

Contents list available at **IJND**
International Journal of Nano Dimension

Journal homepage: www.IJND.ir

Convictional hydrothermal synthesis of high-purity pseudo-cubic $\text{BaTi}_{0.99}\text{Nb}_{0.01}\text{O}_3$ nanocrystals in rotary autoclave

ABSTRACT

A. Khanfekr *
M. Tamizifar
R. Naghizadeh

*Department of Metallurgical and
Materials Engineering, Iran
University of Science and
Technology (IUST), Narmak,
Tehran, Iran.*

Received 21 May 2014
Received in revised form
23 August 2014
Accepted 28 August 2014

Nano-sized BaTiO_3 powders with particular Nb concentrations were prepared by Rotary- Hydrothermal (RH) method. Hydrothermal method was used at 180 °C for 5 hours with new Ti pressure and the teflon vessel was rotated at a speed of 160 rpm during the hydrothermal reaction. New hydrothermal method was used instead of previous solid state reaction for the system $\text{BaTiO}_3 \pm \text{Nb}_2\text{O}_3$ in high temperature to achieve nano sized particles in lower time and temperature. Synthesis with Rotary-hydrothermal has the advantages of faster crystallization, decreased crystal size, more homogenous distribution of dopants at lower temperature and time in comparison with the solid state method.

In case of the phase evolution studies the X-ray diffraction patterns (XRD) measurements and Raman spectroscopy were performed. The Transmission Electron Microscope (TEM) and the Field Emission Scanning Electron Microscopy (FE-SEM) images were taken for the detailed analysis of the grain size, surface and morphology. Synthesis of Nb doped BaTiO_3 with the Rotary- hydrothermal provided advantages of fast crystallization and decreased crystal size.

Keywords: *Ceramics; Chemical synthesis; Convictional -hydrothermal; Pseudo-Cubic; Perovskites.*

INTRODUCTION

Perovskite-type oxides have general formula as ABO_3 in which A is a rare earth or alkaline earth metal and B is a transition metal and these oxides are typically p-type semiconductors. Their composition can be varied in a wide range by partial substitution of lower valent cation in A or B site yielding additional mobile anion vacancies. Perovskite-type oxides are applied in electrochemistry[1-2], oxygen separation membranes[3], chemical sensors for the detection of humidity[4], alcohol sensors [5], gases sensors such as oxygen sensor [6], hydrocarbon sensor [7] and nitric oxide sensor [8] from three decades ago until present.

* Corresponding author:
Arsia Khanfekr
*Department of Metallurgical and
Materials Engineering, Iran
University of Science and
Technology (IUST), Narmak,
Tehran, Iran.*
Tel +989121948661
Fax +982188692396
Email khanfekr@iust.ac.ir

Owing to the strong dependence of ferroelectric properties on grain size and compositional aspects, microstructural control has become very important [9].

The understanding of the structural and physical features of the powders in terms of synthesis parameters as well as their size is essential from the practical and theoretical point of views. The use of an advanced rotary step in this work remarkably enhances the grain size distribution, particle reactivity and further sinterability of the ceramic powder. On this matter, the high mechanical energy activates chemical reactions at low temperatures [10].

In this work, we investigated the effect of the incorporating on the properties of BaTiO₃ doped with Nb with a new hydrothermal method instead of previous solid state reaction for the system BaTiO₃±Nb₂O₃ in high temperature.

EXPERIMENTAL

The RH reactions were performed using a laboratory-made rotary-heating-autoclave system with a PTFE inner vessel with controlled temperature up to the maximum of 220 °C and an auxiliary cooling/heating device is fitted to the system that enables it to operate at a fixed temperature for a long time.

Reagents of C₁₆H₃₆O₄Ti, Ba(OH)₂·8H₂O, NbCl₅ and NaOH were used as raw materials. The molar ratio of Ti/Nb was kept at 0.09/0.01. Starting materials of Ba(OH)₂·8H₂O, NbCl₅ and C₁₆H₃₆O₄Ti were mixed in distilled water respectively containing 1M NaOH at 70° C to control the pH under stirring until it turned into a homogeneous solution. The solution was transferred into a sealed PTFE autoclave followed by distilled water until the total volume reached to 100 ml, 80% of the capacity of the autoclave.

The system was heat treated at 180 °C for 5 h. The Teflon vessel was rotated at a speed of 160 rpm during the hydrothermal reaction. The resulting powders were centrifuged and washed with distilled water and finally oven dried at 85 °C for 24 h. The obtained powders were characterized by X-ray diffraction patterns (XRD) (X' Pert PRO MPD) with Cu-Kα radiation in the 2θ range from 20 to 60° and Raman spectroscopy (BRUKER/

Spectral Range 80-3500 cm⁻¹) Microstructural characterization was performed by the Field Emission Scanning Electron Microscopy (FE-SEM/MIRAI TESCAN) and Transmission Electron Microscopy (TEM, PHILIPS-EM-208).

RESULTS AND DISCUSSION

Figure 1 shows typical X-ray diffraction patterns for the nanoparticles obtained at 180 °C for 5 h. The nanoparticles were pure perovskite Nb-BaTiO₃, without some intermediate carbonate phase that usually was observed in the 2θ equals to 24°, 34° and 42° in solid state method (The XRD result compared with known standard JCPDS 01-075-2116) [11]. The presence of BaCO₃ can be ascribed either to incomplete reaction or due to the presence of carbonate in Ba alkali source or for the reaction of CO₂ in air. The Nb-BaTiO₃ sample crystallized at RH method is carbonate free indicating that Rotary hydrothermal technique was successfully used to produce a pure crystalline nanoparticle [12].

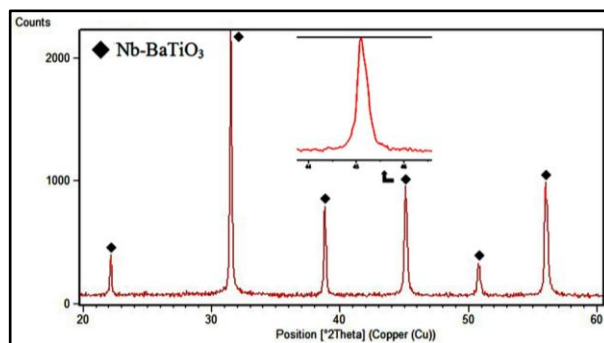


Fig. 1. X-ray diffraction pattern of Nb-BaTiO₃ nanoparticles synthesized at 180 °C for 5 h.

All samples could be ascribed as a cubic structure of Nb-BaTiO₃, no characteristic separation of the peak at 45° 2θ, which correspond with the tetragonal structure, has been found. An eventual tetragonal peak splitting of the reflections cannot be resolved due to overlapping on the (0 0 2) and (2 0 0) planes. [13, 14].

On the other hand, based on Raman studies particles were tetragonal rather than cubic for the occurrence of asymmetry of TiO₆ octahedral. The Raman spectra, for Nb-

BaTiO₃ ceramic powders samples obtained are presented in Figure 2. The peak at 518 cm⁻¹ is assigned to the TO mode of A1 symmetry, and the sharp peak at 305 cm⁻¹ is attributed to the B1 mode, which is the characteristics of tetragonal BaTiO₃. The weak peak at 715 cm⁻¹ is assigned to the highest-frequency longitudinal optical mode (LO) with A1 symmetry [15-17]. This is contrary to the XRD analysis, because XRD- peaks of the nano particles are wider than the larger one, thus the cubic structure cannot be totally excluded and often makes tetragonal peak splitting difficult to determine. An eventual tetragonal peak splitting of the reflections cannot be resolved due to overlapping of the (0 0 2) and (2 0 0) planes [18].

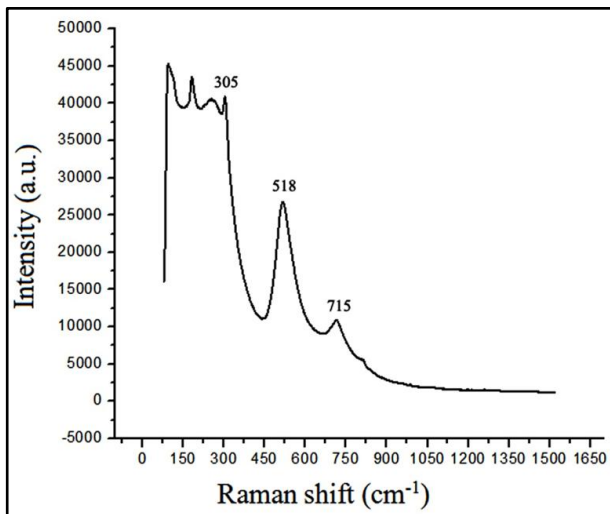


Fig. 2. Raman spectra of the hydrothermal nano-sized Nb-BaTiO₃ powders.

The Field Emission Scanning Electron Microscopy (FE-SEM) of the Nb-BaTiO₃ powders prepared are shown in Figure 3. The FE-SEM micrographs revealed a spherical morphology for the synthesized powders. Size of the particles are between 50-120 nm and the average size of powder was about 80 nm for samples prepared at 180 °C for 5 h with more uniform spherical shaped crystals. In general, with solid state method the microstructure was not uniform and consisted from region with big particles with size more then 5-6 μm and with region with fine structure with size less than 1-2 μm [19-23].

The Transmission Electron Microscope (TEM) images were taken in order to estimate the

size of the grains, also the morphology of the grains of the sample are shown in Figure 4 too. Most particles are spherical shaped crystals with an average size of 80 nm and this result is in good agreement with the XRD and FE-SEM. The decreased crystal size in RH method might be related to the increased nucleation rate and the high mechanical energy which activates chemical reactions at low temperatures.

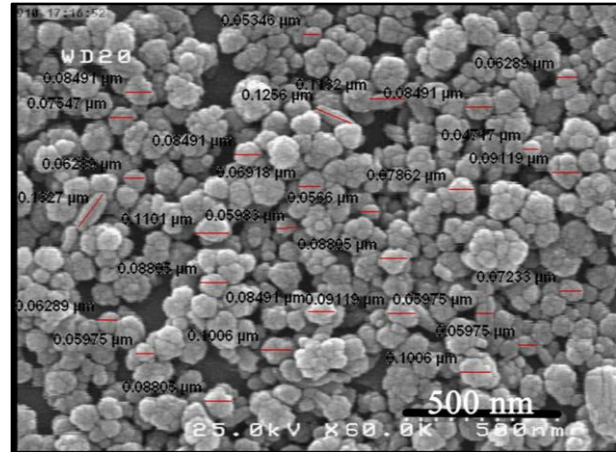


Fig. 3. Nb-BaTiO₃ powders prepared at 180 °C for 5 h.

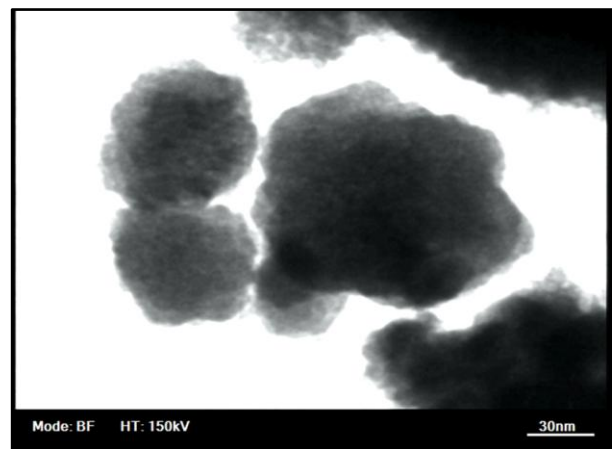


Fig. 4. TEM image of the Nb-BaTiO₃ powders.

One should notices that in solid state method a concentration gradient shell that contains most of the dopants surrounding a core are almost chemically pure ferroelectric BaTiO₃. Such a material is not in thermodynamic equilibrium and is obtained only under certain sintering conditions. Higher temperature or long sintering may promote

a more homogenous distribution of dopants to collapse of the core-shell structure [24-26]. But in this particular case, from TEM image it can be considered that samples are more homogenous with less or without any core-shell structure.

CONCLUSIONS

The present investigation shows that nano particle-sized Nb-BaTiO₃ powders can be crystallized with rapid and cost-effective Rotary-assisted hydrothermal process. Synthesis with Rotary-hydrothermal has the advantages of faster crystallization, decreased crystal size, more homogenous distribution of dopants at lower temperature and time in comparison with the solid state method.

REFERENCES

- [1] Kharton V. V., Yaremchenko A. A., Naumovich E. N., (2000), Research on the electrochemistry of oxygen ion conductors in the former Soviet Union. II. Perovskite-related oxides. *J. Solid State Electr.* 3 : 303-326.
- [2] Bi Z., Cheng M., Dong Y., Wu H., She Y., Yi B., (2005), Electrochemical evaluation of La_{0.6}Sr_{0.4}CoO₃-La_{0.45}Ce_{0.55}O₂ composite cathodes for anode-supported La_{0.45}Ce_{0.55}O₂-La_{0.9}Sr_{0.1}Ga_{0.8}Mg_{0.2}O_{2.85} bilayer electrolyte solid oxide fuel cells. *Solid State Ionics.* 176: 655-661.
- [3] Takamura H., Enomoto K., Aizumi Y., Kamegawa A., Okada M., (2004), Preparation and oxygen permeability of Pr-Al-based perovskite-type oxides. *Solid State Ionics.* 175: 379-383.
- [4] Holc J., Slunečko J., Hrovat M., (1995), Temperature characteristics of electrical properties of (Ba,Sr) TiO₃ thick film humidity sensors. *Sensors Actuat. B-Chem.* 26: 99-102.
- [5] Kong L. B., Shen Y. S., (1996), Gas-sensing property and mechanism of Ca_xLa_{1-x}FeO₃ ceramics. *Sensors Actuat. B-Chem.* 30: 217-221.
- [6] Lukaszewicz J. P., Miura N., Yamazoe N., (1990), A LaF₃- based oxygen sensor with perovskite-type oxide electrode operative at room temperature. *Sensors Actuat. B-Chem.* 1: 195-198.
- [7] Brosha E. L., Mukundan R., Brown D. R., Garzon F. H., Visser J. H., Zanini M., Zhou Z., Logothetis E. M., (2000), CO/HC sensors based on thin films of LaCoO₃ and La_{0.8}Sr_{0.2}CoO₃ metal oxides. *Sensors Actuat. B-Chem.* 69: 171-182.
- [8] Traversa E., Matsushima S., Okada G., Sadaoka Y., Sakai Y., (1995), Watanabe: NO₂ sensitive LaFe₃ thin films prepared by r. f. sputtering. *Sensors Actuat. B-Chem.* 25: 661-664.
- [9] Vijatović M. M., Bobić J. D., Stojanović B. D., (2008), History and Challenges of Barium Titanate: Part I. *Science of Sintering.* 40: 155-165.
- [10] Yuji H., Kiyoka T., Toshihiro I., Kimiysu S., Koji ., (2008), Synthesis of BaTiO₃ powders by a ball milling-assisted hydrothermal reaction. *Mater. Sci. Eng. A.* 475: 12-16.
- [11] Yuan Y., Zhang S. R., Zhou X. H., Tang B., (2009), Effects of Nb₂O₅ doping on the microstructure and the dielectric temperature characteristics of barium titanate ceramics. *J. Mater. Sci.* 44: 3751-3757.
- [12] Xiao W., Gang X., Zhaohui R., Yonggang W., Ge Sh., Gaorong H., (2008), Size-controlled synthesis of BaTiO₃ nano crystals via a hydrothermal route. *Mater. Lett.* 62: 3666-3669.
- [13] Bharat L., Newalkar S. K., Hiroaki K., (2001), Microwave-hydrothermal synthesis and characterization of barium titanate powders. *Mater. Res. Bull.* 36: 2347-2355.
- [14] Weian S., Chuiha Li., Junqin Li., Wen Li., (2006), Microwave-hydrothermal synthesis of tetragonal BaTiO₃ under various conditions. *Mater. Chem. Phys.* 97: 481-487.
- [15] A´vila H. A., Ramajo L. A., Reboredo M. M., Castro M. S., Parra R., (2011), Hydrothermal synthesis of BaTiO₃ from

- different Ti-precursors and microstructural and electrical properties of sintered samples with submicrometric grain size. *Ceram. Int.* 37: 2383-2390.
- [16] Boram M., Moon S.-M., Cho N.-H., (2011), Structural and dielectric features of Nb-doped nano-sized BaTiO₃ powders prepared by hydro-thermal synthesis methods. *Current Appl. Phys.* 11: 1-4.
- [17] Lazarevi Z., Rom-cevi N., Vijatovi M., Paunovi N., Rom-cevi M., Stojanoviand B., Doh-cevi-Mitrovi Z., (2009), Characterization of Barium Titanate Ceramic Powders by Raman Spectroscopy. *Acta Physicapolonica A.* 115: No. 4.
- [18] Weian S., Chuiha L., Junqin L., Wen L., (2006), Microwave-hydrothermal synthesis of tetragonal BaTiO₃ under various conditions. *Mater. Chem. and Phys.* 97: 481-487.
- [19] Yuan Y., Zhang S. R., Zhou X. H., Tang B., (2009), Effects of Nb₂O₅ doping on the microstructure and the dielectric temperature characteristics of barium titanate ceramics. *J. Mater. Sci.* 44: 3751-3757.
- [20] Takamura. H., Enomoto K., Aizumi Y., Kamegawa A., Okada M., (2004), Preparation and oxygen permeability of Pr-Al-based perovskite-type oxides. *Solid State Ionics.* 175: 379-383.
- [21] Brzozowski E., Castro M.S., Foschini C.R., Stojanovic B., (2002), Secondary phases in Nb-doped BaTiO₃ ceramics. *Ceram. Int.* 28: 773-777.
- [22] Kowalski K., Ijjaali M., Bak T., Dupre B., Nowotny J., Rekas M., Sorrell C. C., (2001), Electrical properties of Nb-doped BaTiO₃. *J. Phys. Chem. Solids.* 62: 543-551.
- [23] Shao Y., Maunders C., Rossouw D., Kolodiaznyi T., Botton G. A., (2010), Quantification of the Tioxidation state in BaTi_{1-x}Nb_xO₃ compounds. *Ultramicroscopy.* 110: 1014-1019.
- [24] Emmanuel A., Sandrine P., Mario M., Andreas K., (2010), Surface segregation in Nb-doped BaTiO₃ films. *Appl. Surf. Sci.* 256: 6228-6232.
- [25] Miriam S. C., Walter S., Alberto S., (2007), Electron paramagnetic resonance and positron annihilation study of the compensation mechanisms in donor-doped BaTiO₃ ceramics. *J. Phys. Chem. Solids.* 68: 1315-1323.
- [26] Bin T. , Shu-Ren Zh., Ying Y., Lin-Bo Y., Xiao-Hua Zh., (2008), Influence of tetragonality and secondary phase on the Curie temperature for barium titanate ceramics. *J. Mater. Sci. Mater. Electron.* 19: 1109-1113.

Cite this article as: A. Khanfekr et al.: Convectonal hydrothermal synthesis of high-purity pseudo-cubic BaTi_{0.09}Nb_{0.01}O₃ nanocrystals in rotary autoclave.

Int. J. Nano Dimens. 6 (3): 277-281, Summer 2015.

