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Research Article

Synthesis of Magnesium Oxide Nanopowder by Thermal Plasma Using Magnesium Nitrate Hexahydrate

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Magnesium oxide (MgO) nanopowder was synthesized by thermal plasma in a novel thermal DC plasma torch using magnesium nitrate hexahydrate. Magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$) was obtained from serpentinite ($Mg_3Si_2O_5(OH)_4$; lizardite) (Halilovskiy array, Orenburg region, Russia). The synthesized samples were characterized by analytical techniques including X-ray diffraction (XRD) and transmission electron microscopy (TEM). XRD and TEM characterization studies confirmed that MgO nanopowder obtained has periclase structure with high purity, and the particle sizes vary within the range of 100 nm to 150 nm. We believe that the present work will promote further experimental studies on the physical properties and the applications of MgO nanopowders in the fields such as high-densed ceramics, additives in bactericide, and refractory products.

1. Introduction

Magnesium oxide (MgO) is an attractive material which has many potential applications, such as water purification, optoelectronics, and microelectronics, is an additive in heavy fuel oil, paint, gas separation, and bactericides, and is an insulator in industrial cables, crucibles, and refractory materials. However, the useful properties of MgO are further enhanced when used as nanosized powder with novel nanostructures [1–4]. Many methods like flame spray pyrolysis [5], combustion aerosol synthesis [6], hydrothermal method [7], laser vaporization [8], chemical gas phase deposition [9], solvothermal method [10], aqueous wet chemical method [11], and others [12–14] have been developed for the synthesis of nanosize of MgO.

Among the different techniques commonly used for preparation of magnesium oxide, thermal plasmas which provide high temperatures and steep temperature gradients offer an attractive and chemically unspecific route for synthesizing fine refractory powders [15–18]. Thermal plasmas suitable for synthesis are primarily produced by means of high intensity AC or DC arcs, high frequency discharges, DC-RF hybrid plasmas, and a reactive submerged arc (RSA). Depending on the process, either the discharge itself or the plasma flame downstream of the discharge may be used for synthesizing the powders. In thermal plasma synthesis, the reactants may be gases, liquids, or solids before injection into the plasma [19].

In this paper, we report the synthesis and characterization of magnesium oxide nanopowder by thermal plasma in a novel thermal DC plasma torch using magnesium nitrate hexahydrate as the precursor.

2. Experimental Procedure

Magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$) was obtained from serpentinite (Halilovskiy array, Orenburg region, Russia). Serpentinite consisted mostly of magnesium, silicon, and iron in the form of serpentinite ($Mg_3Si_2O_5(OH)_4$; lizardite).

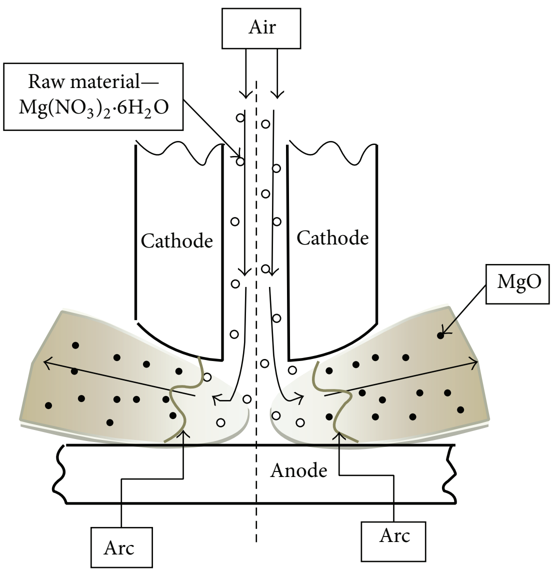

Figure 1: Schematic diagram of a novel thermal DC plasma torch.

Serpentinite was dissolved in 40% nitric acid solution. $MgNO_3$ solution was obtained after the ions like Fe^{3+} and Fe^{2+} were transformed into hydroxide precipitates, and the precipitates were separated by filtration. $MgNO_3$-rich solution was transferred to a glass beaker for evaporation of the solution. The solution started boiling at 90°C and was boiled for 4 h in order to evaporate most of the solvent. The residue of hydrated magnesium carbonate was cooled to room temperature and filtered. $Mg(NO_3)_2{\cdot}6H_2O$ was ground by a vortex jet flow type mill (productivity of 50 g per minute, air pressure of 10 bar, and air volume of 1 m^3/min).

MgO nanopowder was synthesized by using thermal plasma from magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$). $Mg(NO_3)_2{\cdot}6H_2O$ was easily decomposed in the high temperature (T) range of plasma and converted to MgO particle due to rapid quenching:

$$2\mathrm{Mg}\left(\mathrm{NO}_3\right)_2 \xrightarrow{T,{}^\circ\mathrm{C}} 2\mathrm{MgO} + 4\mathrm{NO}_2 \uparrow + \mathrm{O}_2 \uparrow \tag{1}$$

A novel thermal DC plasma torch has been employed for the production of MgO nanopowder (Figure 1). The powder is separated during the passage of the gas-dust mixture through a system of cyclones, and the gas mixture is utilized in the venturi scrubber.

The phase composition of the samples was analyzed by X-ray diffraction (XRD) with Cu$K\alpha$ radiation. A Rigaku Ultima IV X-ray powder diffractometer was used. Crystalline phases were identified by the ICDD PDF-2 (2008) powder diffraction database. The microstructure of MgO nanopowder was carried out using a JEM 2100 (JEOL Ltd., Tokyo, Japan) transmission electron microscope (TEM) equipped with an INCA energy-dispersive X-ray spectrometer (EDS; Oxford Instruments, Oxfordshire, UK) with an acceleration voltage of 200 kV. The TEM specimens are prepared by method for the preparation of micrometer-sized powder particles described in [20].

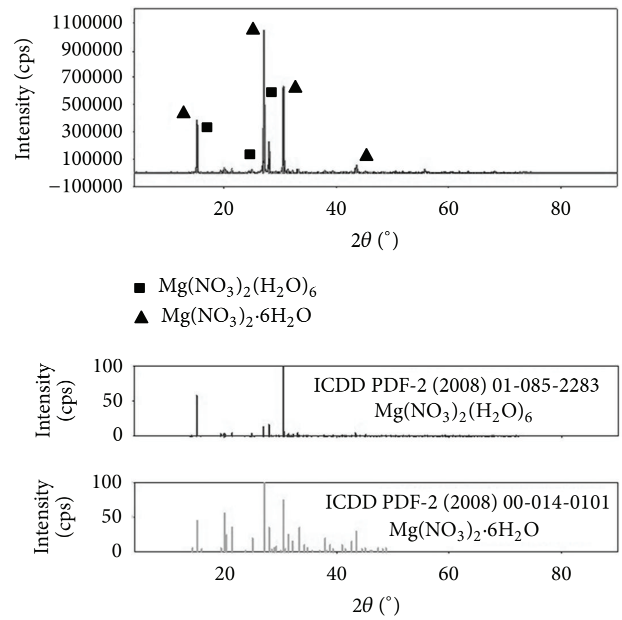

Figure 2: XRD pattern for $Mg(NO_3)_2{\cdot}6H_2O$ produced from serpentinite.

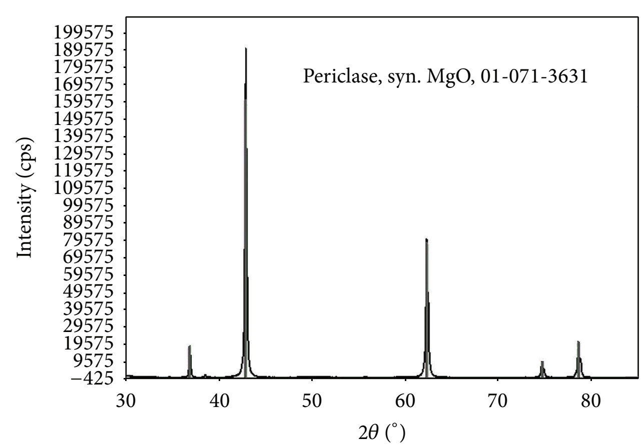

Figure 3: XRD pattern for MgO nanopowder.

3. Results and Discussion

Analysis of the phase composition of the magnesium nitrate ($Mg(NO_3)_2{\cdot}6H_2O$) shows that, according to the ICDD data catalog (Figure 2), the powder consists of $Mg(NO_3)_2(H_2O)_6$ with a monoclinic lattice with P121/c1, unique-b, cell-1 space group and $Mg(NO_3)_2{\cdot}6H_2O$ with a monoclinic lattice with P121/c1, unique-b, cell-1 space group phases.

The key idea in this study is to prepare the nanosized MgO particles with high crystallinity and no impurities.

Analysis of the phase composition of MgO nanopowder (Figure 3) shows that, according to the ICDD data catalog, it is one-phase material MgO (periclase) and had cubic lattice with Fm-3m space group ($a = b = c = 4.215$ Å). No diffraction peaks representing other phases were detected in Figure 2, which indicated high purity of the periclase.

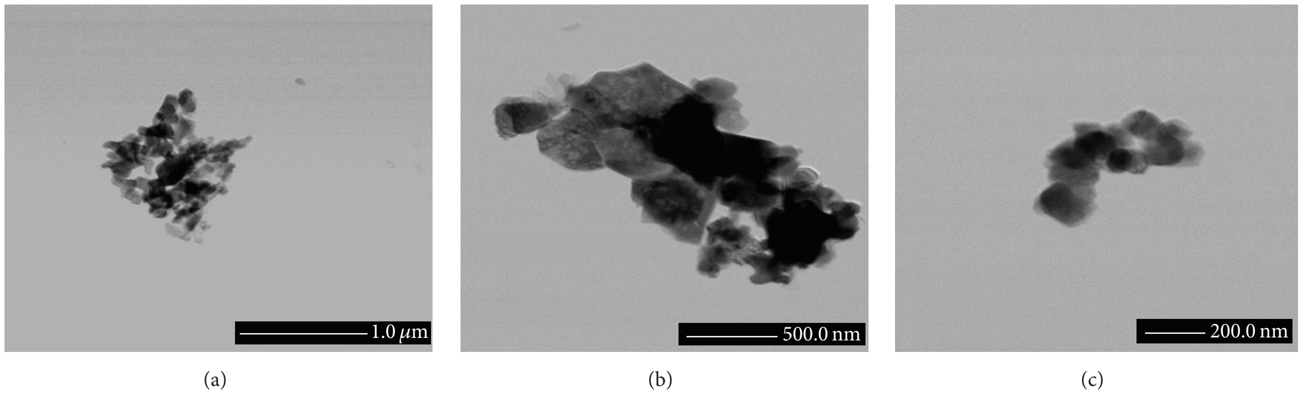

Figure 4: TEM image of MgO nanoparticles for different magnification: (a) 60 K and (b, c) 100 K.

This present value is in good accordance with the literature reports. All reflections are sharp with slight broadening. These reflect the crystalline nature of MgO nanopowder.

Transmission electron microscope (TEM), a powerful method for structure analysis at a nanometer scale, allows for direct observation of the morphological and structural features of MgO samples. The morphological and structural features of MgO nanopowder, shown in Figure 4, were characterized with transmission electron microscope (TEM). The TEM images are shown in different magnifications. These images illustrate that small amount of agglomeration is present in the sample. The results showed that MgO nanopowder with irregular morphology with size in the range of 100–150 nm was fabricated.

4. Conclusions

From our present work, it is concluded that it is easy to prepare MgO nanoparticles by thermal plasma in a novel thermal DC plasma torch using magnesium nitrate ($Mg(NO_3)_2 \cdot 6H_2O$) as precursor. The XRD patterns show that the obtained magnesium oxide (MgO) nanopowder has the periclase structure. The XRD pattern confirmed the crystallinity and phase purity of the nano-MgO powder. MgO powder has very homogeneous structure without any observable pores. MgO materials obtained by thermal plasma using magnesium nitrate ($Mg(NO_3)_2 \cdot 6H_2O$) as precursor may prove potential applications in catalyst, water purification, pigments, optoelectronics, bactericides, insulator, crucibles, substrate, and refractory materials.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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