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Ohmic Contacts to $Al_{0.85}Ga_{0.15}N/Al_{0.7}Ga_{0.3}N$ Heterostructure

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Abstract

AlGaN based high electron mobility transistors (HEMTs) are excellent candidates for high-power applications due to numerous material properties including high critical electric field. Ultra-wide bandgap (UWBG) materials are being pursued in order to obtain the capability for high power applications requiring several kV. One method for achieving an UWBG heterostructure with an increased critical electric field is by increasing the Al mole fraction of both the barrier and channel layer of the heterostructure to $Al_yGa_{1-y}N/Al_xGa_{1-x}N$, where y>x>0.65.

As the critical electric field scales with the bandgap of the material by $E_g^{2.5}$, it is possible to **increase the critical electric field to greater than 3X that of GaN with a $Al_{0.7}Ga_{0.3}N$ channel composition**. However as the bandgap of the material increases, the Ohmic contact resistance increases which can dominate the device parasitic resistance and limit potential device performance. In this work, we have investigated three different fabrication schemes in order to achieve Ohmic contacts to an $Al_{0.85}Ga_{0.15}N/Al_{0.7}Ga_{0.3}N$ heterostructure using a Ti/Al/Ni/Au metal scheme.

Device Schematics

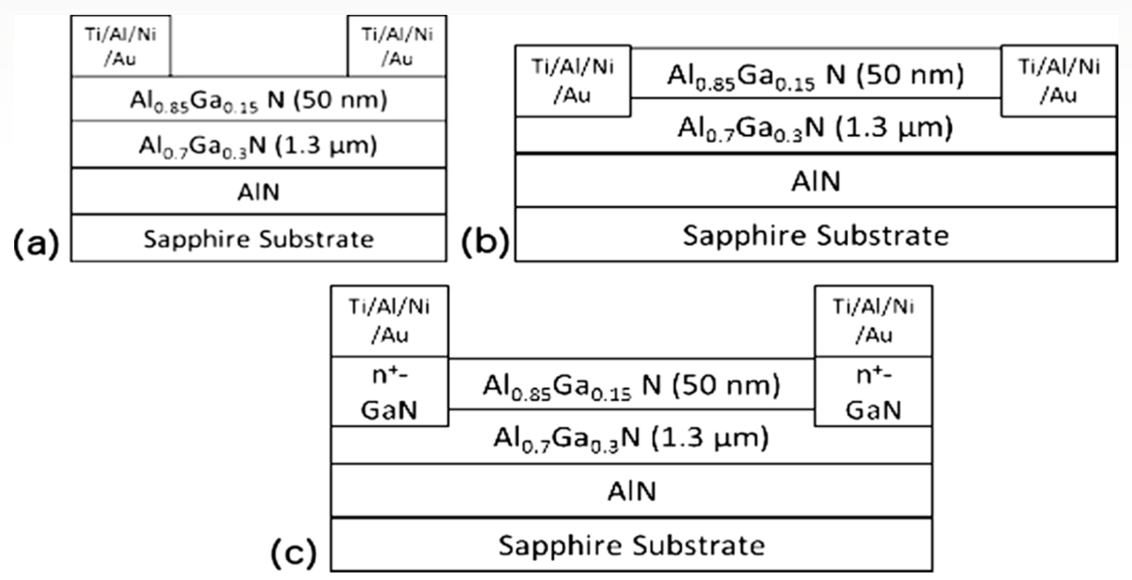


Figure 1. Three fabrication schemes were investigated: (a) planar, (b) recessed, and (c) n^+-GaN regrowth.

(a) Circular transfer length method (CTLM) structures were fabricated by standard photolithography. Several different metal stacks and anneal temperatures were investigated (see Table 1).

(b) PECVD SiN was deposited and patterned for CTLM structures. The SiN served as a hard mask for the recessed dry etch with $BCl_3/Cl_2/Ar$ ICP-RIE. Post dry-etch, the SiN was removed followed by standard photolithography and lift-off to define the metal layer, (e-beam deposition Ti/Al/Ni/Au) and anneal of 850 °C for 30 sec.

(c) PECVD SiN was deposited and patterned. The SiN served as a hard mask for the recessed dry etch with $BCl_3/Cl_2/Ar$ ICP-RIE. The patterned SiN was used as a mask for selective n^+- GaN regrowth by MOCVD. Ti/Al/Ni/Au deposition and anneal (850°C, 30sec) followed regrowth.

Circular TLM pattern was employed for all samples to measure the contact resistance, with spacing between the contact pads ranging from 5 to 40 µm. I-V characteristics were measured with a HP4156C semiconductor parameter analyzer.

Planar Metallization

Numerous metallization stacks and anneal temperatures were investigated for obtaining Ohmic contacts to the heterostructure (small subset shown in Table 1). However, all metallization schemes investigated exhibited high non-linearity and low current (µA).

Sample	Metal	Anneal
1	Zr/Al/Mo/Au 15/120/35/50 (nm)	900°C
2	Zr/Al/Mo/Au 15/120/35/50 (nm)	950°C
3	V/Al/V/Au 15/80/20/100 (nm)	900°C
4	V/Al/V/Au 15/80/20/100 (nm)	950°C
5	Nb/Ti/Al/Mo/Au 20/20/100/40/50 (nm)	900°C
6	Nb/Ti/Al/Mo/Au 20/20/100/40/50 (nm)	950°C
7	Ti/Al/Ni/Au 25/100/15/50 (nm)	850°C

Table 1: Subset of metallization stacks and anneal temperatures investigated for planar Ohmic contacts

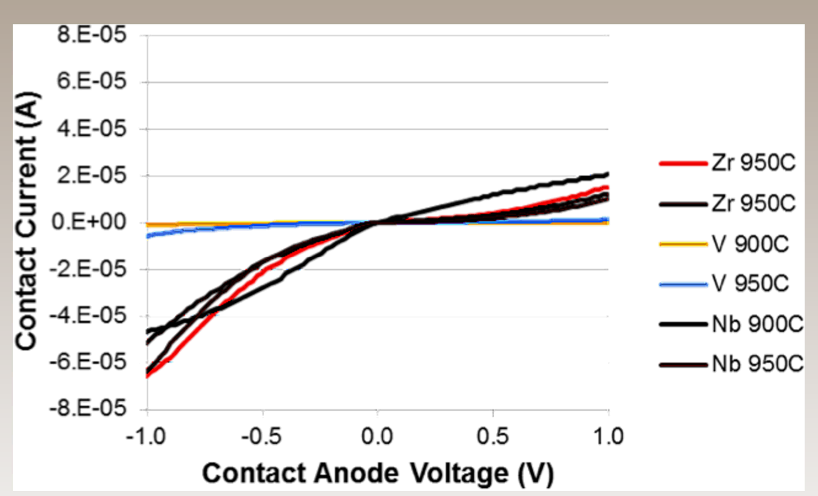


Figure 2. Current-voltage curves for samples 1-6. Labels indicate anneal temperature and metal layer in contact with AlGaN

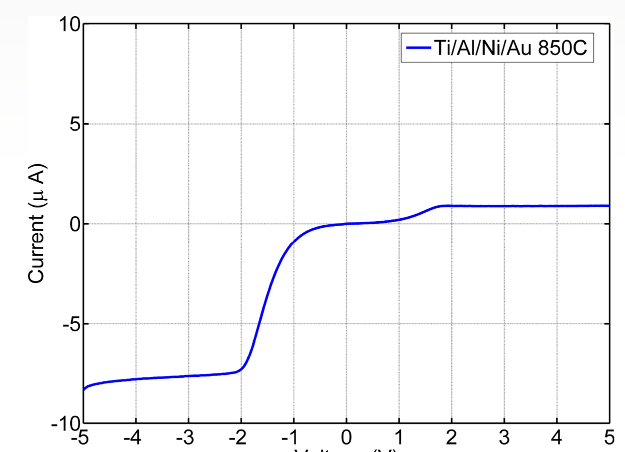


Figure 3. Current-voltage curve for sample 7 (Ti/Al/Ni/Au), annealed at 850 °C with 40µm spacing.

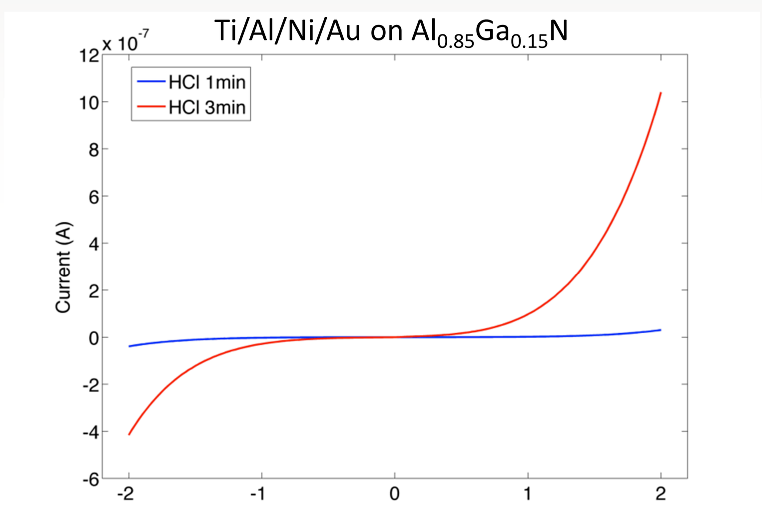


Figure 4. Current-voltage curve for sample 7 (Ti/Al/Ni/Au), annealed at 850 °C with different surface treatments.

Recessed Contact

Ti/Al/Ni/Au metallization was deposited after recessed dry etch into the channel layer. This was done in an effort to allow direct 2DEG contact of the metallization without a high bandgap barrier.

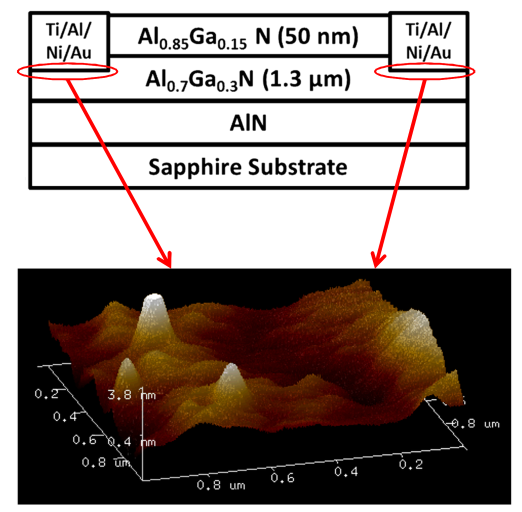


Figure 5. AFM of $Al_{0.7}Ga_{0.3}N$ surface post dry etch. RMS = 0.9nm

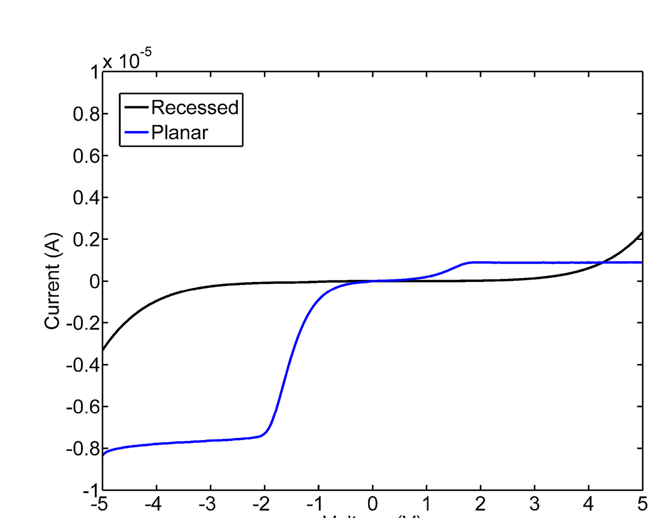


Figure 6. Current-voltage curves for both planar and recessed with Ti/Al/Ni/Au metallization.

Dry etch was optimized to obtain very low surface roughness, with low bias power to minimize ion damage during fabrication. However, recessed contacts exhibited performance similar to back-to-back diodes.

Regrown Contacts

Selective n^+-GaN regrowth into recessed structures was followed with Ti/Al/Ni/Au metallization and anneal of 850 °C for 30 sec. Low resistance, Ohmic contacts were successfully fabricated with this fabrication scheme.

$$R_T = \frac{R_{SH}}{2\pi} ln(r_o/r_i) + \frac{2R_{SH}L_T}{2\pi d} ln(r_o/r_i)$$

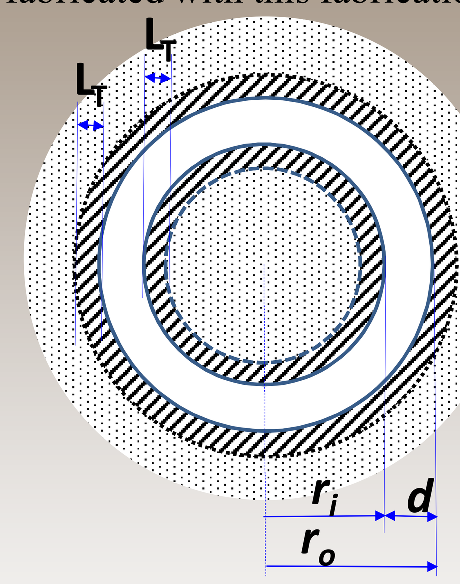


Figure 7. CTLM structure.

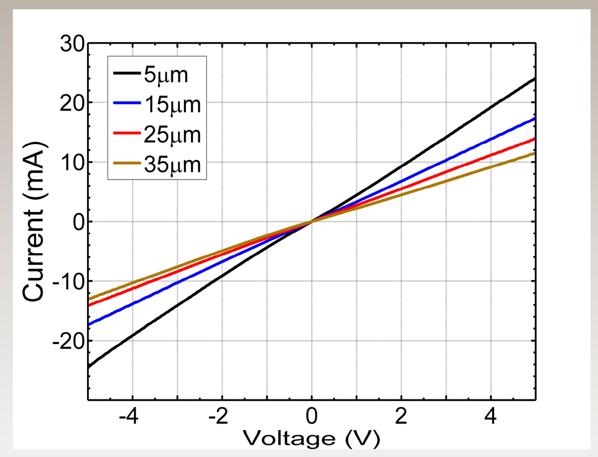
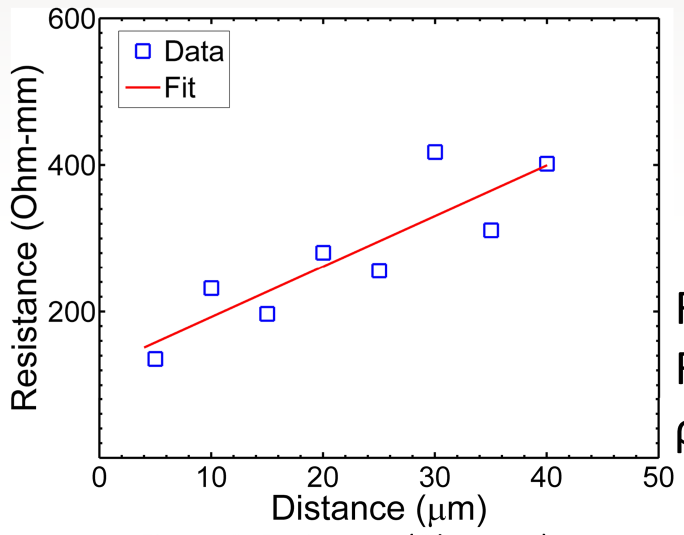


Figure 8. Current- voltage sweep for gaps with spacing from 5-35µm.



R_{SH}=6100Ω

R_C = 62 Ω mm

$ρ_C$ = 5x10^{-3} Ω cm^2

Figure 9. Resistance (Ohm-mm) vs. gap distance.

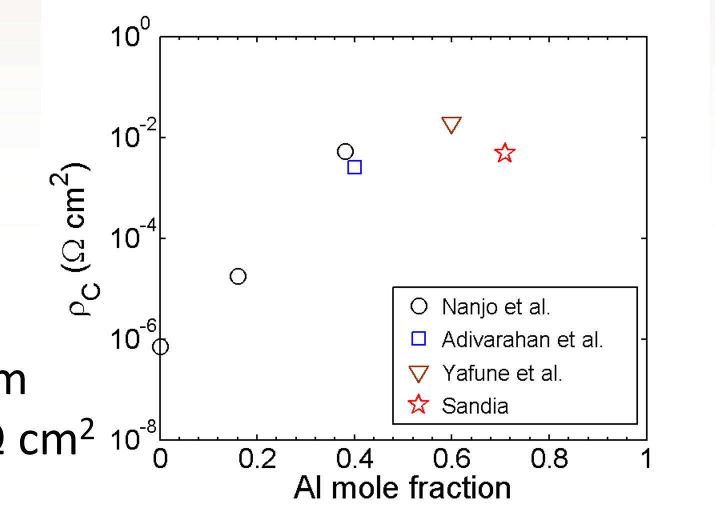


Figure 10. Comparison of $ρ_c$ for state of the art with varying Al mole fraction of channel layer

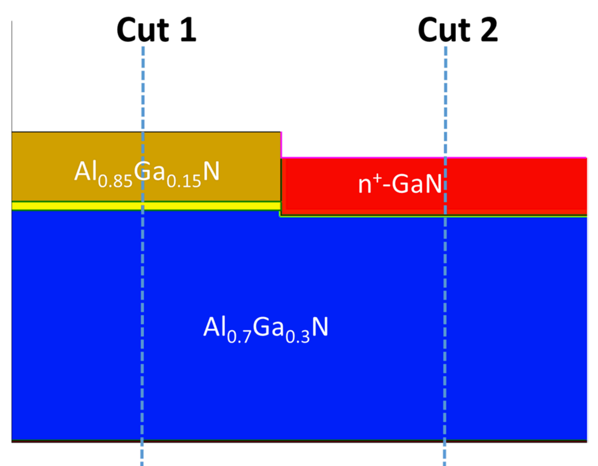


Figure 11. Schematic of structure used for TCAD simulation of band diagram.

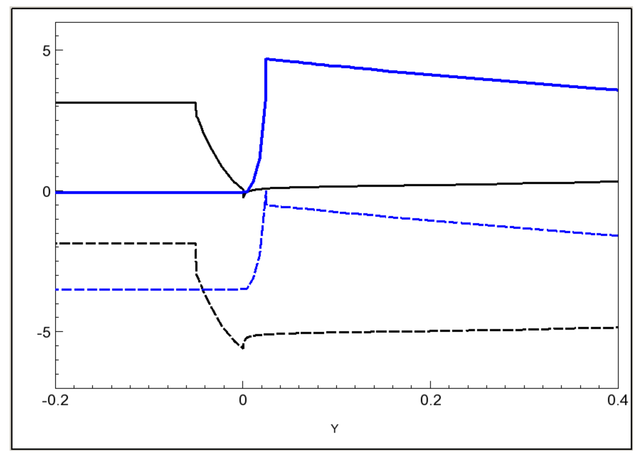


Figure 12. TCAD simulation of band diagram for regrown n^+- GaN contact

Conclusion

Circular TLM structures were evaluated for three different fabrication schemes. Both planar metallization and the recessed structure exhibited highly resistive, non-linear behavior. Implementation of selective regrowth of n^+-GaN, however, exhibited lower resistance Ohmic behavior with Ti/Al/Ni/Au. Additionally, the regrown contact approach results in a lower $ρ_c$ than previously reported by Yafune *et al.* with only 0.6 Al mole fraction for the AlGaN channel.

References

[1] T. Nanjo *et al.*, "Remarkable breakdown voltage enhancement in AlGaN channel high electron mobility transistors," Appl. Phys. Lett. **92**, 263502 (2008).
[2] V. Adivarahan *et al.*, "Indium-silicon co-doping of high-aluminum-content AlGaN for solar blind photodetectors," **79**, 1903 (2001).
[3] N. Yafune, *et al.*, "AlN/AlGaN HEMTs on AlN substrate for stable high-temperature operation," **50**, 3 (2014).

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National Nuclear Security Administration

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