Growth and Characterization of Aluminum Nitride Nanowires

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Abstract:

Nanowires are at the forefront of the advancement in electronics due to their versatility and cost effectiveness when compared to bulk materials. Aluminum nitride (AlN) nanowires have many interesting properties in comparison to other wide bandgap group III-V nitride semiconductors. They have a comparatively high thermal conductivity at low temperatures and a high resistivity along with the largest piezoelectric coefficient of the group. AlN nanowires are therefore very attractive for use in electromechanical and optoelectronic devices. They have shown promise in surface acoustic wave devices, such as those found in cell phones, to keep unwanted frequencies out, and in the touch screen displays that have become commonplace in our electronics. AlN nanomaterials, including wires, have been found to trap hydrogen very well because of their structural makeup. The growth of AlN nanowires however can be difficult to achieve because of the difference in the free energy of formation of aluminum oxide (Al_2O_3) versus that of AlN, making Al_2O_3 the favored product. At a growth temperature of 773°K, the Gibbs free energy of formation for Al_2O_3 is -1432.6, while that for AlN is -219.2 [1]. Any oxygen in the system would therefore bond to the aluminum, preventing the formation of AlN.

Introduction:

Here we attempted to grow AlN nanowires without the aid of a catalyst, though for the sake of experiment, we also attempted grow AlN on samples that had been catalyzed as well. We used a low temperature and low pressure system to allow for a simple and easy to reproduce experiment. In order to test our results, we used energy dispersive spectroscopy (EDS), which shows the elements that are present on a sample and in what percentage. These methods have allowed us to gain valuable data on the affects of growth parameters on manufacturing of nanowires and also on the precision that is at times needed.

Experimental Procedure:

In this work, a horizontal chemical vapor deposition (CVD) system, employing ammonia (NH_3) and aluminum chloride ($AlCl_3$) as the sources of non-diatomic nitrogen (N) and aluminum (Al) respectively, was used. Silicon (Si) substrates were used as seed material and some were coated with thin layers of various metals as catalysts. Also some samples were partially coated with aluminum and kept upstream to promote growth on the Si. Growth temperatures ranged between 1000-1100°C with pressures of 100 Torr and flow rates between 100-500 sccm. In order to keep oxygen in the system to a minimum, the system was flushed during both heat up and cool down with a flow of nitrogen gas at a rate of 100 sccm. Growth times, measured only when the machine was fully heated up, varied but most runs lasted 120 minutes.

Results and Conclusions:

A film of AlN and some micro-scale deposits of AlN were found on silicon- and nickel-coated silicon samples by EDS, which can be seen in Figure 1. However no AlN nanowires wires were found on any samples, even those with catalysts. Chlorine deposits were also found on the surface of some samples, and ammonium chloride deposits were found in the reaction tube. This reaction was expected since $AlCl_3$ was the source of aluminum, and it had little effect on experimental outcomes. However, the main reason for the lack of AlN growth was aluminum oxidation.

The source of the oxygen was possibly due to the $AlCl_3$ and system leaks. A very large deposit of aluminum oxide was formed in the quartz tube used for heating and on the substrates, indicating the extent of oxygen in the system. Figures 2 and 3 show deposits of Al_2O_3 on some samples and the almost artistic way in which they grew due to the changing growth conditions.

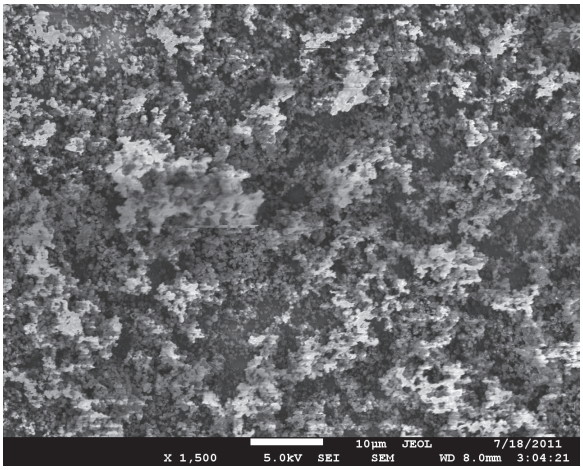

Figure 1: Large growth of AlN on Ni-coated Si.

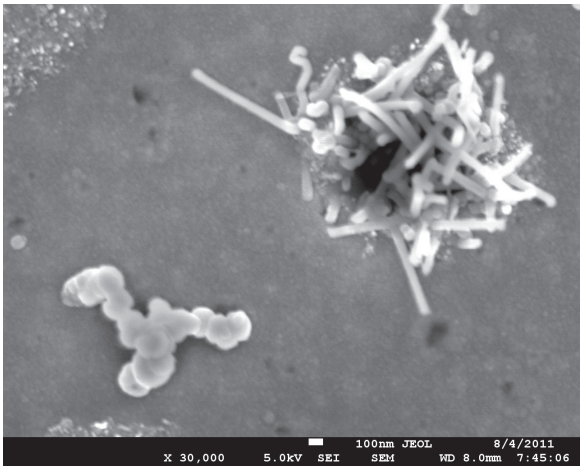

Figure 2: Al_2O_3 spheres and nanowires.

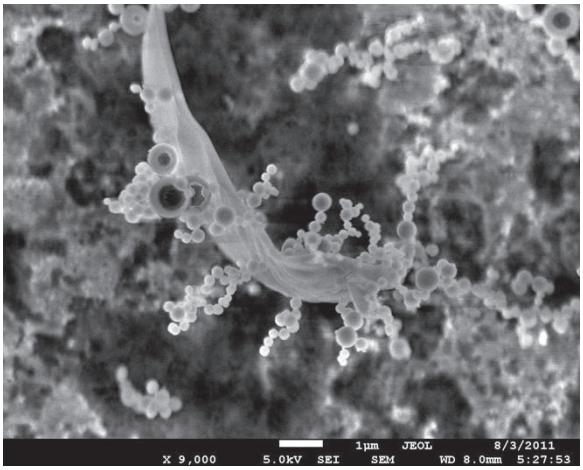

Figure 3: Another example of Al_2O_3 spheres growing off a large Al_2O_3 mass.

Future Work:

In the future, we hope to successfully grow AlN wires by starting with gallium nitride (GaN) wires, which have already been proven to be capable of growth. The source of Ga would slowly be replaced by Al, adjusting variables as necessary to keep the growth of wires stable, until there is no longer any Ga in the wires at all. The hope is that by growing the wires in this fashion the formation of aluminum oxide and ammonium chloride could be kept under control so that AlN would have a chance to form. There is also the possibility of using powdered aluminum as the Al source rather than $AlCl_3$, to stop the chlorine from interacting and to cut down on the amount of oxygen being brought into the system, as there is a chance that oxygen was being trapped in the powder and introduced into the system that way.

Acknowledgments:

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References:

[1] Sharafat, S. and Ghoniem, N.; "Thermodynamic Stability Assessment of Oxides, Nitrides, and Carbides in Liquid Sn-25Li"; APEX Study, UCLA (August 2000).