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Characteristics and optical properties of MgO nanowires synthesized by solvothermal method

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ABSTRACT

Magnesium oxide (MgO) nanowires were synthesized by solvothermal method using magnesium nitrate hexahydrate and sodium hydroxide. Field emission scanning electron microscopy (FE-SEM) and transmission scanning electron microscopy (TEM) measurements indicate that the product consists of a large quantity of nanowires with average diameter of 20 nm and average length of several micrometers. Explorations of X-ray diffraction (XRD), energy dispersive analysis of X-ray (EDAX), Fourier transformer infrared spectroscopy (FTIR), selected area electronic diffraction (SAED) and high-resolution transmission electron microscope (HRTEM) indicate that the product is high-quality cubic single-crystalline nanowires. The optical properties of the samples are investigated using UV–visible spectroscopy to study the refractive index and optical dielectric constant. The photoluminescence (PL) measurement suggests that the product has an intensive emission centered at 437 nm, showing that the product has potential application in optical devices. The advantages of our method lie in high yield, the easy availability of the starting materials and allowing their large-scale production at low cost.

1. Introduction

Considerable interest is focused on the synthesis of nanocrystalline materials because of their unique physical and chemical properties that distinguish them from bulk-phase materials. The particle size and shape of materials significantly affect their properties. Thus, the control of the size and morphology of nanocrystalline materials can lead to the discovery of new physical and chemical properties [1]. One-dimensional (1D) nanostructures, such as nanowires, nanorods, nanobelts, nanoribbons, nanoneedles, and nanotubes, have attracted considerable attention due to their unique and fascinating properties as well as their potential technological applications [2]. In particular, 1D nanostructures are emerging as powerful building blocks for nanoscale photonic devices such as light-emitting diodes, photodiodes, lasers, active waveguides, and integrated electro-optic modulator structures because of their higher luminescence efficiency [3–5]. Among the metal oxides studied, magnesium oxide (MgO), in particular, has received a large amount of attention. MgO is a typical wide band gap (7.8 eV) insulator. Its electronic and optical properties are very attractive because its low heat capacity and high melting point make it an ideal candidate for insulation applications [6]. MgO nanostructures have also been used as protective layers for dielectrics in AC circuits to improve discharge characteristics and panel lifetime as a result of their anti-sputtering properties, high transmittance, and secondary electron emission coefficient [7].

Nowadays, various morphologies of MgO nanostructures such as nanoparticles [8], nanotubes [9,10], nanosheets [11–14], nanowires [10,15], whiskers [11,16], nanobelts

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[10,17], nanofibers [18], and other morphologies [19,20], have been successfully synthesized by various methods, such as chemical vapor deposition (CVD) [21], domestic microwave oven [22], carbothermal reduction [23], sol-gel [24], dual magnetron sputtering [25], hydrothermal synthesis [26] and thermal evaporation [27]. However, large scale, high-efficiency controlled synthesis of MgO nanostructures still remains as a challenge. Hydrothermal synthesis was favored among researchers due to it being an economical and simple method. Al-Hazmi et al.[26] successfully obtained nanostructures 1D magnesium oxide (MgO) nanowires by microwave hydrothermal process at 180 °C for 30 min. In this work, we successfully synthesize MgO nanowires by solvothermal method using magnesium nitrate hexahydrate and sodium hydroxide. The morphological, structural, optical properties and photoluminescence (PL) of the as-prepared MgO nanowires are reported.

2. Experimental

2.1. Materials

Magnesium nitrate hexahydrate [$Mg(NO_3)_2 \cdot 6H_2O$] and sodium hydroxide [NaOH] were purchased from Sigma-Aldrich. All the reagents used in the experiments were of analytical grade and used without further purification.

2.2. Synthesis of MgO nanowires

The starting materials used for the synthesis were magnesium nitrate hexahydrate [$Mg(NO_3)_2 \cdot 6H_2O$] and sodium hydroxide [NaOH]. Mixed solvent of ethanol and water in equal volume ratio was used as the solvent. 6 g of NaOH were added to 70 ml of the mixed solvent and stirred until it dissolves completely (pH-11). 3.446 g of magnesium nitrate were directly added to the above solution and after stirring for a few minutes, a white precipitate was obtained and transferred to 100 ml autoclave. The closed autoclave was then placed inside a preheated hot-air oven maintained at 180 °C for 10 h, after that it was cooled down to room temperature (RT). The obtained precipitate was filtered, washed with distilled water for several times to remove the nitrates and then with ethanol to reduce the agglomeration, and later dried at 80 °C for 2 h. Finally, the white colored material was calcined at 500 °C for 3 h in an electrical oven.

2.3. Characterization techniques

The structure of as-prepared samples were characterized by X-ray powder diffraction (XRPD), being the X-ray patterns from 10° and 80° at 2θ collected by a Philips X'Pert PRO MPD (PANalytical, The Netherlands) using graphite-monochromatized Cu$K\alpha$ radiation (λ=1.54184 Å), operating at 45 kV and 40 mA.

For IR measurements, the films were grown on KBr. The IR measurements were carried out using a fourier transform infrared spectroscopy (FT-IR) spectrophotometer (IRPrestige-21, Shimadzu) in the wave number range 400–4000 cm^{-1} with 4 cm^{-1} resolution.

The morphology of samples was studied by field-emission scanning electron microscopy (FE-SEM), and was performed on a JSM-6100 microscope (JEOL, Japan) with an acceleration voltage of 30 kV. The chemical composition of the synthesized nanostructures was also analyzed using energy dispersive analysis of X-ray (EDAX) unit attached with the FE-SEM. Transmission electron microscopy (TEM) images and the corresponding selected area electron diffraction (SAED) patterns were obtained with a 2000 EX II microscope (JEOL, Japan) at an acceleration voltage of 200 kV. High resolution transmission electron micrographs (HRTEM) were obtained on a JEM-2100F (JEOL, Japan) with an accelerating voltage of 200 kV. For TEM observation, the synthesized products were ultrasonically dispersed in ethanol and a drop of the suspension was placed on a Cu grid coated with carbon film.

The optical properties were measured at room temperature using the Perkin Elmer Lambda 900 UV–vis spectroscopy. The room temperature photoluminescence (PL) spectrum of the products was measured using Edinburgh Instruments FLS920 steady-state fluorescence spectrometer (U.K.) with Xe lamp as the excitation light source (with a wavelength of 350 nm).

3. Results and discussion

3.1. Structural studies

Fig. 1 shows the XRD pattern of the as-prepared MgO nanowires. It can be seen that the nanowires were highly crystalline in nature with diffraction peaks (1 1 1), (2 0 0), (2 2 0), (3 1 1) and (2 2 2) corresponding to the cubic structure of MgO with a lattice constant of a=0.421 nm (JCPDS: 04-0829). The sharp diffraction pattern indicated that the structure possessed good crystallinity. No characteristic peak of impurities was detected in the pattern, indicating the high purity of the obtained product. Therefore, these X-ray diffraction results clearly show that the MgO NWs are pure MgO and well crystallized. This result is similar to several previous reports such as Refs. [28,29]. The crystallite size for the synthesized MgO NWs is calculated by Scherer's formula [30,31]:

$$D = \frac{0.9\,\lambda}{\beta \cos\theta} \quad (1)$$

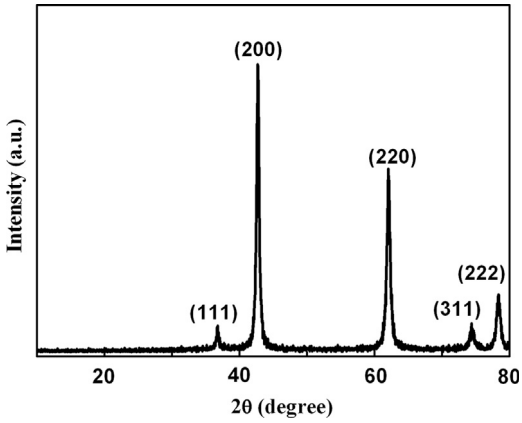

Fig. 1. X-ray diffraction pattern of the MgO NWs.