

Crystal structure and electrical properties of 0.7BiFeO₃–0.3Ba_{1-x}Sr_xTiO₃ solid solutions ($x \leq 0.3$)

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Received 5 December 2024 ♦ Accepted 9 February 2025 ♦ Published 11 April 2025

Citation: Silibin MV, Kiselev DA, Latushka SI, Zhaludkevich DV, Mosunov AV, Karpinsky DV (2025) Crystal structure and electrical properties of 0.7BiFeO₃–0.3Ba_{1-x}Sr_xTiO₃ solid solutions ($x \leq 0.3$). *Modern Electronic Materials* 11(1): 53–61. <https://doi.org/10.3897/j.moem.11.1.143630>

Abstract

Solid solutions of the 0.7BiFeO₃–0.3Ba_{1-x}Sr_xTiO₃ system with compositions in the vicinity of the rhombohedral-cubic morphotropic phase boundary ($x \leq 0.3$) have been synthesized via solid state reactions. The crystal structure and morphology of the solid solutions have been studied using X-ray diffraction, scanning electron microscopy and Raman spectroscopy, and the chemical composition has been studied using energy dispersive X-ray spectroscopy. The dielectric properties of the compositions have been studied using impedance spectroscopy as a function of the concentration of strontium ions over a wide range of temperatures and frequencies. The structure of the solid solutions with $x \leq 0.3$ contains coexisting rhombohedral and cubic phases, strontium ion substitution leading to higher cubic phase volume fraction. The $x = 0$ composition contains almost equal parts of coexisting phases, whereas the $x > 0.25$ solid solutions have single-phase cubic structures. The concentration-related changes in the phase structure of the solid solutions lead to a decrease in the lattice parameters of the coexisting phases and a nonmonotonic decrease in the electrical conductivity and the dielectric permeability of the compositions. The experimental data provide insight into specific changes of the structure and phase composition of the solid solutions in the vicinity of the rhombohedral-cubic morphotropic phase boundary and deliver better understanding of the relationship between the observed structural changes and the electrical properties of the compositions.

Keywords

bismuth ferrite, ferroelectrics, relaxors, X-ray diffraction, electron microscopy, structural phase transitions, morphotropic phase boundary

1. Introduction

The coexistence of magnetic and ferroelectric ordering with transition points far above room temperature

($T_N \sim 640$ K, $T_C \sim 1100$ K) in pure bismuth ferrite is the key factor attracting the attention of researchers over recent decades [1–3]. Various chemical substitution options of bismuth ferrite largely offset the main function-

al disadvantages of the pure compound (high electrical conductivity, lack of random magnetization, and difficult stoichiometric composition achievement process). Chemical substitution of ions in the A- and/or B-sublattices of the Perovskite structure allows controlled variation of the crystal structure, thus governing the performance of the materials [4–8].

Since recently, bismuth ferrite based solid solutions have been often used as electroceramics for power generation, storage and transportation devices. In advanced capacitor designs, the optimum working materials are relaxor electroceramics which require weakly mutually interacting ferroelectric clusters in a paraelectric matrix. Bismuth ferrite based solid solutions with compositions in the vicinity of the rhombohedron-cube, orthorhomb-cube etc. morphotropic phase boundaries can be used as structural counterparts of the above relaxors [9–11]. Thus, chemical substitution of pure bismuth ferrite allows designing solid solutions the structures of which contain two coexisting phases, one of which is dominating and has a cubic structure and the other can be in the form of discrete micro- and nanometer sized clusters with polar-active structural distortions. Materials of this type present a number of challenges related to the identification of crystal structure, morphology, chemical composition, structural defects etc. in the above micro- and nanometer sized clusters, which is indispensable for the design of functional materials with controlled physicochemical parameters.

This work presents experimental data on the structure and electrical properties of $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ system solid solutions with compositions in the vicinity of the rhombohedron-cube morphotropic phase boundary ($x \leq 0.3$). It describes the sequence of changes in the phase composition and crystal structure of the solid solutions on the basis of structural data obtained using local (Raman spectroscopy) and macroscopic (X-ray diffraction) research techniques. This work also describes the evolution of the dielectric and transport properties as a function of chemical and phase composition over a wide range of temperatures, and a relationship between the structural parameters and performance of the experimental $\text{BiFeO}_3\text{--}(\text{Ba},\text{Sr})\text{TiO}_3$ electroceramics. These electroceramics are in demand for advanced electronics as materials of high-power electronics, capacitor ceramics etc.

2. Experimental

The test $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions ($x = 0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30$) were synthesized via solid state reactions from raw analytically pure Bi_2O_3 , Fe_2O_3 , and TiO_2 oxides and BaCO_3 and SrCO_3 carbonates. The raw oxide mixture in stoichiometric ratio was thoroughly mixed in a RETSCH 200 PM planetary mill in an ethyl alcohol media for 60 min. The powders were pressed at ~ 0.1 GPa to 10 mm diam. ~ 1 mm thick tablets. After intermediate crushing and pressing the ma-

terials were synthesized at ~ 1320 K for 12 h, followed by quenching to room temperature. The phase composition and crystal structure of the ceramics were studied using X-ray diffraction on an Adani PowDiX 600 diffractometer using CuK_α radiation. The X-ray diffraction data were processed using the full-profile Rietveld method with the FullProf software [12]. The morphology of individual grains was studied under a Zeiss Evo 10 scanning electron microscope. The elemental composition of the specimens was studied using energy dispersive spectroscopy with an Oxford Instruments EDS system. The morphology of the grains was analyzed with the ImageJ software. Raman studies were conducted on a Confotec MR350 spectrometer (SOL Instruments) at a ~ 532 nm excitation wavelength. The dielectric properties were studied using impedance spectroscopy at 300–1000 K and frequencies of 0.1 and 1.0 kHz, 100 kHz and 1 MHz with an HP4284A immittance meter.

3. Results and discussion

3.1. Crystal structure of $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions

The X-ray diffraction patterns of the solid solutions indicate the absence of impurity phases in all the test compositions accurate to $\sim 1\text{--}3\%$, in agreement with the lab diffractometer rated accuracy. X-ray structural data calculated using the Rietveld method illustrate the structural evolution of the solid solutions as a function of chemical composition. The initial $\text{Bi}_{0.70}\text{Ba}_{0.30}\text{Fe}_{0.70}\text{Ti}_{0.30}\text{O}_3$ solid solution is a two-phase material containing a polar-active rhombohedral phase (space group $R3c$) and a cubic phase ($Pm\text{--}3m$), in almost equal volume fractions. The cubic phase volume fraction grows with an increase in the concentration of strontium ions, the lattice parameters of both phases decreasing and hence the unit cell size also diminishing (Fig. 1). The decrease in the lattice parameters is caused by the difference in the ionic radii of barium and strontium: their oxidation degrees and anionic neighborhood being the same, the ionic radius difference is $\sim 14\%$, the difference in the unit cell volumes between the rhombohedral and cubic phases being $\sim 10\text{--}12\%$ (normalized to the basic unit cell) and remaining almost constant over the entire test concentration range. The $x \sim 0.2\text{--}0.25$ strontium concentration solid solutions exhibit a dramatic decrease in the lattice parameters of both phases and lower structural distortions in the rhombohedral phase (the c/a unit cell parameter ratio, see Fig. 1). The anomalous change in the structure and the significant change in the volume fractions of the coexisting phases for the $x \sim 0.2$ compositions lead to respective changes in the electrical transport and dielectric properties of the ceramics, which are discussed later. Further chemical substitution completes the structural transformation to the cubic phase, as indicated by the evolution of the reflections originating

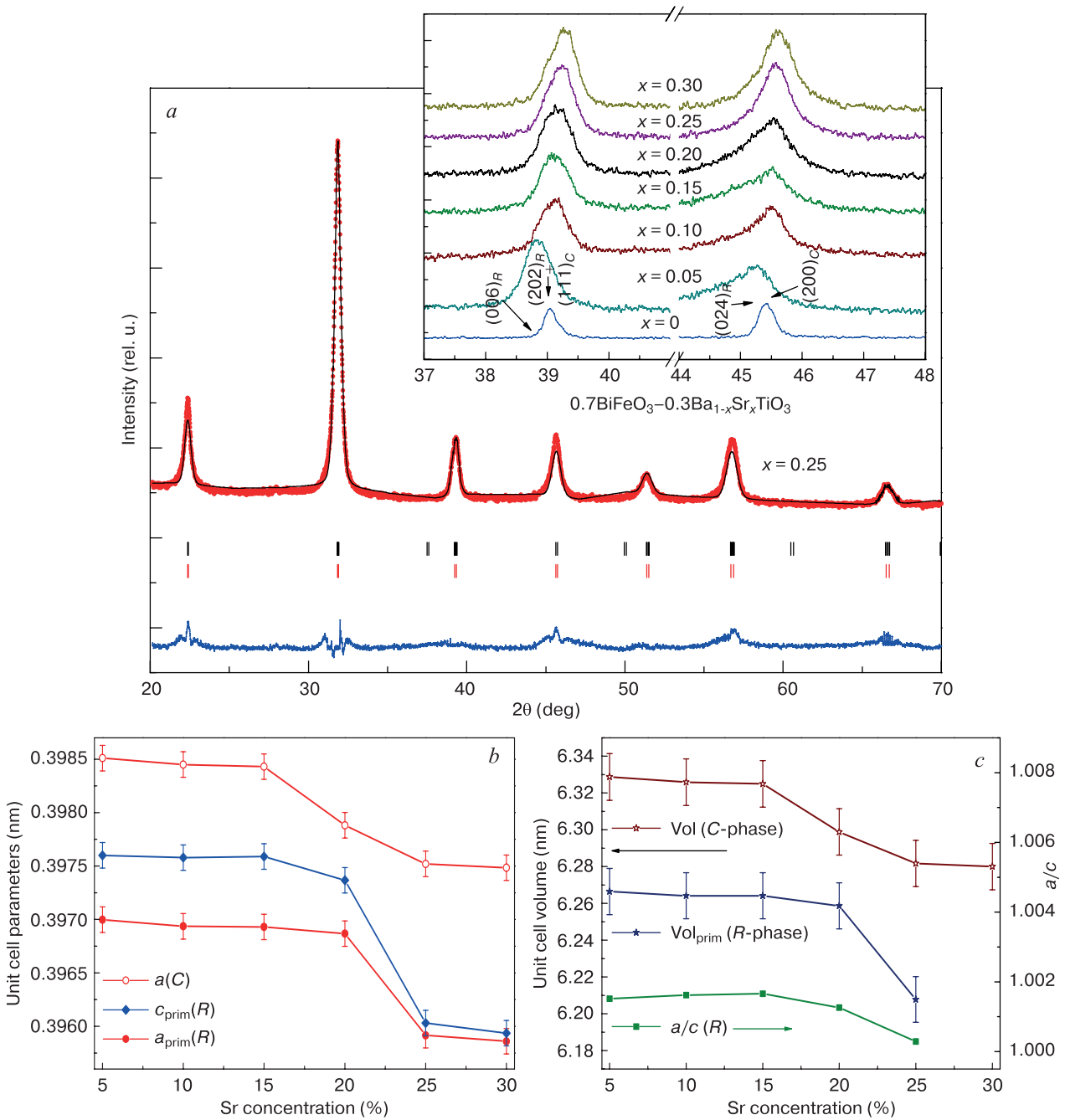


Figure 1. (a) X-ray diffraction patterns of $0.7\text{BiFeO}_3-0.3\text{Ba}_{0.75}\text{Sr}_{0.25}\text{TiO}_3$ solid solutions and (b) parameters and (c) volume of unit cell as a function of strontium ion concentration. Inset: cubic and rhombohedral phase reflections of $0.7\text{BiFeO}_3-0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions with $x = 0-0.30$

from distortions of the oxygen octahedrons (see Fig. 1). The structural state of the $x > 0.25$ solid solutions is virtually single-phase with a cubic unit cell.

The X-ray diffraction patterns of the $x \geq 0.25$ solid solutions show asymmetric profiles of some reflections (see Inset, Fig. 1a), potentially indicating a locally inhomogeneous structure of the solid solution. X-ray diffraction studies show that these solid solutions are single-phase and have a cubic unit cell. The $0.7\text{BiFeO}_3-0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions in the experimental $0 \leq x \leq 0.3$ concentration range represent a continuous series, as confirmed by the monotonic change in the unit

cell volumes of the coexisting phases. Noteworthy, the unit cell volume of the cubic phase is greater than that of the rhombohedral phase. The difference in the unit cell volumes of the coexisting phases cannot be caused by the large (above 3–5 %) inhomogeneity in the chemical composition of the material due to any inhomogeneity in the barium or strontium ion distributions in either of the phases, which agrees with energy dispersive X-ray spectroscopy data. One should also bear in mind that the difference in the unit cell volumes of the phases decreases with an increase in the strontium ion concentration. In bismuth ferrite based systems, the cubic phase is typically

stabilized with an increase in the unit cell volume due to chemical substitution or an increase in temperature, as was observed for the basic $\text{BiFeO}_3\text{--BaTiO}_3$ solid solution system [7, 9, 13–15]. Thus, the difference in the unit cell volumes of the coexisting phases originates from the closer packing of the rhombohedral phase. The structural distortions in this phase decrease with a decrease in the unit cell volume, this structural behavior being unusual for bismuth ferrite based systems [16, 17].

3.2. Morphology and chemical composition of $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions

The microstructure of the solid solutions was studied using scanning electron microscopy (SEM). SEM images of the $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions are shown in Fig. 2. The sizes and shapes of the grains depend but slightly on strontium ion concentration, and all the solid solutions contain agglomerated particles with linear sizes of 2–5 μm consisting of rounded grains typically sized 0.2–0.4 μm .

At a substituting ion concentration of above 15%, the number of agglomerated particles decreases, probably due to a more homogeneous chemical composition and hence a more homogeneous particle morphology, leading, in turn, to greater particle mobility during synthesis, as shown earlier [18]. An increase in the strontium ion concentration also slightly reduces the average grain size from ~ 0.6 μm for $x = 0.05$ to ~ 0.5 μm for $x = 0.3$, leading to a lower porosity of the ceramics and a lower electrical conductivity of the solid solutions. The shape of the

grains is virtually insensitive to the chemical composition and structural state of the specimens, and hence one cannot attribute grains to specific phases in the two-phase solid solutions.

Energy dispersive X-ray spectroscopy (EDS) data suggest the following 1) the chemical composition of the $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions is consistent with the claimed chemical formulas; 2) the material contains no impurities; 3) with an increase in the strontium ion concentration, the contents of the chemical elements are consistent with the suggested chemical substitution scheme; 4) the oxygen concentration remains close to the stoichiometric composition. The EDS-estimated chemical element ratios for several grains in different areas of the specimens indicate but minor differences in the chemical composition. For two-phase solid solutions, the variation of the chemical element concentrations is within 2–5% at different points of discrete grains and over the specimen surfaces. This indicates high chemical homogeneity of the test solid solutions. Thus, analysis of the morphology and chemical composition of different grains does not allow attributing them to specific phases (rhombohedral or cubic), the coexistence of which was confirmed by X-ray diffraction.

3.3. Raman structural studies of $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions

The Raman spectra of the solid solutions indicate the presence of active Raman phonon modes consistent with the rhombohedral distortions typical of the basic

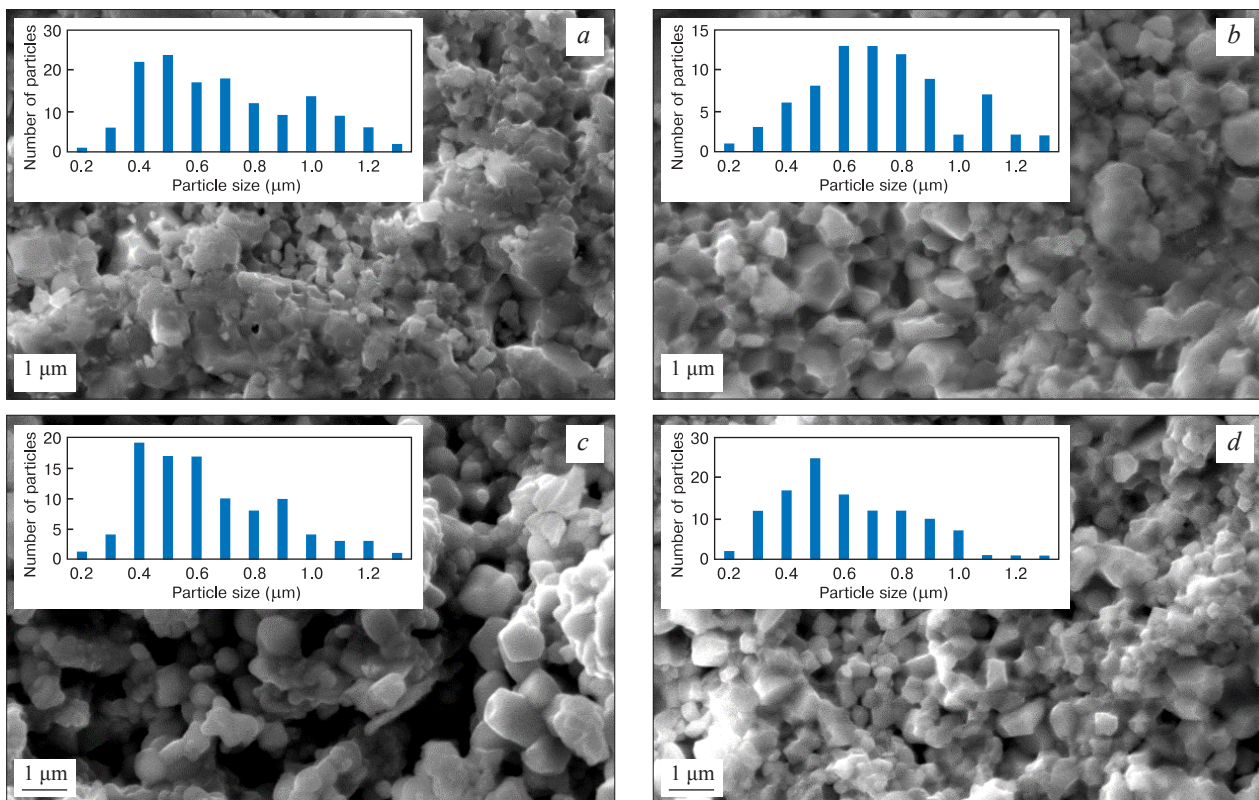


Figure 2. SEM images of $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions: (a) $x = 0.05$; (b) $x = 0.15$; (c) $x = 0.20$; (d) $x = 0.30$

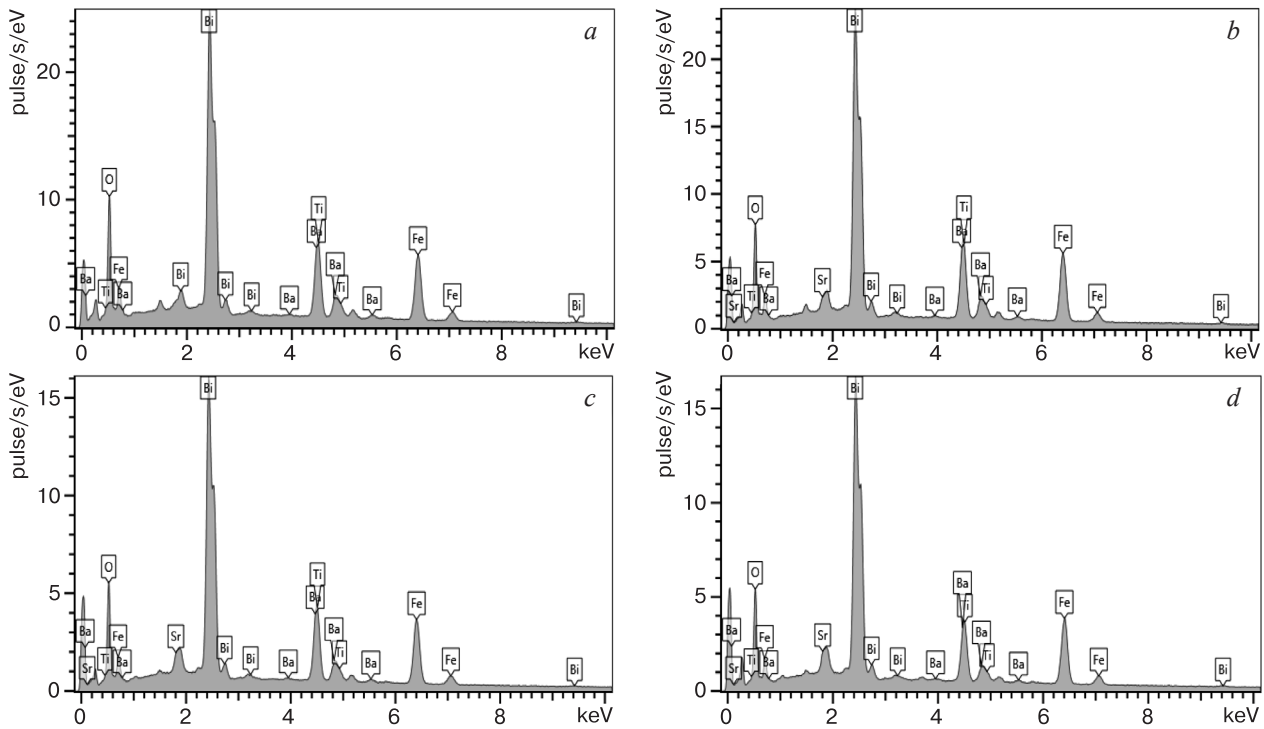


Figure 3. EDS spectra of $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions: (a) $x = 0.05$; (b) $x = 0.15$; (c) $x = 0.20$; (d) $x = 0.30$

BiFeO_3 composition [19, 20]. According to theoretical group analysis, there are $\Gamma_{R3c} = 4A1 + 9E = 13$ active Raman modes for the $R3c$ space group, but the modes observed are broadened due to the combined structural state of the ceramics, thus complicating structural analysis. The low-frequency $\sim 70\text{ cm}^{-1}$ and $\sim 135\text{ cm}^{-1}$ modes (the $E(1)$ и $E(2\text{TO})$ doublets, respectively) are typical of rhombohedral distortions and originate from the polar oscillations of bismuth ions in the oxygen polyhedrons. The intensity of the $E(2\text{TO})$ mode decreases with an increase in the strontium ion concentration, and the mode profile becomes more broadened, confirming lower rhombohedral distortions suggested by X-ray diffraction data. The $\sim 135\text{ cm}^{-1}$ phonon mode pertaining to bismuth (barium, strontium) ion oscillations is slightly shifted towards higher frequencies with an increase in the strontium ion concentration, due to a decrease in the effective mass of ions in the A-sublattice of Perovskite and a decrease in the lattice parameters of the unit cell. The mode frequencies typical of iron and titanium ion oscillations ($\sim 270\text{ cm}^{-1}$, 515 cm^{-1} and 650 cm^{-1}) remain almost the same with an increase in the strontium ion concentration, confirming the consistence of the structure of the solid solutions with the chemical formula describing strontium ion occupation of the A-sites in the Perovskite structure (Wyckoff position – $6a(0,0,z)$), in which the bismuth and barium ions are located.

The rise of the spectral background at above 800 cm^{-1} is likely to originate from oscillations of light oxygen anions, as well as two- and multiple-phonon scattering processes, the high-frequency mode intensity decreasing with an increase in the strontium ion concentration. Noteworthy, all the modes observed in the spectrum are

broadened. For the $x = 0.3$ solid solution, the phonon modes are also broadened, probably due to nanosized rhombohedral phase inclusions. The presence of broadened active modes in the Raman spectra of the solid solution specimens for all the experimental compositions indicates that polar structural distortions typical of the $R3c$ space group are retained in all the solid solutions studied, including the cubic ones with $x \geq 0.25$, as per X-ray diffraction. It is most likely that the solid solutions of this composition contain the rhombohedral phase in the form of nanosized clusters which are not detectable by X-ray diffraction. At above 670 K , the $\sim 135\text{ cm}^{-1}$ active mode which is typical of rhombohedral inclusions disappears, suggesting a structural transition to a single-phase state in all the test solid solutions.

3.4. Thermogravimetric studies and differential thermal analysis

Thermogravimetric (TG) studies and differential thermal analysis (DTA) allowed assessing the thermal stability of the structure and phase composition of the solid solutions. The thermogravimetric data provided a more accurate assessment of changes in the phase ratio depending on the chemical composition and temperature. The DTA curve for the $x = 0.05$ solid solution contains a strong anomalous feature at $\sim 570\text{ K}$ (Fig. 5). Noteworthy, our earlier X-ray diffraction data [14] showed that the basic $0.7\text{BiFeO}_3\text{--}0.3\text{BaTiO}_3$ solid solution undergoes a cubic transition at $\sim 570\text{--}720\text{ K}$. Thus, the thermal anomalous feature in the DTA curve for the $x = 0.05$ solid solution, most likely, marks a transition to a single-phase cubic state. For the $x = 0.15$ solid solution, a similar thermal

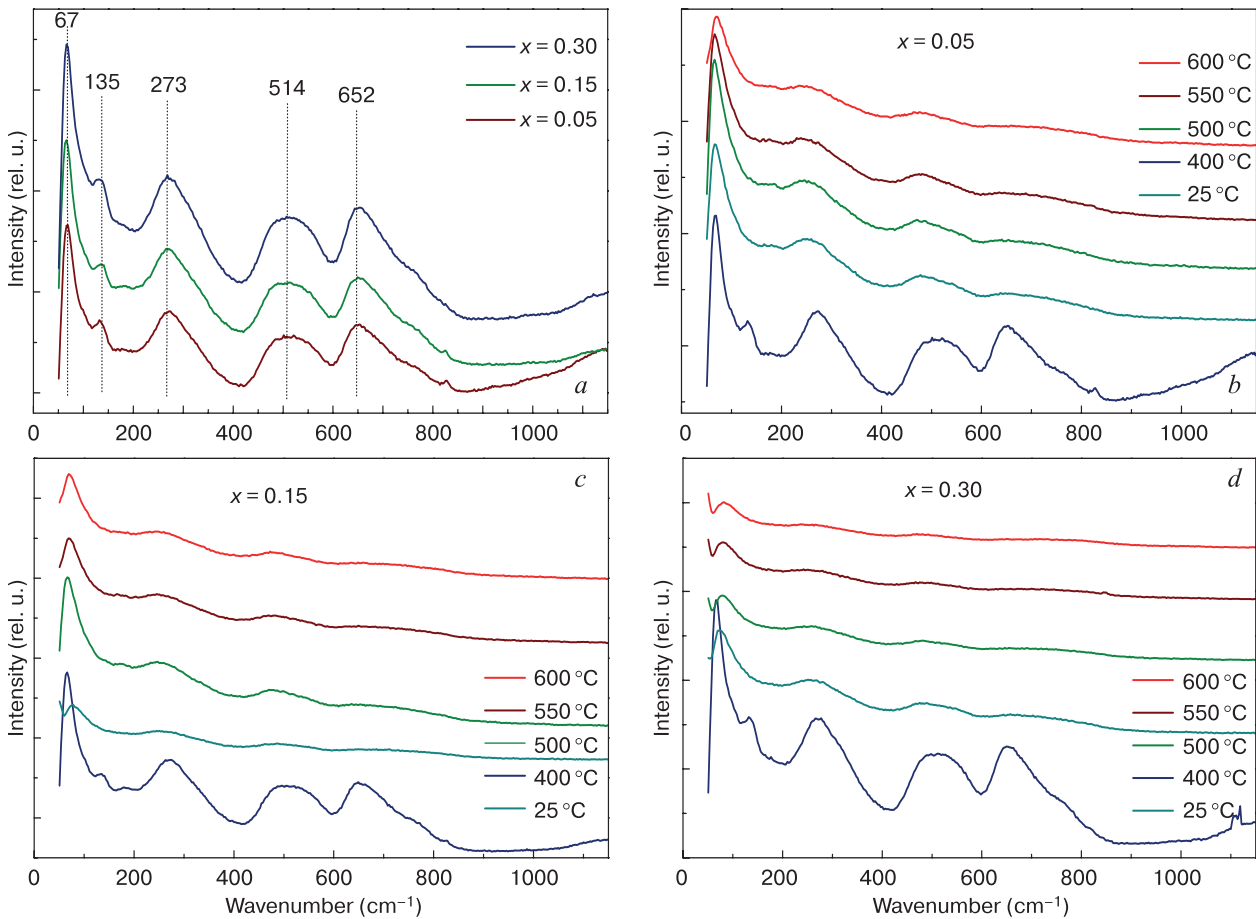


Figure 4. Raman spectra of $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions (a) at room temperature and (b–d) at 300–900 K

anomalous feature occurs at ~ 580 K, also indicating a cubic transition. The DTA curve for the $x = 0.30$ solid solution does not contain the above anomalous feature in the $\sim 470\text{--}770$ K range, due to the phase composition of this solid solution, which, according to the X-ray diffraction data, is single-phase pseudo-cubic. These results are in agreement with X-ray diffraction data and provide additional information on the solid solutions in the 300–870 K range.

3.5. Dielectric properties of $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions

Figure 6 shows the real part of the dielectric permeability and dielectric loss for the solid solutions with $x = 0.05$, 0.15 , and 0.30 as a function of temperature for a wide range of temperatures and frequencies. At below ~ 500 K, the dielectric response of all the test compositions is controlled by the dynamics of the ferroelectric domains detected by X-ray diffraction and Raman scattering. Above ~ 500 K, the relative dielectric permeability grows tangibly for all the experimental compositions. This sharp growth of the relative dielectric permeability at above 500 K is caused by an increase in the electrical conductivity of the solid solutions due to the thermal activation of defect mobility, this effect being the strongest at below 10^4 Hz. The difference in the dielectric permeabilities of the solid

solutions at low (below 10^3 Hz) and high frequencies can be as large as one order of magnitude, which is also caused by the high electrical conductivity of the solid solutions. The dielectric signal vs temperature functions of the solid solutions contain broad peaks (more than 200 K), indicating thermal evolution of the dielectric permeability in relaxor ferroelectrics and agreeing with the two-phase structural model of the test solid solutions. This process

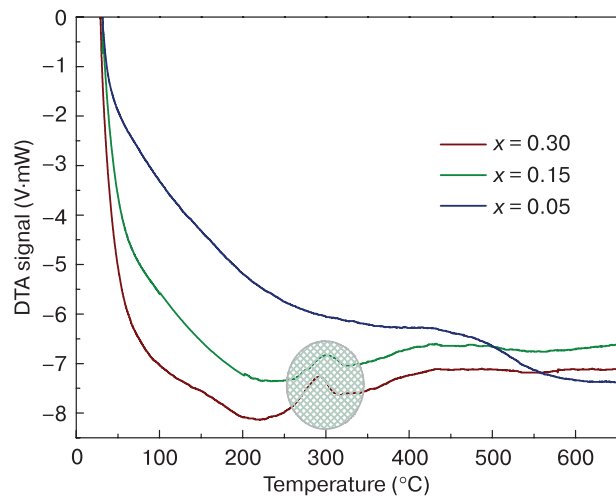


Figure 5. DTA/TG signal as a function of temperature for $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions with $x = 0.05$, 0.15 , and 0.30 in the 300–870 K range

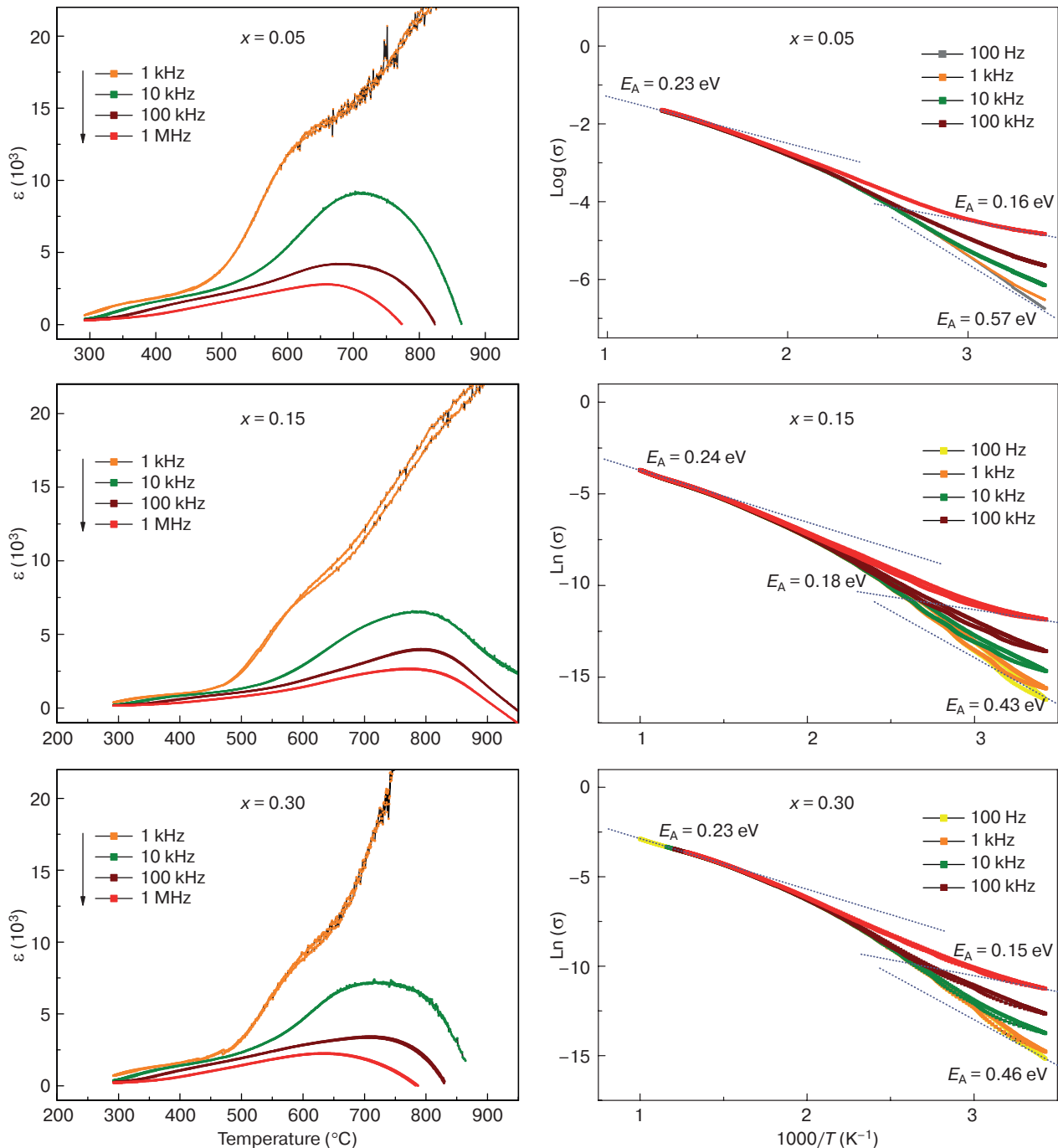


Figure 6. Real part of dielectric permeability and electrical conductivity of $0.7\text{BiFeO}_3\text{--}0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions with $x = 0.25, 0.5, 0.75$ and 1.0 as a function of temperature in $300\text{--}900\text{ K}$ range at stable frequencies in $10^2\text{--}10^6\text{ Hz}$ range

involves charge accumulation at the boundaries of grains pertaining to different phases. The decrease in the dielectric permeability peak temperature with an increase in frequency also testifies to chemical inhomogeneity of the solid solutions. It should be noted that the dielectric permeability peak temperature varies irregularly with an increase in the strontium ion concentration. The dielectric permeability peak temperature is the highest for the $x = 0.15$ solid solution, regardless of frequency. The slight increase in the dielectric permeability peak temperature for the $x = 0.15$ solid solution is likely to stem from stronger rhombohedral distortions. This anomalous

feature was earlier observed for $\text{Bi}_{1-x}\text{Ba}_x\text{Fe}_{1-x}\text{Ti}_x\text{O}_3$ two-phase compositions with an increase in temperature [7, 14], which is consistent with the thermal Raman scattering data.

Figure 6 shows electrical conductivity of experimental compositions as a function of temperature for $100\text{ Hz} - 1\text{ MHz}$ range. The data indicate a semiconductor conductivity type over the whole experimental temperature range. Analysis of the electrical conductivity curves suggests a slight decrease in the conductivity of the solid solutions due to strontium ion substitution. The electrical conductivity of the $x = 0.15$ solid solution is

the lowest among all the test compositions over the entire temperature and frequency ranges. The conductivity type of the solid solutions at below ~ 500 K is largely frequency-controlled. For example, the difference in the room-temperature electrical conductivities of the solid solutions at 100 Hz and 100 kHz can be as large as three orders of magnitude. The frequency dependence of the electrical conductivity originates from the hopping electronic conductivity mechanism, which is further confirmed by the low estimated activation energy for the compositions, i.e., ~ 0.2 – 0.6 eV. The conductivity type of the test compositions is most likely controlled by electron hopping between different-valence $\text{Fe}^{3+}/\text{Fe}^{2+}$ and Ti^{4+} ions. Oxygen vacancies significantly increase the electrical conductivity. The decrease in the activation energy with an increase in the applied field frequency is consistent with a model according to which the surface layer of grains containing a large number of structural defects accounts for the greatest contribution to the conductivity of the compositions, this effect becoming the most noticeable at high frequencies. At above ~ 500 K, the conductivity of the compositions is not frequency-sensitive. At higher temperatures, the growth of the conductivity is decelerated, and the carrier activation energy decreases to $E_A \sim 0.24$ eV, becoming almost insensitive to the chemical composition of the test solid solutions (see Fig. 6). Note that the room-temperature conductivity of the solid solutions is almost insensitive to their structural state, and at above 670 K the structure of all the test solid solutions is single-phase cubic, their conductivity also being virtually insensitive to the chemical composition.

Acknowledgments

The work was carried out with support from the Russian Science Foundation (No. 23-19-00347); electron mi-

4. Conclusion

The structure and electrical properties of 0.7BiFeO_3 – $0.3\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ solid solutions with compositions in the vicinity of the rhombohedron-cube morphotropic phase boundary ($x \leq 0.3$) were studied using microscopic and local methods. Substitution of barium ions for strontium ones reduces the content of the rhombohedral phase from $\sim 50\%$ in the initial 0.7BiFeO_3 – 0.3BaTiO_3 solid solution to $\sim 100\%$ in the $x \approx 0.25$ solid solution. Further increase in the strontium ion concentration stabilizes the single-phase cubic state. According to X-ray diffraction with Raman data confirmation, the single-phase solid solutions contain nanosized clusters with rhombohedral distortions. All the solid solutions transit to single-phase cubic state with an increase in temperature. Near the cubic transition point, the $x = 0.15$ solid solution has the greatest rhombohedral distortions which shift the dielectric response peak towards higher temperatures. The dielectric signal vs temperature curves of the solid solutions indicate the formation of relaxor ferroelectrics, in agreement with the two-phase structure of the solid solutions. The electrical conductivity of the experimental solid solutions is virtually insensitive to their structural state, the conductivity mechanism being electron hopping between adjacent transition metal ions and oxygen vacancies.

croscopy and Raman experiments were conducted with support from the Belarusian Republican Foundation for Fundamental Research.

References

1. Blaauw C., van der Woude F. Magnetic and structural properties of BiFeO_3 . *Journal of Physics C: Solid State Physics*. 1973; 6(8): 1422. <http://doi.org/10.1088/0022-3719/6/8/009>
2. Lebeugle D., Colson D., Forget A., Viret M., Bonville P., Marucco J. F., Fusil S., Room-temperature coexistence of large electric polarization and magnetic order in BiFeO_3 single crystals. *Physical Review B: Condensed Matter*. 2007; 76: 024116. <https://doi.org/10.1103/PhysRevB.76.024116>
3. Xu B., Dupé B., Xu C., Xiang H., Bellaiche L. Revisiting spin cycloids in multiferroic BiFeO_3 . *Physical Review B: Condensed Matter*. 2018; 98: 184420. <https://doi.org/10.1103/PhysRevB.98.184420>
4. Karpinsky D.V., Silibin M.V., Trukhanov A.V., Zhaludkevich A.L., Latushka S.I., Zhaludkevich D.V., Sikolenko V., Khomchenko V.A. Evolution of crystal structure of Ba and Ti co-doped BiFeO_3 ceramics at the morphotropic phase boundary. *Journal of Alloys and Compounds*. 2019; 803: 1136–1140. <https://doi.org/10.1016/j.jallcom.2019.06.145>
5. Khomchenko V.A., Karpinsky D.V., Paixão J.A. Magnetostructural correlations in BiFeO_3 -based multiferroics. *Journal of Materials Chemistry C*. 2017; 5(14): 3623–3629. <https://doi.org/10.1039/C7TC00833C>
6. Singh J., Singh C., Kaur D., Narang S.B., Jotania R.B., Kaggi A., Joshi R., Bezerra A.S., Zhou Di, Trukhanov S., Panina L., Trukhanov A. Optimization of performance parameters of doped ferrite-based microwave absorbers: their structural, tunable reflection loss, bandwidth, and input impedance characteristics. *IEEE Transactions on Magnetism*. 2021; 57(7): 2800619. <https://doi.org/10.1109/TMAG.2021.3063175>
7. Pakalniškis A., Lukowiak A., Niaura G., Gluchowski P., Karpinsky D.V., Alkin D.O., Abramov A.S., Zhaludkevich A., Silibin M., Kholkin A.L., Skaudžius R., Strek W., Kareiva A. Nanoscale ferroelectricity in pseudo-cubic sol-gel derived barium titanate – bismuth ferrite (BaTiO_3 – BiFeO_3) solid solutions. *Journal of Alloys*

- and Compounds. 2020; 830: 154632. <https://doi.org/10.1016/j.jallcom.2020.154632>
8. Abramov A.S., Alikin D.O., Neradovskiy M.M., Turygin A.P., Ushakov A.D., Rokeah R.O., Nikitin A.V., Karpinsky D.V., Shur V.Ya., Kholkin A.L. Local electromechanical characterization of Pr doped BiFeO₃ ceramics. *Ferroelectrics*. 2018; 525(1): 64–75. <https://doi.org/10.1080/00150193.2018.1432930>
 9. Fan T., Ji C., Chen G., Cai W., Gao R., Deng X., Wang Z., Fu C. Enhanced the dielectric relaxation characteristics of BaTiO₃ ceramic doped by BiFeO₃ and synthesized by the microwave sintering method. *Materials Chemistry and Physics*. 2020; 250: 123034. <https://doi.org/10.1016/j.matchemphys.2020.123034>
 10. Ji C., Fan T., Chen G., Bai X., Wang J., He J., Cai W., Gao R., Deng X., Wang Z., Lei X., Fu C. Influence of sintering method on microstructure, electrical and magnetic properties of BiFeO₃–BaTiO₃ solid solution ceramics. *Materials Today Chemistry*. 2021; 20: 100419. <https://doi.org/10.1016/j.mtchem.2020.100419>
 11. Abramov A.S., Alikin D.O., Yuzhakov V.V., Nikitin A.V., Latushko S.I., Karpinsky D.V., Shur V.Y., Kholkin A.L. Indentation induced local polarization reversal in La doped BiFeO₃ ceramics. *Ferroelectrics*. 2019; 541(1): 1–9. <https://doi.org/10.1080/00150193.2019.1574634>
 12. Rietveld H.M. A profile refinement method for nuclear and magnetic structures. *Journal of Applied Crystallography*. 1969; 2: 65–71. <https://doi.org/10.1107/S0021889869006558>
 13. Futakuchi T., Kakuda T., Sakai Y. Multiferroic properties of BiFeO₃–BaTiO₃ based ceramics. *Journal of the Ceramic Society of Japan*. 2014; 122(1426): 464–468. <https://doi.org/10.2109/jcersj2.122.464>
 14. Karpinsky D.V., Silibin M.V., Trukhanov S.V., Trukhanov A.V., Zhaludkevich A.L., Latushka S.I., Zhaludkevich D.V., Khomchenko V.A., Alikin D.O., Abramov A.S., Maniecki T., Maniukiewicz W., Wolff M., Heitmann V., Kholkin A.L. Peculiarities of the crystal structure evolution of BiFeO₃–BaTiO₃ ceramics across structural phase transitions. *Nanomaterials*. 2020; 10(4): 801. <https://doi.org/10.3390/nano10040801>
 15. Karpinsky D.V., Silibin M.V., Zhaludkevich D.V., Latushka S.I., Sysa A.V., Sikolenko V.V., Zhaludkevich A.L., Khomchenko V.A., Franz A., Mazeika K., Baltrunas D., Kareiva A. Magnetic properties of BiFeO₃ – BaTiO₃ ceramics in the morphotropic phase boundary: A role of crystal structure and structural parameters. *Journal of Magnetism and Magnetic Materials*. 2021; 539: 168409. <https://doi.org/10.1016/j.jmmm.2021.168409>
 16. Palai R., Katiyar R.S., Schmid H., Tissot P., Clark S.J., Robertson J., Redfern S.A.T., Catalan G., Scott J.F. β -phase and γ - β metal-insulator transition in multiferroic BiFeO₃, *Physical Review B: Condensed Matter*. 2008; 77, 014110. <https://doi.org/10.1103/PhysRevB.77.014110>
 17. Fox A.J., Drawl B., Fox G.R., Gibbons B.J., Trolier-McKinstry S. Control of crystallographic texture and surface morphology of Pt/TiO₂ templates for enhanced PZT thin film texture. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*. 2015; 62(1): 56–61. <https://doi.org/10.1109/TUFFC.2014.006671>
 18. Wang C., Chen S.-H. Factors influencing particle agglomeration during solid-state sintering. *Acta Mechanica Sinica*. 2012; 28(3): 711–719. <https://doi.org/10.1007/s10409-012-0029-3>
 19. Bielecki J., Svedlindh P., Tibebe D.T., Cai S., Eriksson S.-G., Börjesson L., Knee C.S. Structural and magnetic properties of iso-valently substituted multiferroic BiFeO₃: insights from Raman spectroscopy. *Physical Review B: Condensed Matter*. 2012; 86, 184422. <https://doi.org/10.1103/PhysRevB.86.184422>
 20. Li C., Zheng T., Wu J. Competitive mechanism of temperature-dependent electrical properties in BiFeO₃–BaTiO₃ ferroelectrics controlled by domain evolution. *Acta Materialia*. 2021; 206, 116601. <https://doi.org/10.1016/j.actamat.2020.116601>