Green synthesis of MgO nanowires employing solar thermal energy

Geun-Hyoung LEE

Department of Advanced Materials Engineering, Dong-eui University, 176 Eomgwangno, Busanjin-gu, Busan 614–714, Republic of Korea

MgO nanowires were synthesized by an unique thermal evaporation technique employing solar energy at atmospheric pressure in air. In the conventional thermal evaporation technique, electrical furnace was heated to high temperatures and kept for a long time at the high temperatures for vaporizing source materials. Thus the significant amount of electric energy is consumed. However in the present method, solar thermal energy instead of electricity was used as the heat source for the evaporation of metal precursor. Sunlight was focused on the Mg powder through a magnifying lens to concentrate solar thermal energy. The concentrated solar energy created heat enough to vaporize the Mg powder. Then the Mg vapor reacted with oxygen in air to form MgO nanowires. Furthermore, the MgO nanowires were synthesized within a few seconds, which indicates that this method has also an advantage of synthesizing rapidly MgO nanowires.

Key-words : Magnesium oxide, Nanowires, Thermal evaporation, Solar energy, Green synthesis

1. Introduction

Nanostructured materials have attracted considerable interest because their physical and chemical properties are distinctly different from those of the bulk materials. The unique properties of nanostructured materials make them favorable for wide variety of applications. Metal oxides exhibit many interesting and important properties including electronic, optical and magnetic properties. Thus metal oxide nanostructures have potential applications in many fields including electronics, optoelectronics, optics, sensors and catalysis, which leads to intensive studies on the synthesis of metal oxide nanostructures.

MgO is a wide bandgap insulator (7.8 eV) with the extensive applications in catalysis, superconductors, heat resistance, reflecting and antireflection coating, magnetoresistance and so on. The useful properties of MgO can be improved when the dimension of MgO reduces to the nanoscale. In particular, nanostructures such as nanowires and nanoneedles enhance performance in catalysts and gas sensors due to their higher surface-to-volume ratio. So far, several methods have been used for the synthesis of MgO nanostructures, including chemical vapor deposition, precipitation method, hydrothermal method, thermal evaporation, solvothermal method, microwave oven. Among these methods, thermal evaporation method is widely used due to its low cost and simplicity. In the commercial thermal evaporation method, an electric furnace is used to generate a temperature sufficiently high to melt and vaporize metal precursor. Thus the method consumes significant amount of electricity.

In this paper, a green synthesis method for MgO nanowires is demonstrated. The synthesis method is an unique thermal evaporation method employing solar energy without using electric energy. Thus, this method can effectively reduce electricity consumption. Moreover, solar energy is a clean form of energy and so this synthesis method doesn’t pollute the environment.

2. Experimental procedure

Mg powder with a purity of 99.99% was placed in an alumina crucible. Sunlight was focused onto the Mg powder by using a magnifying lens. Then solar thermal energy was concentrated on the Mg powder to melt and vaporize the Mg powder. The Mg vapor reacted with oxygen in air to form MgO product. A schematic of the experimental environment is shown in Fig. 1. The product was collected for characterization. The morphology of the as-synthesized product was observed using field emission scanning electron microscope (FESEM) equipped with energy dispersive X-ray (EDX) spectroscope. The crystal structure was studied by X-ray diffractometry (XRD) with Cu Ka radiation. The components were investigated by the EDX. The phase composition of the product was studied by Fourier transform infrared spectrometer (FTIR).

Fig. 1. A schematic of the experimental environment.
3. Results and discussion

The morphology of the as-synthesized product was observed by SEM. Figures 2(a) and 2(b) show the low magnification and high magnification SEM images of the product. It is clearly shown that numerous nanowires with a relatively uniform diameter were formed. The nanowires ranged from 30 to 60 nanometers in diameter and up to a few tens of micrometers in length. The SEM analysis indicates that the product is composed of nanowires, and the nanowires have high aspect ratio and large surface area-to-volume ratio.

FTIR measurement was performed for identifying the material and the phase composition of the nanowires. The FTIR data was achieved for a powdered sample. Figure 3 shows the FTIR spectrum of the nanowires. In the FTIR spectrum, the absorption peaks are observed in the wavenumber range of 400–600 cm\(^{-1}\), which is the feature of the absorption peaks of the Mg–O bond in MgO.\(^3\),\(^7\) The absorption peaks are observed in the FTIR spectra of MgO nanomaterials.\(^3\),\(^7\) The FTIR analysis reveals that the nanowires are MgO material. The constituents and the chemical composition of the nanowires were studied by EDX analysis. Figure 4 shows the EDX spectrum of the nanowires. The EDX spectrum indicates that the nanowires are made up of Mg and O elements. The atomic ratio of Mg to O is estimated to be 56.8%:43.2% from the EDX spectrum, which shows the presence of nearly equal amounts of Mg:O within the error limit of ±5%. Any other impurities except Mg and O are not detected. Figure 5 shows the XRD pattern of the product consisted of the nanowires. The diffraction peaks at 36.9, 42.9, 62.3, 74.6 and 78.5° can be indexed to (111), (002), (022), (113) and (222) lattice planes of the cubic structure of MgO with the lattice constants of \(a=b=c = 0.421\) nm. These values are in good agreement with the values of bulk MgO crystal. Mg peaks with much lower intensity are also detected. The XRD pattern indicates that the product is mainly composed of MgO with cubic structure and MgO nanowires are obtained via this synthesis method.

The size of nanowires grown by thermal evaporation method is dependent on growth temperature and growth time. Hence the diameter and the length of nanowires may be controlled by the intensity of solar thermal energy and irradiation time in the present method. The intensity of solar thermal energy concentrated on source material is determined by the light-gathering power of lens.

On the other hand, a large number of MgO nanowires have a bent at the end as shown in Fig. 6. The bending indicates the switching of growth direction. The nanowires were formed from the nuclei of MgO particles. Because MgO has a cubic crystal
structure, MgO nucleus consists of six equivalent low index \{100\} planes. Thus the growth rates are the same for all the six planes from the viewpoint of thermodynamics of crystal growth. Therefore the formation of the MgO nanowires should be considered by the kinetics of crystal growth. When MgO cluster adsorbs onto the surface of MgO nucleus with cubic shape, it diffuses randomly on the surface. When it diffuses to high energy sites or surface defect sites such as kink, ledge and ledge-kink sites, it will be incorporated into crystal lattice, resulting in the growth of the crystal. Accordingly, a high growth rate is found on the plane with high defect density, which results in the formation of nanowire. Hence MgO nanowire may change the direction of growth between the six equivalent \{100\} planes, which originates from the change of the surface defect density on the six planes during the growth. It has been reported that the bending of MgO wires was ascribed to a change in growth direction by planar defects.\(^6\) On the other hand, three dimensional (3D) growth occurs on the six surfaces of cubic MgO nucleus when the supersaturation is very high. The 3D growth can change the surface defect density on each \{100\} plane of the nucleus, which may switch the growth direction during the growth of MgO nanowire. Therefore it can be supposed that in the present work, the bending of the nanowires was attributed to the variation in supersaturation ratio during the growth.

There are two growth mechanisms for the nanowires. One is vapor–solid (VS) mechanism, and the other is vapor–liquid–solid (VLS) growth mechanism. In VLS mechanism, metal catalysts are used to act as a liquid forming agent during the growth of nanowires. The growth species dissolves into the liquid catalyst droplets. Saturated growth species in the liquid droplet precipitates at the growth surface, resulting in the growth of nanowires. Therefore the catalyst droplets are generally observed at the tips of resulting nanowires.\(^6\) In the present work, no catalyst was used and no droplet was observed at the tip of the nanowires. Hence it is concluded that the growth of the MgO nanowires in the current work was governed by the VS mechanism.

4. Conclusion

MgO nanowires with a diameter of several tens of nanometers were synthesized by a simple, novel thermal evaporation method employing solar energy as the heat source. The solar energy was concentrated on the Mg powder with a magnifying lens, which created heat. This heat was hot enough for metallic Mg powder to be melted and evaporated. Then Mg vapor was oxidized in air to form MgO nanowires within a few seconds. This synthesis process is green and environmental friendly and furthermore offers many advantages such as its simplicity, rapid rate of synthesis, low cost and low energy consumption.

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