Advances and Applications in Electroceramics

Edited by
K. M. Nair
Quanxi Jia
Shashank Priya

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New areas of materials technology development and product innovation have been extraordinary during the last few decades. Our understanding of science and technology of the electronic materials played a major role in meeting the social needs by developing innovative devices for automotive, telecommunications, military and medical applications. There is continued growth in this area and electronic technology development has enormous potential for evolving societal needs. Rising demands will lead to development of novel ceramics materials which will further the market for consumer applications. Miniaturization of electronic devices and improved system properties will continue during this decade to satisfy the requirements in the area of medical implant devices, telecommunications and automotive markets. Cost-effective manufacturing should be the new area of interest due to the high growth of market in countries like China and India. Scientific societies should play a major role for development of new manufacturing technology by working together with international counterparts.

The Materials societies understand their social responsibility. For the last many years, The American Ceramic Society has organized several international symposia covering many aspects of the advanced electronic material systems by bringing together leading researchers and practitioners of electronics industry, university and national laboratories. Further, The American Ceramic Society has been aggressive in knowledge dissemination by publishing the proceedings of the conferences in the Ceramic Transactions series, a leading up-to-date materials publication, and posting news releases on its website.

This volume contains a collection of 26 papers from four symposia that were held during the 2010 Material Science and Technology Conference (MS&T’10) held at the George R. Brown Convention Center, Houston, Texas, USA, October 17-21, 2010. These symposia include: “Advanced Dielectric Materials and Electronic Devices,” “Magnetoelectric Multiferroic Thin Films and Multilayers,” “Recent Developments in High Temperature Superconductivity,” and “Multifunctional
Oxides.” MS&T’10 was jointly sponsored by The American Ceramic Society (ACerS), the Association of Iron & Steel Technology (AIST), ASM International, the Minerals, Metals & Materials Society (TMS) and the National Association of Corrosion Engineers (NACE).

We, the editors, acknowledge and appreciate the contributions of the speakers, co-organizers of the four symposia, conference session chairs, manuscript reviewers and Society officials for making this endeavor a successful one.

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Dielectric Materials
and Electronic Devices
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ABSTRACT

The optimization of grinding parameters for silicon wafers is necessary in order to maximize the reliability of electronic packages. This paper describes the work performed to simulate a back grinding process for silicon wafers using the commercial finite element code ABAQUS. The silicon wafer analyzed had a thickness of 120 μm and was mounted on a backing tape. The wafer was thinned to a thickness of 96 μm, by simulating the grinding with a diamond particle cutting through successive silicon layers. The modeled residual stresses induced in the wafer were compared with experimental data, and they were shown to agree well. A shear band of intense plastic deformation with a certain orientation angle was generated in the specimen, and the value of this angle was compared with experimental data for similar materials. The numerical model developed can be used to better understand the local conditions in wafers during this back grinding process.

INTRODUCTION

The development of electronic packages is based on strict weight and size requirements. Smaller, lighter, and higher capacity devices at low cost are what consumers demand. In order to achieve this goal, electronic packaging plays a major role in this industry. The silicon wafer thickness affects the package size, thus, the thinner the wafer the lower the overall package height. The manufacturing process of wafers faces many challenges. One of these challenges is the thinning process, which is performed during the back grinding of the wafer. Significant research efforts have been devoted to the development and improvement of this process. Most of the studies have been experimental or analytical in nature, with few analyses considering numerical simulations that studied the wafer-wheel behavior. In order to better understand the details of the wafer grinding process; a micron scale study is needed to clarify the internal stresses, strains, and deformations that take place into the wafer material while and after the grinding process.

In this paper a numerical study is performed to simulate the grinding process at the micron level in order to understand the stresses and deformations developed in the wafer during
Numerical Simulations of a Back Grinding Process for Silicon Wafers

this process\textsuperscript{5,6}. The model developed showed good correlation with the experimental data measured using Raman spectroscopy for similar silicon wafers.

NUMERICAL MODEL

The goal of this study is to simulate the back grinding process of the silicon wafer in order to be able to measure the stress field at different locations in the wafer, and to achieve a good understanding of the grinding process. The numerical simulations involved varying operating parameters affecting this manufacturing process to determine the optimum operating conditions.

To simulate the grinding process the commercial finite element software ABAQUS, Explicit was used. In the literature, there are different finite element grinding models, which can be categorized by the scale of the modeling approach as macro-scale or micro-scale models. Macro-scale models consider the overall wheel–workpiece interaction, which captures the aggregate effects of the abrasive wheel on the workpiece with no attempts to study the effect of the individual abrasive grain on the workpiece\textsuperscript{7}. The micro-scale models focus on the individual grain–workpiece interactions, which can examine the actual material removal mechanism. Thus, micro-scale models have the potential to allow the estimation of the grinding forces directly without resorting to measurements or empirical modeling. This model simulates the micro-scale grinding process, which includes the effect of a single diamond crystal (abrasive grain) while it removes layers from the silicon wafer (workpiece) as shown in figure 1.

A two-dimensional model was built to simulate a part of the silicon wafer and a small particle of diamond which moves and cuts through successive silicon layers. In the present simulations, the number of the cutting passes was chosen as 12. The cutting depth of each pass was set at 2 μm, where we found a realistic cutting depth for the grinding process. After the
Numerical Simulations of a Back Grinding Process for Silicon Wafers

Completion of the 12 cutting passes the model was allowed a relaxation time. The model considers only a part of the silicon wafer which is completely attached to a plastic backing film Poly Ethylene Terephthalate (PET) as shown in figure 2.

![Figure 2. Finite element model used to simulate the micro-scale grinding.](image)

The back grinding process of the silicon wafers is performed in three steps. First is the coarse grinding, the second step is the intermediate grinding, which involves the thinning of the wafer to a thickness of approximately 85 μm. This step is the focus of our study. The third and final step is the fine grinding, when the wafer thickness is reduced to the desired value.

The boundary conditions shown in figure 2 were set as:

1) The bottom of the model is pinned to simulate the attachment to the vacuum chuck.
2) The sides of the model are symmetry boundary conditions along the X-axis to simulate the effect of the remaining parts of the wafer and the adhesive tape on each side which have not been included in the model.
3) The diamond crystal was displaced in the X direction to simulate the cutting action and returning back, and was displaced in the Y direction to simulate the cutting depth.

An initial mesh with a global element size of 5 μm was used for both the silicon and PET material. The mesh was further refined to a global element size of 1 μm. Finally, a more refined mesh of 0.5 μm global element size was used for the silicon wafer, and a mesh with a larger element size of 20 μm was used for the PET adhesive tape. This mesh size was used to extract the data presented in this paper.

The model consists of two materials, silicon as the wafer and PET as the backing tape materials. Silicon <100> single crystal at room temperature is a hard and brittle material. As the working temperature is kept at 23 °C by the effect of the coolant during the grinding process, the stress-strain curve for the silicon at 25 °C was used to model the material behavior as elastic-plastic with a damage criterion. A damage criterion and an element deletion scheme have been used to simulate the material removal during grinding.

ELASTIC-PLASTIC AND DAMAGE MODEL

Because of the crystalline nature of the silicon <100>, orthotropic elasticity was chosen to model the elasticity of the material. Linear elasticity in an orthotropic material can be defined by nine independent elastic stiffness parameters. These parameters can be functions of temperature and other predefined fields, such as the strain rate. In our model there is no effect of the temperature due to the cooling process that maintain the wafer at 23°C, and the model is not
Numerical Simulations of a Back Grinding Process for Silicon Wafers

strain rate dependent. In this case the stress (σ)-strain (ε) relations take the form shown in equation 1, with the constants $D_{ij}$ shown in table I.

$$
\begin{bmatrix}
\sigma_{11} \\
\sigma_{22} \\
\sigma_{33} \\
\sigma_{12} \\
\sigma_{13} \\
\sigma_{23}
\end{bmatrix} =
\begin{bmatrix}
D_{1111} & D_{1122} & D_{1133} & 0 & 0 & 0 \\
D_{1212} & D_{2222} & D_{2233} & 0 & 0 & 0 \\
D_{1313} & D_{2323} & D_{3333} & 0 & 0 & 0 \\
0 & 0 & 0 & D_{1212} & 0 & 0 \\
0 & 0 & 0 & 0 & D_{1313} & 0 \\
0 & 0 & 0 & 0 & 0 & D_{2323}
\end{bmatrix}
\begin{bmatrix}
e_{11} \\
e_{22} \\
e_{33} \\
\gamma_{12} \\
\gamma_{13} \\
\gamma_{23}
\end{bmatrix}
$$

(1)

An isotropic plasticity model with a von-Mises hardening criterion was used to simulate the plasticity of the silicon material. Silicon does not deform significantly in the plastic region before damage onset and fracture. The plasticity of the silicon was modeled by building the effective stress-strain curve using the data from table 2.

<table>
<thead>
<tr>
<th>Table I. $D_{ij}$ matrix constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{1111}$</td>
</tr>
<tr>
<td>$D_{1122}$</td>
</tr>
<tr>
<td>$D_{2222}$</td>
</tr>
<tr>
<td>$D_{1133}$</td>
</tr>
<tr>
<td>$D_{2233}$</td>
</tr>
<tr>
<td>$D_{3333}$</td>
</tr>
<tr>
<td>$D_{1212}$</td>
</tr>
<tr>
<td>$D_{1313}$</td>
</tr>
<tr>
<td>$D_{2323}$</td>
</tr>
</tbody>
</table>

A shear damage initiation criterion with an element deletion scheme was used to simulate the material removal that occurs due to the grinding process. The shear damage criterion predicts the onset of damage due to shear band localization, and it is used in conjunction with the von Mises plasticity model.

<table>
<thead>
<tr>
<th>Table II. Plasticity constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress MPa</td>
</tr>
<tr>
<td>1000</td>
</tr>
<tr>
<td>1100</td>
</tr>
<tr>
<td>1200</td>
</tr>
</tbody>
</table>
The shear damage criterion model assumes that the equivalent plastic strain at the onset of damage $\varepsilon_{pl}^{*}$ is a function of the shear stress ratio $\theta_s$, and strain rate $\dot{\varepsilon}$.

$$\theta_s = \frac{(q + k_s p)}{r_{max}}$$

where $r_{max}$ is the maximum shear stress, $k_s$ is a material parameter, which was set to 0.3, $q$ is the equivalent stress, and $p$ is the pressure stress. The criterion for damage initiation is met when the following condition is satisfied:

$$w_s = \int \frac{d \varepsilon_{pl}^{*}}{\varepsilon_s^{*} (\theta_s, \varepsilon)} = 1$$

where $w_s$ is a state variable that increases monotonically with the plastic deformation and is proportional to the incremental change in equivalent plastic strain. At each increment during the analysis the incremental increase in $w_s$ is computed as:

$$\Delta w_s = \frac{\Delta \varepsilon_{pl}^{*}}{\varepsilon_s^{*} (\theta_s, \varepsilon)} \geq 0$$

PET is a hyper-elastic polymeric material used as a thin layer to model the tape on which the wafer is mounted, before both wafer and tape are mounted on the vacuum chuck as one assembly. In order to simulate the behavior of this material, the Mooney-Rivlin model for hyperelastic materials was used

$$U = C_{10} (\overline{T} - 3) + C_{01} (\overline{I}_2 - 3) + \frac{1}{D_1} (J^T - 1)^2$$

where $U$ is the strain energy per unit of reference volume $C_{10}, C_{01}, D_1$ are temperature-dependent material parameters; $\overline{T}$ and $\overline{I}_2$ are the first and second deviatoric strain invariants which are defined as:

$$\overline{T} = \lambda_1^2 + \lambda_2^2 + \lambda_3^2$$

and

$$\overline{I}_2 = \lambda_1^{-2} + \lambda_2^{-2} + \lambda_3^{-2}$$

where $\lambda_1$, $\lambda_2$, and $\lambda_3$ are the three principal stretches, and $J^T$ is the elastic volume ratio, which relates the total volume ratio to the thermal volume ratio. The constant $D_1$ was set to a large number to eliminate the effect of the thermal expansion because of the effect of the cooling process. The $C_{10}, C_{01}$ constants were chosen 0.3. These values were found from literature by curve
fitting experimental data with the Mooney-Rivlin strain energy potential model used by ABAQUS\textsuperscript{12}. 

RESULTS

An intense shear deformation band was observed forming at an angle of $30^\circ$ with the surface of the specimen. A similar angle, called the shear angle ($\phi$), has been reported in the literature in reference to the machining of metals\textsuperscript{13}. Comparing the angle value that was observed in the model and the data from the literature, a similar behavior can be found as in the case of other brittle materials, as shown in figures 3 and 4. Figure 3 also shows surface elements that experienced damage on the surface after machining. The damage of the surface elements is due to intense stresses induced by the grinding operation on the surface of the specimen, which forms surface cracks and the usual surface roughness observed in real wafers. Surface cracks and roughness are removed in the fine grinding process. Figure 4 illustrates the stress distribution in the $x$-direction and the shear stress band in the model.

![Figure 3. Shear angle $\phi$ as observed in the simulation with a value of $30^\circ$.](image)

The residual stress induced in the model after grinding was investigated in two ways: first by comparing the stresses at the back of the wafer after grinding with literature data, and then by comparing the stress distribution through the depth of the wafer with experimental data.
Numerical Simulations of a Back Grinding Process for Silicon Wafers

The residual stress at the back of the wafer after grinding was found from the literature to be ranging between -100 MPa and -150 MPa \(^{14}\). This data was originally measured using Raman spectroscopy for grounded wafers. These residual stress values match the simulation results as observed in figure 5.

![Figure 4. Illustration of the stress distribution in the horizontal direction during the cutting operation and the shear stress band.](image)

The second verification of the residual stresses induced in the model was observed by comparing the simulation results of the stress distribution through the wafer cross section, at a depth of up to 20\(\mu\)m, with Raman spectroscopy data. This data obtained from the literature for

![Figure 5. Simulated stress distribution at the back of the wafer after grinding.](image)
Numerical Simulations of a Back Grinding Process for Silicon Wafers

the same type of measurement, shows a good agreement between the simulation results and the Raman spectroscopy measurement as shown in figure 6\textsuperscript{14}.

The graph shows a good agreement between the model results and the measurements at the center of the wafer for a depths greater than or equal to 4 μm. At depths less than 4 μm, there is a small discrepancy between the model and experimental results, which will be investigated in the future.

![Graph showing stress distribution comparisons between model output and Raman spectroscopy](image)

Figure 6. Stress distribution comparisons between model output and Raman spectroscopy

CONCLUSIONS

The continuing development of electronic devices leads to slim, cheap and high capacity packages. The development of such products increases the need of thinner wafers, which are achieved by optimized grinding processes. Experimental studies are expensive and can significantly increase the wafer price. In this paper we built a model that simulates the back grinding processes of a silicon wafer. The accuracy of the model was verified by measuring the shear angle in the cutting operation and comparing it with literature data. Good agreement was observed between the model results and the literature data. The residual stresses induced in the back side of the wafer after the grinding process also agreed with Raman spectroscopy data, after releasing the wafer from the vacuum chuck and the adhesive backing tape. An additional verification showed a good agreement between the stress distributions in the cross-section of the wafer that was measured by Raman spectroscopy with the model output.

The model is able to accurately simulate the back grinding process of silicon wafers, and it can be used to develop a better understanding of the parameters affecting the grinding process.
ACKNOWLEDGMENT

The authors would like to thank the Micron Foundation for their financial support of this work.

REFERENCE


ABSTRACT

Multiferroic magnetoelectric are materials that present potential applications where the ferroelectric and magnetic ordered materials have been used. Among these materials, the BiFeO₃ is a very promising candidate. Due to the difficult to synthesize this material, nanometric grains are desirables in a powder preparation route. In this sense, the sol-gel synthesis can carry out the requests above mentioned. In this work, a detailed sol-gel process to obtain the BiFeO₃ powders and ceramics was studied. A structural and a microstructural study was conducted through X-ray diffraction and scanning electron microscopy. Crystallographic parameters were refined by carrying out a Rietveld analysis. The diffraction peaks were assigned as single BiFeO₃ phase. The electron micrographs indicated no compositional fluctuations and that dense ceramics were obtained. The dielectric measurements (impedance spectroscopy) showed a transition near 300 °C. Typical BiFeO₃ saturation values and high resistivity shape curves were obtained by ferroelectric hysteresis.

INTRODUCTION

Ferroelectric materials have attracted much academic and technological attention in the last years.¹ This is because they present potential applications in those areas where (anti)ferroelectric and (anti)ferromagnetic materials are extensively employed.²,³ In this way, the electric and magnetic order parameter coupling opens the possibility of the integration between the ferroelectromagnetics physical properties through the magnetoelectric effects,⁴ and can promote interesting technological advances in many electro-electronic technologies, in spite of the open issues concerning to the origin of the ferroelectromagnetism.⁵,⁶

Due to their potential applications, the BiFeO₃ has reawakened the interest of researchers because it has electrical and magnetic properties simultaneously, i. e., the magnetoelectric properties. In fact, this compound presents ferroelectric (Tₑ ~ 830 °C) and antiferromagnetic orderings (canted weak ferromagnetism – Tₙ ~ 370 °C),⁷ which can be explored in many technological applications.

Therefore, many researchers have been developing procedures for the synthesis of the BiFeO₃ compound. These procedures involve solid state reaction and chemical routes. The main problem, frequently encountered in the synthesis of BiFeO₃, is the presence of unwanted phases such as Bi₂Fe₄O₁₁ and Bi₁₂FeO₄₀, which may be due to the time or the atmosphere of calcinations, the purity of precursors, the stoichiometry of the system, among other factors.⁸
According to the phase diagram for the Bi$_2$O$_3$-Fe$_2$O$_3$ system, proposed by Palai et al.,$^9$ single phase BiFeO$_3$ is only obtained when exactly the same equimolar proportions of Fe and Bi atoms is reached. In this phase diagram there are three possible BiFeO$_3$ states (α, β and γ states). Up to 825 °C the compound has a ferroelectric phase (α), above this temperature the compound undergoes a α - β transition (ferroelectric – paraelectric and rhombohedral – orthorhombic transitions). Above 925 °C, until 933 °C, occurs a β - γ transition corresponding to orthorhombic – cubic transition.

Among the researches that wanted to synthesize BiFeO$_3$ compounds, Fruth et al.,$^{10}$ discuss the sol-gel formation of BiFeO$_3$ and the influence of precursors and calcination conditions. The obtained material presents several unwanted phases. Palkar et al.,$^{11}$ using pulsed laser deposition, discussed the synthesis of oxygen controlled stoichiometry BiFeO$_3$ thin films. The single phase was just obtained after washing the powder with dilute nitric acid. This was also an alternative found by Kumar et al.$^{12}$ They synthesized a powder by solid state reaction and obtained the desired single phase only after washing with nitric acid. However the nitric acid washing of BiFeO$_3$ powders to remove unwanted phases provide coarser powders and the reproducibility of the process is quite poor.

Owing to the unwanted phases, it is difficult to obtain single phase BiFeO$_3$ bulk ceramics. The unwanted phases and low resistivity lies to high leakage current, which make the observation of intrinsic saturated ferroelectric hysteresis loop difficult and is an obstacle to application of BiFeO$_3$ ceramics in practical devices.$^{13-14}$ Alternative synthetic routes have been pursued to prepare single phase BiFeO$_3$ ceramics, and some saturated ferroelectric hysteresis loops have been observed in those ceramics.$^{13,14}$ High resistivity single phase BiFeO$_3$ ceramics were obtained by hot pressed sinterization, solid state reaction followed by either leaching impurity phases, rapid liquid phase sintering and high heating rate sinterization followed by rapid cooling.$^{15,11,13}$

An alternate to obtain single-phase BiFeO$_3$ ceramics with high resistivity is to synthesize the ceramics from fine (nanometric) BiFeO$_3$ powders. Sol-gel derived fine powders are usually more homogeneous and reactive than those prepared by conventional solid-state reaction since the mixing of the reagents occurs on atomic-level scale. Thus, in this paper, single phase high resistivity BiFeO$_3$ ceramics were obtained by high heating rate sinterization followed by rapid cooling from sol-gel synthesized nanometric BiFeO$_3$ powders. The structural, microstructural, and electric properties of the obtained powders and ceramics were carefully studied.

EXPERIMENTAL

The BiFeO$_3$ powders were obtained using Bi(NO$_3$)$_3$.9H$_2$O (Aldrich), Fe(NO$_3$)$_3$.9H$_2$O (Aldrich) and NH$_4$OH (Vetec). Solutions of 0.5 M Bi(NO$_3$)$_3$.9H$_2$O and 0.5 M Fe(NO$_3$)$_3$.9H$_2$O were prepared by dissolving the precursors in distilled water. To precipitate the sol-gel BiFeO$_3$ precursors, the NH$_4$OH solution was peptized from individual separator funnels into a 1:1 molar ratio Bi:Fe mixture with continuous magnetic stirring to homogenize the system. After precipitation, the precursor was filtered and the cake-like precipitate was washed with distilled water. After processing, the mixture was oven-dried at 80 °C overnight. After that, the dried powders were annealed at 700 °C, in an air atmosphere, during 1h.

Structural, microstructural and chemical studies in annealed powders were conducted through X-ray Diffraction (DRX), Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS). The XRD measurements were conducted in a Shimadzu XRD7000 diffractometer, with a Cu Kα radiation. The SEM/EDS micrographs/measurements were
Sol-Gel Processing of Single Phase BiFeO$_3$ Ceramics

obtained using a Shimadzu SuperScan SS-550 microscope. The crystal structure and the crystallographic parameters were refined through Rietveld method. As a refinement tool and reference for consultation, it was used, respectively, the FullProff software$^{16}$ and the ICDD-JCPDS database.

The BiFeO$_3$ single phase powders were isostactically cold-pressed (50 MPa) in disc format, and sintered in a high heating rate (30 °C/s) – at 850 °C during 20 minutes in air atmosphere – followed by rapid cooling. The obtained bulk ceramics were characterized by XRD, SEM/EDS, ferroelectric hysteresis loops measurements (performed in a modified Sawyer-Tower circuit), and dielectric measurements (impedance spectroscopy – 4291A Agilent impedance analyzer).

RESULTS AND DISCUSSIONS

Figure 1 shows the Rietveld refined XRD pattern for the 700 °C/1h air heat treated BiFeO$_3$ powder. The refinement assigned the pattern as being single-phase BiFeO$_3$ (R3c space group). The lattice parameters obtained from refinement are $a = 5.5771(3)$ Å and $c = 13.871(9)$ Å. In the Rietveld refinement in the sintered ceramics (not shown), a very low level (< 2%) of undesired phases takes place. The lattice parameters of the BiFeO$_3$ compound (R3c space group) are $a = 5.6112(5)$ Å and $c = 13.949 (5)$ Å.

The SEM analysis of the 700 °C/1h air heat treated BiFeO$_3$ powder (Figure 2 (a)) showed a very sharp distribution of ~200 nm in diameter spherical particles. The EDS measurements showed no compositional fluctuations, in accordance with the XRD characterization. In the BiFeO$_3$ ceramics (Figure 2 (b)), the SEM micrograph showed an anomalous grain growth with a relatively higher porosity. The relative ceramic density, obtained from the ratio between the theoretical density ($\rho_{\text{th}}$—obtained from calculated unit cell parameters) and the apparent one ($\rho_{\text{app}}$—obtained by Archimedes principium in distilled water), was calculated as being 90 %, which is an acceptable value considering the observed porosity level.

Figure 3 shows the ferroelectric hysteresis loop for BiFeO$_3$ ceramic at 100 Hz and 300 K. The ceramic present typical ferroelectric behavior with remnant polarization of 3.4 μC/cm$^2$ and coercive field of 2.09 kV/cm. This behavior can be security attributed to bulk polarization, attesting samples quality indirectly indicating their higher electrical resistivity (1 MΩ).

Focusing the dielectric behavior of the BiFeO$_3$ ceramic, the temperature dependence of the loss factor (tan δ) was collected at 100 kHz. It can be observed a transition near 300 °C besides a loss, which can be probably associated to the higher electrical conductivity, causing higher leakage current. This result corroborates with the SEM ones, where a relatively large porosity, coupled to relatively lower relative density, was observed. Because the low level of the undesired phases have been observed in sintered ceramic (XRD analysis), further experiments and investigations are necessary to reveal the origin of the high loss in the obtained ceramic, and also to synthesize BiFeO$_3$ ceramics appropriated to practical applications.

In summary, the BiFeO$_3$ multiferroic ceramic was synthesized through sol-gel powders, isostactically cold-pressed, followed by a high heating rate and rapid cooling. Even though, further investigations should be conducted to produce ceramics with characteristics interesting for practical applications.

CONCLUSIONS

In this paper were presented the results of detailed structural, microstructural, ferroelectric and dielectric studies in the BiFeO$_3$ powders and ceramics obtained from a sol-gel route with a high heating rate sintering. The samples were investigated by X-ray diffraction,
scanning electron microscopy, ferroelectric hysteresis loop measurements, and dielectric measurements (impedance spectroscopy). Analysis of the crystallographic data revealed a single-phase BiFeO\textsubscript{3} powder and a low level (< 2%) of unwanted phases in the ceramic body. Typical ferroelectric behaviour was observed in hysteresis loop measurements. The dielectric measurements (impedance spectroscopy) showed a transition near 300 °C.

Further investigations should be conducted to produce ceramics with characteristics interesting for practical applications.

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Figure 1. Rietveld refined X-ray diffraction patterns for the 700 °C/1h air heat treated BiFeO\textsubscript{3} powder.