



Studies on BaTiO₃ Anode Material for Intermediate Temperature Solid Oxide Fuel Cell (IT-SOFC)

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ABSTRACT

BaTiO₃ (0 ≤ x ≤ 0.5) nano crystalline powders were synthesized by Ba(NO₃)₂, TiO(NO₃)₂, and aspartic acid (fuel) in a combustion method with heating at 550 °C for 6 hours. This process remarkably reduced the synthesis time and less energy consumable to obtain BaTiO₃. The structure of BaTiO₃ nano powders were confirmed by x-ray diffraction. The average crystallite size was determined from X-ray line broadening analysis by using the scherrer equation. The surface morphology of the synthesized product was observed by SEM studies. The formation of the product BaTiO₃ was confirmed by FTIR studies. The synthesis and crystallization were followed by thermochemical techniques (TGA/DTA) studies. The synthesized materials showed reasonable electrical conductivity. These results indicate that assisted combustion method is a promising method to prepare nanocrystallite BaTiO₃ anode material for solid oxide fuel cell.

Keywords: Electrical conductivity, SEM, Schererequation, TGA & DTA, XRD and FTIR.

1. INTRODUCTION

Fuel cells are electrochemical device that converts the chemical energy of a directly into electrical energy. The electrochemical reactions take place at the electrodes to produce an electric current. Those presently under research development and demonstration generally use as fuel the H₂ and CO gas of a reformed hydrocarbon. Although the SOFC operates at a high temperature, it has several significant applications because it promises cleaner, more efficient energy conversional power plant or lower temperature polymer-based fuel cells. Targeted applications include the bottoming cycle of an electric power plant, domestic heat, power units and even electric vehicles. Stationary fuel cells are used for commercial, industrial and residential primary and backup power generation. Fuel cells are very useful as power source in remote locations, such as spacecraft remote weather stationary, large parks, communications centers, rural locations including research stations, and in certain military applications.

The anode material must be compatible (chemical and thermal expansion) with the electrolyte and provide means for transport of gas from the fuel, oxygen ions from electrolyte and electrons to the interconnect. The catalytic properties of the anode to the fuel oxidation reaction are also important, particularly as the operating temperature is decreased. The performance of a solid oxide fuel cell depends strongly on the anode structure which is mainly determined by fabrication method. In addition, electrochemical reactions are quite different from normal heterogeneous reactions in some

aspects. Therefore, it is necessary to consider how to anode work on a microscope scale. It is well known that the electrochemical reaction can only occur at the three-phase boundary, which is defined as the collection of sites where oxygen ion conductor (the electrolyte), the electron-conducting metal phase, and the gas phase all meet together.

As a fuel arriving at the anode is a reducing agent, the anode can be made of metal. However, the material must not be oxidize during operation, thus limiting the cathode metals to nickel, cobalt and the noble metals. Nickel is most often used because of its low cost compared to the others. In order to enable flow of the fuel to the electrolyte, the anode must remain porous at the elevated operating temperature. Another requirement is to sufficiently minimize the mismatch in thermal expansion between the anode and electrolyte to maintain adhesion at the interface. These two requirements are achieved by dispersing the nickel within the solid electrolyte material to form a cermet.

Fuel cell systems have the advantage of being modular and can therefore be built in a wide range of power requirements from a few hundred watts up to multi-kilowatt and megawatt sizes. This range allows the construction of highly efficient power plants at specific locations. Long term planning, based on predictions of expected increased needs, can be more flexible and the early investment in over-sized systems can be avoided. Because of their low emission level, fuel cell power plants can be installed on-site, where energy is consumed, even in densely populated areas. As a result,

power transmission lines are more economic and transmission losses are reduced.

The basic principles of a fuel cell are those of the well-known electrochemical batteries, which are involved in many activities of our everyday life. The large difference is that, in the case of batteries, the chemical energy is stored in substances located inside them. When this energy has been converted to electrical energy, the battery must be thrown away (primary batteries) or recharged appropriately (secondary batteries). In a fuel cell, the chemical energy is provided by a fuel and an oxidant stored outside the cell in which the chemical reactions take place. As long as the cell is supplied with fuel and oxidant, electrical power can be obtained.

2. EXPERIMENTAL

The following chemicals were used for the synthesis of Bariumtitanate: Barium nitrate 99.99% (Sigma-Aldrich), TitaniumDioxide 99% (Sigma-Aldrich), Aspartic acid. All the chemicals were analytical grade and used without further purifications. Deionized water was used as solvent for all the synthesis.

3. SYNTHESIS OF BaTiO₃

BaTiO₃ Powder was synthesized by assisted combustion method where 0.39 g of TiO(NO₃)₂, dissolved in 2N nitric acid and mixed with 1.30 g of Ba(NO₃)₂ and 1.10 g of Aspartic acid in a beaker. It was then heated in a heating mantle at 80 °C until gel liquid and finally foamy powder was obtained. The foamy powder was crushed and kept at 550 °C for 6 hours to get calcined powder of BaTiO₃. The yield was 90%.

The TiO(NO₃)₂ solution was prepared by following method. The 1.99 g of TiO₂ (AR grade), and 10 gram of ammonium sulphate (AR grade) were added to 80 ml of concentrated H₂SO₄ and the mixture was stirred on a hot plate until clear solution was obtained where Ti-oxo sulphate formed and then treated with ammonia at cold condition. The precipitated TiO₂.XH₂O was filtered and washed free from the sulphate solution. This was treated with cold 1:1 nitric acid to get TiO (NO₃)₂ solution.

4. CHARACTERISATION

Powder X-ray diffraction patterns were recorded in the 2θ range of 20-80° on a Philips X'pert X-ray powder diffraction using Cu Kα (λ=1.54178 Å) radiation. Thermogravimetric analysis (TGA) was performed on Mettler-Toledo (TGA/DTA) in air at a heating rate of 10 °C /min. A scanning electron microscope (SEM) (Leo series 1430 VP) equipment with INCA was used to determine the morphology of samples. The FTIR measurement was carried out using a Agilent

Cary 630 FTIR spectrometer in the range 400-4000 cm⁻¹. Thermogravimetric analysis (TGA) was performed on Mettler-Toledo (TGA/DTA) in air at heating rate of 10 °C/min.

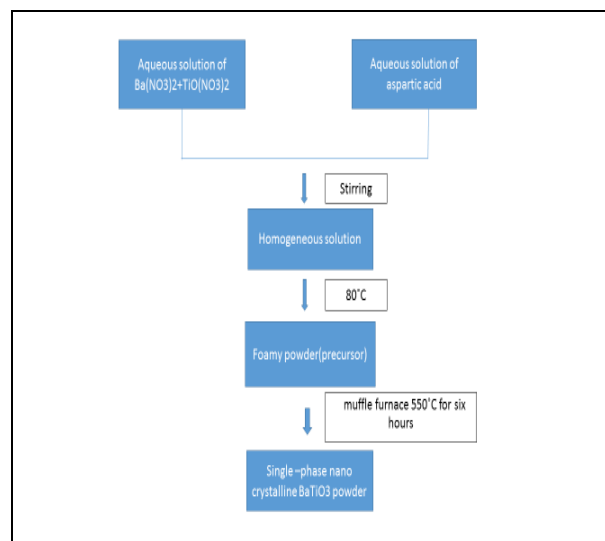


Fig. 1: Flow chart of assisted combustion synthesis of BaTiO₃

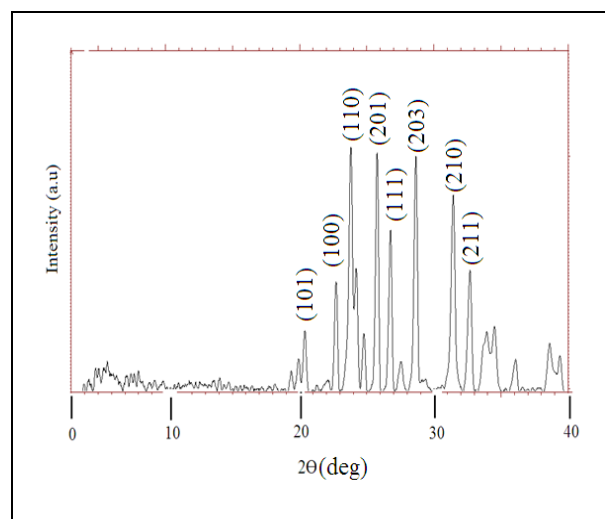


Fig. 2: X-ray diffraction pattern of BaTiO₃

5. RESULTS & DISCUSSION

5.1 X-ray Diffraction Studies

The powder XRD analysis was performed on the prepared BaTiO₃ nanocrystalline powders at 550 °C for 6 hours, significant 100, 110, 201, 111, 203, 210, and 211 planes of a cubic fluorite structure of BaTiO₃. The XRD pattern in the 2θ range of 30-40 showed presence of the (211) peak in synthesized material at low temperature. The peak broadening of an individual reflection decreases and become sharper with an increase in the reaction temperature, suggesting the increased crystallite. The average crystallite sizes of the BaTiO₃ particles

calculated from X-ray line broadening of the 110 diffraction using scherrer equation. It was in the range 3-15 nm. The crystallite size and lattice parameters calculated from XRD data. The lattice constant ($a=6.8685\text{\AA}$, $b=2.5961\text{\AA}$, and $c=3.4343\text{\AA}$) and their lattice volume [61.2381\AA^3] indicates that the BaTiO_3 belongs to orthorhombic. It is identical with the sample prepared by conventional solid state method. The crystallite size of the BaTiO_3 is 32 nm.

5.2 SEM Studies

Fig. 3 shows the microstructure of BaTiO_3 powder obtained at the 550 °C for 6 hrs. The surface morphology of material in the form of Ortho rhombic structure and agglomeration were investigated with scanning electron microscope. The particle size was distribution for BaTiO_3 powders, the average grain size was 32 nm. The particles are uniformly distributed. There is agglomeration of the particles. The particles of the synthesized products are in nano range.

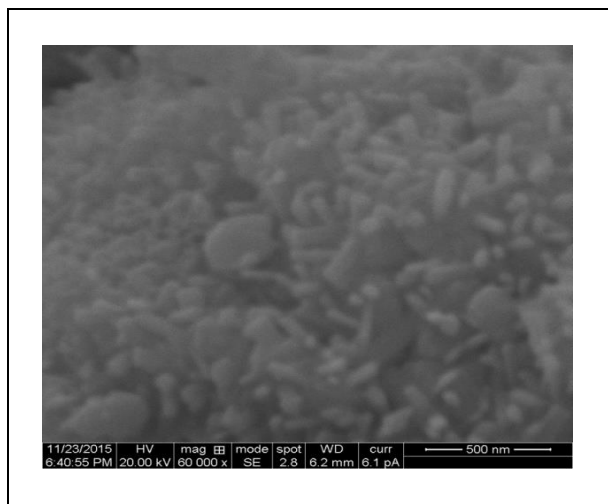


Fig. 3: SEM photograph of BaTiO_3

5.3 Particle Size Analysis

The average particle size of the prepared BaTiO_3 was calculated from X-ray line broadening analysis using Scherrer equation

$$D = 0.9\lambda/\beta\cos\theta$$

Where, D is the average particle size, λ is the wave length of Cu $K\alpha$ radiation, β is the width (in radian) of the X-ray diffraction peak at half of its maximum intensity, and θ is the Bragg diffraction angle of the line. The average crystallite size values of BaTiO_3 nano powder obtained at 550 °C for 6 hours and it was 32 nm. The smaller average crystallite size (nanoparticles) was achieved by assisted combustion method compared to conventional solid state reaction method.

5.4 Differential Thermal Analysis (DTA) / Thermo Gravimetric Analysis (TGA)

In fig 4 shows that TGA/DTA pattern obtained on BaTiO_3 anode powder. In the TGA pattern the BaTiO_3 sample showed a weight loss of about 0.0464 mg/min until 65 °C. The sample on further heating from 65 °C - 335.97 °C, showed slight weight gain and loss of about 0.123mg/min. Again the sample showed a weight increase from 335.97 °C-560.53 °C and then a loss of 0.580mg/min during further heating up to 584.53 °C. The weight gain and weight loss indicated that the BaTiO_3 powder exhibited easy reversible absorption-desorption of oxygen from air.

From the DTA curve, it is seen that a broad exothermic peak at 586.83 °C occurred due to the weight losses between 39.95 °C-725.7 °C in TGA curve. From the above TGA/DTA data, the BaTiO_3 gradually absorbs the oxygen from air with temperature.

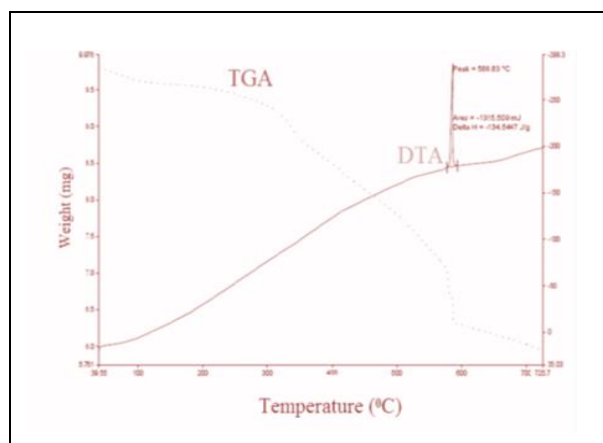


Fig. 4: TGA & DTA of BaTiO_3

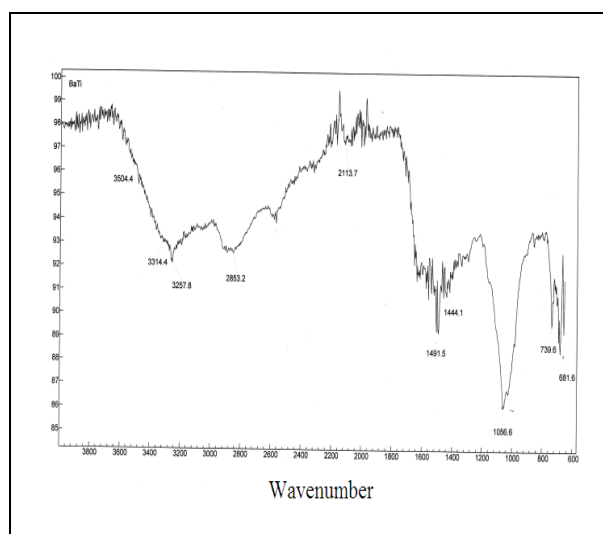


Fig. 5: FT-IR spectrum of BaTiO_3

5.5 Fourier Transform Infrared (FT-IR) Spectroscopy

Fig. 5 shows that the FT-IR Spectrum obtained on BaTiO₃ anode powder. The powder exhibited a strong bond at 600-800 cm⁻¹ due to the stretching vibration mode of the Ba-O bond in the structure.

The peak appeared at 1491.5 cm⁻¹ corresponds to the H-O-H bond mode confirming the presence of moisture in the sample. The peak appeared at 2113.7 cm⁻¹ is due to the presence of CO₂ in the sample. The sample BaTiO₃ exhibited a low intensity peak at 2600.09 cm⁻¹

The BaTiO₃ sample exhibited four peaks obtained between the wavelength region 2800-3800 cm⁻¹ and are observed at 2853.2, 3257.8, 3314.4 and 3504.4 cm⁻¹. The peak appeared at 3257.8 cm⁻¹ is related to the O-H stretching vibration of H₂O in the sample. The major peak reported for BaTiO₃ in literature coincide with the observed FT-IR spectrum for BaTiO₃ which confirmed the single phase of this anode material

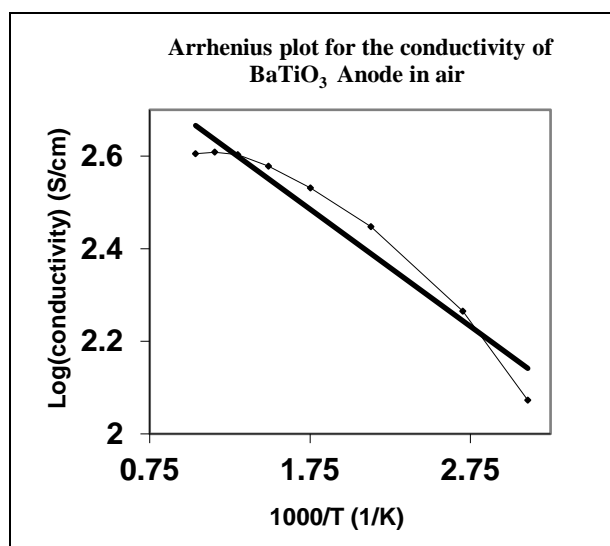


Fig. 6: Electrical conductivity of BaTiO₃

5.7 Electrical Conductivity

The Electrical Conductivity of BaTiO₃ was measured at temperature 100-700°C in air is shown in fig 6. The BaTiO₃ Anode was a mixed conductor. The total conductivity involved both electronic and ionic conductivity terms, due to the presence of holes and oxygen vacancies. The ionic conductivity was about two orders of magnitude lower than electrical conductivity. The charge imbalance caused by a replacement of Ba²⁺ could be accommodated either by an oxidation of Ti⁴⁺ (electronic compensation) or by the formation of oxide ion vacancies (ionic compensation) in BaTiO₃. Electrical

conductivity of BaTiO₃ increased gradually with temperature. For the composition with semi conducting behavior, the temperature dependence of the conductivity can be described by the small polaron hopping mechanism as $\sigma = A/T \exp(-E_a/KT)$ the activation energies obtained from the Arrhenius plots of $\log \sigma$ vs $1000/T$. The changes in the activation energy with temperature for BaTiO₃ are attributed to the spin state transition.

6. CONCLUSIONS

The present investigation was carried out to improve the performance of BaTiO₃ by the synthesis method. The electrochemical behavior of BaTiO₃ based anode materials depends upon the method of synthesis and sintering temperature. Hence, these conditions were adopted for the present work to synthesis the phase-pure, nanocrystallite materials. The present work was mainly focused on synthesis, and electronic conductivity of BaTiO₃.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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