

the transparency necessary for the self-waveguided propagation are sustained intact in the materials after the melt-recrystallization. The observed ASEs are also associated with the highly ordered molecular alignments, again maintained after melt. Once ASE has been established for various conjugated crystalline materials, the injection lasing is expected to be achieved on suitably constructed device configurations.

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Synthesis of Ultra-Long and Highly Oriented Silicon Oxide Nanowires from Liquid Alloys

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In recent years, nanoscale one-dimensional materials have attracted much attention due to their remarkable physical properties and their great potential for nanoscale electronics and optoelectronics.^[1] Nanowires and nanotubes made of many different materials have been synthesized, including C,^[2] Si,^[3,4] SiO₂,^[5-10] GaN,^[11,12] ZnO,^[13] etc. Silicon oxide, as a good candidate for photoluminescence materials, has been studied extensively.^[14-17] Several methods have been discovered to produce amorphous silicon oxide nanowires, including laser ablation,^[5] sol-gel,^[6] thermal evaporation,^[7] and chemical vapor deposition (CVD).^[8-10] In most of the cases, the underlying growth mechanism of the nanowires is either

vapor-liquid-solid (VLS) deposition, which requires a nano-sized catalyst as the seed for growth, or templated growth, where the nanowires are made within confined one-dimensional templates such as anodic alumina.^[6] Here, we report a new method to synthesize bulk quantity, ultra-long, uniform, and well-aligned silicon oxide nanowires on millimeter-sized liquid Ga balls. Silicon oxide nanowires up to 5 mm in length can be made routinely. To the best of our knowledge, this is the first time such long and highly oriented silicon oxide nanowires have been prepared. In addition, unlike other VLS methods for the growth of nanowires, one of the reactants (Si) comes from the solid substrate, which reacts with gaseous water vapor to form nanowires on the surface of a liquid Ga ball. It is possible that this approach can be extended to the preparation of other nanomaterials.

The discovery was actually made by accident. Our initial attempt was to make GaN nanowires following a reported method.^[11] The equipment used in the study is a simple CVD system made of a tube furnace, a quartz or alumina tube, and flow meters. A drop of liquid Ga was placed on a Si wafer freshly etched in dilute HF and placed in an alumina boat at the center of the tube furnace. More Si wafers with Fe nanoparticles on top were placed downstream for the growth of GaN nanowires. NH₃ was used as both a carrying gas and reactant for GaN formation. The furnace was heated to 920 °C for 3 h and slowly cooled to room temperature. To our surprise, in addition to the growth of GaN nanowires on the Si wafers with Fe catalyst, similar to previous reports,^[11] the Ga ball on the Si wafer is covered with a thick layer of white hair-like structures with a thickness of a few millimeters. Figure 1a shows a picture of the product. The ball is white in color and the diameter is ~10 mm. It was broken into two halves to show the inside. Mol-

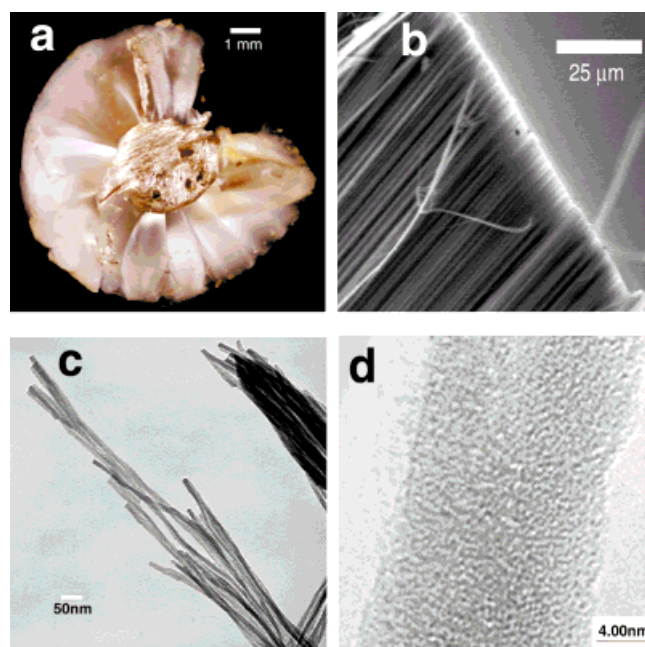


Fig. 1. a) A camera picture of the SiO_x nanowires product. b) SEM image of oriented silicon oxide nanowires. c) TEM image of SiO_x nanowires. d) HRTEM image of SiO_x nanowires.

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ten gallium still occupied the center of the ball. Highly ordered and millimeter-long wires extended from the gallium ball. A scanning electron microscopy (SEM) image (Fig. 1b) shows that the nanowires are very well aligned. By following through the whole length of the aligned nanowires, we observed no sudden change in regularity, which indicated that the nanowires are well aligned throughout the whole length. Energy dispersive X-ray (EDX) analysis indicated that the nanowires are composed of only Si and O and the atomic ratio is about 1:1.5. No metal was found in the nanowires. Such observation showed that the observed white “hair” is made of highly oriented SiO_x nanowires. Further studies have convinced us that NH₃ is not responsible for the growth of the SiO_x nanowires, and similar nanowires can be made by using wet H₂ or wet Ar as carrying gas. To avoid the complication of GaN formation, we focus on the nanowires grown using wet H₂ as carrying gas.

Transmission electron microscopy (TEM) (Fig. 1c) shows the general morphology of the SiO_x nanowires. It is clear that the nanowires have a high purity and a uniform diameter distribution around 12 nm. Among all the nanowires we observed, none have nanoparticles attached at the tip. High-resolution TEM (HRTEM) observations (Fig. 1d) show the SiO_x nanowires microstructure. The nanowires are amorphous and homogeneous without elemental Si cores inside. X-ray photoelectron spectroscopy (XPS, Fig. 2) also confirmed the

formation of silicon oxide nanowires. With a non-monochromatized Mg Kα X-ray as the excitation source, two peaks at 106.5 eV for Si^{IV} 2p and 536.5 eV for O^{II} 1s from the nanowires were identified.

All the experimental data shown above clearly indicated that we have made well-aligned, long, and uniform SiO_x nanowires. How did these nanowires grow? The normal VLS mechanism is not applicable to explain the growth of SiO_x nanowires since no nano-sized metal balls were observed at the tip of the nanowires. In addition, we do not have a gaseous Si precursor to feed the growth of the nanowires as is the case for most CVD methods. We have performed a series of experiments to understand the growth mechanism of the nanowires. We first proved that the Si source for the nanowires growth was the Si wafer on which the Ga ball was placed. We have observed that after each experiment, the Si wafer under the Ga ball was partially dissolved forming a hole. The only other possible Si source is the evaporation of Si and SiO_x from the quartz tube. We have ruled it out because similar results can be obtained using an alumina tube. In addition, if the Si wafer were first oxidized in air to form a SiO₂ protection layer before adding Ga metal, no growth of nanowires could be observed under the same experimental conditions. We have also observed that moisture is an important factor for the growth of nanowires. Growth of SiO_x nanowires was observed in both wet H₂ and wet Ar but not in dry Ar. Based on these observations, we have proposed the following growth mechanism. The Si wafer was first dissolved in molten Ga at elevated temperature; the solubility of Si in Ga at 920 °C is ~10 at.-%.^[18] Then, the dissolved silicon was oxidized by the water vapor through the following reaction:



Since silicon oxide is not soluble in gallium, it had to precipitate out of the solution in a certain form. This is the driving force for nanowires growth. The growth of SiO_x nanowires can be broken down to four steps:

- the formation of clusters of SiO_x as nucleation centers on the Si–Ga melt surface due to the low solubility of SiO_x in Ga
- the growth of the SiO_x nanowires
- the dissolving and diffusion of Si from the substrate to the Si–Ga melt surface due to the concentration gradient formed by the Si oxidation reaction
- the diffusion of nanowires on the surface of the molten Ga–Si to form well-aligned structures

The sphere shape of the final product indicates that the orientation of the nanowires is not caused by the flow of the carrier gas.^[4] We believe that overcrowding of the nanowires out of the Si–Ga melt is the main reason for the formation of the self-assembly. However, there still remain several questions about the mechanism: 1) Why is silicon oxide produced in the form of nanowires instead of other forms in the first place? 2) What determines the diameter of the nanowires and why is the diameter distribution so narrow? 3) Could a similar

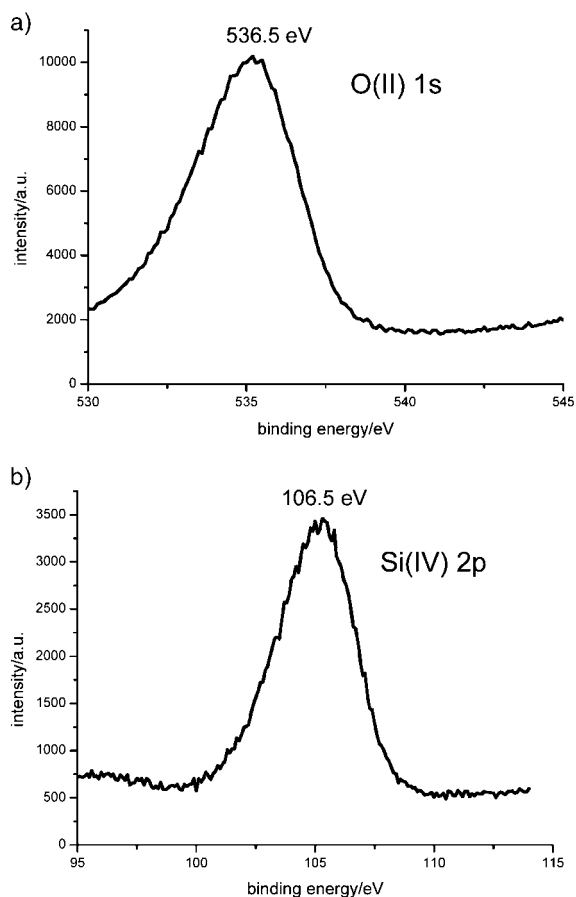


Fig. 2. XPS spectra of the SiO_x sample: a) O^{II} 1s. b) Si^{IV} 2p.

growth method be applied to the growth of nanowires made of other materials? These questions are the subject for further studies in our group.

In conclusion, we discovered a new method for synthesizing long and highly ordered amorphous silicon oxide nanowires in bulk quantities. The length of the nanowires can reach a few millimeters. These aligned nanowires have a great potential for use as intense blue light emitters.^[5,8,9] More work is underway to better understand the growth mechanism and to prepare nanowires with different diameters and/or different materials.

Experimental

SiO_x nanowires were prepared in a typical CVD setup equipped with a one-inch tube furnace and gas flow controller. P-type Si(111) wafers were ultrasonically cleaned in acetone for 5 min, then etched in 10 % HF for 5 min, and finally rinsed in deionized water. A drop (0.3 g) of molten gallium (99.999 %) was placed on a Si wafer, which was then transferred into the center of a 1-inch-diameter quartz tube inside the tube furnace. Another small alumina boat with 1–3 mL deionized water was then placed inside the tube at the carrier gas entry point. The system was degassed under vacuum and purged with hydrogen at 200 sccm for 10 min before the starting materials were heated. The reaction temperature was ~920–940 °C and the reaction time was 1–3 h. During the reaction, the hydrogen flow rate was constant at 30 sccm. After the furnace was slowly cooled down to room temperature, one or several pearl-like white balls were found on the Si wafer.

The as-grown SiO_x nanowires were analyzed by SEM (HITACHI S-3200N) at 5 kV. The microstructure characterization was carried out using TEM (Philips 301) at 80 kV. The HRTEM image was taken in a Philips CM-200 microscope operated at 200 kV. The chemical compositions were determined by an XPS instrument (Riber MIQ 236) and by an EDX spectrometer attached to the SEM instrument.

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Imaging Transport Disorder in Conducting Arrays of Metallic Quantum Dots: An Experimental and Computational Study**

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Self-assembled quantum dot (QD) artificial solids^[1,2] can serve as model systems for interrogating fundamental solid-state physical phenomena.^[3] In such solids, the site charging energy,^[4] the nature and strength of dot–dot interactions, and the symmetry of the lattice are all subject to experimental control,^[5] and so these artificial solids may be manipulated, through chemical and physical control, into systems specifically designed for interrogating complex phenomena such as quantum phase transitions.^[6] One distinct advantage of QD solids is that the fundamental building block is a nanoparticle, rather than an atom. This opens up the possibility of coupling high-resolution imaging experiments^[7] with more traditional charge transport measurements,^[8,9] and therefore allows for a direct correlation of the structural characteristics of the artificial solid with electrical measurements. If the nanoparticles are simple metals, then the dominant electronic characteristic that contributes to the collective electronic properties of the superlattice is the single electron energy. This implies the possibility of quantum mechanical calculations that can explicitly address, for a statistically significant number of dots, how the details of crystallographic packing and size-distribution disorder impact superlattice electronic structure,^[10] and therefore electron transport phenomena.

At sufficiently small interparticle separation distances, the electrical response of a QD solid can be a collective one,

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