

# Heterojunction Growth of $\text{Si}_{1-x}\text{Ge}_x$ and $\text{C}_3\text{N}_4$ Nanowires on Silicon

**Siatta Adams**

**Chemistry, Mercer University**

*NNIN REU Site: Howard Nanoscale Science and Engineering Facility, Howard University, Washington, DC*

*NNIN REU Principal Investigator(s): Dr. Gary Harris, Electrical Engineering, Howard University*

*NNIN REU Mentor(s): Mr. Crawford Taylor, Electrical Engineering, Howard University*

*Contact: osiatta@gmail.com, gharris@msrce.howard.edu, crawford@msrce.howard.edu*

## Abstract:

Silicon germanium ( $\text{Si}_{1-x}\text{Ge}_x$ ) and carbon nitride ( $\text{C}_3\text{N}_4$ ) nanowires (NWs) constitute promising building blocks for future electronic and medical applications respectively. SiGe's energy bandgap and thermal conductivity makes it very attractive for use in mobile communication applications. On a nearly strain free material, the energy-band discontinuity of SiGe allows for enhanced speed and performance, allowing for smaller and more defect free transistors. Carbon nitride has promising biological applications for the treatment of breast cancer. Carbon nitride nanowires conjugated to Herceptin can selectively target breast cancer cells.

Silicon germanium and carbon nitride nanowires were grown using chemical vapor deposition (CVD). Wires were grown on silicon substrates of  $\langle 111 \rangle$  and  $\langle 100 \rangle$  orientation with metal catalysts (5 nm and 20 nm gold nanoparticles (Au NPs), and 1 nm and 3 nm thick nickel (Ni), aluminum (Al) and platinum (Pt) films). High purity silane ( $\text{SiH}_4$ ) and germane ( $\text{GeH}_4$ ) were used for the synthesis of SiGe NWs. Carbon nitride nanowires were grown using high purity propane ( $\text{C}_3\text{H}_8$ ) and ammonia ( $\text{NH}_3$ ) gas. The synthesized nanowires were then studied by energy dispersive spectroscopy (EDS), Raman and Auger spectroscopy. The SiGe NWs were 100-300 nm in diameter with an average length of greater than 200  $\mu\text{m}$ .

## Introduction:

Nanowires will play a key role in future electronic and optoelectronic devices [1] due to their relatively easy and low-cost synthetic preparation by CVD [2]. Researchers are interested in silicon-germanium and carbon nitride because of their abilities to produce high performance devices. Group IV NWs (Si, Ge, and SiGe) are ideal for complementary metal oxide semiconductor (CMOS) processes [3]. Nitrogen's presence within the carbon nanostructures can enhance the mechanical, conducting, field emission, and energy storage properties of materials making for more efficient electronic devices. This has been the driving force behind  $\text{C}_3\text{N}_4$  NWs. This work studied the effects of  $\text{SiH}_4$  and  $\text{C}_3\text{H}_8$  concentration on the synthesis of silicon-germanium and carbon nitride NWs respectively by CVD.

## Experimental:

SiGe and  $\text{C}_3\text{N}_4$  NWs were synthesized using a cold-walled reduced pressure CVD reactor. NWs were grown on an Si wafer of  $\langle 111 \rangle$  and  $\langle 100 \rangle$  orientation with gold (Au), nickel (Ni), aluminum (Al), and platinum (Pt) metal catalysts.

Si wafers were first washed with acetone, followed by isopropyl alcohol to remove any surface contaminants and then dried using nitrogen (N) gas. Three nanometers of Ni

and 1 nm of Al were deposited on the surface by electron-beam evaporation to serve as metal catalysts for SiGe and  $\text{C}_3\text{N}_4$ , respectively. Poly-L-lysine (0.1 v/w) was used as an adhesive to apply Au NPs to the Si wafer.

The samples were dipped in poly-L-lysine for two minutes, then rinsed with deionized (DI) water, and dried with nitrogen before being washed with a 10% isopropyl solution. After washing, the samples were dipped into either a 5 nm or a 20 nm Au NP solution ( $7 \times 10^{11}$  particles/ml) for two minutes. The samples were then rinsed with DI water and dried in an oven for 30 minutes. Finally, any remaining organic traces were removed by a 200W oxygen plasma step for two minutes. The Pt catalyst was deposited by sputtering at a current of 2 mA and a voltage of 8kV for five minutes. After deposition of the metal catalysts, substrates were then placed in a horizontal quartz tube in a cold-wall CVD reactor. The chamber was pumped down to 10 mtorr and purged with  $\text{H}_2$  for 10 minutes.

Growth parameters for SiGe and  $\text{C}_3\text{N}_4$  were determined from the previous work of Givian, et al. [1] and Sakamoto, et al. [4], respectively. Table 1 lists the growth parameters of both SiGe and  $\text{C}_3\text{N}_4$ . Energy dispersion spectroscopy (EDS) was used to analyze the NWs composition.

## Results and Conclusions:

Figure 1(a) shows a scanning electron microscopy (SEM) image of the SiGe NWs, and Figure 1(b) shows the spectral analysis of the NWs. The highest atomic percentage of germanium was 3.83 in all SiGe NWs grown.

The diameter of SiGe NWs was between 100-300 nm. Optimal NW growth was achieved with Au NPs at a temperature of 700°C with gas flow ratio of 15/10 standard cubic centimeters per minute (sccm) for SiGe. No growth was observed with Al and Ni catalysts. Pt produced micro-sized NWs, with gas flow ratios of 100/5 sccm for SiGe at 700°C. Shorter wires were observed when the concentration of silane was increased. Silane concentration on the synthesis of SiGe NW showed that higher concentrations of germane affected the length of the wires. Silane concentration also affects the amount of germane present in NWs. NWs with high Ge content were observed when germane concentrations exceeded that of silane.

Figure 2 shows an SEM image of carbon nitride rods. Rods grew at 950°C with the gas flow rates of 10 and 20 sccm for propane and 200 sccm for ammonia. Large growth clusters were seen on <111> and <100> wafers coated with the Ni catalyst. Au, Al and Pt catalysts had no rod growth. Results for carbon nitride rods were inconclusive due to the difficulty in obtaining elemental nitrogen within the reactor.

## Acknowledgements:

I would like to thank Dr. Gary Harris, Crawford Taylor, James Griffin, Karina Moore, Mallory Lambert and all other faculties at the Howard Nanoscale Facility. I would also like to extend my gratitude to both the NNIN REU Program and the NSF for funding this research project.

## References:

- [1] Givan, U., and Patolsky, F. "Pressure Modulated Alloy-Composition in  $\text{Si}_{1-x}\text{Ge}_x$  Nanowires"; *Nano Letters* Vol. 9 No. 5, 1775-1779.
- [2] X.-J. Huang, S.-W. Ryu, H.-S. Im, and Y.-K. Choi. Wet Chemical Needlelike Assemblies of Single-Walled Carbon Nanotubes on a Silicon Surface. *Lagmuir* 2007, 23, 991-994.
- [3] X. Lu, H. Wang, S. Zhang, D. Cui, and Q. Wang. "Synthesis, Characterization and Electrocatalytic Properties of C<sub>3</sub>N<sub>4</sub> NTs for Methanol Electrooxidation"; *Solid State Science* 11 (2009), 428-432.
- [4] Sakamoto, Y., and Takaya, M. "Growth of carbon nitride using microwave plasma CVD"; *Thin Solid Films* 475 (2005) 1981-201.

C <sub>3</sub> H <sub>8</sub> flow rates (SCCM)	7,10,20,30,40,50
NH <sub>3</sub> (SCCM)	100
Pressure	200 torr
Growth temperature	950-1100°C
SiH <sub>4</sub> flow rates (SCCM)	5, 15, 100
GeH <sub>4</sub> (SCCM)	10
Pressure	200 torr
Growth temperature	700-900 °C

Table 1: Growth parameters of C<sub>3</sub>N<sub>4</sub> and SiGe.

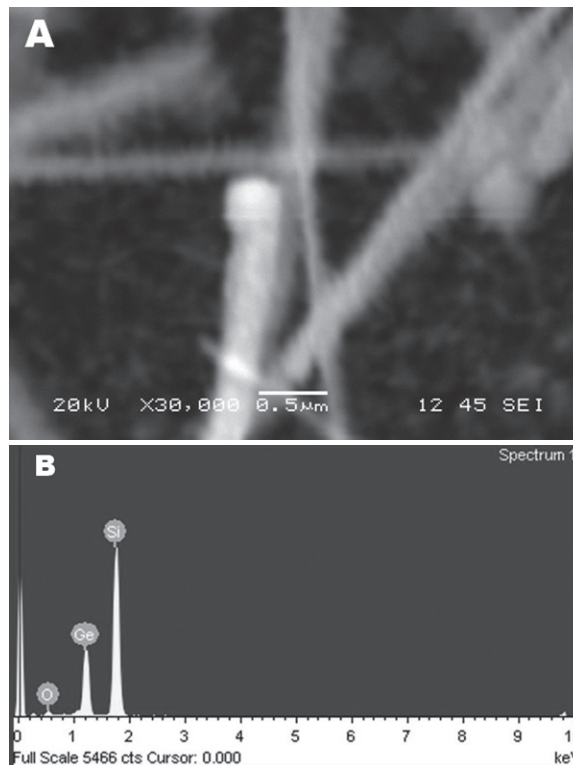


Figure 1: A (top), SEM of SiGe NWs on 20 nm gold nanoparticles <100> orientation. B (bottom), EDS spectrum of SiGe NWs.



Figure 2: Carbon nitride rods in Ni <100> catalyst.