Growth of Silicon, Germanium, Si_xGe_{1-x} and Various Polytypes of Silicon Carbide Nanowires

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MATERIALS

Abstract:

The silicon-germanium (SiGe) alloy has played an important role in the semiconductor industry because of its inexpensive production and high power capabilities [1]. Silicon carbide (SiC) has also played an important role due to its high thermal conductivity and wide energy band gap [2]. In this study, silicon, germanium, Si_xGe_{1-x} and various polytypes of SiC nanowires were grown via a chemical vapor deposition (CVD) reactor. Nanowires are 1-dimensional nanostructures with very interesting properties such as a high electron mobilities, several times higher than conventional structures. Polytypes of SiC were grown on silicon substrates using silane and propane with nickel (Ni) as a catalyst. The polytypes were achieved by varying the temperature of the CVD reactor during growth. In doing this, we changed the phase of the nanowires from cubic SiC (3C) to hexagonal SiC (6H). The silicon, germanium, and Si_xGe_{1-x} structures were grown using silane and germane. X-ray and other characterization techniques were used to examine the structure and nature of the 1-dimensional system.

Introduction:

With its low energy band gap, high mobility, and ability to synthesize nanowires at low temperatures, germanium has become one of the key players in the semiconductor industry [3]. Silicon-germanium's high power capabilities make it ideal for wireless communications devices [1]. Silicon carbide is another key player in the semiconductor industry because of its high thermal conductivity. Polytypes of silicon carbide refer to the stacking structure of the silicon and carbon atoms, with the basic crystalline structures being cubic (3C), hexagonal (6H), and rhombohedral (15R), with each structure having its own unique optical and electronic properties.

Experimental Procedure:

Silicon (100) substrates were cut into 1 cm × 1 cm sized pieces and cleaned using detergent, trichloroethylene, acetone, and methanol. Electron-beam evaporation was used for the deposition of a 10 nm film of nickel for silicon nanowire catalysis, and a 10 nm film of aluminum was deposited for SiC nanowire catalysis. A thin gold film of approximately 10 nm was required for germanium and silicon-germanium nanowires catalysis, and was deposited by thermal evaporation. Nanowire growth took place in a cold wall, temperature controlled, horizontal CVD reactor.

Germanium nanowires were grown with germane (GeH_4) as the precursor gas, while silicon-germanium nanowires required germane and silane (SiH_4). Silane and propane (C_3H_8) were the precursor gases used for silicon carbide nanowires. In each reaction, hydrogen was used as the carrier gas. Hydrogen created a laminar flow within the growth chamber and was also used as a carrier gas for the precusors.

Results and Conclusions:

Gold proved to be an effective catalyst for both the germanium [4] and silicon-germanium nanowires. Germanium nanowire growth was achieved at 800°C and a growth time of 30 minutes. Growth was sparse across the sample, but denser along the edge (Figure 1). The silicon-germanium wires, while technically not "nano" in size, were successfully grown at 900°C (Figure 2). Energy dispersive spectroscopy (EDS) was performed on the wires and it was determined that there was in fact the presence of both silicon and germanium along the wire. Silicon nanowire growth was attempted, but efforts were unsuccessful, even though silicon nanowires had been successfully grown previously in this reactor.

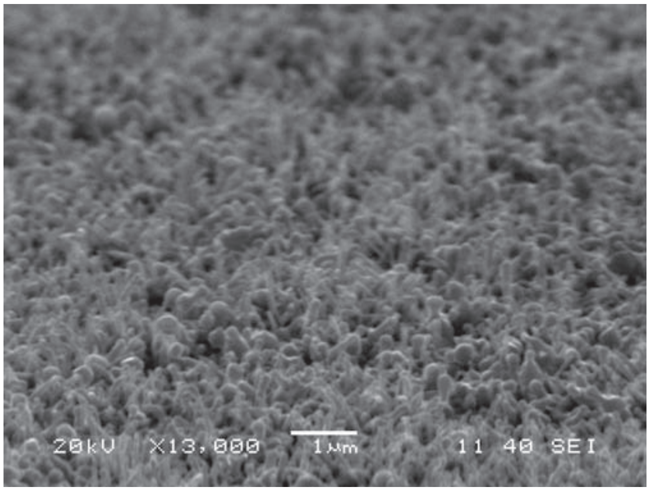

Figure 1: SEM micrograph of Ge nanowires.

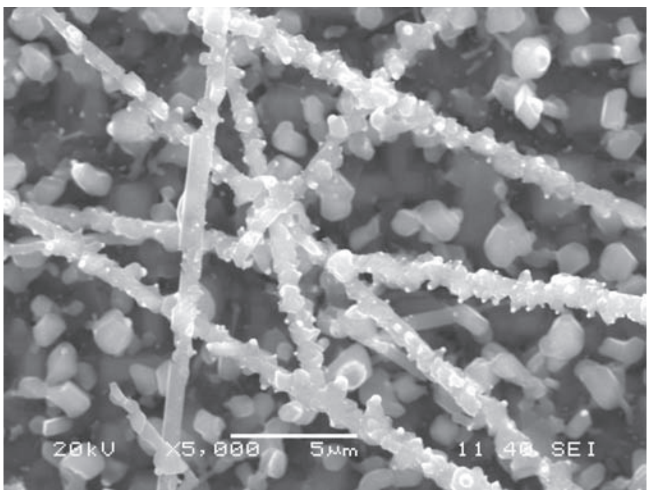

Figure 2: SEM micrograph of Si_xGe_{1-x} nanowires.

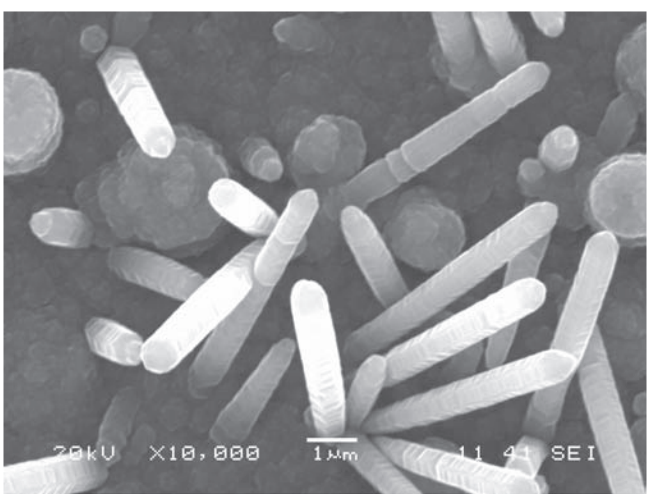

Figure 3: SEM micrograph of SiC nanowires.

Nickel proved to be an effective catalyst for various polytypes of silicon carbide nanowires. To grow different polytypes required changing the growth temperature at different times during the growth cycle. This was done to examine the temperature dependence on polytype formation. During the first growth cycle the temperature was ramped to 1050°C and held for 15 minutes, then ramped to 1336°C and held for another 15 minutes, and then ramped down to 1050°C and held for a final 15 minutes. SEM imaging showed that there were a plethora of wires of different lengths and diameters (Figure 3). The tips of these wires appeared to be hexagonal, which may indicate different polytypes were successfully formed. The second growth was done with only one temperature change, 1050°C to 1330°C. The wires appeared to have a hexagonal shape and may be evidence of a phase shift dependence on temperature, which would further proved that different polytypes of silicon carbide were obtained.

Future Work:

In the future, the nanowires should be probed to determine their electrical properties. Photoluminescence data should also be collected to determine the purity of the nanowires, along with transmission electron microscopy (TEM) to determine their exact crystalline structure along the length of the nanowires.

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