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Catalyst-free Growth of Large Scale Ga$_2$O$_3$ Nanowires

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ABSTRACT
Large scale of straight Ga$_2$O$_3$ nanowires is grown on a fused silica substrate by a simple catalyst-free CVD method using Ga metal and N$_2$ / H$_2$O reactants. The Ga$_2$O$_3$ nanowires with diameters ranging from 60 to 150 nm can be as long as several micrometers. XRD and TEM analyses indicate that the Ga$_2$O$_3$ nanowires exhibit a monoclinic structure. PL characteristic of the Ga$_2$O$_3$ nanowires shows a UV emission of 375 nm at room temperature.

INTRODUCTION
The synthesis of nanometer scale one-dimensional materials, for example β-SiC [1-3], GaN [4,5], In$_2$O$_3$ [6], and Si [7,8], has received intensive research because of their great potential for fundamental studies of the roles of dimensionality and size in their physical properties as well as for the application to optoelectronic nanodevices [9].

Gallium oxide, β-Ga$_2$O$_3$, is a wide band gap compound (Eg = 4.9 eV), and has potential applications in optoelectronic devices including flat panel displays, solar energy conversion devices, and high temperature stable gas sensors [10,11]. Even more, upon optical excitation through the band gap, β-Ga$_2$O$_3$ exhibit up to three different emissions, UV, blue, and green [12-14]. Recently, β-Ga$_2$O$_3$ nanowires have been synthesized by an arc discharge method [15], and physical deposition [16]. Here, we present a simple catalyst-free CVD approach for the growth of the straight β-Ga$_2$O$_3$ nanowires at a temperature of 800°C.

EXPERIMENTAL DETAILS
The schematic representation of the β-Ga$_2$O$_3$ nanowires growth apparatus is shown in Fig. 1. Typically, an excess amount of molten gallium (Alfa Aesar, 99.99%) was placed on the fused silica substrate A (1x1cm$^2$) that was put in the end of the Al$_2$O$_3$ boat. The fused silica substrate B (1x1cm$^2$) was put away from substrate A about 3mm. An Al$_2$O$_3$ plate (4x4cm$^2$) put on the
Fig. 1 Schematic diagram of the high temperature furnace used for the synthesis of the straight \( \beta \)-Ga\(_2\)O\(_3\) nanowires.

top of the Al\(_2\)O\(_3\) boat was used to increase the reactants space time in the Al\(_2\)O\(_3\) boat. Then the Al\(_2\)O\(_3\) boat was inserted into the center of a 3 in. diameter furnace. Before the synthesis process, the furnace was evacuated to a base pressure of 1 x 10\(^{-2}\) Torr. The temperature of the furnace was increased to 800°C within 1 hr at a constant N\(_2\) flow of 200 sccm and a pressure of 500 Torr. As the temperature reached 800°C, the H\(_2\)O vapor was carried from an isothermal bath by another N\(_2\) flow into the furnace. The synthesis processes were conducted under the following condition: furnace temperature, H\(_2\)O vapor rate, N\(_2\) flow rate, furnace pressure of 800°C, 3 sccm, 200 sccm and 500 Torr, respectively. After the 6-hr reaction, the furnace was cooled to room temperature and white products were deposited on the fused silica substrate B.

The morphology and size distribution of the products were examined using SEM (Hitachi, S-4200). The crystal structure of the products was analyzed using XRD (Rigaku) and HRTEM (JEOL 2010), which equipped with an EDS. Micro-Raman with 514.5 nm photons was also employed to characterize the products. Photoluminescence studies were conducted with a Hitachi F-4500 fluorescence spectrophotometer with a Xe lamp at room temperature. The excitation wavelengths were 320 nm.

**RESULTS AND DISCUSSION**

Figure 2(a) shows a typical SEM image of the products on the fused silica substrate. Large scale of needle-like nanowires was formed with random direction on the fused silica substrate with diameters in the range of 60-150 nm. Fig. 2(b) shows a cross-sectional image of the nanowires, it reveals that the length of the nanowires is about several ten micrometers.
The typical XRD pattern of the nanowires is shown in Fig. 3. The diffraction peaks can be indexed to a monoclinic structure of $\beta$-Ga$_2$O$_3$ with lattice constant $a=5.8$ Å, $b=3b$. 1.2 Å, $\beta=1$. Further structural characterization of the $\beta$-Ga$_2$O$_3$ nanowires was performed using TEM. As shown in Fig. 4(a), the image reveals that the surfaces of the nanowire are smooth without any step edge and sheathed amorphous phase. Moreover, there is no additional metal particle appeared at the ends of the wires, implying a non-VLS approach for the growth of the straight $\beta$-Ga$_2$O$_3$ nanowires is achieved. Fig. 4(b) shows a high-resolution TEM image of the individual nanowire. The insert shows a corresponding selected area electron diffraction pattern.
Fig. 4 (a) High resolution TEM image of individual nanowire. (b) Lattice image of the individual nanowire, and a corresponding selected area electron diffraction pattern (inset).

The composition of the Gallium oxide nanowires is confirmed by EDX. As shown in Fig. 5, the EDX spectrum reveals that the nanowires are composed of gallium and oxygen without any additional metal. Quantitative analysis shows that the atomic ratio of Ga : O is about 2:3. The Raman spectrum of the $\beta$-Ga$_2$O$_3$ nanowires is shown in Fig. 6. The peaks appeared in this spectrum are consistent very well with the FT-Raman spectrum of the $\beta$-Ga$_2$O$_3$ nanowires produced by arc discharge [15].

Fig. 5 EDX spectrum of the $\beta$-Ga$_2$O$_3$ nanowires on a fused silica substrate.
To examine the optical properties of the $\beta$-Ga$_2$O$_3$ nanowires, the photoluminescence (PL) measurement was conducted at room temperature. As shown in Fig. 7, the broad PL emission band is mainly located in the UV region with its maximum intensity centered at 375 nm.

CONCLUSION

Large scale of straight Ga$_2$O$_3$ nanowires was synthesized on a fused silica substrate by a simple catalyst-free CVD method using Ga metal and N$_2$ / H$_2$O reactants. The Ga$_2$O$_3$ nanowires, which have diameters ranging from 60 to 150 nm and lengths of several micrometers, are
identified to be monoclinic Ga$_2$O$_3$ using XRD. PL emission band centered at 375 nm are observed at room temperature.

ACKNOWLEDGMENTS

The authors would like to thank Dr. K.H. Chen and Prof. Y. Chen for technical support. The financial support of this work, by the National Council in Taiwan under contracts No. NSC 89-2214-E-006-052, is gratefully acknowledged.

REFERENCES