Growth of 3C-Silicon Carbide Nanowires using Chemical Vapor Deposition

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Abstract:

The focus of this project was the characterization and growth of 3C-silicon carbide (β-SiC) nanowires using the vapor-liquid-solid method. Chemical vapor deposition (CVD) occurred at temperatures ranging from 1050ºC to 1100ºC using silane and propane as precursor gases. Experimentation with various surface preparations, including metal catalysts such as nickel (Ni) and aluminum (Al) deposited by electron beam evaporation on silicon and silicon dioxide (SiO_2) coated silicon substrates, were found to be the most effective in aiding SiC nanowires growth. Nanowires with lengths up to 50 μm and with diameters of 50-100 nm were achieved. The SiC nanowire growth parameters are compared to that of Si. The nanowires grown were further characterized using scanning electron microscope (SEM) and electron dispersion spectroscopy (EDS).

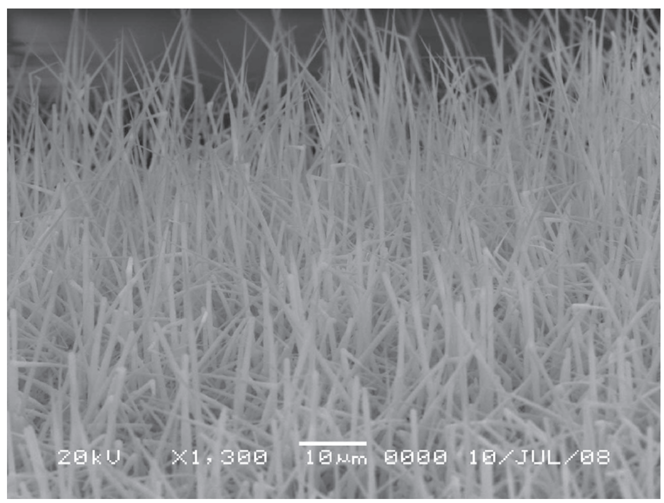
Introduction:

Silicon carbide has many advantages over other semiconducting materials. Some of these advantages include its wide bandgap energy, high thermal conductivity, high electric field breakdown strength, and its high mechanical strength [1]. These properties make SiC highly desirable over many other materials for semiconducting nanowires for the next generation of electronics. SiC nanowires also have the ability to withstand high temperature and harsh environments.

Experimental Procedure:

To optimize the growth, different parameters were tested using data from previous literature and the theory on the vapor-liquid-solid process for nanowire growth as a guideline [1,2]. Low resistivity Si(100) substrates, cut in 1 cm × 1 cm sizes, were cleaned using detergent, trichloroethylene, acetone, and methanol. Different metal catalysts and surface treatments were performed on the samples. Gold (Au) particles of 50 nm in diameter were deposited on one set of samples using poly-l-lysine as an adhesive. A second and third set had Al and Ni deposited respectively, with varying thicknesses by electron beam evaporation. An undulated surface was created on a final set of samples by removing the manufacturer's polish with an abrasive pad. With each set of growths, an untreated Si sample was used as a control. The horizontal CVD growth system employed for this work was a cold wall reactor with a maximum growth temperature over 1500ºC. Both time and temperature were variables in the reaction, with all reactions being performed at a pressure of 200 torr.

Silane (SiH_4) and propane (C_3H_8) were the precursor gases in the reaction and hydrogen (H_2) was the carrier gas. Hydrogen also served to create a reducing growth environment and a laminar flow within the reaction chamber. For comparison, Si



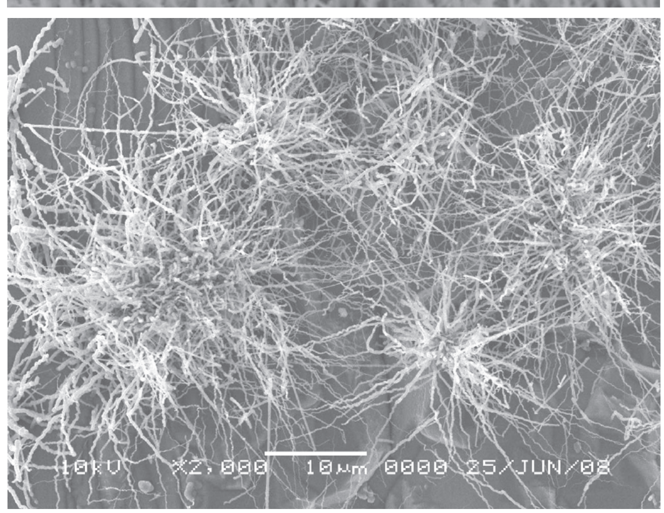
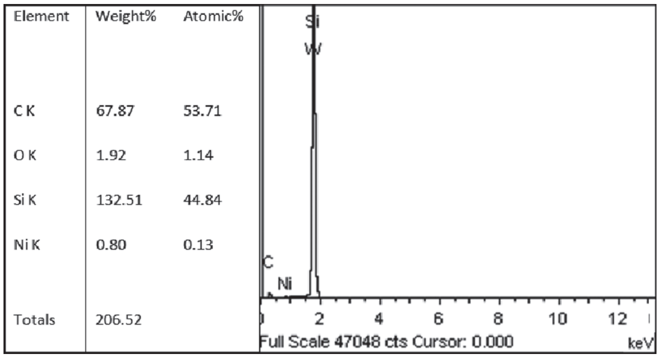


Figure 1, top: SEM image of SiC nanowires with 100_ Ni catalyst.

Figure 2, bottom: SEM of SiC nanowires with 100_ Al catalyst.



Element	Weight%	Atomic%
C K	67.87	53.71
O K	1.92	1.14
Si K	132.51	44.84
Ni K	0.80	0.13
Totals	206.52	

Figure 3: EDS plot of SiC nanowires on Si with Ni catalyst.

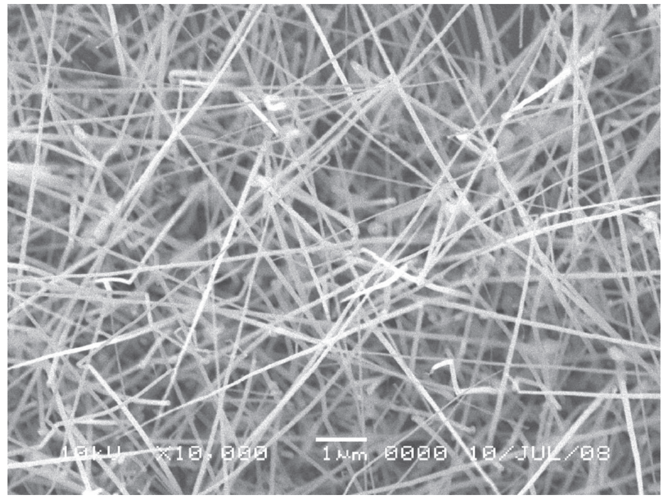


Figure 4: SEM image of Si nanowires on undulated Si.

nanowires were grown using similar wafers and catalysts, with silane as the single precursor gas. In addition to the Si(100) substrates, different substrates such as Si(111), Si(110), Si with 2 μm SiO_2 were also tested for growth.

Results and Conclusion:

The growth of β-SiC nanowires was successfully achieved using the CVD system. Although different parameters produced varying results, the optimum growth condition was found at temperatures between 1100-1150°C. This temperature was substantially higher than the 750-800°C for Si nanowires. This was due to the higher energy needed for the formation of SiC crystal structures in comparison with Si structures. For both sets of growths, the optimal growth time was around 60 minutes. In support of earlier literature, the length of the nanowires seemed to be dependent on the time of growth up to a certain threshold point, and temperature was the main factor in determining this point. The most effective catalysts for SiC growth were the evaporated layers of 100Å of Ni and 100Å of Al. These two catalysts produced differing results in terms of structural appearance of the nanowires as seen through scanning electron microscopy (SEM) images in Figure 1 and Figure 2.

The nanowires were confirmed using electron dispersion spectroscopy (EDS) to be a compound of Si and carbon (C), see Figure 3. As predicted by the vapor-liquid-solid theory of nanowire growth, a small trace of the catalyst remained on the tip of the nanowires throughout the reaction. These metal traces were also confirmed by EDS.

On average, the SiC nanowires grown were about 50-200 nm in diameter and about 40-80 μm in length. In comparison, the Si nanowires had diameters of around 30-50 nm and lengths between 100-150 μm. It is interesting to note that Si nanowires grew best on the undulated surface for Si(100) samples, Figure 4, and moderately well on samples with 50 nm particles of Au, which seems to suggest that a catalyst is not necessary for Si nanowire growth.

Overall, the research has supported the vapor-liquid-solid process of growth for SiC nanowire and optimized the growth of both SiC and Si nanowires. In theory, the nanowires grown should be β-SiC, having 3-C crystalline structure due to the growth conditions.

Future Work:

Further work with tunneling electron microscopy (TEM) of the nanowires will be necessary to characterize the crystal structure, stacking faults, and other properties of the nanowires. Further characterization of the growth parameters may also be beneficial. Instead of the heterogeneous growth of SiC on various substrates, SiC nanowire growth on SiC substrates or SiC epilayers may produce better results.

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References:

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