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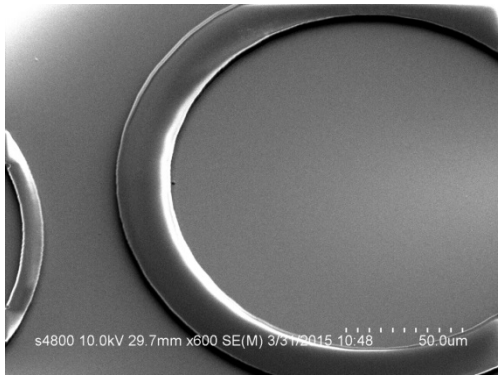

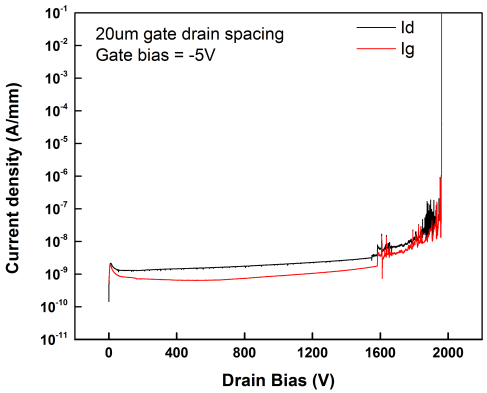

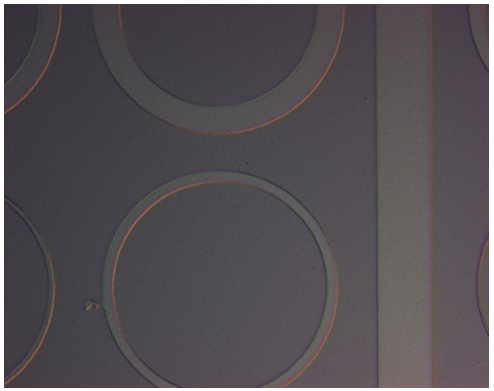

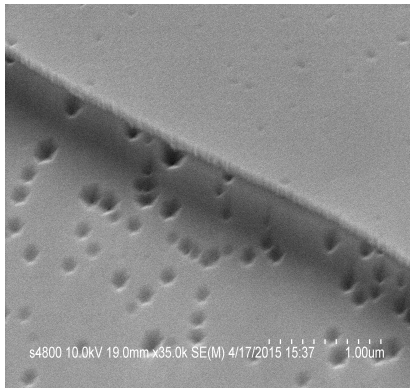

Inductively Coupled BCl_3/Cl_2/Ar Plasma Etching of High Al Content AlGaN

Erica A. Douglas, A. A. Allerman,
R. J. Kaplar, C. A. Sanchez, and A. G. Baca

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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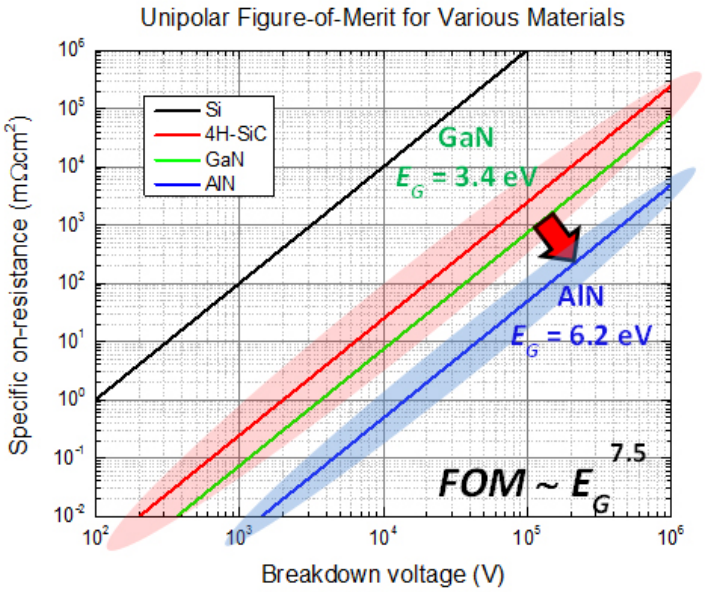
Overview

- Effect of Bias
  - Etch Rate
  - Surface Morphology
  - OES
- Effect of % BCl_3
  - Etch Rate
  - OES
  - Surface Morphology
  - Effect of % BCl_3 on Al_2O_3
- Ohmic Contact to $Al_{0.85}Ga_{0.15}N/Al_{0.7}Ga_{0.3}N$

Motivation

- Wide bandgap materials for power electronics have been investigated for quite some time.
- Interest is gaining to push towards Ultra-wide bandgap materials to increase breakdown voltage in power devices, overall increasing the Unipolar Figure of Merit.

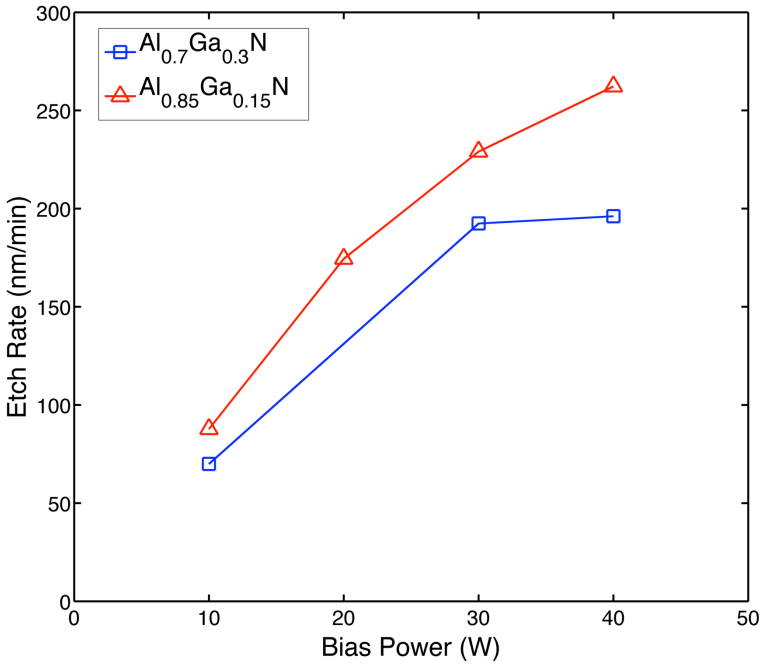


- High Al content AlGaN for high electron mobility transistors (HEMTs) is of interest as a means to increase material bandgap.
- Processing issues increase with increasing bandgap.

Effect of Bias

Etch development with $BCl_3/Cl_2/Ar$ inductively coupled plasma

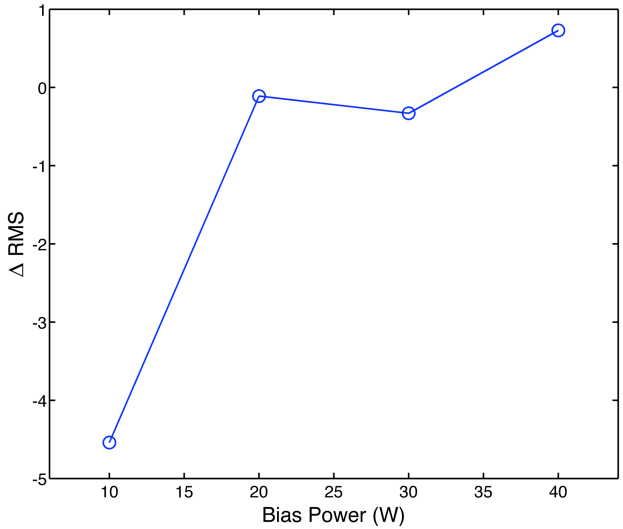
1070C – 85% AlGaN (500Å)
1070C - 68% AlGaN (UID: 500Å)
1120C - 70% AlGaN (UID: 2kÅ)
AlN Overgrowth
Thick Sapphire



$AlCl_x$ has a lower volatility than $GaCl_x$, and the bond energy of Ga-N is lower than that of Al-N. As Al content increases, requires greater physical bombardment to remove $AlCl_x$ compounds.

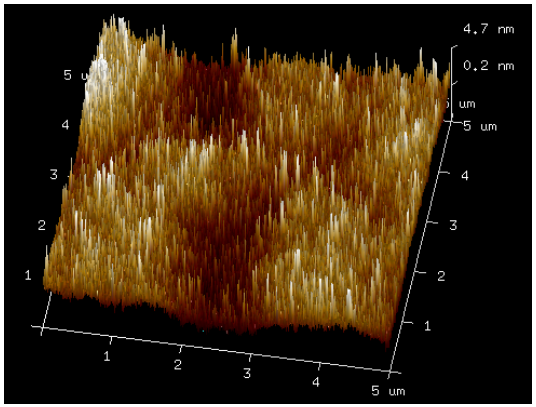
Bias Power and Surface Morphology

$Al_{0.85}Ga_{0.15}N$

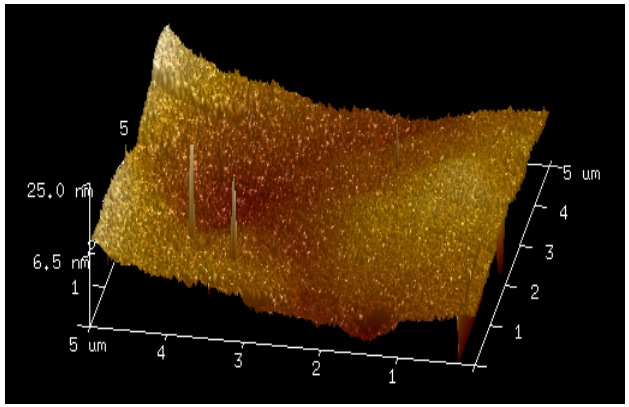


Surface roughness increases with increasing power due to increase ion bombardment.

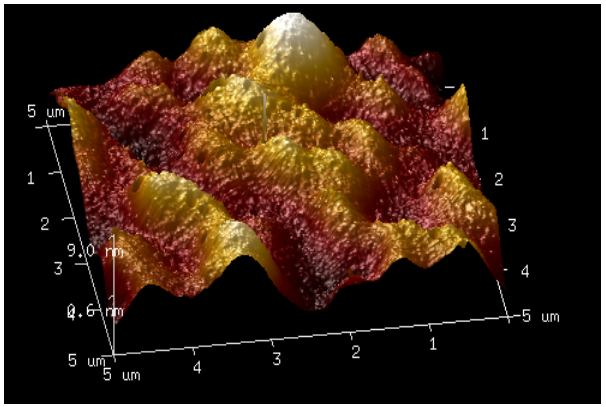
Sample at 10W had rough surface prior to etch.



20W

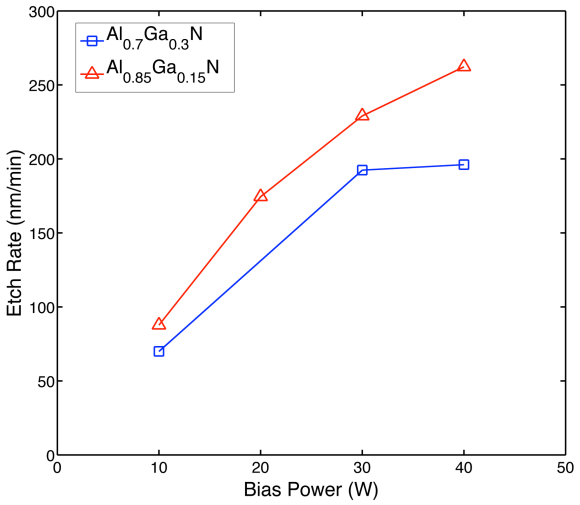


30W

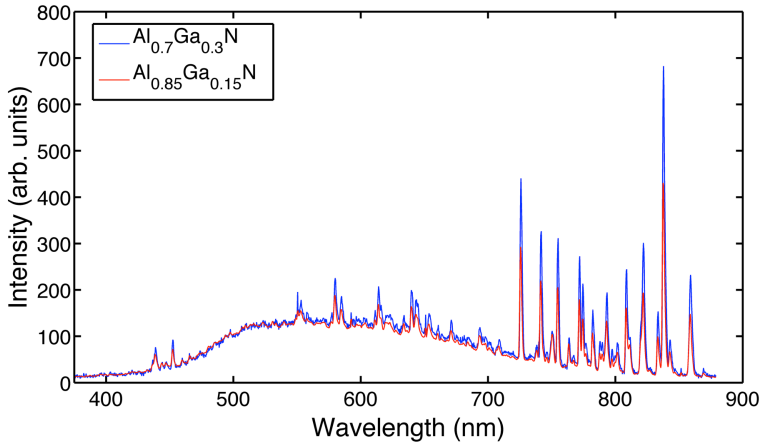


40W

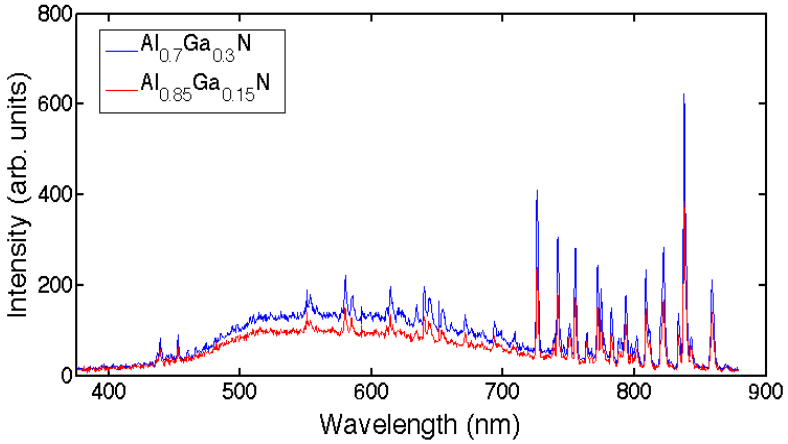
OES – Bias Power



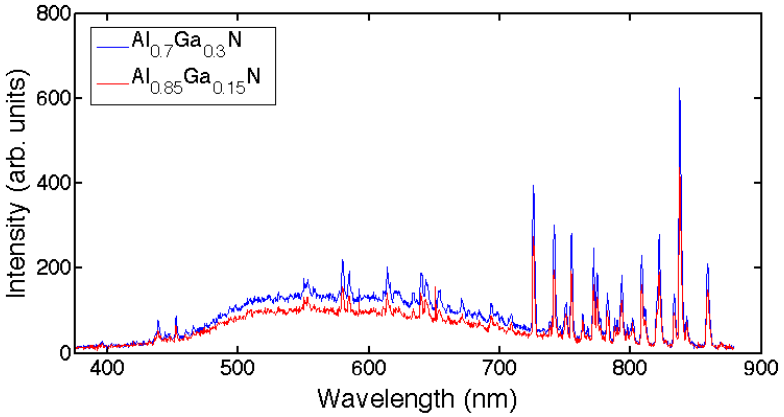
10W



30W



40W



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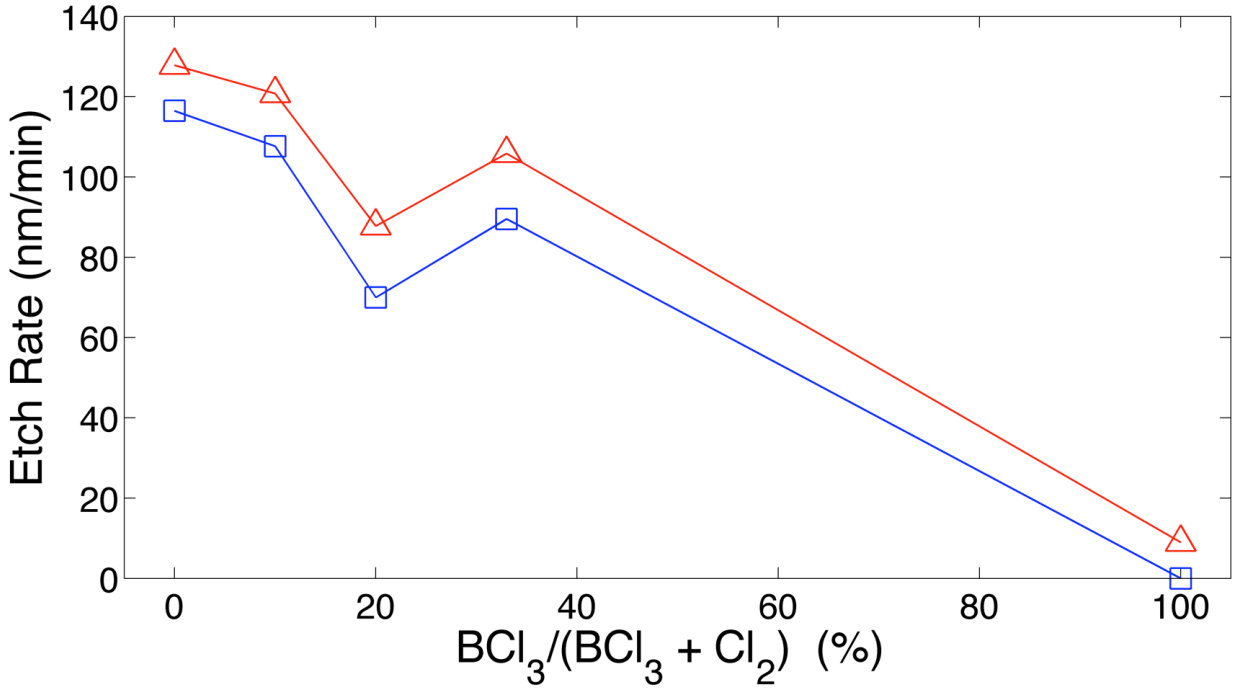
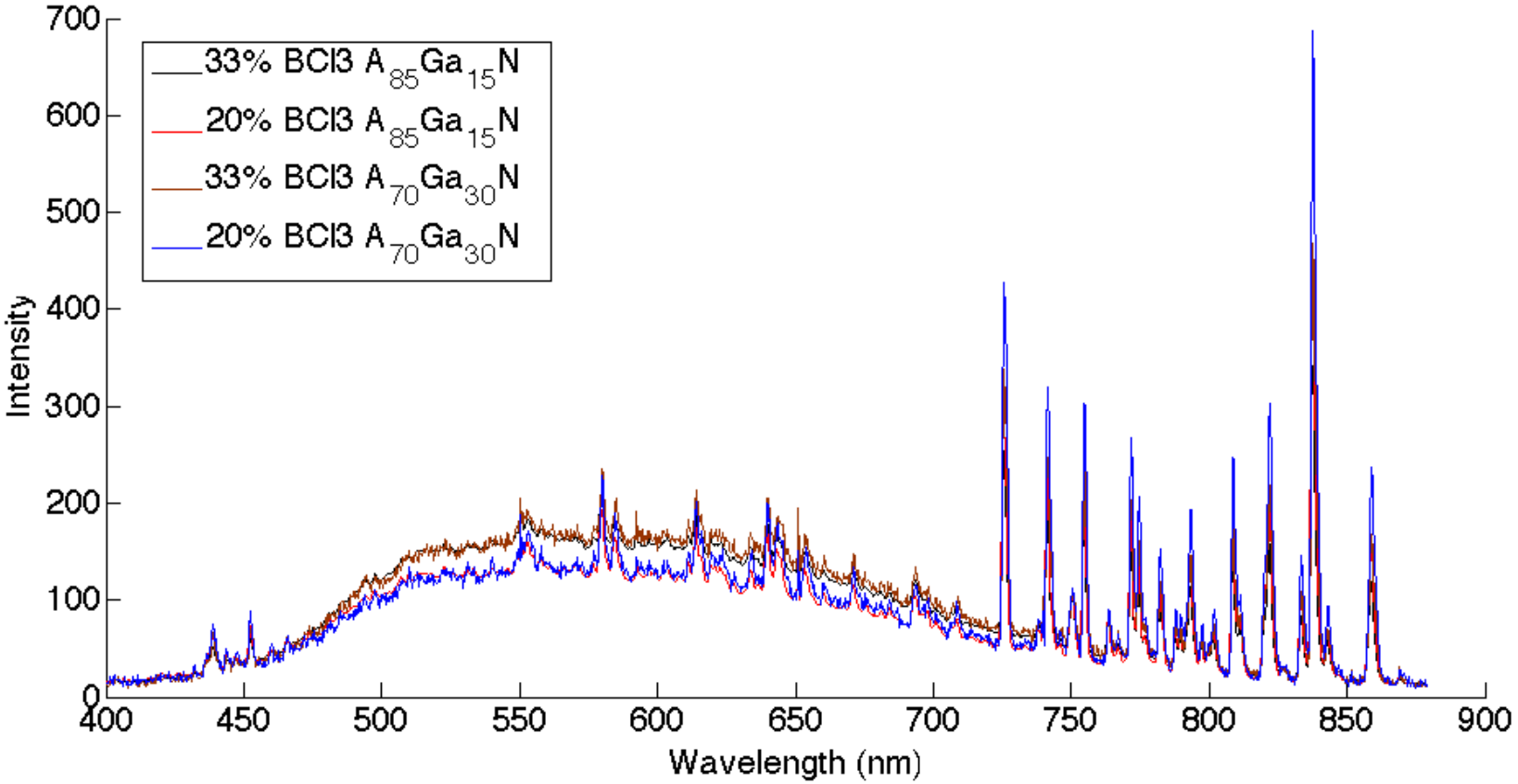
Effect of Chemistry

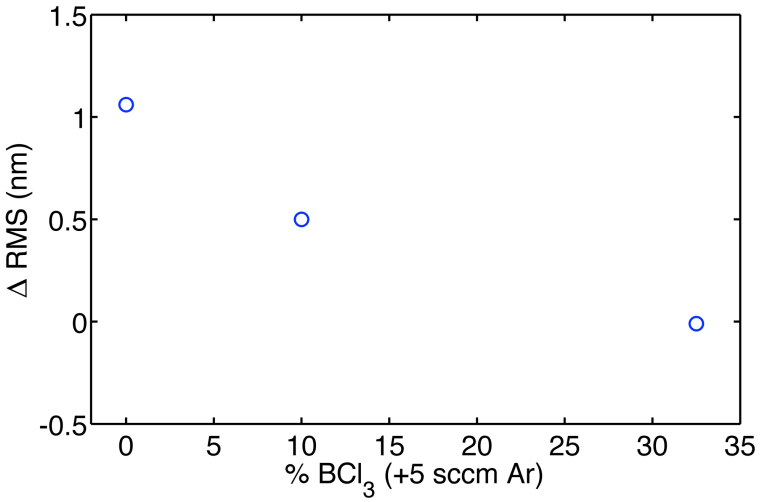
- As % BCl_3 increases, etch rate for both 85% and 70% Al content decreases. BCl_3 is heavy and requires significant ICP power to fully dissociate. Decrease in etch rate due to increased non-volatile BCl_x compounds.

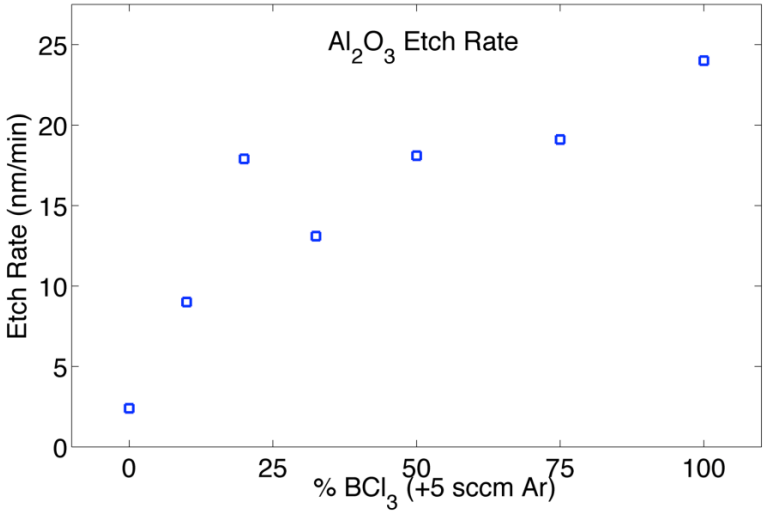


Effect of Chemistry - OES



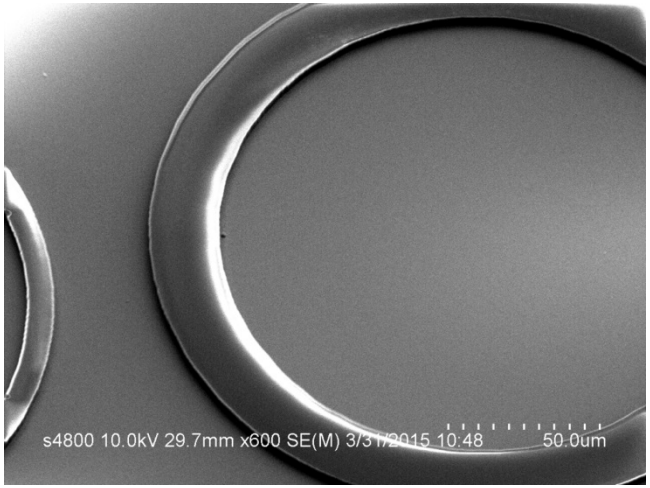
Controlling Surface Morphology





Increased %BCl_3 results in slower etch rate. However, surface roughness decreases with an increase in %BCl_3.

Al_2O_3 etch rate is an order of magnitude lower than AlGaN. Any surface oxidation can result in micro-masking, thus increasing surface roughness. Increasing BCl_3 increases the Al_xO_y etch rate, decreasing the effect of micro-masking.



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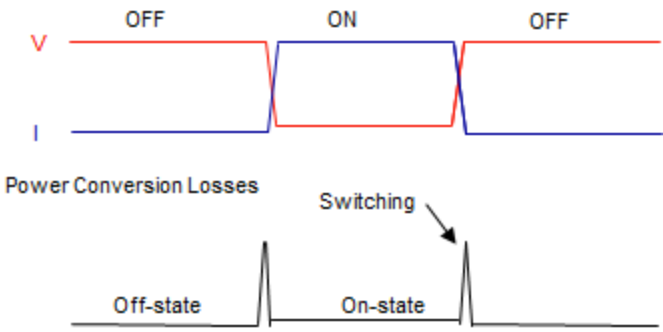
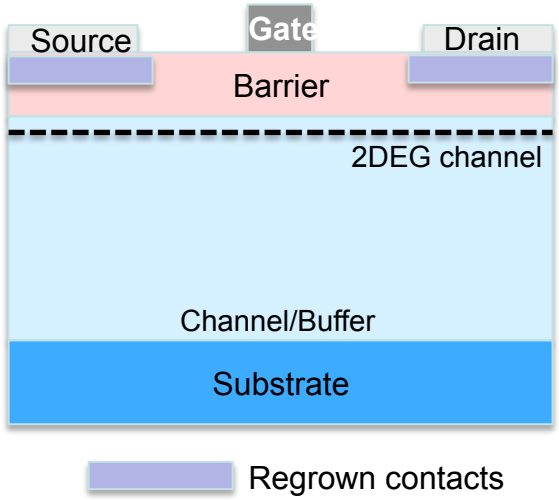
Technical Challenge: Achieve High Efficiency

- On-State: Low on-state voltage with high current density and low R_{ON}
- Off-state: High standoff voltage and low leakage
- Switching: Fast rise & fall times lead to high efficiency PE circuits



- Ohmic contact becomes increasingly difficult as E_G increases
  - Possible need for regrown contact

$$FOM = V_B^2/R_{on,sp} = \varepsilon\mu_n E_C^3/4$$

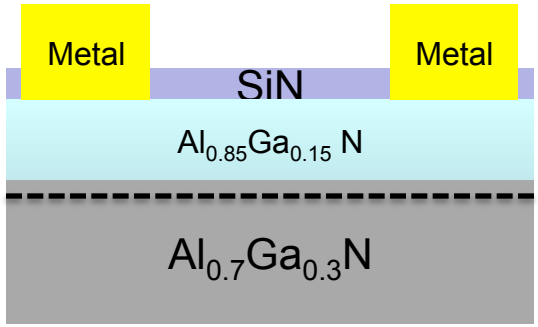


A. Baca

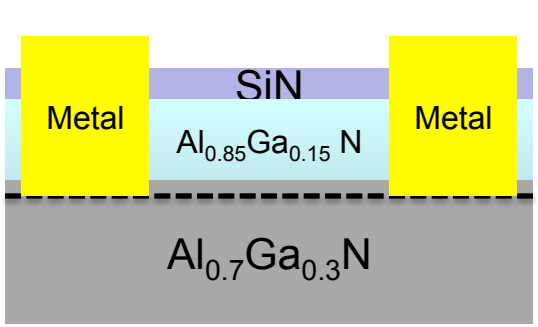
Overview

- 3 approaches for Ohmic contacts on $Al_{0.85}Ga_{0.15}N/Al_{0.7}Ga_{0.3}N$
  1. Planar Ohmic Metallization on $Al_{0.85}Ga_{0.15}N/Al_{0.7}Ga_{0.3}N$
  2. Recessed Ohmic Metallization on $Al_{0.85}Ga_{0.15}N/Al_{0.7}Ga_{0.3}N$
  3. Regrown Ohmic Contacts

1.



2.



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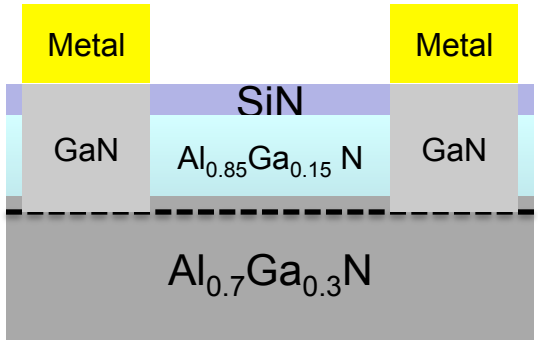
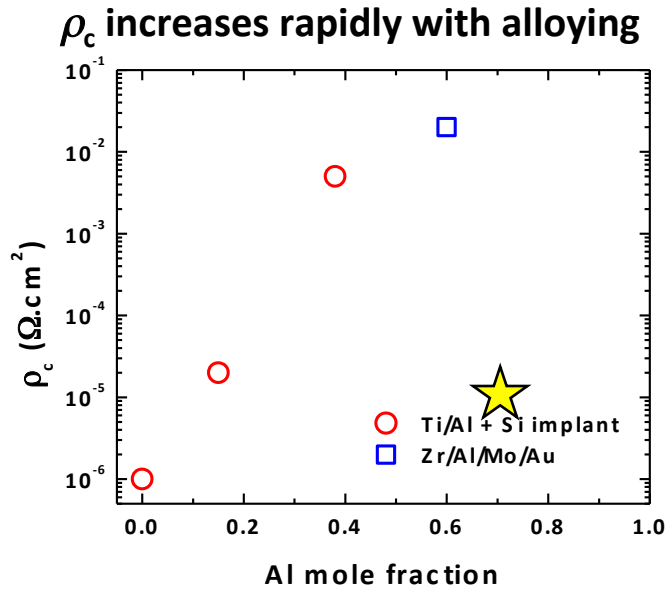
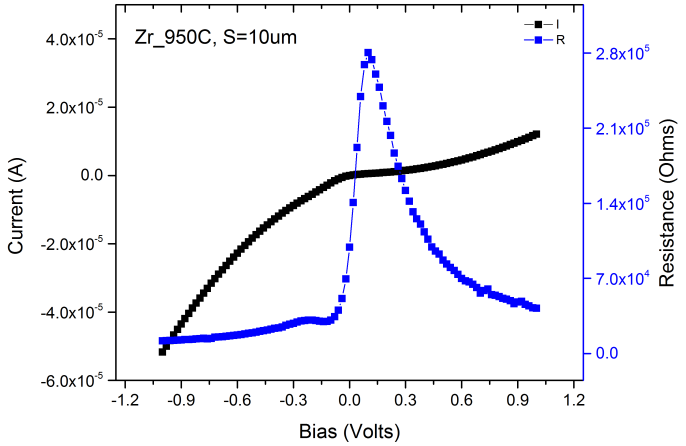


Lateral Ohmic Contacts



Nanjo et al. APL92 263502 (2008).



Zr(15Å) / Al(120Å) / Mo(35Å) / Au(50Å)

Significant number of iterations of metal stacks and anneal temperatures investigated to obtain low resistance Ohmic contacts. All showed non-linear behavior on $Al_{0.85}Ga_{0.15}N/Al_{0.7}Ga_{0.3}N$.

Metal 1	Metal 2	Metal 3	Metal 4
Ti	Al	Ni	Au
Nb		Mo	
V		V	
Zr			
Ta			

Effect of surface treatment

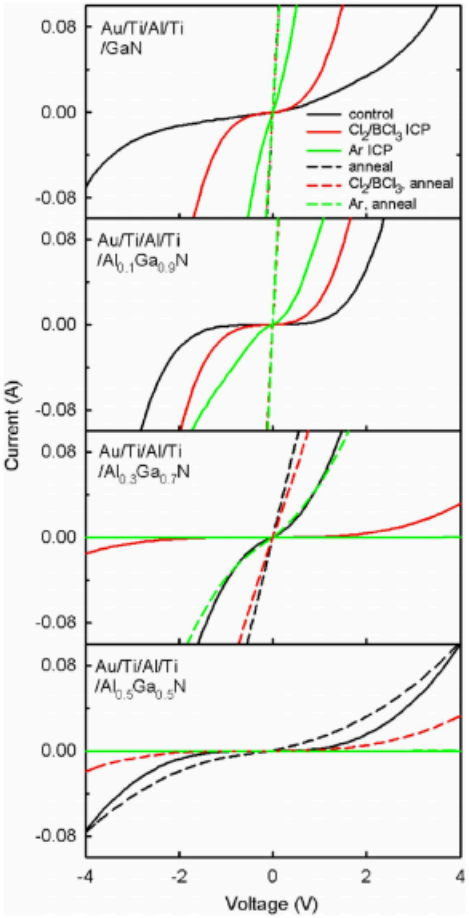
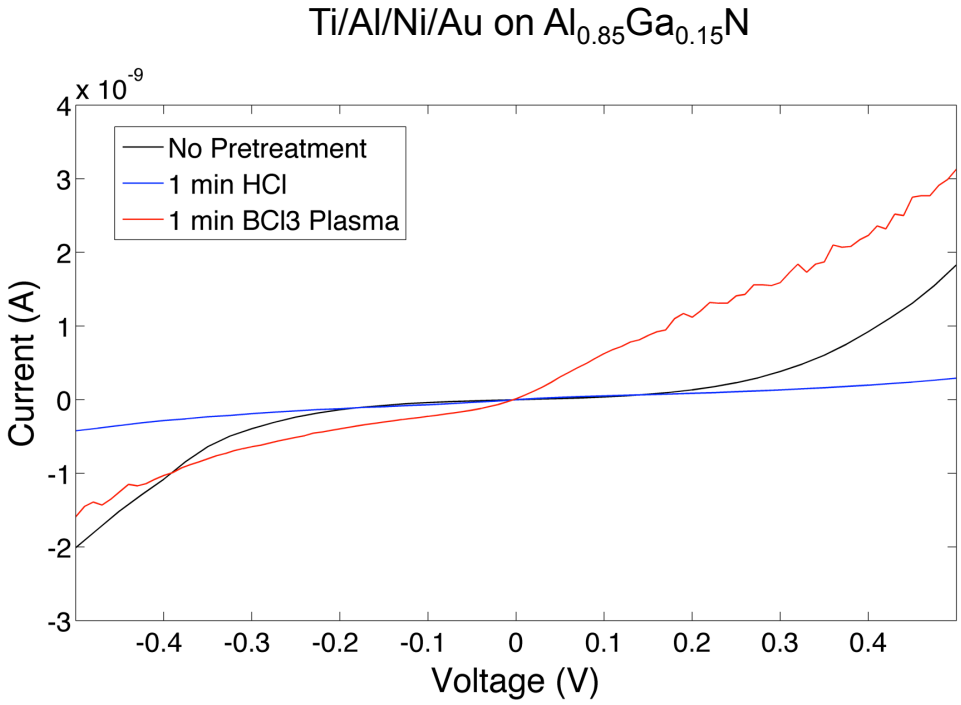


FIG. 1. (Color online) *I-V* characteristics of Ti/Al/Ti/Au contacts on control and ICP-treated $Al_xGa_{1-x}N$ (x=0–0.5) samples, before and after annealing at 900 °C in N_2.

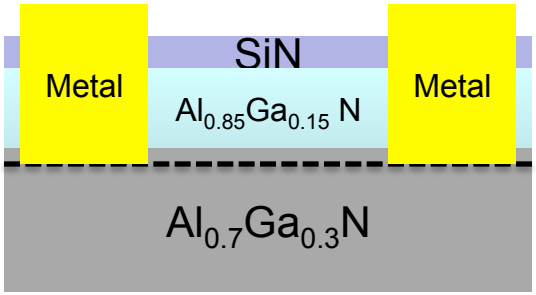
Research has shown that surface treatments prior to metal depositions can effect contact resistance. This effect can become even more important as bandgap increases.

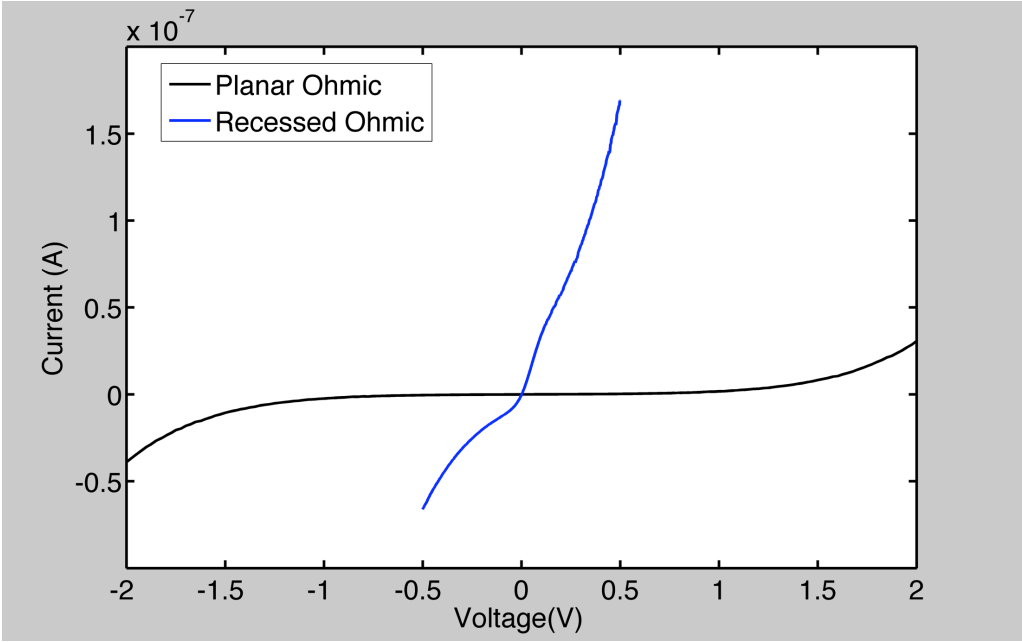


Cao et al., APL, **89**, 082109 (2006).

Recessed Ohmic

- Dry Etch into $Al_{0.7}Ga_{0.3}N$
- Ti/Al/Ni/Au deposition, followed by 850C anneal for 30 sec.





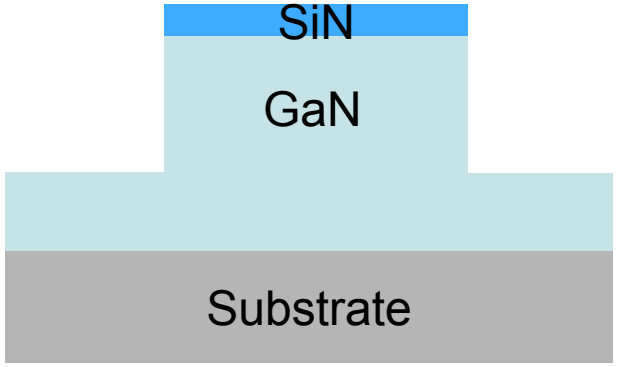
Marked improvement over planar Ohmic scheme with same metallization.

However, non-linear behavior still persists.

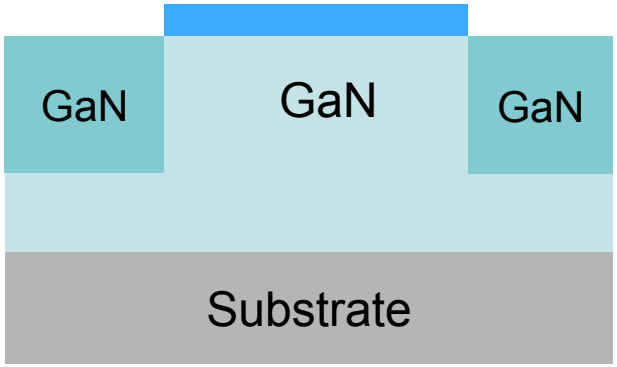
Regrown Ohmic

Step1: GaN on GaN Regrowth

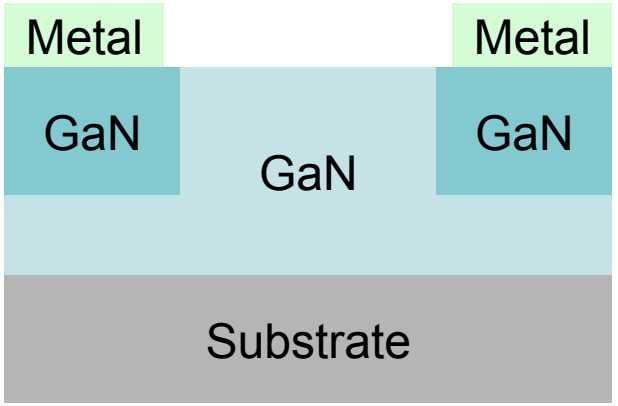
SiN dep and pattern
AlGaN dry etch

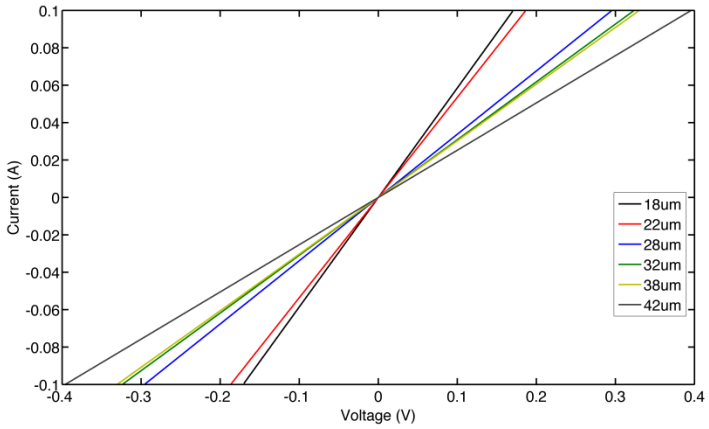


GaN regrowth



Ohmic Metallization





R_C=0.1403 Ω
L_T=3.631 μm
R_{sh}=88.2 Ω/□
ρ_c=5.1x10^{-6} Ω cm^2

First Ohmic Contacts for SNL 70% AlGaN

Step 2: GaN regrowth on $Al_{0.7}Ga_{0.3}N$

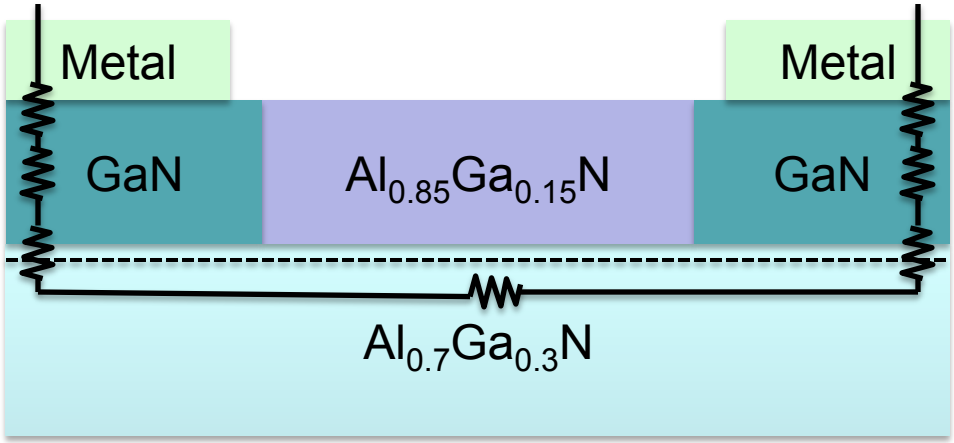
As grown

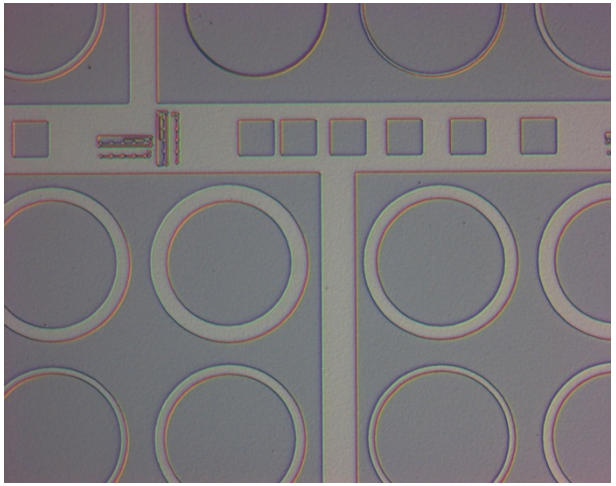
$Al_{0.85}Ga_{0.15}N$
0.05µm, Si = 1e18

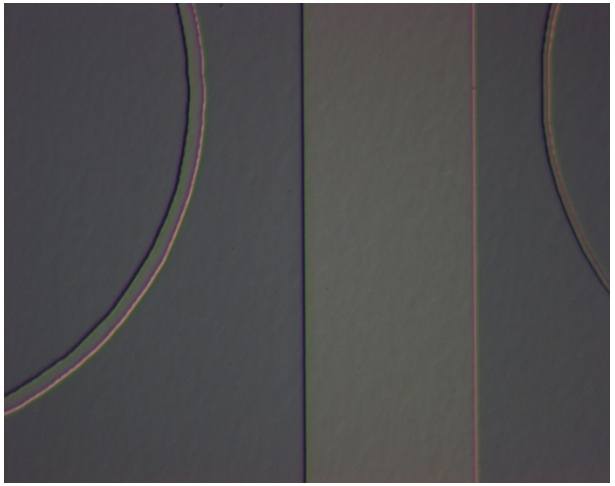
$Al_{0.7}Ga_{0.3}N$
~1.3µm, UID

AlN

Sapphire

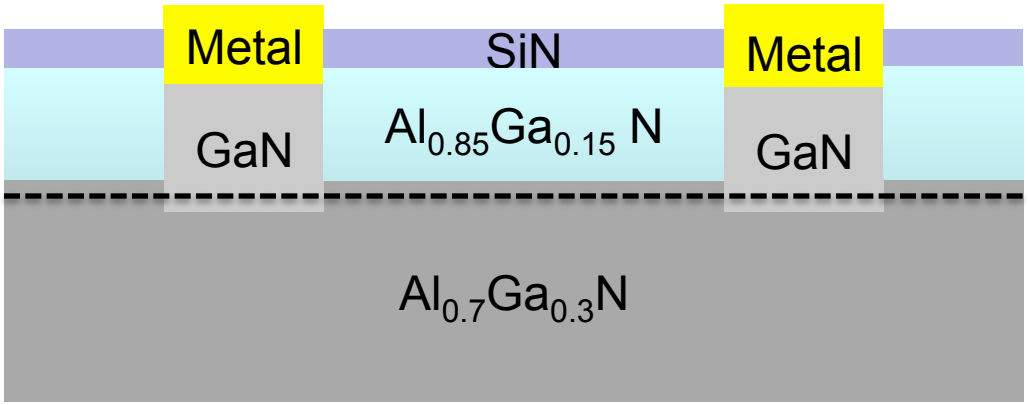


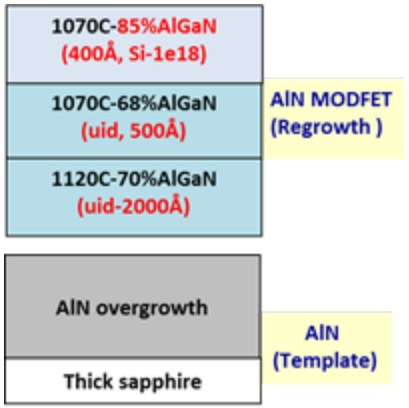


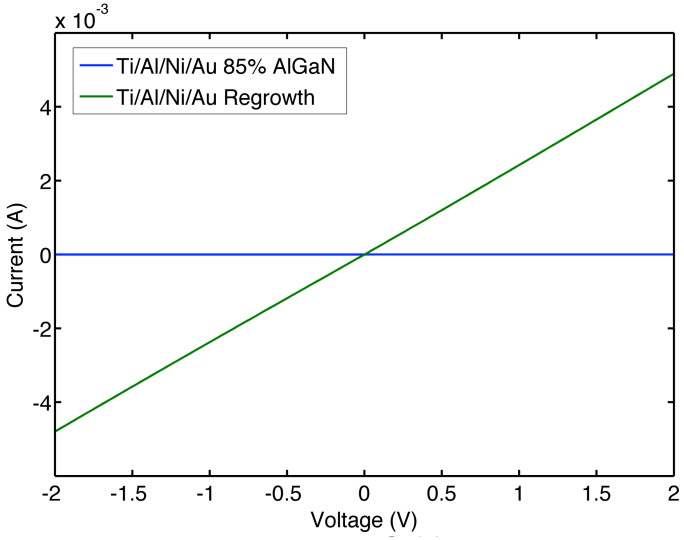


First Ohmic Contacts for SNL 70% AlGaN

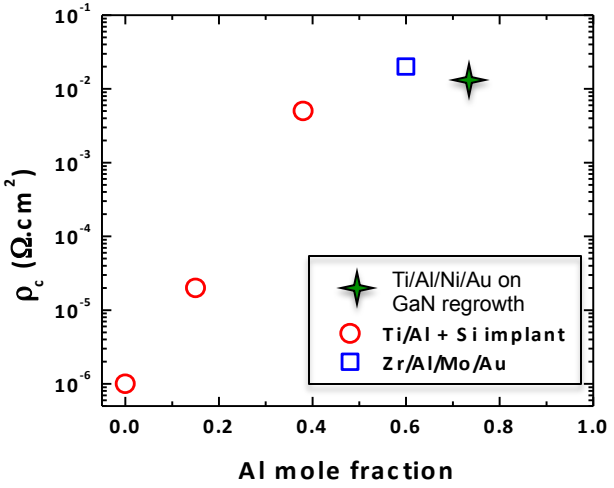
GaN on 70% AlGaN







Lt=7.5um
R_C=49.2 Ω
Rsheet=13.9kΩ/□
ρ_C=2.8e-2 Ωcm²



Nanjo et al. APL92 263502 (2008).

Summary

Even at 30W bias power, etch rate deviates for $Al_{0.7}Ga_{0.3}N$ and $Al_{0.85}Ga_{0.15}N$

Etch rate decreases for both $Al_{0.7}Ga_{0.3}N$ and $Al_{0.85}Ga_{0.15}N$ as % BCl_3 increases. Surface roughness also decreases as % BCl_3 increases.

Investigated 3 approaches for Ohmic contacts

- **Achieved $\rho_c = 2.8x10^{-2}\ \Omega\ cm^2$ with $GaN/Al_{0.7}Ga_{0.3}N$.**