low frequencies then remain almost constant for the other frequencies, which indicate the normal ferroelectrics behavior. In addition, the decrease in tan \(\delta\) at low frequencies is attributed to the fact that the jump frequency of the charge carriers cannot follow the variations of the electric field applied beyond a certain frequency limit.
**Figure 8.** Evolution of dielectric permittivity as a function of frequency for BBTF$_x$ ceramics at $x=$ a.0.00, b. 0.20, c.0.40, d.0.60, e.0.80 and f.1.00.

**Figure 9.** Evolution of dielectric loss as a function of frequency for BBTF$_x$ for $x=$ a.0.00, b. 0.20, c.0.40, d.0.60, e.0.80 and f.1.00.
IV. Conclusion

In this work we have study the dielectric properties of Ba$_{0.95}$Bi$_{0.05}$Ti$_{1-x}$Fe$_x$O$_3$ ceramics as function of temperature and frequency. The results show the existence of three phase transitions $T_{R,O}$, $T_{O,T}$ and $T_m$ which exhibit a relaxation behavior with a diffuse phenomenon. The relaxation parameters $\Delta T_{\text{relax}}$ and the dispersion factor $\Delta \varepsilon'_{\text{r, max}} / \varepsilon'_{\text{r, max}}$ calculated show that the phase transition $T_{O,T}$ for $x = 0.00$ has the highest value of $\Delta T_{\text{relax}}$ while the dispersion factor has the highest value for the phase transition $T_m$ at $x = 0.60$. The diffuseness parameter $\gamma$ refined from modified Uchino law showed a diffuse phase transition for all the ceramics. While $\gamma$ has a value close to 1 for $T_{R,O}$ at $x = 0.00$, which indicate a standard Curie-Weiss law.

Conflict of Interest
The authors declare that they have no conflict of interest.

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