CdS/SiO$_2$ nanowire arrays and CdS nanobelt synthesized by thermal evaporation*

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Abstract: CdS/SiO$_2$ nanowire arrays and CdS nanobelts were synthesized by thermal evaporation of CdS and CdO mixture powders, with highly selective etching occurring on the silicon substrate surfaces. Study of the growth mechanism of CdS/SiO$_2$ nanowire arrays and the growth process of CdS nanobelts showed that the growth of CdS dendrites plays an important role in the formation of CdS/SiO$_2$ nanowire arrays, and that the mechanism of CdS/SiO$_2$ nanowire arrays growth was in good agreement with “self-assembling nanoelectrochemistry”. In the thermal evaporation process, an interaction between Si from silicon substrate and Cd took place.

Key words: CdS/SiO$_2$ nanowire arrays, CdS nanobelts, CdS dendrites, Self-assembling nanoelectrochemistry

INTRODUCTION

The richness of fundamental phenomena and the potential applications in nano-technologies has aroused rapidly growing interest in nano-dimensional materials. Quasi-one-dimensional (1D) nano-semiconductors in the form of nanowires and nanoribbons have recently been successfully fabricated in many laboratories and by many methods (Wu et al., 2004; Yang et al., 2005; Gan et al., 2004; Soumitra et al., 2006). To synthesize CdS nanowires, people have developed a series of synthetic methods, such as atmosphere pressure chemical vapor deposition (Ge and Li, 2004), solvothermal synthesis CdS nanowires in high yield (Jin et al., 2005), sacrificial template growth of CdS nanotubes from Cd(OH)$_2$ nanowires (Li et al., 2006), CdS nanowires synthesized in microemulsion system (Fu et al., 2004), CdS/Si coaxial CdS/Si coaxial nanowires fabricated via a simple one-step thermal evaporation of CdS powder (Fu et al., 2006). The most popular method is using anodic porous alumina template (Wang et al., 2005; Xu et al., 2000; Yang et al., 2002), with the growth mechanism being usually understood as space-limited nucleation followed by growth along the template channels. However, the process of preparing anodic porous alumina template is very complex and controlling the size of pores is difficult. Therefore, the synthesis of aligned nanowires is an important topic worthy of exploration. Recently Tsinghua University Zhu Jing group found that large-area silicon nanowire arrays could be formed on silicon substrates when they are immersed into aqueous HF solution containing silver nitrate (Peng and Zhu, 2003). To explore the possible general use of this method and also the origin of the silicon nanowire arrays formation in HF-based etching solution, one new mechanism—the so called “self-assembling nanoelectrochemistry”, which is based on the local passivation of the Si dissolution induced by the growth of metal nuclei—was proposed.

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for the formation of Si nanowire arrays. It was suggested that numerous nanometer-sized electrolytic cell arrays could be spontaneously assembled on the surface of silicon substrates in ionic metal HF solution. So that it is believed that highly selective etching could occur on the silicon substrate surface due to the presence of the nanometer-sized electrolytic cell arrays.

In this paper, we demonstrate that CdS/SiO$_2$ nanowire arrays could also be created on silicon substrate, which is not immersed in HF etching solution. On the surface of Si substrate compact CdS dendrite film and large areas CdS/SiO$_2$ nanowire arrays are always found.

EXPERIMENTAL PROCESS

Sample preparation

The equipment used for the present work is similar to that described previously. An alumina tube was mounted inside a tube furnace. Three grams CdS (99.999%) and CdO (99%) mixture powders (mass ratio=1:1) were placed near the middle of the high-temperature zone of the furnace. Ten polished silicon substrates about 5 mm wide and 10 mm long were ultrasonically cleaned in acetone, ethanol, deionized water for 20 min each, dipped in 20% HF for 20 min. And then, all the substrates were placed abreast at the alumina tube. The right side of the first Si substrate is apart from the left side of the source material 9.5 cm. The tube had previously been evacuated to a base pressure of 10$^{-2}$ torr by a mechanical pump before the starting materials were heated. The carrier gas of Ar admitted at the other end of the alumina tube flowed at 50 sccm (standard cubic centimeters per minute) at 300 torr after that, The temperature of the furnace was increased to 1150 °C and kept at the temperature for 1 h.

Characterization methods

The as-prepared product was first directly examined by scanning electron microscopy (SEM). Micro-structural characterization was carried out in a transmission electron microscopy (TEM) at accelerating voltage of 200 kV. The chemical compositions of the samples were determined by an energy dispersive X-ray (EDX) spectrometer attached to the SEM.

RESULTS AND DISCUSSION

The deposit CdS/SiO$_2$ nanowire arrays product includes two colors with yellow upside and white underside. The chemical composition of deposition is determined by X-ray energy dispersion (EDX) attached to SEM. The results showed that the white is SiO$_2$ and the yellow is CdS. SEM showed that continuous CdS dendrites and porous structure are on the silicon substrate (Fig.1a). From Fig.1a it also could be found that there are many yellow particles with the same color as the CdS powders. Dense oriented CdS/SiO$_2$ arrays could be observed in areas where continuous CdS dendrites are formed. Most of these oriented CdS/SiO$_2$ nanowire arrays grow normally on the silicon substrate surface and band together in bundles (Fig.1b). Fig.1c shows a high-magnification SEM image of nanowire arrays. Continuous CdS dendrites could be found at the CdS/SiO$_2$ nanowires end. Fig.1d is a porous structure cross section, showing that uniform diameter SiO$_2$ nanowire arrays aggregated together are quite clean, with very few particles attached to its surfaces. Further sample characterization was carried out by TEM. The selected-area electron diffraction (SAED) pattern of these CdS/SiO$_2$ nanowire arrays is given in the inset of Fig.1d, showing that the nanowire arrays’ microstructure is amorphous. Fig.2a is a high-magnification of the yellow particle in Fig.1a, showing many CdS nanobelts, some of which are curved to an angle without being broken, which suggests that the nanobelts are very flexible. For a typical nanobelt, the width decreases along the growth direction. Fig.2b shows an SEM image of single nanobelt with width of 2.6~33.3 µm. The SAED pattern of the nanobelts is shown in the inset of Fig.2a showing that the nanowire arrays’ microstructure is a single-crystal.

Our experimental results revealed that the HF solution concentration plays an important role in determining the morphology of CdS dendrites and silicon substrate. When the HF solution concentration is less than 10%, pure CdS nanowires could be obtained. The silicon substrate begins to dissolve absolutely when the HF solution concentration is higher than 40%.

To investigate the source composition on silicon substrate, CdS powders are used instead of CdS and