ARO DURIP Report – Custom Scanning Tunneling Microscope

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Introduction

The provided funding allowed for the purchase of an atomic force microscope / scanning tunneling microscope (AFM/STM) custom-designed by RHK Technology, an industry leader in scanned probe microscopy (SPM). The custom-designed aspect of this unit is what makes it ideal for our system. In a typical STM system, only small pieces are transferred for characterization. This limits undesired affect on the system due to thermal variations, but also limits possible sample size. Our STM was custom designed to accept the large 3" blocks used in our molecular beam epitaxy (MBE) growth systems, as illustrated in Figures 1 through 6.

Figure 1. Transfer arm with 3" sample block.

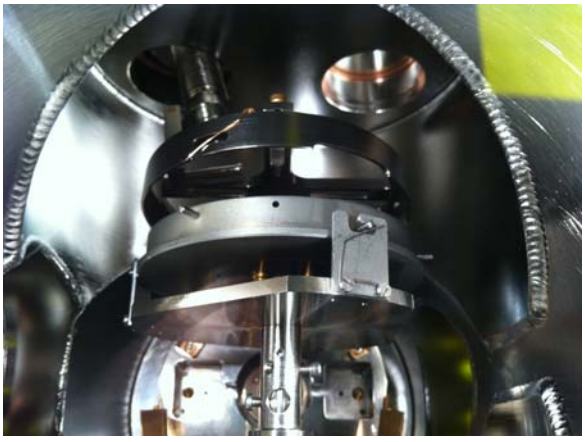

Figure 2. Block approaching STM sample acceptor

Figure 3. Block mated to sample acceptor.

Figure 4. Arm retracted after mounting block.

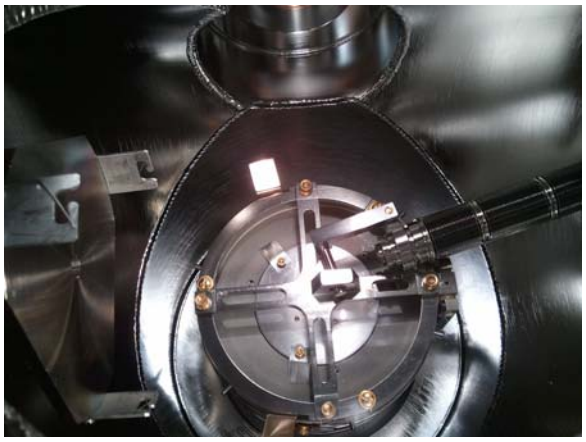

Figure 5. Sample acceptor lowered by wobble stick.

Figure 6. STM in scan position.

The customized sample mount allows us to seamlessly transfer from the growth chamber through the transfer line and into the STM chamber without ever taking the sample out of vacuum. Keeping the as-grown sample under UHV conditions is important to prevent surface contamination and, more importantly, surface oxidation that is native to the III-Nitride material system. The entire transfer system in Figure 7 comprises two Riber MBE systems, one Varian MBE system and the STM chamber for sample analysis and characterization. With three growth systems connected through the transfer line, the STM will see extensive use and will greatly increase our ability to characterize samples with no exposure to atmosphere.

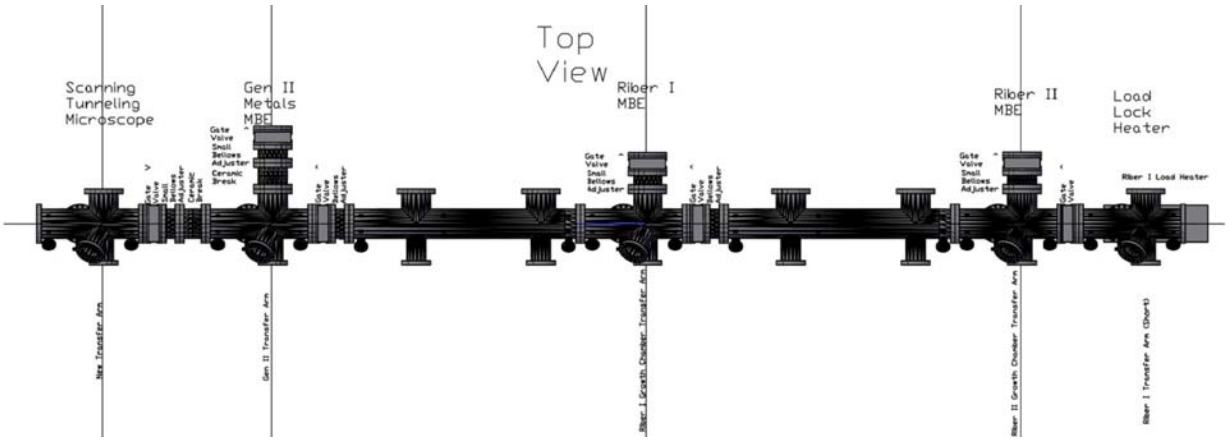

Figure 10. Top-down view of full transfer system. From left to right: STM, Varian MBE, Riber MBE #1, Riber MBE #2

Results and Progress

In the time since the unit was installed in October, a number of promising results have been obtained. Figures 8 through 11 show some topographic scans taken on the STM, compared to an AFM scan of the same sample. As is apparent from these images, the STM provides similar results for topographic scans, and in many cases can achieve a much higher resolution image especially over smaller areas.

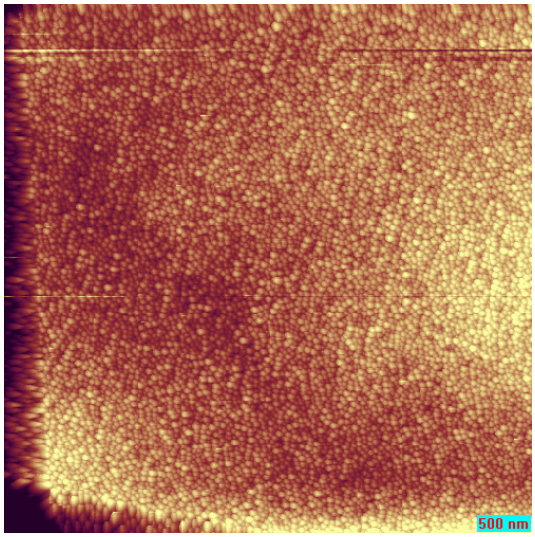

Figure 8. STM scan of p-type GaN
(5µm scan size, -2.8V bias, 600pA tunnel current)

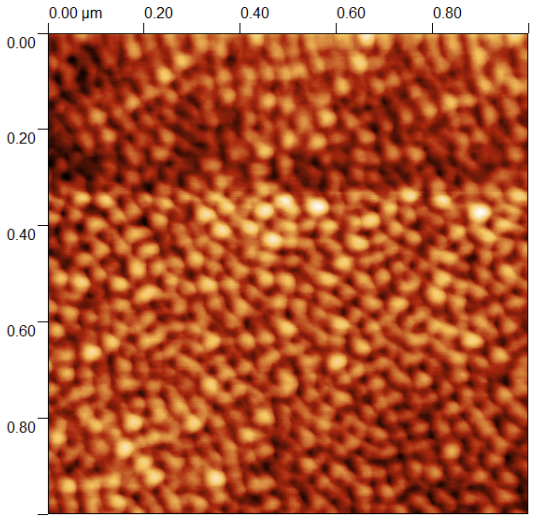

Figure 9. AFM scan of p-type GaN
(1µm scan size)

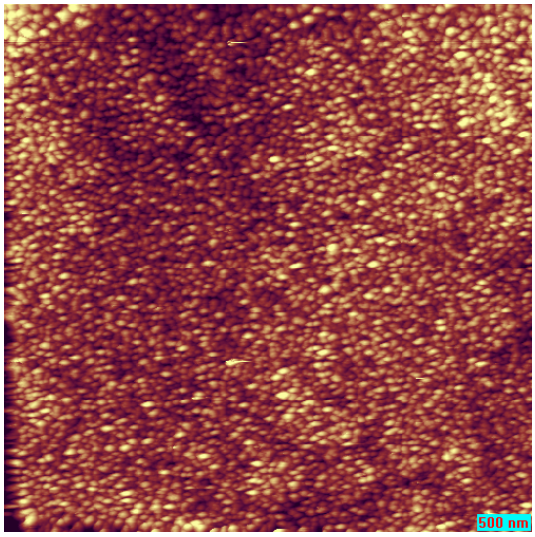

Figure 10. STM scan of $In_{.75}Ga_{.25}N$
(5µm scan size, -2.3V bias, 800pA tunnel current)

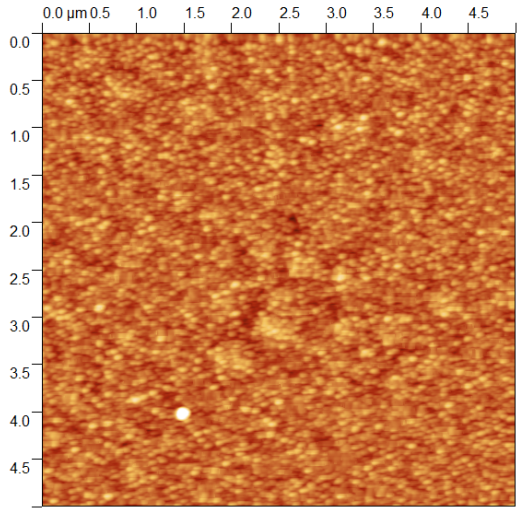

Figure 10. AFM scan of $In_{.75}Ga_{.25}N$
(5µm scan size)

Simply having an in-vacuum replacement for AFM is wonderful for characterization, but the STM is vastly more powerful than that with many more capabilities than just topographic scans. Using the scanning tunneling spectroscopy (STS) function of the STM, one can plot I-V curves as seen in Figure 11, I-z curves (current vs. tip-to-sample distance at a set bias), dI/dV spectra to derive information about the bandgap as in Figure 12, and even the density of states of the material. These are all powerful characterization tools for any semiconductor, but especially so for III-Nitride materials due to its specific challenges and subtleties.

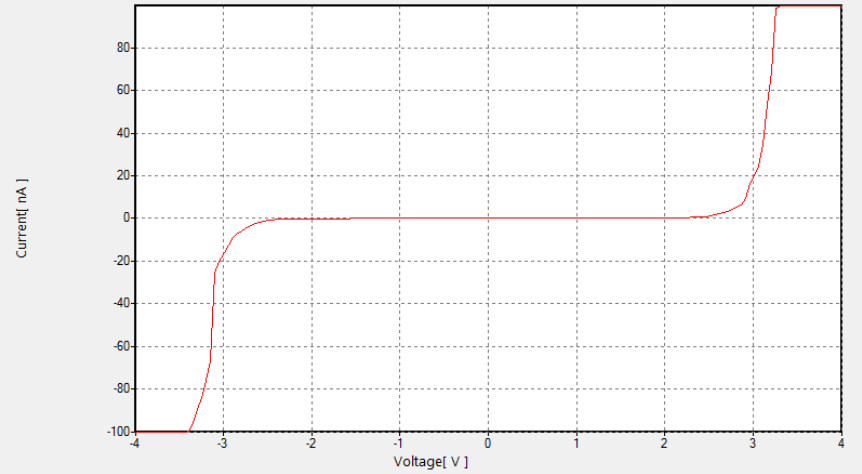

Figure 11. I-V Curve of heavily p-type GaN

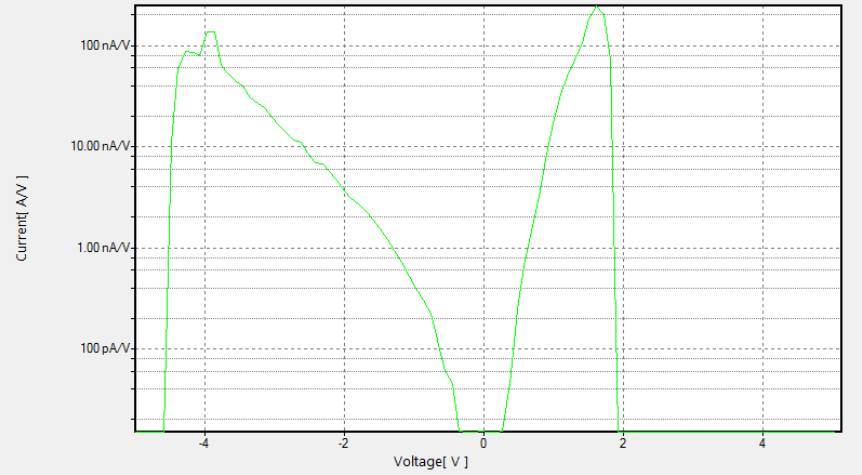

Figure 12. dI/dV spectra used for deriving bandgap

With InGaN, one major problem is surface segregation where the material separates into two distinct material phases, each with a different composition. As the bandgap of InGaN is dependent on the In/Ga ratio, we can use the dI/dV spectra to determine if different phases of the material are present. Another common issue in InGaN is indium droplet formation, which can turn into InN droplets on the surface if exposed to the nitrogen plasma during growth. This can be seen clearly in a topographic scan as droplets. It is also seen as anomalies (i.e. bright/dark spots) in a constant-height scan where the tip-to-sample distance is kept constant rather than the tunneling current.

A similar affect might be seen for our degenerately p-type GaN samples. These samples are doped heavily with Mg, which tends to cluster in the material. This can create compositional variation across the sample, with some regions of higher Mg concentration and some regions of lower Mg concentration. The two regions would exhibit different electrical characteristics which could then easily be seen using a constant-height scan, and compared using the powerful spectroscopy functions. The STM can also be used to derive the local density of states (LDOS) of the p-type GaN samples, helping to better understand how we are able to achieve extremely high hole concentration and Mg activation while others are not.

Figures 13 through 16 on the next page are additional scans obtained with the STM.

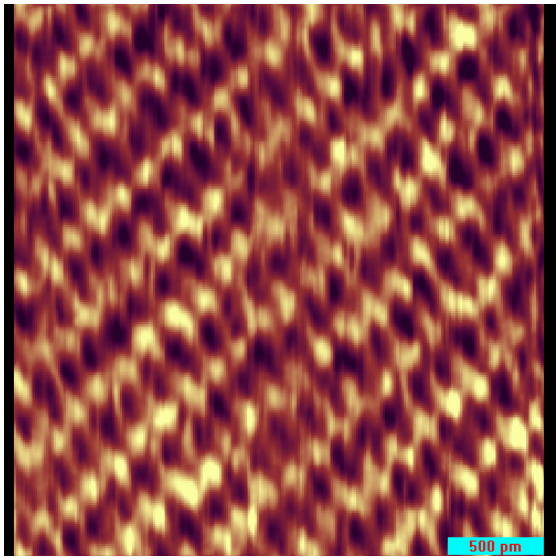

Figure 13. Highly ordered pyrolytic graphite (HOPG) Bright spots are single carbon atoms, scan size 3nm.

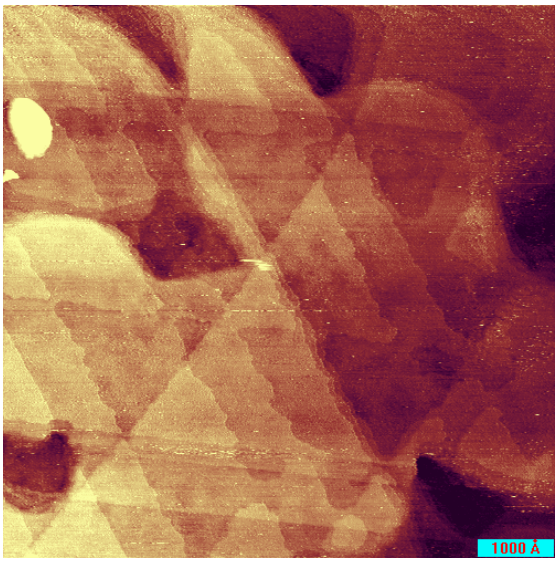

Figure 14. Gold, scan size 726nm

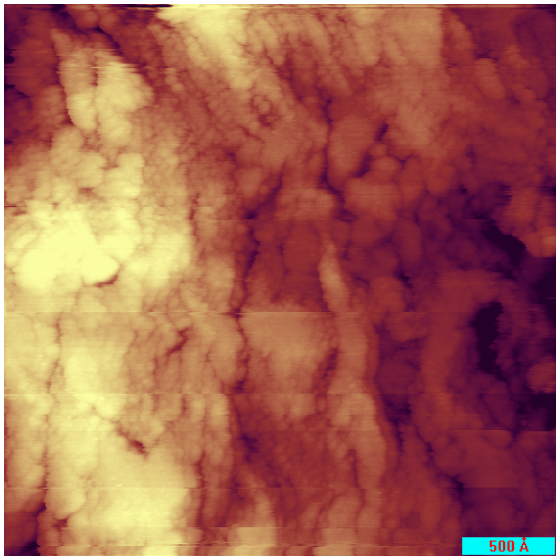

Figure 15. P-type GaN, scan size 300nm

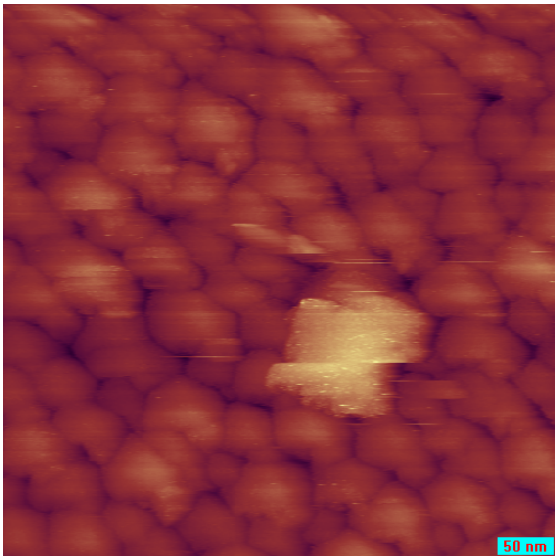

Figure 16. Close-up of grains from Figure 15, Scan size 50nm