

Growth, characterization and I-V characteristics of tin oxide (SnO₂) nanowires

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ABSTRACT

One-dimensional wire shaped tin oxide (SnO₂) nanostructures have been synthesized by thermal evaporation method. The growth of SnO₂ nanostructure was carried out on gold catalyst layer coated silicon substrate. X-ray diffraction (XRD) results reveals that synthesized SnO₂ nanowires have polycrystalline nature with tetragonal rutile structure. SEM, TEM and EDX observation concludes that the uniform SnO₂ nanowires (diameter ~ 40 nm and length ~ 50 μm) grow with vapor-liquid-solid (VLS) mechanism. I-V characteristics of single SnO₂ nanowire show semiconducting behaviour. Due to structural and electrical properties of SnO₂ nanowire, these nanowires would be a promising candidate for gas sensing applications.

Keywords: SnO₂; nanowire; gold; TEM; thermal evaporation.



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Introduction

Quasi-one-dimensional (1D) nanostructures have unique electronic, optical, and mechanical properties [1] due to their low dimensionality and the quantum confinement effect. As a semiconductor, tin oxide (SnO₂) has been intensively explored with regard to its synthesis and applications [2]. Tin dioxide (SnO₂) is an n-type

semiconductor with a wide band gap ($E_g = 3.62$ eV, at 300 K) and is well known for its potential applications in gas sensors [3], dye-based solar cells [4], transparent conducting electrodes [5], optical devices [6] and electronic devices [7]. The various growth techniques used for SnO₂ nanomaterials are laser ablation [8], electro-deposition [9], hydrothermal treatment [10], thermal decomposition, thermal evaporation [11] and template free synthesis [12]. Thermal evaporation technique seems to be the most popular process due to its simplicity, low-cost infrastructure and high throughput. 1 D tin oxide may be formed in the form of tubes [13], belts [14], rods, wires [15] and sheet, and these structures with high aspect ratio (i.e., size confinement in two coordinates) offer better crystallinity, higher integration density, and lower power consumption. Motivated by applications of tin oxide nanostructures, numerous efforts have been made to control the size and shape of SnO₂ nanostructures. Controlling the morphology of SnO₂ nanomaterials is critical to the development of new devices.

In present work, we have focused on the growth of tin oxide nanostructures so that they can offer a higher sensitivity for gas sensing application. For this purpose, the SnO₂ nanostructures were grown on Au coated Si substrate. The synthesized product was characterized by SEM, XRD, EDX, TEM spectroscopy and I-V measurements for analyzing surface morphology, crystal structure, composition and electrical properties.

This efficient, cost effective and energy saving method allows the preparation of SnO₂ nanowires in large quantity. We believe that the presented approach is a simple one to

synthesize SnO₂ nanostructures for the practical application of gas sensing in which structural properties play a key role.

Experimental

Silicon wafer [N-type (100)] was used as a substrate for the growth of SnO₂ nanostructures. First, the Si substrate was atomically cleaned by using Isopropyl alcohol (IPA) with ultrasonic vibrations for removing dust and organic substance, a mixture solution of H₂SO₄ and H₂O₂ for removing the grease and inorganic impurities, and 10% HF solution for removing the native SnO₂. The gold (Au) catalyst thin film (~ 50 nm) was then deposited on the Si surface in radio-frequency (RF) sputtering chamber at the pressure of 1×10^{-6} mbar and 100 watt power. Next, the synthesis was carried out at an elevated temperature in a horizontal tubular furnace. Analytically pure SnO₂ and Graphite (4:1) powder were thoroughly mixed and then used as a source powder and gold (Au) coated silicon substrate (Au/Si) was used as substrate for the synthesis of products. The source powder was loaded into the maximum temperature zone and substrate was loaded at the downstream end of the tubular furnace. Then Nitrogen (N₂) gas was introduced into the tubular furnace and kept flowing at a rate of 1 liter/min. The furnace was allowed to heat up to a temperature of 1100°C and samples were processed at 1100°C for 120 minutes. Finally, the substrate was cool down to the room temperature and then unloaded from the furnace. A gray colour film was found on processed Au/Si substrate. The as-synthesized products were characterized and analyzed with Scanning Electron Microscopy (SEM) by using ZEISS (EVO-50), X-Ray diffraction microscopy (XRD) with Cu Ka radiation ($\lambda = 0.1542$ nm), Energy Dispersive X-Ray Spectroscopy (EDX) using RONTEC instrument, Transmission Electron Microscope (TEM) using Philips CM12 and I-V measurement setup (Summit-11000M).

For electrical properties measurement of single SnO₂ nanowire, as-synthesized SnO₂ nanowires were dispersed in alcohol by ultrasonication process and then deposited on the pre-deposited gold (Au) electrode substrate in a way that a single SnO₂ nanowire bridge-up between two gold electrodes. The electrical properties of single SnO₂ nanowire based device were demonstrated by using Probe station (Summit 11000M). The electrical properties of single SnO₂ nanowire were measured in nitrogen ambience at different temperatures ranging from 25 (RT) to 200°C. We have studied the effect of different measurement temperature on the electrical properties of single SnO₂ nanowire.

Results and discussion

Fig. 1 represents the morphology of the as-synthesized SnO₂ nanowires prepared by thermal evaporation method. These samples were annealed at 1100°C in the N₂ ambience. The surface morphological study concludes the growth of one dimensional wire-like SnO₂ nanostructures and these nanowires are homogeneously grown over large area on Au/Si substrates. The typical length of the SnO₂ nanowires is several tens of micrometers whereas, the

diameter is in nanometers. These wire like nanostructures were then characterized by TEM microscope for extracting their exact diameter.

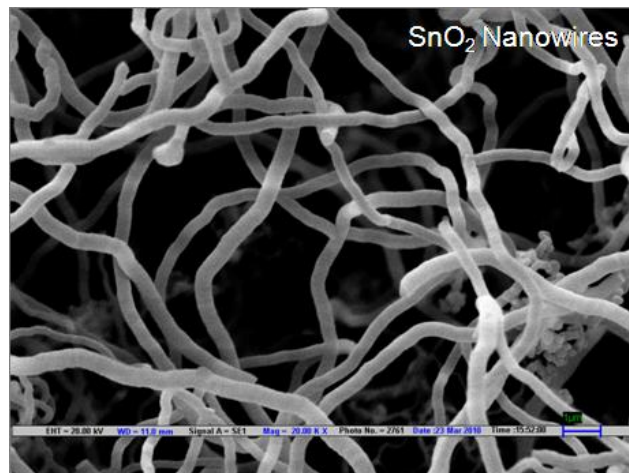


Fig. 1. Surface morphological description of SnO₂ nanowires by using scanning electron microscope (SEM).

The XRD pattern (**Fig. 2**) reveals the overall crystal structure and phase purity of the SnO₂ nanowires. All diffraction peaks can be indexed to the tetragonal rutile structure of SnO₂ with lattice constants of $a = 4.740$ Å and $c = 3.190$ Å. No characteristic peaks of impurities, such as elemental Sn or other tin oxides, were observed. The strong and sharp reflection peaks suggest that the high crystalline SnO₂ nanowires were successfully obtained through the present synthesis method.

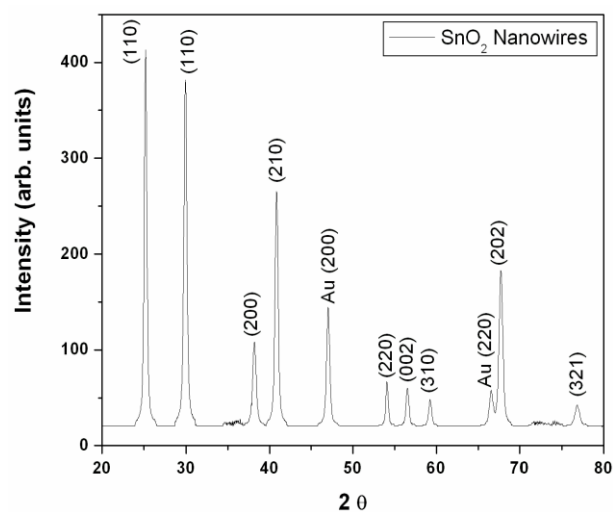


Fig. 2. XRD pattern of SnO₂ nanowires.

The chemical composition of as synthesized SnO₂ nanowires was investigated by EDX analysis. **Fig. 3** depicts the typical EDX spectra for SnO₂ nanowires. The EDX analysis of SnO₂ nanowires shows that the synthesized products consist of Au, Sn and O elements, which indicated that the nanowires are indeed made up of Sn and O only, thus suggested the high purity of SnO₂ nanowires. However, presence of Au confirms that the nanowires growth was initiated with the help of the Au

catalyst nanoparticle and during the growth process; the source powder decomposes, condenses on the nanoparticles and eventually nucleates in the form of Au nanoparticles alloy. After obtaining the super saturation, the nanostructures start growing outwards. This confirms the Vapor-Liquid-Solid (VLS) growth [13] of the SnO₂ nanowires. The impurities such as C and Cu in EDX spectra are due to Cu grids and carbon film on Cu grids.

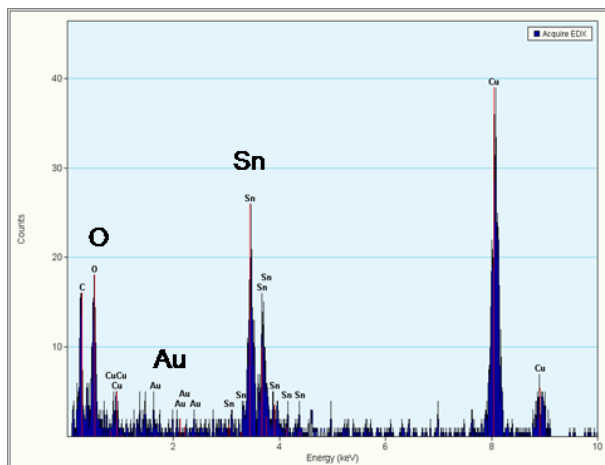


Fig. 3. EDX Spectrum of an individual SnO₂ nanowire.

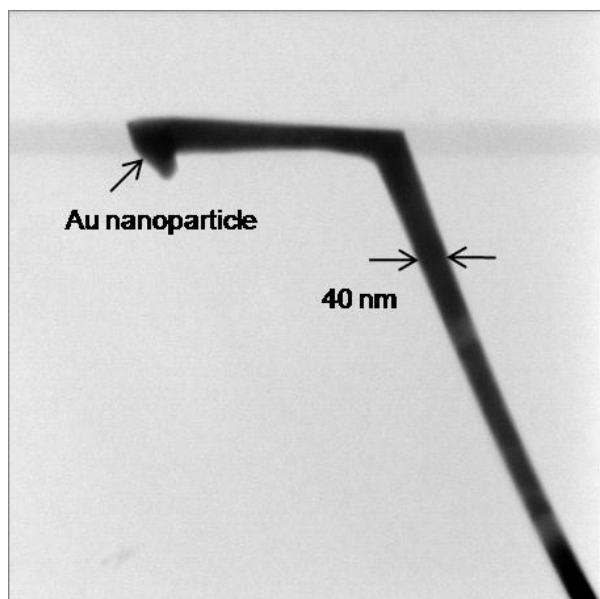


Fig. 4. TEM micrograph of an individual SnO₂ nanowire.

Fig. 4 shows the TEM micrograph of as-synthesized SnO₂ nanowires. The TEM study of SnO₂ nanowire concludes Vapor-Liquid-Solid (VLS) growth of the SnO₂ nanowires (diameter ~ 40 nm) on Au/Si substrate. The VLS growth of SnO₂ nanowire has been concluded due to the presence of Au nanoparticle on the tip of SnO₂ nanowire (as shown in Fig. 4). Fig. 5 shows the current-voltage (I-V) characteristics of single SnO₂ nanowire measured at different temperatures. The SnO₂ nanowire shows semiconducting behavior as the resistance of SnO₂ nanowire is decreasing with increase in the I-V

measurement temperature. The resistance of single SnO₂ nanowire was found to be about 5 MΩ at 200°C. The electrical properties (I-V) of as fabricated single SnO₂ nanowire device also show good ohmic behavior. The ohmic behavior is very important to the gas sensing properties, because the sensitivity of the gas sensor is affected by contact resistance. We have measured the I-V characteristics at temperature up to 200°C and found that there is no difference in the I-V curve.

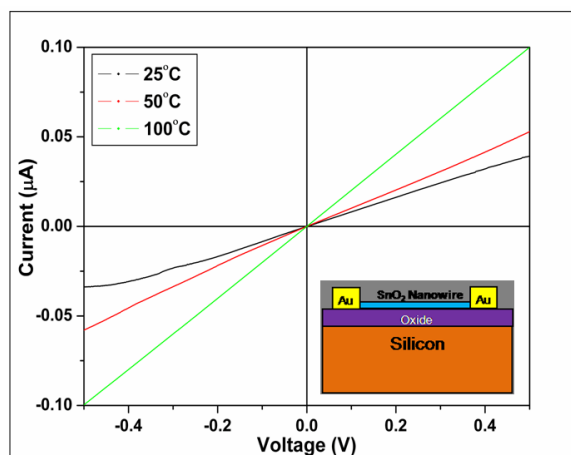


Fig. 5. I-V characteristics of an individual SnO₂ nanowire.

Conclusion

In summary, we have demonstrated that wire-like, homogeneous and enhanced crystalline SnO₂ nanostructures could be synthesized at atmospheric pressure also. The SnO₂ nanowires with diameter and length of ~40 nm and ~50 μm, respectively, obtained by SEM and TEM, have been successfully synthesized by using the thermal evaporation method. The VLS growth of SnO₂ nanowires on Au catalyst coated Si substrate were confirmed with TEM and EDX analysis. The XRD patterns confirmed the formation of tetragonal rutile SnO₂ nanowires and their polycrystalline nature. The electrical measurement of single SnO₂ nanowire shows semiconducting behaviour as the resistance of SnO₂ nanowire is decreasing with the increase in IV measurement temperature. As-grown SnO₂ nanostructures can be used as a sensing element in gas sensor.

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