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Short communication

Superiority of sonochemical processing method for the synthesis of barium titanate nanocrystals in contrast to the mechanochemical approach

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ABSTRACT

The results indicated that the ultrasonic sonochemistry which brings into play the acoustic cavitation phenomenon is more powerful and feasible in synthesizing the mixed oxides in contrast to the conventional solid-state approaches. The obtained results demonstrated that the sonochemical approach is able to obtain highly pure powder product at a much lower processing temperature of about 323 K (50 °C) in contrast to 1173 K (900 °C) which is essential for the synthesis by the mechanochemical approach. Sonochemical synthesis benefits from homogenous ordering the reactant ions (which have been dissolved in the solution mixture) into perovskite structure using ultrasonication. This indicates that the acoustic cavitation phenomenon is much more powerful and cost-effective than high energy ball milling in synthesizing nanopowders of the mixed oxide materials. Moreover, the sonochemical processing method is able to prepare the final powder products in a much shorter time by a one-step synthesis approach without the need for the successive calcination in contrast to the solid-state approach.

1. Introduction

It is well known that the barium titanate ($BaTiO_3$; BTO)-based materials provide properties that are important for a variety of electrical and electronic applications because of their piezoelectric, pyroelectric and ferroelectric characters [1–4]. It has been mentioned that the processing route of BTO powders has an important role on the dielectric properties of the final ceramic components [5–8]. Recently, the wet chemical processing approach is making a significant involvement in the development and built-up the electro-ceramic materials for assembling in high-tech devices. The approach is also successful in exploiting the different practical performances of the electro-ceramics. Considering the potential applications of BTO in various fields, many different synthesis methods such as sonochemical, polyol, solution-combusting, sol–gel processing, modified Pechini, stearic acid gel, co-precipitation, pulsed laser deposition and mechanochemical methods were adopted to prepare nano-scale BTO products [9–14].

The conventional preparation approaches such as solid-state processing or mechanical milling methods result in large BTO particles exhibiting uncontrolled sizes and morphologies [15]. These drawbacks limit the applications of the obtained powder products in many high-tech applications. The conventional processing methods for preparation of BTO require a calcination treatment for the powder mixture at a high temperature in the range of 1373–1573 K (1100–1300 °C); this disadvantage results in the coarse-grained powder products while they contain agglomerated particles of different size as well as impure phases as a result of incomplete reactions [15]. Modified high energy mechanochemical approaches have been recently developed to address these shortcomings partially [16,17].

As a one-step facile wet chemical processing method, ultrasonication-assisted preparation (sonochemical processing method) is able to be operated at room temperature [1,2]. As an advanced preparation method, sonochemical approach concerns with understanding the effect of ultrasound irradiation and acoustic cavitation phenomenon on the formation of the final product expected [1,2]. Ultrasonication of a solution mixture of the precursors results in the initiation and enhancement of chemical activity of the reactant ions and clusters at low temperatures [18,19]. Sonochemical preparation method utilizes the acoustic cavitation phenomenon which includes the formation of the bubbles and their successive growth and implosive collapse in a mixture of the reactant ions and clusters [1–2]. As a mostly adiabatic process, this collapse of the grown bubbles leads to a massive energy build-up ensuing high pressures of about 2000 atm and very high temperatures more than 5273 K (5000 °C) in localized microscopic regions inside the sonicated solution mixture [20,21]. The benefits of the sonochemical processing method for obtainment of the oxide materials are high purity, narrow particle size distributions, controllable reaction conditions, ability to obtain nanoparticles with mostly uniform shape and

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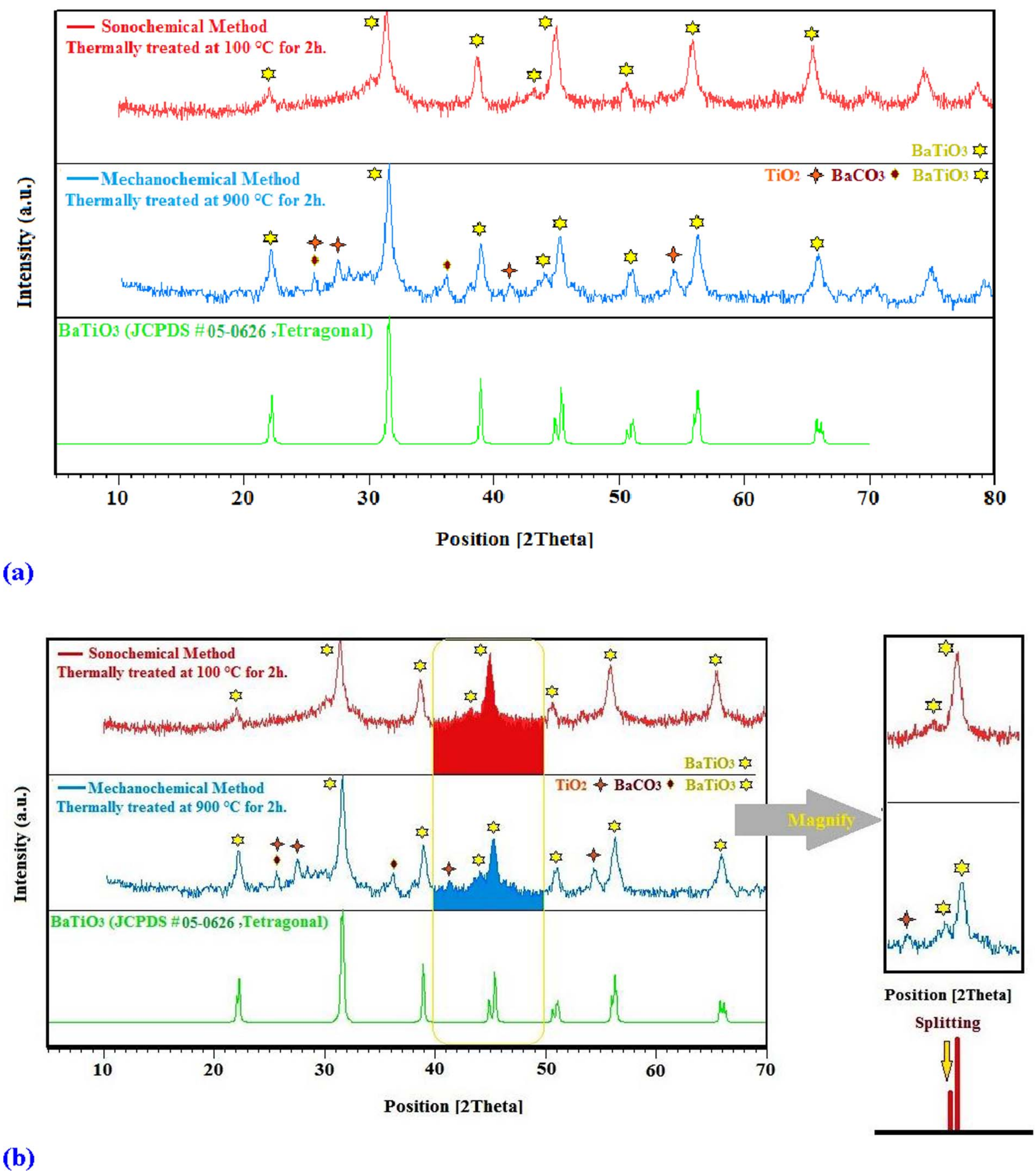

Fig. 1. (a) XRD patterns of the powder products in contrast to standard XRD data and (b) XRD pattern magnification in 2θ range of 40–50° comparing the tetragonality of the samples.

rapid synthesis at much lower temperatures in contrast to other synthesis methods [1,2].

In absence of any published work comparing the mechanochemical and sonochemical preparations of BTO nanopowders, the current work tries to study the feasibility of obtainment of carbonate-free BTO nanopowders by mechanochemical and sonochemical processing methods. Moreover, it is tried to compare these processing methods by comparing the role of acoustic cavitation and high energy mechanical activation phenomena on the outcome of the synthesis process. This comparison is of significant importance because the mechanochemical is the mostly used approach for mass production of mixed oxides while the results presented in this work indicate that the sonochemical approach benefits from the fast facile one-step preparation at much lower temperature in contrast to the mechanochemical approach suggesting its better capability for mass production of BTO.

2. Experimental procedure

2.1. Materials and synthesis method

2.1.1. Sonochemical method

All the chemicals reagents used in our experiments were of analytical grade, purchased from Merck and used as received without further purification. BTO was obtained by sonochemical processing method in