Synthesis and photoluminescence of aligned SiO$_x$ nanowire arrays

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ABSTRACT Aligned SiO$_x$ nanowire arrays standing on a Si substrate were successfully synthesized using a simple method by heating a single-crystalline Si slice covered with SiO$_2$ nanoparticles at 1000°C in a flowing Ar atmosphere. The SiO$_x$ nanowire arrays were characterized by scanning electron microscopy and transmission electron microscopy. The SiO$_x$ nanowires become progressively thinner from bottom to top. The formation process of the SiO$_x$ nanowire arrays is closely related to a vapor–solid mechanism. Room-temperature photoluminescence measurements under excitation at 260 nm showed that the SiO$_x$ nanowire arrays had a strong blue–green emission at 500 nm (about 2.5 eV), which may be related to oxygen defects.

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1 Introduction

Recently, nanostructured arrays [1–4] have attracted much attention in theoretical studies and for potential applications in nanotechnology and nanodevices. These arrays have been synthesized using different methods, such as template methods (including anodic-alumina templates [1, 2] and polymer templates [3]), self-organization methods [4], and so on. Recently, one-dimensional (1D) silica nanostructures have attracted considerable attention because of their potential application in the high-resolution optical heads of scanning near-field optical microscopes and future nano-interconnection integrated optical devices [5]. On the basis of the vapor–liquid–solid (VLS) growth mechanism, silica nanowires have been synthesized by laser ablation [5] and thermal evaporation [6]. In contrast, silica nanotubes and nanofibers have also been synthesized via a vapor–phase process [7]. All the above-mentioned 1D-silica nanostructures were randomly oriented. In this communication, we report a simple method for the synthesis of aligned SiO$_x$ nanowire arrays. These SiO$_x$ nanowire arrays, grown on a Si substrate, were obtained from a Si slice covered with SiO$_2$ nanoparticles at 1000°C. We have also studied the photoluminescence properties of these nanowire arrays and we have found that there exists a blue–green emission from these arrays at room temperature, peaking at 500 nm (about 2.5 eV).

2 Experimental

The experimental procedure was as follows: A single-crystalline Si slice was cleaned by H$_2$O$_2$ and a HF aqueous solution. The Si slice was then placed in a ceramic boat and covered with some SiO$_2$ nanoparticles (about 70 nm in diameter). The boat was then placed in a ceramic tube with a 25-mm inner diameter and heated in an apparatus using silicon–carbon rods in a horizontal electronic-resistance furnace. The system was rapidly heated to 1000°C and kept at this temperature for 60 min in a flowing Ar atmosphere (160 sccm). After the system had cooled to room temperature, a thin layer of wool-like product was found on the Si slice. The as-synthesized products were characterized by SEM (JEOL JSM 6300), TEM (JEOL 2010, operated at 200 kV) and energy-dispersive X-ray fluorescence (EDX) (EDAX, DX-4), attached to the JEOL 2010. For SEM observations, the as-synthesized product was pasted on an Al substrate by carbon conducting paste. For TEM investigations, the as-synthesized product was briefly ultrasonicated in ethanol, and then a drop of the suspension was placed on a holey copper grid with carbon film behind. The photoluminescence (PL) spectrum was obtained using a Hitachi 850-fluorescence spectrophotometer excited at 260 nm with a filter at 310 nm and a Xe lamp at room temperature.

3 Results and discussion

Figure 1a shows the SEM morphology of the SiO$_2$ nanoparticles on the Si substrate before heating the system. Figure 1b and c show the typical SEM morphologies of the as-synthesized product. It can be observed that all the nanowires are parallel to each other and perpendicular to the Si substrate, and form self-oriented, regularly aligned arrays. Furthermore, the diameter of each nanowire becomes smaller and smaller from the bottom to the top, which may be attributed to the decrease
in SiO$_x$ vapor in the later deposition process.

Figure 2a shows a TEM image of a single nanowire. The inset is the corresponding selected-area electron diffraction (SAED) pattern recorded from the nanowire. It can be seen that the nanowire is about 70 nm in diameter and of an amorphous state, indicated by the highly diffusive SAED ring pattern. The corresponding EDX spectrum shown in Fig. 2b reveals that the nanowire consists of Si and O, with an atomic ratio of Si : O = 1 : 1.4.

The PL spectrum from a bulk quantity of SiO$_x$ nanowire arrays is shown in Fig. 3. There exists a strong blue-green emission from these nanowire arrays, with a peak at about 500 nm (about 2.5 eV). The PL of various silica glasses and nanowires has been studied extensively [8–11], because amorphous SiO$_2$ films are widely used as passivation or insulation layers in integrated circuits.

Several luminescence bands in various silica glasses and nanowires, with different peak energies ranging from 1.9 to 4.3 eV, have been observed. It has been revealed that the 2.7 eV band can be attributed to the neutral oxygen vacancy ($\equiv$ Si – Si $\equiv$), while the 3.0 eV band corresponds to some intrinsic diamagnetic defect center, such as twofold-coordinated silicon lone-pair centers (O – Si – O). These defects are clearly due to a high oxygen deficiency dur-