Fabrication of Ge Nanotubes Using Zinc Oxide Nanowires as Templates

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Introduction

As the size of the semiconductor materials reduces to the nanoscale, the electrical and optical properties can be improved due to its high surface ratio, high integration density, and light trapping effect. There are many kinds of semiconductor nanomaterials, such as nanoparticles (NPs), nanowires (NWs), etc. Recently, nanotubes (NTs) have been attracting much attention for its much higher surface ratio. In my previous work, silicon (Si) NTs have been fabricated successfully. Since germanium (Ge) has much higher electron and hole mobilities and smaller band-gap than Si, it can be applied to the anode material in lithium-ion batteries [1], next-generation NT transistors [2], light emitted diodes [3] and so on.

In this study, we focus on fabricating GeNTs and controlling the growth parameters by wet-etching of ZnO/Ge core-shell NWs.

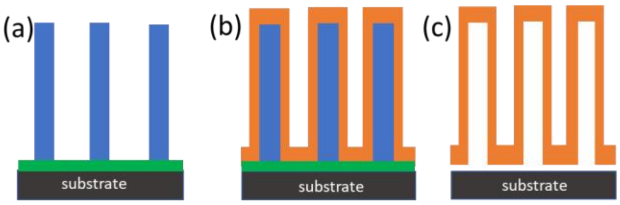

Fig 1. Schematic illustration of the full procedure of the fabrication of GeNTs: (a) Synthesis of ZnO NWs on a Si substrate with a ZnO seed layer. (b) formation of Ge layer on the ZnO core. (c) fabrication of GeNTs by etching of ZnO.

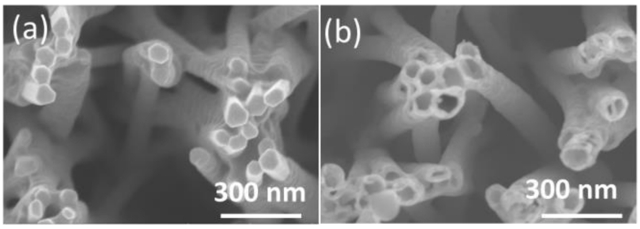

Fig 2. Top view of SEM image of (a) Ge/ZnO core-shell nanowire and (b) GeNTs after wet etching.

Experimental section

As shown in Fig. 1, first of all, we grew arrays of ZnO NWs by a hydrothermal synthesis method. The reaction materials include 2.5 mM of hexamethylenetetramine (HMTA), Zinc nitrate (5 mM), and ammonia (1 mL). Then, we use a chemical vapor deposition (CVD) process to form the Ge layer on the ZnO NWs. The temperature and time were varied from 400 °C to 500 °C and 1 to 5 min respectively. Next, the samples were etched by phosphoric acid (85%) to remove ZnO NWs and form GeNTs.

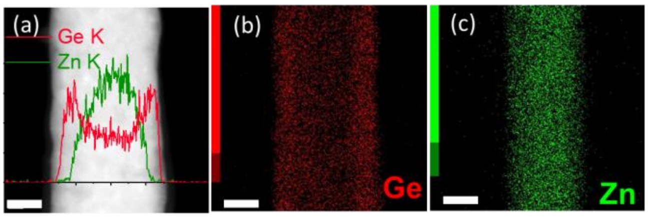

Fig 3. (a) TEM EDX linescan of Ge/ZnO core-shell nanowire. (b), (c) TEM EDX mapping of Ge/ZnO core-shell nanowire.

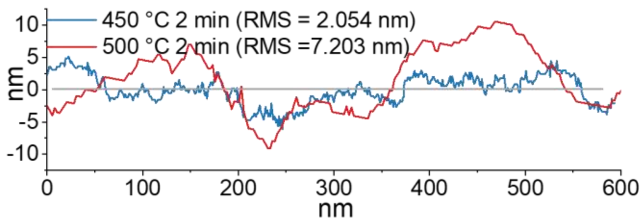

Fig 4. Surface roughness of Ge shell.

Results and discussion

Fig. 2a shows a SEM image of the ZnO/Ge core-shell NWs. Fig. 2b shows a SEM image of the GeNTs after wet-etching. From the top view image, we could clearly see the hollow space in the middle, which proves the tubular shape of the NT structure. Fig. 3a, b, c show that Ge shell was grown on the surface of the ZnO core successfully. EDX linescan in Fig. 3a further demonstrates the core-shell structure. Fig. 4 shows the surface roughness of Ge shell with various formation temperatures by measuring the outline of surface through TEM images for 2 min samples. Compared to the 500 °C sample, the root mean square (RMS) of 450 °C sample is smaller. A smoother surface of 450 °C sample can be attributed to the slow migration of the Ge atoms at low temperature.

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[3] Taghinejad, M., et al. *Nano Letters* **13,** 889 (2012).