# Influence of $Al_2O_3$ Coating on the Annealing Behavior of Si Nanowires

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## Abstract:

Doped semiconductor nanowires have been utilized in many prototype energy harvesting, molecular detection, and plasmonic devices. The use of these materials, which are synthesized via the vapor-liquid-solid (VLS) technique, is dependent on the robust control of carrier concentration. To enable the electrical activation of previously incorporated dopant atoms, rapid thermal annealing (RTP) is generally required. However, due to rapid surface diffusion, silicon nanowires deform at temperatures (~1000°C) far lower than that expected from their bulk melting point (1414°C). To this end, we investigated conformal aluminum oxide ($Al_2O_3$) coatings as a route to suppress silicon (Si) atom surface diffusion and preserve nanowire structure. $Al_2O_3$ has a melting point around 2072°C. We studied how nanowire morphology was impacted under annealing in a nitrogen ambient for no more than one second at 900°C, 1000°C, and 1100°C, and used scanning electron microscopy (SEM) to analyze our data. We observed that none of the coated and non-coated nanowires melted, even at the highest temperature, which contradicts previous data collected under vacuum conditions in our laboratory. We then annealed the nanowires at the highest temperature (1100°C) for ten seconds and observed that the non-coated nanowires melted. We suspect the observed differences are due to the ambient chemistry and plan to test different gases, including Ar and $H_2$, in the future. Shorter annealing times will also be explored in attempt to fully map the process window.

## Introduction:

The main goal of this research project was to suppress the Si atom surface diffusion with an $Al_2O_3$ coating. $Al_2O_3$ coats conformally, is very cost efficient, and forms a strong bond with Si nanowires, which makes it an ideal system to use in this experiment. Si is ubiquitous, which causes it to have an extensive knowledge base and many well-established methodologies. Dopants make Si conducive, however not all dopants may be active by taking up interstitial sites instead of substitutional in the diamond cubic crystal lattice. Thermal energy can activate dopants by allowing a dopant to take place of a silicon atom and become substitutional. In this experiment, phosphorus was our dopant, and in order for our dopant to be activated, annealing was necessary. Doped Si nanowires could be used for many applications such as plasmonic devices, which are devices that convert light into energy, energy harvesting such as solar cells, and molecular detection.

## Experimental Procedure:

Researchers in this study performed atomic layer deposition (ALD), rapid thermal processing (RTP), and a scanning electron microscope (SEM) was used. Nanowires were grown using the vapor-liquid-sold technique. After the wires were complete, the gold was removed using an aqua regia solution. Researchers used two samples, one with $Al_2O_3$ coating and one without. Using ALD, we first coated the gold-removed Si nanowires with 30 nm of $Al_2O_3$ at 250°C. We then used RTP to spike-like anneal both samples of our nanowires at ~ 900°C, ~ 1000°C, and ~ 1100°C for less than one second. We also annealed our wires at the highest temperature (~1100°C) for ten seconds. During the annealing process, we used a continuous flow of nitrogen throughout the chamber. SEM was used to analyze our data.

## Results and Conclusions:

In conclusion, we observed that the coated and non-coated nanowires that were annealed for less than one second did not melt. We believe that the non-coated nanowires remained in tact longer than expected may have occurred due to the continuous flow of the ambient gas, nitrogen, during the annealing process, which cooled down the nanowires. We also observed that when we annealed the nanowires for ten seconds at 1100°C, the alumina coating protected the wires from melting, and the non-coated wires were completely melted.

## Future Work:

In the future, shorter annealing times could be applied to see if that affects the morphology of the nanowires. Also, we could test to see if different ambient gasses such as argon or hydrogen would have a major effect on the preservation of nanowires while being annealed.

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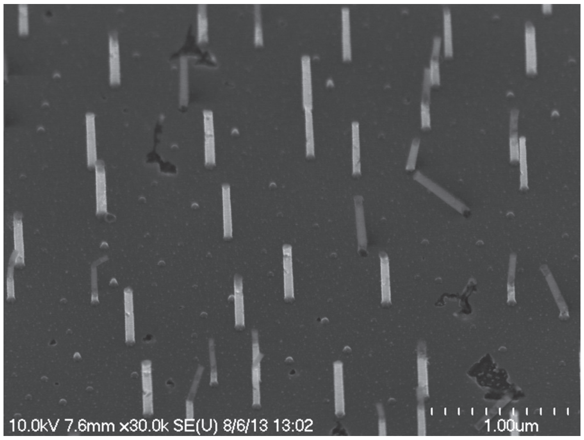


*Figure 1: Nanowires coated with $Al_2O_3$, annealed at the highest temperature (1100°C) for one second.*

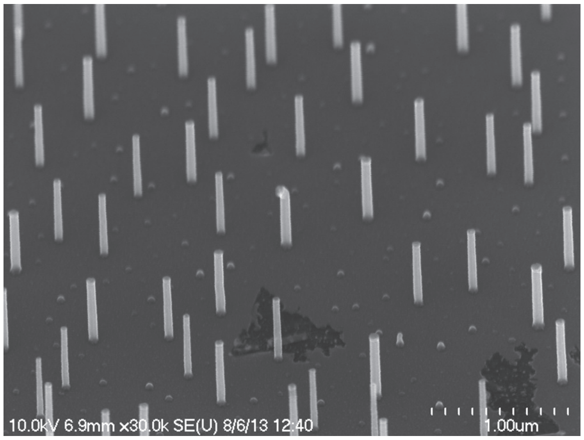


*Figure 2: Nanowires with no coating, annealed at the highest temperature (1100°C) for one second.*

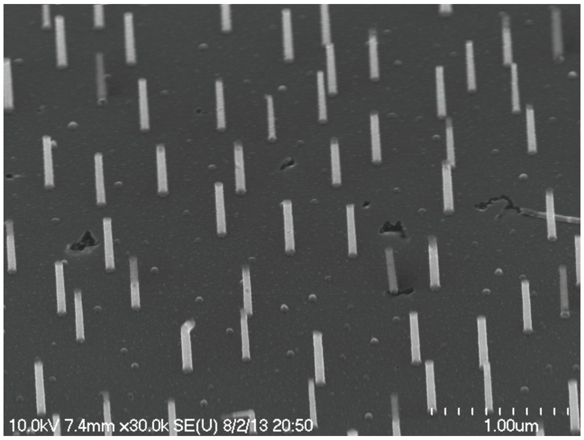


*Figure 3: Nanowires coated with $Al_2O_3$, annealed at the highest temperature (1100°C) for ten seconds.*

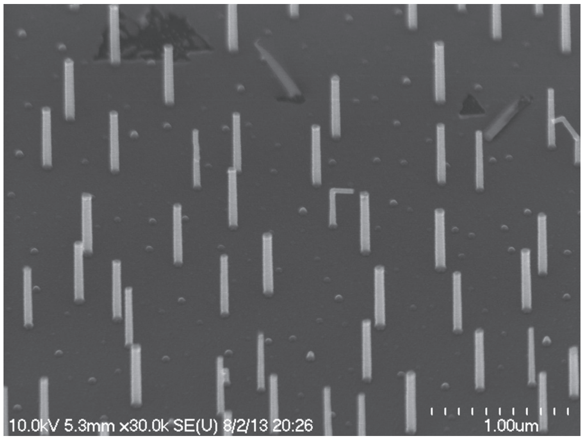


*Figure 4: Nanowires with no coating, annealed at the highest temperature (1100°C) for ten seconds.*

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