Growth of Silicon, Silicon Carbide, and Boron Nitride Nanowires for Electronic Applications

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Abstract:

The objective of this project was to explore the growth of silicon, silicon carbide, and boron nitride nanowires for electronic device applications. These nanowires were chosen because they all have excellent mechanical, optical and electrical properties. In this project, we grew Si and silicon carbide wires with diameters less than a hundred nanometers (nm). The wires were grown in a horizontal chemical vapor deposition system using precursors of silane, propane, ammonia and diborane at 200 torr. The deposition temperatures were varied from 800 to 1100°C. The wires were grown on silicon substrates using catalysts of 5-10 nm nickel, aluminum, gold, iron and cobalt. Experiments with the boron nitride nanowires did not produced any significant results.

Introduction:

Nanowires hold a lot of promise for applications in the next generation of electronics because they can be used to create extremely powerful and versatile circuits. They can be mass-produced by chemical vapor deposition (CVD). This project focused on the growth of silicon, silicon carbide, and boron nitride nanowires by low pressure CVD.

Bulk silicon (Si) is the base material for most modern electronics in use today. Si, on the nanoscale, carries many of the same mechanical, electrical, and optical properties of bulk Si that make it viable for electronic applications. Furthermore, Si nanowires have been shown to display a thermoelectric effect, which allows them to convert excess heat back into electrical energy. With this effect, Si nanowires can be applied to electronics ranging from car engines to computer chips to increase their efficiency and reduce thermal waste.

Silicon carbide (SiC) nanowires display high thermal conductivity and mechanical strength. While Si is used for general semiconductor construction, SiC, due to its high bandgap, can be applied in high power or high temperature applications. Furthermore, SiC nanowires are chemically inert, allowing them to be used in many different biological and medicinal applications.

Like SiC, boron nitride (BN) is also a wide band gap semiconductor, allowing it to be applied in similar harsh environments. BN is shown to be compatible with complementary metal oxide semiconductor (CMOS) chips, allowing it to be easily incorporated into currently existing technology.

Procedure:

Nanowires were grown on Si <100> wafers using a low pressure CVD reactor. The Si wafer was cut in sample pieces 0.5 inch by 0.5 inch and then ultrasonically cleaned with tricholoroethylene, acetone, and methanol. Some of the samples were then coated with 5 to 10 nm of nickel (Ni), aluminum (Al), gold (Au), cobalt (Co), or iron (Fe) using an electron beam evaporator. Also, some of the wafers were sand-blasted or left untouched as control samples.

The Si samples were placed on a graphite susceptor inside a quartz inner liner tube of the CVD reactor. Control parameters included the flow rates of the various gases, the temperature within the reactor, as well as the length of each run. A scanning electron microscope (SEM), fitted with an energy dispersive x-ray spectroscopy (EDS) attachment, was then used to characterize the nanowires.

Results and Conclusions:

Figure 1 shows an SEM image of the Si nanowires grown on Au catalyst. Even on the Au catalyst, there were few nanowires with a diameter of a 100 nm or less. Although some wires were grown on the other metal catalysts, these wires were not at the nanoscale. The image in Figure 1 zooms in on a long Si nanowire with a diameter of around 80 nm. The EDS results confirm that the wire was made up of silicon, with it being 93.75% silicon and 6.25% oxygen. The growth parameters for this run can be seen on Table 1.

Figure 2 shows an SEM image of SiC nanowires on Ni catalyst, while Figure 3 shows an SEM image of SiC nanowires on Fe catalyst. There was an abundance of long wires with diameters of 100 nm or less on both catalysts, with Ni promoting a little more growth than Fe. The EDS results for Figure 2 confirm that the wires are SiC with 50.74% carbon and 49.26% silicon. They also confirm the wires in Figure 3 to be SiC as well, with 41.36% carbon, 52.02% silicon, and the other 6.62% being iron and oxygen. The growth parameters for this run can also be found on Table 1.

Unfortunately, the experiments on growing boron nitride nanowires did not yield any wires. The main problem may have revolved around the diborane and ammonia reaction, which required specific conditions to form boron nitride. The diborane source used was 880 parts per million, and the maximum diborane flow was restricted to 100 sccm, therefore restricting the concentration of diborane into the chamber to very dilute concentrations.

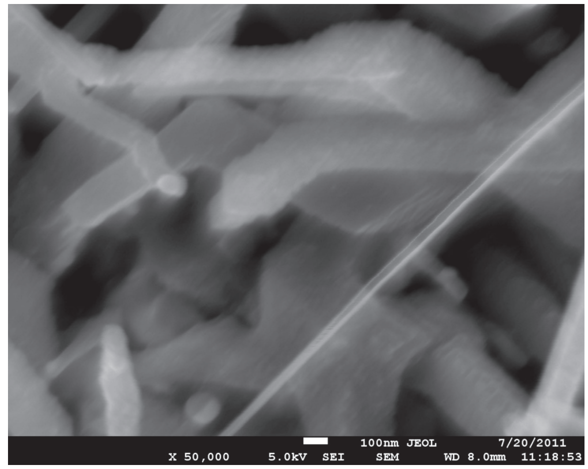

Figure 1: SEM of Si nanowire on Au catalyst.

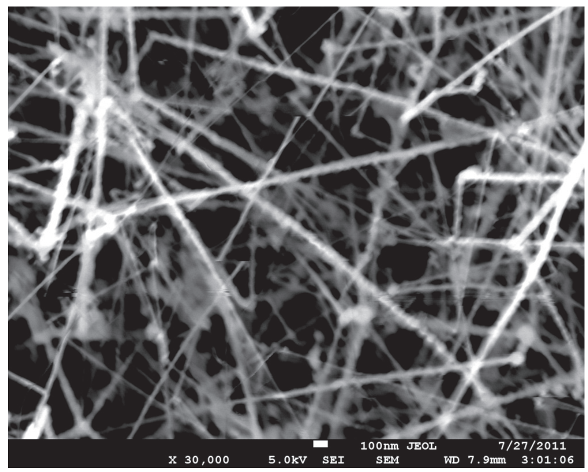

Figure 2: SEM of SiC nanowire on Ni catalyst.

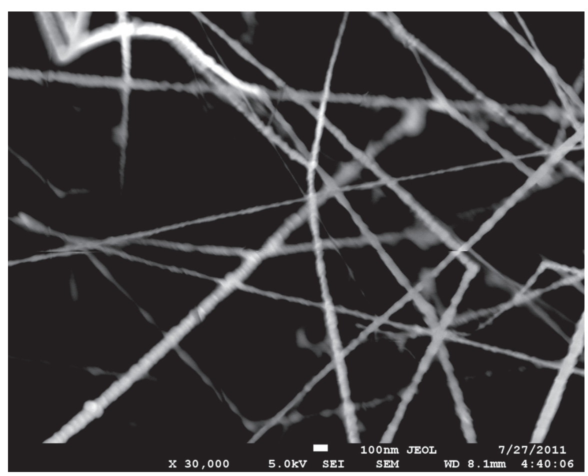

Figure 3: SEM of SiC nanowire on Fe catalyst.

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	Si Nanowires	SiC Nanowires
Time (min)	60	10
Tempurature (°C)	770	1050
H_2 (sLm)	10	10
CaHa (sccm)	–	15
SiH_4 (sccm)	25	25

Table 1: Growth parameters for Si and SiC nanowires.