The Preparation of SiO2 Nanotubes with Controllable inner/outer Diameter and Length using Hydrothermally Grown ZnO Nanowires

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1. Introduction

Recently, one-dimensional (1-D) inorganic nanotubes, such as ZnO, TiO2, Al2O3, ZrO2, and SiO2 etc., have attracted a lot of attention due to their unique properties, structural versatility, specific chemical and physical properties, which make much potential applications in nanoelectronic and optoelectronic devices [1]. Among various inorganic nanotubes, SiO2 nanotubes (SiO2-NTs) have attracted considerable interests owing to their hydrophilic nature, easy colloidal suspension formation, and surface functionalization accessibility for both inner and outer walls. Furthermore, silica nanotubes have the characteristic of their room-temperature light-transmission properties in the visible range, and possible usage for hosting materials in bioanalysis and bioseparation and potential applications in optoelectronic nanodevices [2-3]. The SiO2-NTs can be fabricated by various approaches such as surfactant intercalation method, electroless deposition, sol-gel technique, templated-assistance method, MOCVD method and thermal evaporation method [4-7]. However, these techniques are less suitable for commercial applications because of the high cost of equipments, small-scale production, long processing time, and requiring working in an ultra-high vacuum. To overcome these drawbacks, the synthesis of vertically aligned SiO2-NTs by deposition of SiO2 on hydrothermally grown Zinc-Oxide nanowires (ZnO-NWs) and then removal of the ZnO-NWs were reported in this study. The optical properties of the SiO2-NTs with superior transmittance performances were also investigated and discussed.

2. Experiments

Figure 1 illustrates the flowchart of SiO2-NTs fabrication. In experiments, ITO-glass was used as the substrate which was cleaned ultrasonically using acetone, methanol, rinsed in DI water, blown dry with N2, and then dipped into chemical solution (HCl:H2O = 3:1) for 10 min to remove the surface particle; and a 100 nm thick aluminum-doped-zinc-oxide (AZO) film was sputtered on ITO-glass substrates to serve as a seed layer for the growth of Zinc-Oxide nanowires (ZnO-NWs) and then removal of the ZnO-NWs were reported in this study. The optical properties of the SiO2-NTs with superior transmittance performances were also investigated and discussed.

3. Results and Discussion

Figure 2 shows SEM images of the key fabrication processes of SiO2-NTs as shown in Fig. 1(c) - 1(f). From Fig. 2(a), it can be observed that the hexagonal ZnO-NWs with an average length of 2 μm, average diameter of 20-200 nm, and high density of 2×10^6 cm^-2 were grown vertically-aligned on the AZO layer. Figure
2(b) shows the ZnO-NWs were firmly covered with CVD SiO$_2$. Figure 2(c) shows the SEM image of ZnO-NWs after CVD SiO$_2$ coating and ICP etching with the top view shown in the inset. As shown in Fig. 2(c), the top portion of the ZnO-NW arrays (~0.5 μm) was unveiled after the ICP dry-etching. In Fig. 2(d), it shows that SiO$_2$-NTs with inner diameter/length and thickness of the tube wall determined by the diameter/length of ZnO-NWs and thickness of the CVD SiO$_2$, respectively, were synthesized successfully after the removal of ZnO-NWs. SiO$_2$-NTs were observed anchoring firmly on AZO layer during measurements. Note that in the present case, the inner diameter, length, and thickness of the tube wall were 20-200 nm, 2 μm, and 10-100 nm, respectively.

Figure 3 show the EDS analyses of the ZnO-NWs, ZnO-NWs after CVD SiO$_2$ coating and ICP etching, and the SiO$_2$-NTs. The chemical components of the grown ZnO-NWs were confirms mainly comprising of pure metallic Zinc and oxygen. After ICP treatment and the removal of ZnO-NWs, the EDS analysis shows that the prepared NTs were mainly comprised of silica and oxygen without any residual ZnO.

Fig. 2 The SEM images of the sample at key fabrication step: (a) ZnO-NWs on AZO layer, (b) ZnO-NWs covered with CVD SiO$_2$, (c) the sample after ICP etching, (d) SiO$_2$-NTs formed after the removal of ZnO-NWs.

Fig. 3 The EDS analyses of ZnO-NWs, ZnO-NWs after CVD SiO$_2$ coating and ICP etching, and the SiO$_2$-NTs, respectively.

Figure 4 shows the transmittance of the prepared SiO$_2$-NTs grown on AZO film. The prepared SiO$_2$-NTs was seen having a superior transmittance (92%) compared with that of ZnO-NWs (80%) in the visible light spectrum ranging from 400 to 800 nm. The room-temperature transparent properties would have great potential in optics, optoelectronics, and bio devices. Applications of SiO$_2$-NTs on the surface of solar cells to increase their light collection efficiency are now under way.

Fig. 4 The transmittance of the ZnO-NWs, ZnO-NWs after CVD SiO$_2$ coating and ICP etching, and the SiO$_2$-NTs, respectively.

4. Conclusion

In summary, the fabrication and optical properties of SiO$_2$-NTs have been demonstrated. The SiO$_2$-NTs with tunable inner and outer diameters and lengths have been synthesized successfully by a simple method using SiO$_2$ deposition on a hydrothermally grown ZnO-NWs template and then followed by the removal of the ZnO-NWs. A superior transmittance of around 92% of SiO$_2$-NTs in the visible light spectrum, which is higher than that of ZnO-NWs of the same geometry by about 12%, was reported in this study. The proposed SiO$_2$-NTs fabrication method would provide a simple and low-cost building block for future applications and developments of optic and optoelectronic devices.

Acknowledgments

This work was supported by the National Science Council (NSC) of Taiwan, under Contract No. NSC 96-2221-E-006-285-MY3, NSC 96-2221-E-006-081-MY2, and NSC 97-2221-E-274-013. The authors would like to thank the Advanced Optoelectronic Technology Center, the National Nano Device Laboratories, and the Center for Micro/Nano Science and Technology, National Cheng Kung University, Taiwan, for equipment access and technical support.

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