Facile Synthesis and Properties of Single-Crystal SnO_2 Nanostructures

Oleg LUPAN, Vasilii CREŢU, Serghei RAILEAN
Technical University of Moldova
railean@mail.utm.md

***Abstract* — Single-crystal tin oxide (SnO_2) nanostructures with rutile structure have been synthesized through a facile hydrothermal process. The morphologies and structural properties of the nanorods/nanoneedles/nanowires were characterized by scanning electron microscopy (SEM), selected area electron diffraction (SAED), and X-ray diffraction (XRD). The SEM images reveal tetragonal nanoneedles in cross-sectional view. The XRD peaks indicate a typical rutile phase of the SnO_2. The effects of the synthesis parameters on the growth mechanism are discussed.**

***Index Terms* — SnO_2, nanostructures, rutile, SEM, nanoscale materials.**

I. INTRODUCTION

Quasy-one-dimensional (Q1-D) nanoarchitectures, such as nanowires, nanorods, and nanoneedles have been synthesized and attracted great attention in the materials research community [1]. This attention is motivated by the physical and chemical properties, which are highly dependent on the aspect ratio and shape and can enhance sensorial properties [1-3]. In this context, rutile tin oxide SnO_2, an *n*-type semiconductor with a wide band gap (E_g=3.62 eV at 300 K), and excellent optical and electrical properties, is a strategic material for a range of technological applications [4]. Its uses include ultra-sensitive gas sensors [5], optoelectronic devices [6], and anode material for lithium batteries [7].

Tin oxide nanostructures have been grown by the vapor-liquid-solid (VLS) method [6], chemical vapor deposition [8], thermal evaporation [1, 9], etc. All these techniques require a high growth temperature (about 900 °C or higher), which makes them difficult for certain device applications [10]. Guo et.al [11] has reported a low-temperature hydrothermal synthesis of SnO_2 nanorods at 160 °C, but the process requires at least 12 h. Vayssieres and Graetzel [12] reported SnO_2 nanorods arrays grown on F-SnO_2 glass substrates by aqueous thermohydrolysis at 95°C for 2 days.

In this work, a facile and rapid hydrothermal method was used to synthesize long SnO_2 nanoneedles at low temperature (95°C). The microstructures of the synthesized SnO_2 nanoneedles/nanowires were investigated by SEM, X-ray diffraction and SAED techniques.

II. EXPERIMENTAL

Rutile-structured SnO_2 nanoneedles/nanowires were synthesized at a low temperature via hydrothermal method without any other seeds, templates or surfactant. A solution containing tin chloride [$SnCl_4 \cdot 5H_2O$, 0.01M-0.03M] (purity 99.5%) and ammonia [$NH_4(OH)$, 29.5%] (Fisher Scientific) was employed for growth of tin oxide nanoneedles and nanowires. Both reagents were used in the received form without further purification. A hydrothermal reactor [2-3,13] with a cap was filled with aqueous solution. More technological details can be found in our previous work [2-3,13].

III. RESULTS AND DISCUSSIONS

Figure 1 shows the XRD patterns from the tin oxide samples which demonstrates the SnO_2 tetragonal rutile structure with lattice constants *a*=*b*=0.4743 nm and *c*=0.3186 nm, which match well with the standard XRD data file of SnO_2 (JCPDS-041-1445)(ICSD data) [14]. The peaks were sharp indicating high crystallinity of SnO_2 nanoneedles.

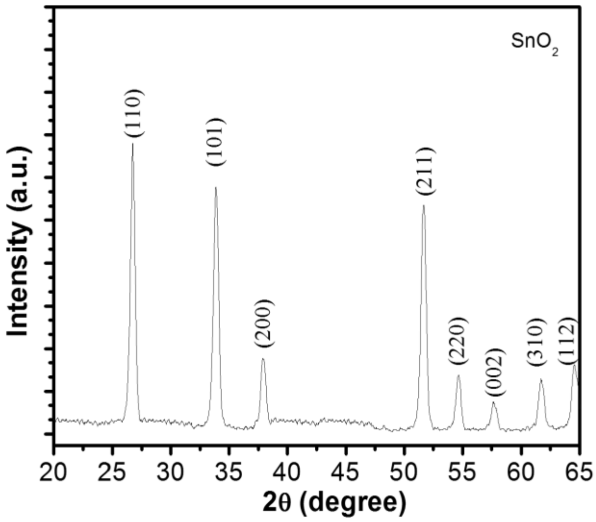

Fig. 1. X-ray diffraction XRD pattern of SnO_2 nanostructures.

Figure 2 shows the SEM morphologies of the SnO_2 nanoneedles/nanowires prepared through the hydrothermal reaction. The nanoneedles have a uniform length of about 10-20 μm and diameters of about 0.1-0.2 μm (Fig 2a). In the inset of Figure 2 the end planes of the SnO_2 nanoneedles clearly reflect the tetragonal symmetry.

The morphology of nanoneedles was found to be dependent on the synthesis conditions. The dimensions and aspect ratio are a function of growth time, temperature and Sn^+/OH^- ratio in solution (not shown here).

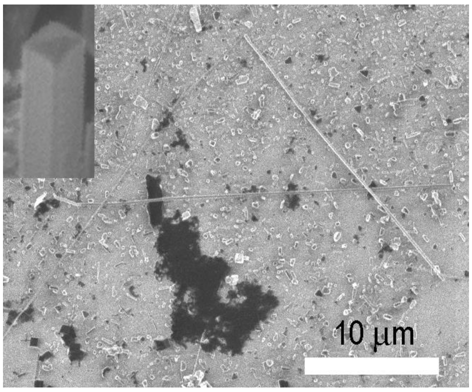

Fig. 2. SEM image of SnO_2 nanostructures and inset is the end planes of the SnO_2 individual nanowire.

Thus, by this method, we also synthesized SnO_2 nanorods and thinner nanowires by decreasing the concentration of $SnCl_4$ in solution. The products consisted of nanowires as well as nanoparticles. The diameters of tin oxide nanowires are in the range of 100-150 nm with lengths of the order of 20-100 μm.

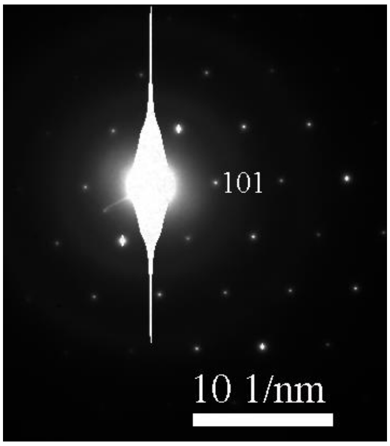

Fig. 3. SAED image of SnO_2 nanostructures.

A typical selected-area electron diffraction (SAED) pattern (Fig 3), indicates that the nanowires are high quality with rutile SnO_2 structure. According to the SAED pattern taken, the growth direction of SnO_2 nanoneedles is along [101] direction. This is in agreement with reports [15].

IV. CONCLUSION

In summary, we investigated the synthesis of SnO_2 nanoneedles/nanowires by a low-temperature hydrothermal method at relative low temperature. The as-grown SnO_2 nanoneedles have diameters of 100 nm and lengths of 10-20 μm. The individual straight nanoneedles have a rectangular cross-section. The SAED and XRD pattern demonstrates that the nanoneedles/nanowires are single crystalline SnO_2 with rutile structure.

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