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Synthesis and photoluminescence of gallium oxide ultra-long nanowires and thin nanosheets

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Abstract

β-Ga_2O_3 long nanowires and thin nanosheets have been successfully synthesized on a large scale through simple thermal evaporation of Ga/Ga_2O_3 mixture powders in the presence of Au catalyst. The as-synthesized products were investigated by X-ray powder diffraction (XRD), scanning electron microscopy (SEM), high-resolution transmission electron microscopy (HRTEM), energy dispersive X-ray spectroscopy (EDS), room-temperature photoluminescence (PL) and optical absorbance. The diameters and lengths of Ga_2O_3 nanowires range from 30–50nm and 60–80 μm in lengths. The nanosheets have thickness of 10–20 nm and lengths up to 20 μm. The SAED and HRTEM observations suggest that both nanowires and nanosheets are single crystalline and free from defects. However, different interplanar spacings were observed for nanowires and nanosheets, indicating the different growth pattern of these two structures. The PL spectrum of β-Ga_2O_3 nanostructures exhibits a broad, strong blue emission band centered at 465 nm. The optical absorption spectrum shows intensive absorption feature in the UV spectral region. The possible growth mechanism of β-Ga_2O_3 nanostructures was also discussed.

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1. Introduction

One-dimensional (1-D) structures such as nanotubes and nanowires (or nanorods) have aroused great interest worldwide due to their importance in understanding the dependence of properties on size and dimensionality of materials, and their

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promising applications as functional building blocks for electrical, optical and magnetic devices [1–5]. Much attention has been focused on carbon nanotubes, semiconducting and metallic nanowires in the recent years [6–11].

β-Ga_2O_3, a transparent conducting oxide (TCO) material with wide band-gap ($E_g = 4.8$ eV), is one of the most promising materials for high-temperature-stable gas sensors [12]. And Ga_2O_3 is also expected to have potential applications for optoelectronic devices such as flat-panel displays, optical emitters, and solar energy conversion devices because of its particular conduction and luminescence properties [13,14]. Much effort has been made to synthesize β-Ga_2O_3 nanowires by a number of groups. Zhang et al. prepared Ga_2O_3 nanowires by evaporating bulk gallium target under controlled conditions [15]. Liang et al. synthesized Ga_2O_3 nanowires by heating GaAs in oxygen atmosphere using Au as catalyst [16]. Choi and co-workers achieved the growth of Ga_2O_3 nanowires through arc discharge of GaN powders mixed with a small amount of transition metals [17]. Also, a laser ablation method has been exploited for the synthesis of Ga_2O_3 nanowires without the presence of catalyst [18]. Chang and Wu have realized the growth of aligned β-Ga_2O_3 nanowires from a single-source organometallic precursor in lower temperature [19]. Recently, the successful synthesis of an interesting belt- and sheet-like oxide nanostructures such as ZnO, SnO_2, In_2O_3 and Ga_2O_3 provided a new component for researchers' microscopic toolbox [20]. The nanosheets and nanobelts of Ga_2O_3 have been prepared via evaporation of GaN powders at 1100 °C in an oxygen ambient atmosphere [21]. Also, the synthesis of Ga_2O_3 nanoribbons has been achieved through hydrogen reduction of Ga_2O_3 powder at high temperature [22]. In this paper, we reported the preparation of β-Ga_2O_3 long 1-D nanowires and thin two-dimensional (2-D) nanosheets through thermal evaporation of Ga/Ga_2O_3 powders in the presence of Au catalyst. The findings showed the growth of nanowires and nanosheets could follow different growth pattern. And the growth mechanism of Ga_2O_3 nanostructures was discussed. Also, the optical properties of the Ga_2O_3 low-dimensional structures were investigated through PL and UV-Vis absorption spectra. These long nanowires and thin nanosheets may provide more alternatives as building blocks for optoelectronic nanodevices.

2. Experimental procedure

The growth process is based on thermal evaporation of Ga/Ga_2O_3 mixture powders in the presence of Au catalyst. Firstly, a bare silicon (1 0 0) wafer was ultrasonically cleaned for 30 min in an acetone bath. Then the cleaned Si wafer was coated with about 30 Å of gold film via ion sputtering and was employed as substrate for the growth of Ga_2O_3 nanostructures. About 2 g Ga/Ga_2O_3 mixture powders were loaded into an alumina boat and Au-coated Si substrate was positioned at the downstream end of the boat with a separation of 8–10 mm away from Ga source. The boat was transferred into a ceramics tube inside a horizontal tube furnace. The tube was sealed and pumped to remove residual air, then was filled with high purity Ar gas. Subsequently, the furnace was heated to 950 °C and was held at this temperature for 2 h under a constant flow of Ar gas of 150 ml/min. After the reaction completed, the furnace was allowed to cool down. A thick white layer was deposited on the surface of substrate.

The structural properties and morphology of the as-prepared products were characterized by X-ray powder diffraction (XRD, Rigaku D/max-2400) with CuKα radiation, field-emission scanning electron microscopy (FESEM, Hitachi S-4500), and transmission electron microscopy (TEM, JEOL JEM-2010, accelerating voltage of 200 kV) and energy dispersive X-ray spectroscopy (EDS). For TEM observation, the product was scraped from the silicon substrate, and then ultrasonically dispersed in ethanol and a drop was placed on an amorphous carbon-coated copper grid. Photoluminescence (PL) spectra were recorded at room temperature using fluorescence spectrophotometer (Hitachi F-4500) with Xe lamp as excitation source. The optical absorption spectra were obtained at room temperature using a Hitachi U-4100 UV-visible spectrophotometer with a