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Applied Surface Science 242 (2005) 29–34
applied surface science
www.elsevier.com/locate/apsusc

Gallium oxide nanomaterials produced on SiO_2 substrates via thermal evaporation

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Accepted 26 July 2004
Available online 25 September 2004

Abstract

We have prepared the novel gallium oxide (Ga_2O_3) nanomaterials on SiO_2 substrates by a thermal evaporation of GaN powders. We found that the products consisted of the nanobelts with additional nanostructures formed on the sides of nanobelts. The nanobelts had a single-crystalline monoclinic structure with a width in the range of 100–300 nm. We have discussed the possible mechanism leading to the formation of the Ga_2O_3 nanomaterials. Photoluminescence spectrum under excitation at 325 nm showed a blue emission.

PACS: 81.07.Bc

Keywords: Evaporation; Monoclinic; Gallium oxide; Nanomaterials

1. Introduction

One-dimensional (1D) nanostructures, such as nanobelts, -rods, and -wires, have the potential to show enhanced physical properties due to their decreased size, increased surface-to-volume ratio, and the novel morphologies, making them attractive materials with many possible applications [1–3]. Gallium oxide (Ga_2O_3) is a wide gap (E_g = 4.9 eV) compound and it has long been known to exhibit both conduction and luminescence properties [4]. Therefore, 1D Ga_2O_3 nanostructures should have potential applications in 1D optoelectronic nanodevices. The 1D Ga_2O_3 nanostructures have been synthesized by various methods, including a dc arc discharge [5] and an evaporation or heating [6–17].

In this paper, we report the formation of Ga_2O_3 nanomaterials on SiO_2 substrates using GaN powders without employing a catalyst, at a temperature of 900 °C and we have examined the structural and optical properties of the products. Although the 1D β-Ga_2O_3 nanostructures have been synthesized from GaN powders on alumina [13,15] or on indium (In)-coated Al_2O_3 substrates [14] and also from Ga

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0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2004.07.062

powders on quartz [6], the investigation on the production of β-Ga_2O_3 nanomaterials on SiO_2 substrate from GaN powders, which we believe, has never been reported.

2. Experimental

The SiO_2 substrates used in our experiments were prepared by thermally depositing 60 nm-thick SiO_2 layers on p-type (1 0 0) Si wafers. A dry oxidation technique has been used with the hotwall horizontal diffusion furnace, in which O_2 gas was an oxygen source. They were ultrasonically cleaned for 10 min in acetone solution. The experimental apparatus is described in Fig. 1. The 99.99%-pure GaN powders and the SiO_2 substrates, respectively, were placed on the lower and the upper holder in the furnace. The powder-to-substrate distance was 5 mm. During the experiment, a constant flow of nitrogen (N_2) was maintained at flow rate of 500 sccm. The temperature near the substrate was about 900 °C for 2 h. After evaporation, the substrate was cooled down and subsequently taken out from the furnace for structural and optical characterization.

The structural properties of the as-grown products were investigated using X-ray diffraction (XRD) with Cu Kα1 radiation (λ = 0.154056 nm), scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDS) installed, and transmission electron microscopy (TEM) with an accelerating voltage of 200 kV. For SEM observation, we have coated platinum (Pt) using ion sputtering system onto specimens after they have been mounted on stubs. For TEM observation, the products were ultrasonically dispersed in acetone and drops were placed on a carbon-coated copper grid. The photoluminescence (PL) measurement was carried out at room temperature using a He-Cd (325 nm, 55 mW) laser as the excitation light source.

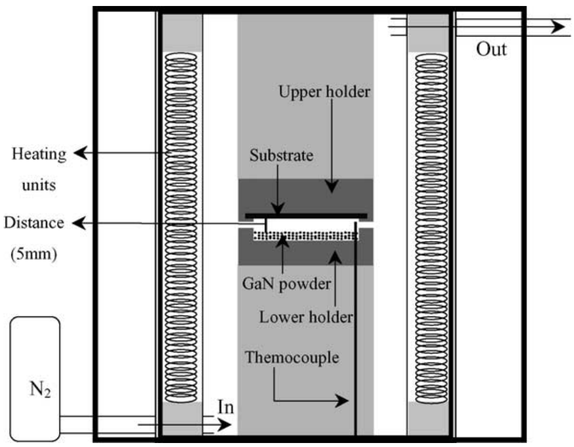

Fig. 1. Schematic illustration of the apparatus used in this work.

3. Results and discussion

Fig. 2 displays the XRD patterns taken from the products on SiO_2 substrates. Miller indices are indicated on each diffraction peak. Within experimental error, all the relatively sharp diffraction peaks in the XRD pattern can be indexed to a monoclinic β-Ga_2O_3 with lattice parameters of a = 5.80 Å, b = 3.04 Å, and c = 12.23 Å (JCPDS-International Center for Diffraction Date No. 11-370), revealing the production of β-Ga_2O_3 deposits. No crystalline phases other than Si were found within the detection limit. The Si diffraction peaks come from the substrate.

Fig. 3a and b are typical cross-sectional and plan-view SEM images of deposits on SiO_2 substrate, respectively, revealing that the products consist of a large quantity of 1D nanomaterials with typical lengths mostly <180 μm. Fig. 3c is the high-magnification SEM image of the deposits. The products comprise nanobelts with high aspect ratio. Certain other irregularly shaped structures, with a

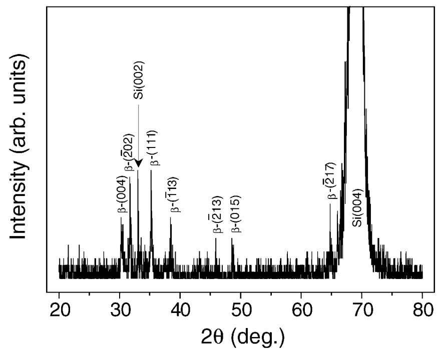

Fig. 2. XRD pattern of the as-deposited products. The Si diffraction peaks come from the substrate.