Growth of Boron Nitride Nanowires

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Abstract:

The objective of this project was to use a horizontal chemical vapor deposition (CVD) reactor to grow boron nitride nanowires on a silicon (Si) substrate using a metal catalyst. Boron nitride is shown to have properties that are compatible with complementary metal oxide semiconductors (CMOS) chips allowing it to be easily incorporated into current and future technologies. Efforts to grow boron nitride nanowires on <111> silicon substrates, <111> silicon with silicon dioxide (SiO_2) and <100> silicon with a 7 nm metal catalyst of aluminum, cobalt, iron and nickel have not produced nanowires. Boron nanowires however were grown on <100> silicon substrate using a gold catalyst. All experiments were carried out in a CVD system at a pressure of 200 torr, at temperatures of 900-1200°C and flow rates of diborane at 100 standard cubic centimeters per minute (sccm) and ammonia at 250-800 sccm.

Introduction:

Nanowires, a future technology, hold a lot of promise for use in powerful and versatile circuits. Nanowires are on the order of 100 nm or less, with the electrons being quantum-confined laterally, and thereby occupying energy levels that are different from the traditional continuum of energy levels or bands found in three dimensional materials. We used the vapor liquid solid (VLS) growth method, which is a mechanism for the growth of one-dimensional structures such as nanowires. This method uses chemical vapor deposition (CVD), which is a chemical process used in the semiconductor industry to produce thin film deposition. In CVD, a substrate is exposed to one or more precursors, in our case ammonia (NH_3) and diborane (B_2H_6), which react on the substrate surface to produce the desired material boron nitride (BN).

BN is a wide band gap semiconductor, thus making it applicable in high power and high temperature applications. BN has one of the lowest densities of all the ceramic elements and has excellent machinability, which also makes it ideal for light components for aerospace applications.

Experimental Procedure:

Si <100>, Si <111> and Si <111> with SiO_2 wafers were cut into one-inch by 0.5-inch pieces, brushed with a soap solution, rinsed with deionized (DI) water then dried with nitrogen. The samples were then sonicated in trichloroethylene, acetone, and methanol for three minutes before being rinsed in DI water and dried with nitrogen. Each substrate was then coated with either 7 nm of aluminum (Al), cobalt (Co), iron (Fe) or nickel (Ni) by electron beam evaporation or gold (Au) by thermal evaporation.

The substrates were placed on a graphite susceptor on a quartz holder and inside of a quartz inner tube of the CVD reactor. Flow rates of the precursors, NH_3 and B_2H_6, were set before being injected into the CVD chamber. Using a radio frequency generator, the substrate was ramped up to the growth temperature and the growth was conducted for a set time. The substrate was then analyzed using a scanning electron microscope (SEM) for nanowire growth, and the energy-dispersive x-ray spectroscopy (EDS) attachment was then used to determine the composition.

Results and Conclusions:

Growth of BN nanowires proved to be very difficult to accomplish, even after many runs with various changes to growth conditions. Figure 1 is an SEM image of an initial approach with 7 nm of Co on Si <100>, but it did not produce

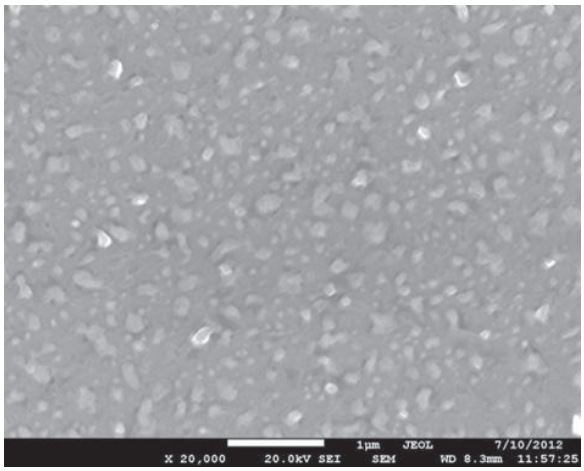

Figure 1: SEM image of Si <100> with 7 nm Co after initial approach.

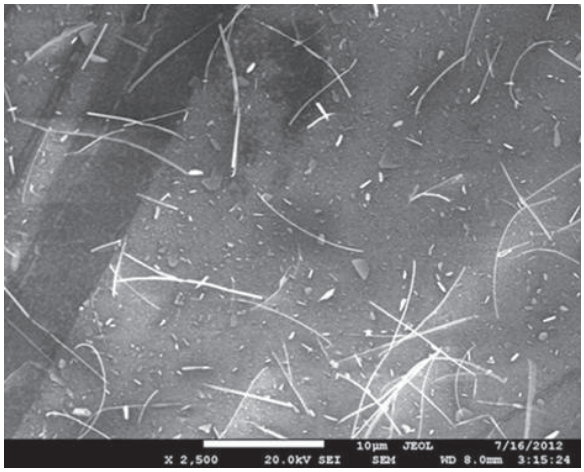

Figure 2: SEM image of Si <100> with 7 nm of Au with Si NW.

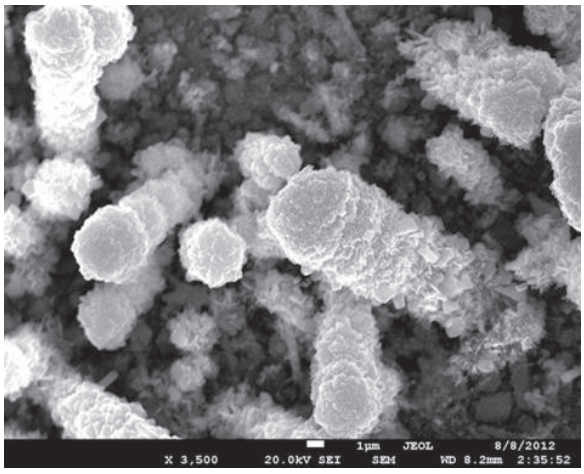

Figure 3: SEM image of Si <100> with 7 nm of Au with BN wire.

any nanowire growth. There were droplet formations on the surface of the substrate, which would suggest that the gases at least reacted with the metal on the surface.

Figure 2 shows an SEM image of nanowire growth on the surface of Si <100> with 7 nm of Au. These nanowires were grown for 60 minutes at a temperature of 900°C, 200 torr pressure, with flow rates of NH_3 at 150 sccm and B_2H_6 at 100 sccm. Upon doing EDS analysis of this sample, the wire was found to contain 38.38% of boron, 61.62% of silicon, but no nitrogen.

Figure 3 is an SEM image showing BN wire growth on <100> silicon with 7 nm of Au. These BN wires could not be classified as nanowires since their diameter was not less than 100 nm. Table 1 shows the growth parameters used for this sample. First, Si wires grown with silane (SiH_4), the Si wires were then doped with B_2H_6 for 30 minutes, and with both B_2H_6 and NH_3 for another 30 minutes. After performing EDS on this sample, the tip of the wire showed there was 34.38% of boron, 60.67% of nitrogen and 4.94% of Au.

	Si wires	Si wires doped with B_2H_6	BN wires
Temperature (°C)	900	900	1100
Time (min.)	15	15	30
Pressure (torr.)	200	200	200
H_2 (sLm.)	9.5	9.5	9
SiH_4 (sccm.)	50	50	0
B_2H_6 (sccm.)	0	100	100
NH_3 (sccm.)	0	0	250

Table 1: Growth parameters for BN wire growth.

After weeks of manipulating growth conditions for BN nanowires, the deposition of BN wires was a major accomplishment. Even though BN nanowires were not successfully grown on the silicon substrates with the catalysts used, further efforts to grow BN nanowire and the testing of different thicknesses of Au in dots or films should be attempted.

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