The Optimization of High Growth Rate GaN Thin Film Mobility

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Abstract:

We explored how n-type gallium nitride (GaN) electron mobility is affected by plasma assisted molecular beam epitaxy (PAMBE) growth conditions. The primary goal was to determine the conditions that produce the highest mobility. First, we performed a doping study to determine which carrier concentration produced the highest mobility. We then optimized mobility by varying plasma power and flow rate. All carrier concentrations and mobilities were determined using the Hall Effect. The doping study demonstrated that the optimal carrier concentration was ~ 1.5 × 10^{15} cm^{-3}. The highest mobility at this optimal carrier concentration was ~ 550 cm^2/ V·s, thus achieving our primary goal.

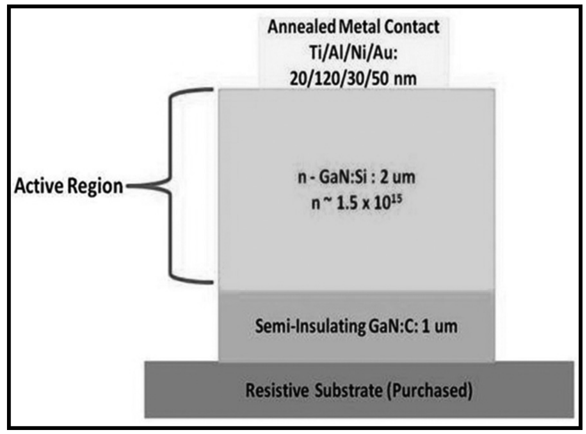

Figure 1: Cross section of a completed sample (schematic).

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Introduction:

GaN is a semiconductor of interest because of its current use in light emitting diodes (LEDs) and because of its potential future applications in high power and high frequency devices. However, there are still issues with GaN that need to be explored in order to make these exciting future applications more feasible for large scale implementation. We need to determine how to grow the best quality GaN possible. PAMBE is one prominent GaN growing method used primarily in research settings that gives the user precise control over the samples produced, though it is generally slower than other methods. However, the plasma source used in this study produced growth rates higher than any PAMBE system recorded to date [1]. We hoped to grow the highest mobility GaN possible using this new plasma source by optimizing PAMBE growth conditions. Though many different growth parameters could be varied, the two parameters focused on here were plasma power and nitrogen flow rate into the power source.

Experimental Procedure:

To optimize the PAMBE growth conditions, the experiment was broken into two parts: an optimizing carrier concentration study and an optimizing mobility study. The first part determined the optimal carrier concentration.

Various doping concentrations were tested by changing the temperature of the growth chamber. After PAMBE growth with the Nitride Gen III system onsite, each sample was characterized with atomic force microscopy (AFM) to ensure proper morphology. After checking the structure, we added many metal contacts on each sample for testing by a simple two mask contact photolithography process. The metal contacts were arranged in a Greek cross formation, and from each cross, a single Hall Effect measurement could be taken. The Hall Effect measurements determined the carrier concentrations and mobilities. Figure 1 shows a schematic of the cross-section of a completely processed sample. The measured carrier concentration that produced the highest mobility could then be matched with its corresponding doping so that way the mobility could be further optimized in part two.

After the optimal carrier concentration was determined, various plasma powers and nitrogen flow rates were tested to find the combination that produced the highest overall mobility. The samples in this series all had the carrier concentration determined in the first study. The same procedure of sample preparation and testing was used for this series as well.

Results and Conclusions:

Figure 2 is an AFM image showing typical morphology of the samples tested in both series. The step-like features present are indicative of proper PAMBE growth. This step was done as a quality check so that poor films were not processed. Figure 3 shows the results of the carrier concentration study. The two data sets presented were taken at the two plasma conditions shown. Both data sets indicate that the carrier concentration producing the greatest mobility is about 1.5×10^{15} cm^{-3}.

Figure 4 shows the results of the optimization study. All samples presented in Figure 4 have the same carrier concentration of about 1.5×10^{15} cm^{-3} so that they can be fairly compared. The highest mobility recorded in this series was ~ 550 cm^2/ V·s. The plasma power and nitrogen flow rate that produced this highest mobility were 200 W and 10 standard cubic centimeters per minute (sccm).

The results of both studies make sense. In the doping study, lower carrier concentration corresponds to lower doping. Lower doping means fewer possible scattering sites for the charge carriers in the film. Less scattering events corresponds to higher mobility, which is supported by the results of that series. The results of the optimization series also make sense because higher powers and flow rates may have the potential of damaging the film which would lower the mobility.

Future Work:

We hope to continue the optimization study for it to include other plasma powers and nitrogen flow rates so that it is more complete. Once the optimization study is fully complete, other parameters could be tested to further optimize mobility. Also, temperature dependent Hall Effect measurements should be taken so that defect concentrations can be determined. These results could be correlated to the mobilities measured for a more complete understanding of the material.

Acknowledgements:

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References:

[1] B.M. McSkimming, F. Wu, T. Huault, C. Chaix, J.S. Speck. Plasma assisted molecular beam epitaxy of GaN with growth rates > 2.6 μm/h, J. of Crystal Growth, Volume 386, 15 January 2014, Pages 168-174 (2013).

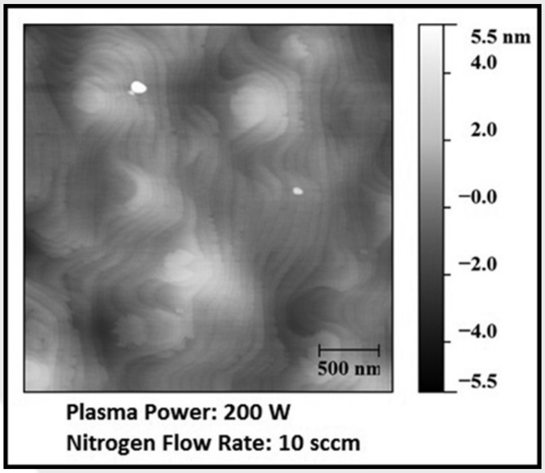

Figure 2: Typical morphology of a GaN film used in this study. All samples tested had similar morphologies.

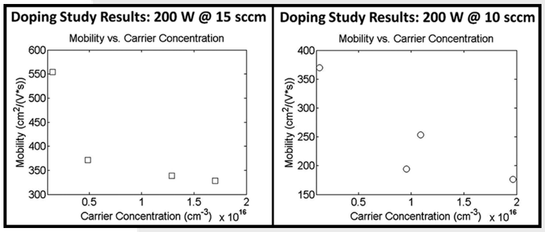

Figure 3: Mobility vs. carrier concentration for the listed growth conditions.

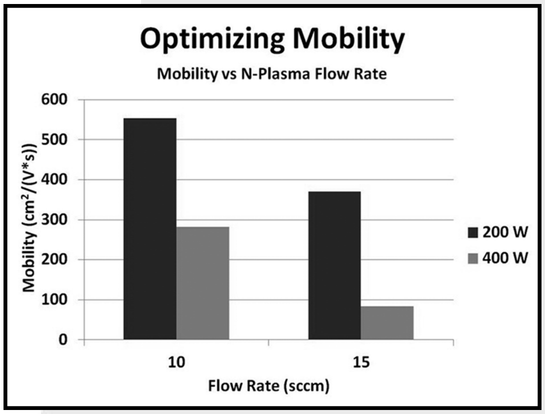

Figure 4: Mobility vs. nitrogen flow rate for plasma powers of 200 W and 400 W.