Evaluating Gallium as a Catalyst for Silicon Nanodot Synthesis

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Abstract

Silicon nanostructures, such as silicon nanowires and silicon nanodots, exhibit notably different thermoelectric, electric, and optical properties from bulk silicon. These nanostructures are ideal for utilization in a variety of electronic and optical devices ranging from batteries to solar panels. While various synthesis methods and catalysts exist for making silicon nanowires, gallium exhibits unique nanowire shapes compared to other catalyst metals such as gold or silver. This experiment uses gallium as a catalyst to form silicon nanostructures on <111> oriented silicon substrate at temperatures of 0, 850, and 900ºC. Analyzing dosed samples via SEM resulted in several samples showing possible evidence of nucleation.

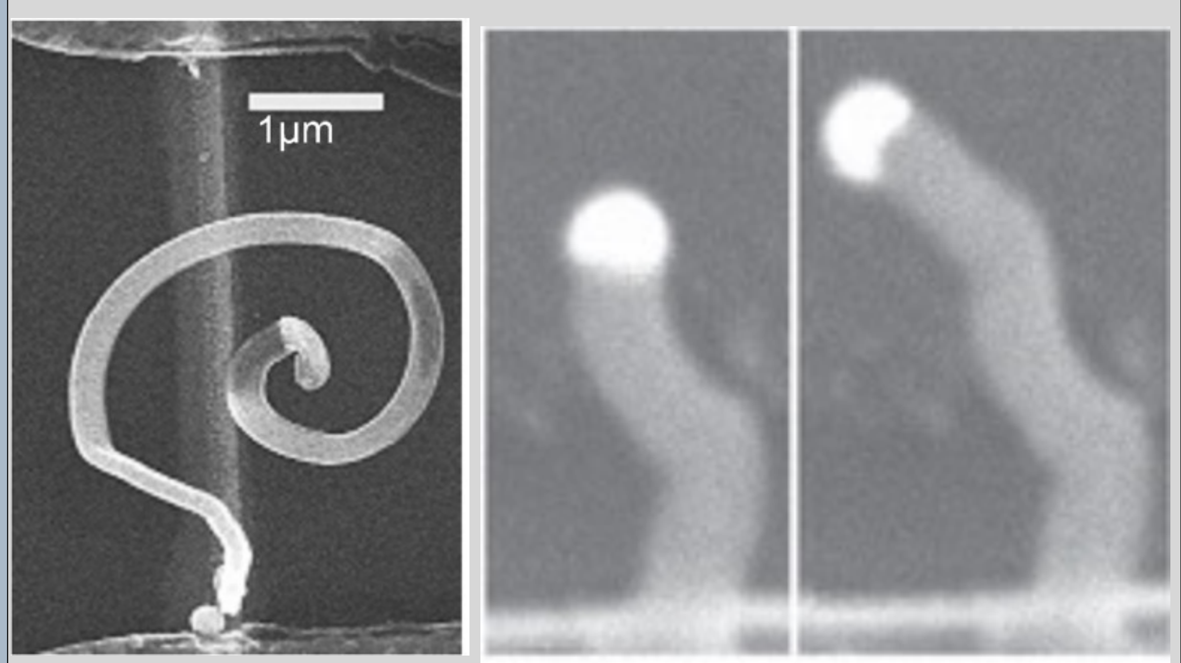

Figure 1: The notable difference in nanowire shape exhibited by gallium (left) as compared to gold (right) catalyzed nanowires[1].

Introduction

Figure 1 shows the unique twisting and bending exhibited by gallium-catalyzed silicon nanowires. This shape is though to be the result of the silicon-gallium eutectic forming with a significantly lower atomic percent silicon compared to traditional catalysts . <111> oriented silicon substrates were prepared and dosed with gallium via a dosing well at temperatures of 0, 850, and 900ºC to evaluate nanowire growth. Following dosing, each sample was analyzed via scanning electron microscope (SEM).

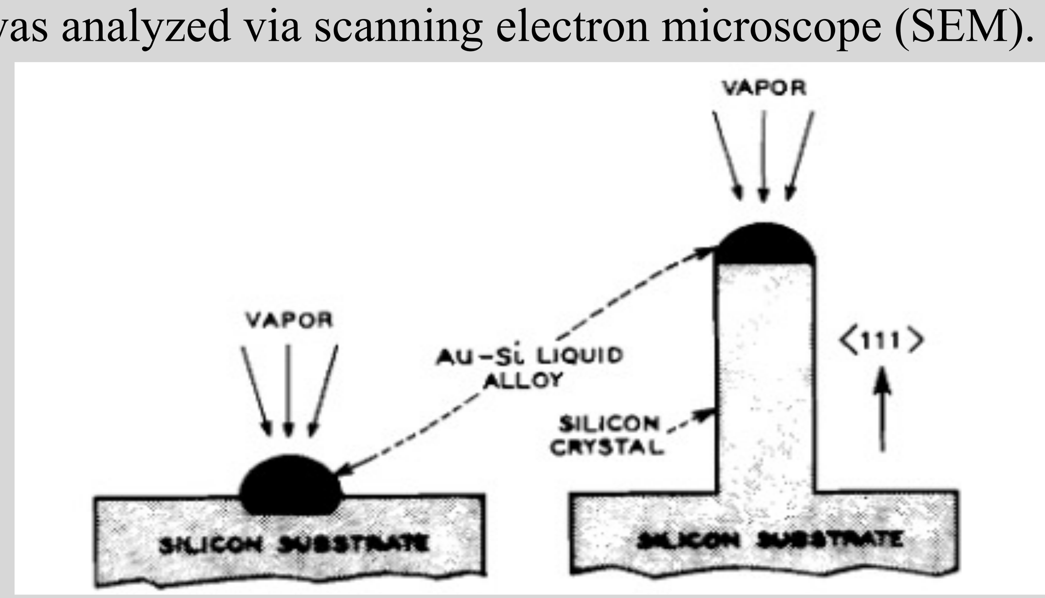

Figure 2: Diagram of the VLS Mechanism for silicon nanostructure synthesis[2].

Materials and Methods

Initially, 5mm x 20mm rectangular silicon samples were cut from a larger <111> oriented wafer. These samples were then placed into the sample holder shown in Figure 3. After this, samples were then placed into a vacuum chamber and allowed to reach a pressure of approximately 10^{-7} to 10^{-8} Torr as determined via ion gauge. Current was then applied until the sample reached a temperature of approximately 500ºC where it was held for 30 minutes. The samples were then flashed to a temperature of 1200ºC as determined via optical pyrometer where they were held for 5 seconds with a 5-minute cooling time at 500ºC followed by two additional flashes. Following this, the dosing temperature of the sample was then set, and current was applied through the gallium well in order to induce dosing with dosing being monitored via a crystal growth monitor (XTL). Each sample was then dosed for a time period of 30 minutes, after which it was removed and imaged via the Phenom Desktop Pro SEM.

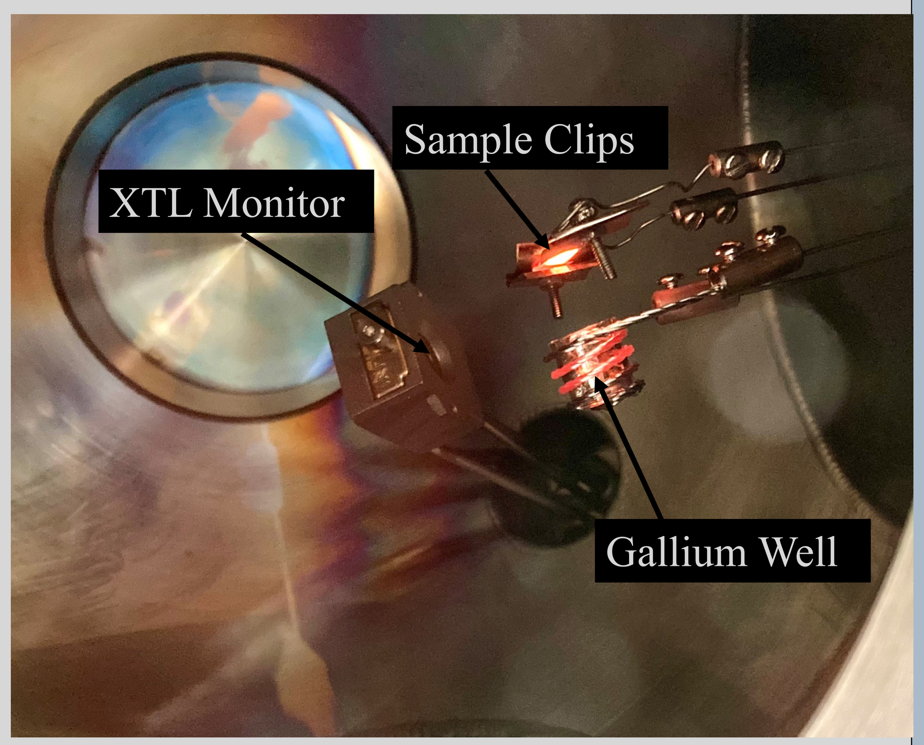

Figure 3: The dosing apparatus for silicon samples, with sample clips, gallium well, and XTL Monitor shown

Results

Table 1: Dosing Summary and Observations for Samples

Sample Number	Dosing Temperature (ºC)	Final Thickness (nm)	Visual Observations	SEM Observations
0-Blank	850	N/A	Uneven clouding	Dark patches, lack of bright spots
1	850	5.171	Even clouding	Notable areas of dosing that are more prominent near edges and infrequent in center
2	850	3.626	Very even with minimal clouding	Uneven bright spots throughout
3	850	5.171	Reflective, minimal clouding	Significant dark patches, reduced bright spots
4	850	5.171	Highly reflective, no clouding	Dark patches, lack of bright spots. Notable differentiation between dosed and covered portions.
5	850	4.174	Highly reflective, no clouding	Dark patches, lack of bright spots
6	0	2.586	Very highly reflective, no clouding	Notable areas of dosing, again frequent near edges and reduced in center.
7	900	4.138	Notable clouding	Notable areas of dosing, mostly uniform throughout sample.
8	900	Get from lab	Notable clouding	Scattered, unevenly shaped bright spots
9	900	4.465	Highly reflective, minimal clouding	Dark patches, lack of bright spots
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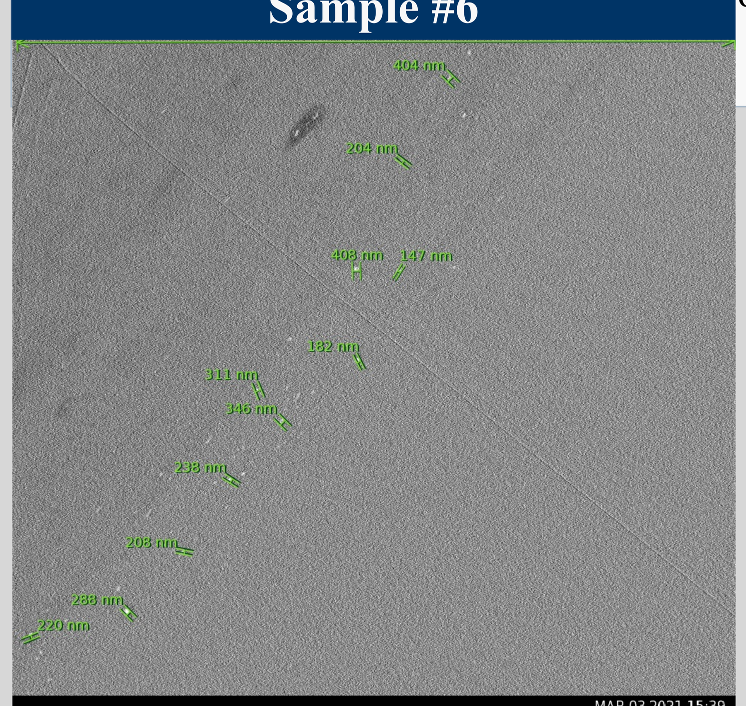
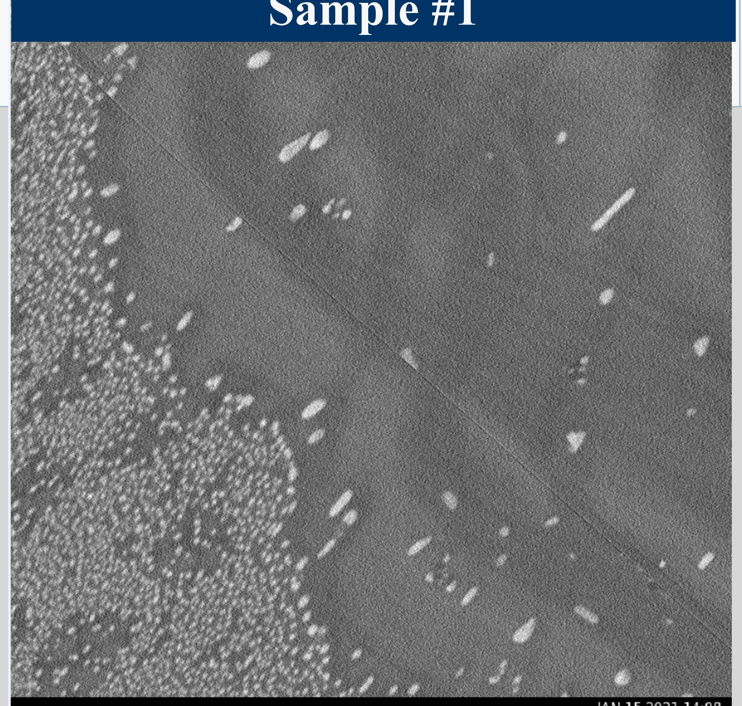
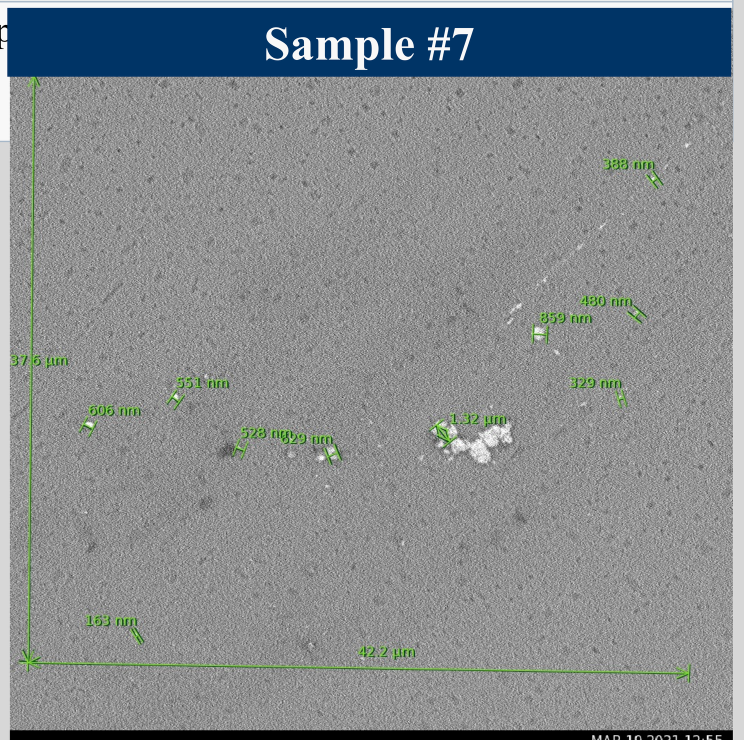
Sample #6



Sample #1



Sample #7



Discussion

SEM analysis of the dosed samples shows evidence of silicon nanostructure deposition on Samples #3, #6, and #7 with substrate temperature ranging between 850 and 900ºC. These samples do show evidence of deposition, it cannot be considered uniform or highly reproducible as it occurred on a limited number of samples within a relatively large sample set. To increase the reproducibility of this method, it is recommended that further trials be carried out at lower dosing temperatures as the silicon-gallium eutectic is known to form at temperatures just above 30ºC, the high temperatures employed for this experiment may decrease the probability of nanostructure formation. While the relationship between the thickness from the crystal growth monitor (XTL) and calculated thickness is somewhat notable, it does not fully confirm the presence of a gallium-silicon eutectic on the substrate surface. Additionally, all samples showed evidence of transfer via the XTL monitor, yet only the aforementioned samples showed evidence of transfer during imaging with the SEM.

Conclusion

SEM images of several dosed samples show evidence of possible gallium transfer and silicon nanostructure formation, the process did not result in uniform or highly reproducible dosing of the silicon substrate. Further testing at lower temperatures, closer to the silicon-gallium eutectic point, are recommended in order to enhance these factors.

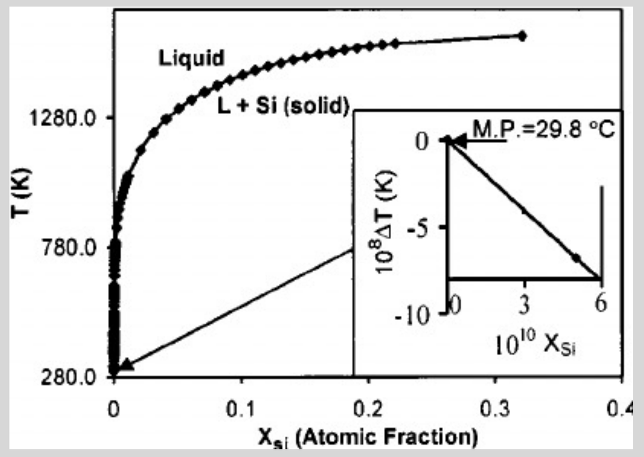


Figure 3: Gallium-Silicon phase diagram with eutectic temperature shown as 29.8ºC[4]

Acknowledgments

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References

1. Reguer, A.; Dallaporta, H. Growth Study of Silicon Nanowires by Electron Microscopies. Materials Science in Semiconductor Processing 2009, 12 (1-2), 44–51.
2. Schmidt, V.; Wittemann, J. V.; Gösele, U. Growth, Thermodynamics, and Electrical Properties of Silicon Nanowires†. *Chemical Reviews* **2010**, *110* (1), 361–388.
3. Sunkara, M. K.; Sharma, S.; Miranda, R.; Lian, G.; Dickey, E. C. Bulk Synthesis of Silicon Nanowires Using a Low-Temperature Vapor–Liquid–Solid Method. *Applied Physics Letters* **2001**, *79* (10), 1546–1548.