Engineered Tunneling Contacts with Low-Temperature Atomic Layer Deposition of AlN on GaN

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Ultrathin AlN deposited on GaN is highly promising for developing low-resistance ohmic contacts since removing the gallium concentration from the standard AlGaN/GaN heterojunction maximizes the polarization strain and theoretically the two-dimensional electron gas (2DEG) concentration between the two materials. [1] This work describes the use of low-temperature atomic layer deposition (ALD) to deposit AlN on GaN and achieve ohmic contacts using quantum tunneling from the 2DEG to the metallic contact.

Atomic layer deposition was performed at 250ºC using trimethylaluminum (TMA) and nitrogen plasma precursors. Dielectric AlN layers with 3-5 nm nominal thicknesses were deposited on 5 µm GaN substrates with two different donor concentrations: 7×10^{17} cm^{-3} (N+) and ~10^{14} cm^{-3} (N-). Circular planar MOSCAP structures were developed in-house [2] with Cr as the contact metal. Current-voltage (JV) plots displayed contact behavior while capacitance-voltage plots (CV) were used to extract 2DEG concentrations using the circuit model in Figure 1.

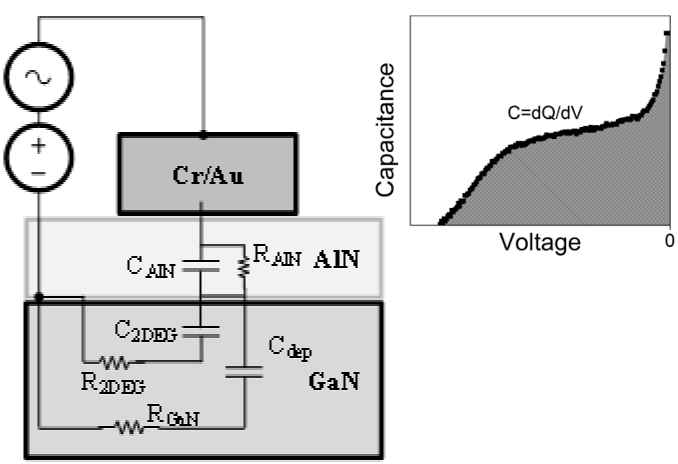

Figure 1: Schematic of the AlN/GaN MOSCAP along with plot of reverse bias integration method to determine 2DEG.

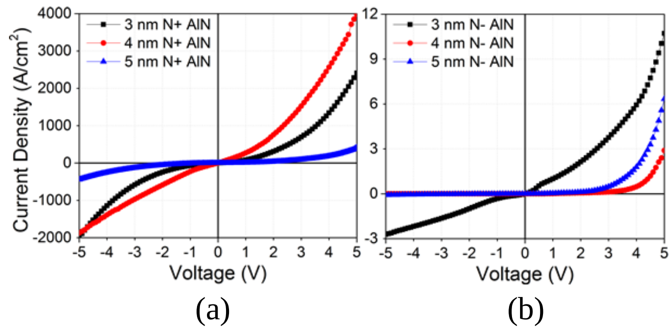

Figure 2: JV plots of AlN on (a) N+ GaN and (b) N- GaN.

Figure 2 compares the AlN/GaN junction for the two different doping levels. The N+ GaN samples consistently demonstrated pseudo-ohmic JV curves, with 4 nm AlN as the most linear while 5 nm AlN most resembled a double Schottky diode. For N- GaN, only 3 nm AlN was thin enough to display significant quantum tunneling effects through the barrier [3], with the JV showing pseudo-ohmic behaviour as a result. In contrast, the thicker AlN layers blocked the tunneling current and behaved as Schottky diodes.

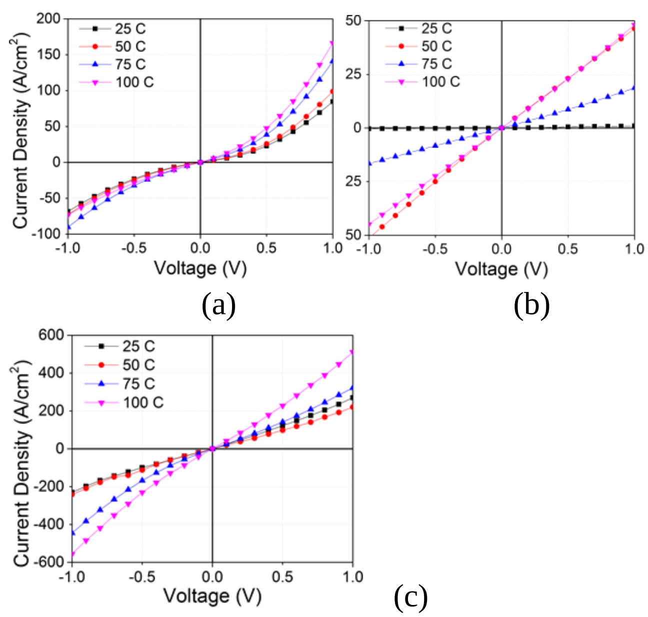

Figure 3: Temperature-dependent JV plots of (a) 3 nm AlN on N+ GaN, (b) 3 nm AlN on N- GaN, and (c) 4 nm AlN on N+ GaN

Doping type	N+			N-		
Thickness	3 nm	4 nm	5 nm	3 nm	4 nm	5 nm
Q_{2DEG} ($x10^{12}$ cm^{-2})	18	22	7	5.9	6.2	19

Table I: Summary of MOSCAP CV results for the AlN/GaN junctions.

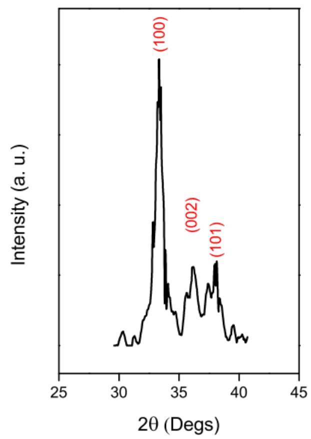

Figure 4: XRD plot of AlN on Si(100). Polarization strain is indicated by the 002 orientation.

Figure 3's temperature-variant JV plots further confirm the influence of quantum tunneling. For N+ GaN with 3 nm AlN, the curve minimally changes with temperature, but with 4 nm, its JV characteristic steadily becomes more linear, with particularly ohmic behaviour demonstrated at 100 C. The JVs for 3 nm AlN on N- GaN transition more drastically, as a virtually perfect ohmic relation appears as early as 50 C. Due to the minimal temperature dependence displayed, these parameters are the most conductive to quantum tunneling and thus are preferred for contacts.

The 2DEG concentrations calculated from the MOSCAP CV plots are shown in Table I. The sharp concentration peaks at 4 nm AlN on N+ GaN and 5 nm AlN on N- GaN are attributed to the onset of strain relaxation. [4] This is especially noticeable with N+ GaN due to the rapid concentration fall with a 5 nm AlN layer. Though the polarization strain of the junction is noticeably weaker than higher-temperature processes as Figure 4 shows, the concentrations still compare favourably with the higher values found in AlGaN/GaN junctions. [1]

Since current is proportional to the product of the transmission current and the charge

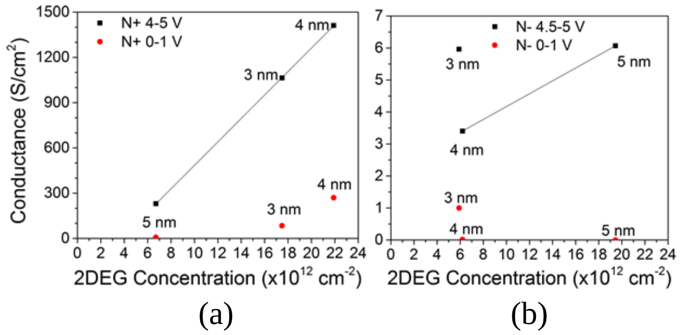

Figure 5: Linear fit of conductance plotted against 2DEG concentration for (a) N+ and (b) N- GaN.

concentration, the AlN/GaN junction conductivity values calculated from the JV slopes in Figure 2 at high and low voltages were plotted against the 2DEG concentration to analyze quantum tunneling effects with varying thicknesses and doping. Figure 5a shows that N+ GaN promotes minimal tunneling probability variation through the AlN barrier. In fact, the conductivity becomes wholly dependent on the 2DEG concentration at higher voltages as indicated by their linear relation. As a result, 4 nm AlN results in the most ohmic junction due to its high amount of polarization charge. Figure 5b indicates that the tunneling probability is highly dependent on AlN thickness for N- GaN, which favours the thin 3 nm barrier layer.

In conclusion, 4 nm AlN on N+ GaN and 3 nm AlN on N- GaN have been established as the potentially ideal parameters for developing ohmic contacts using low-temperature ALD processes. Further details will be presented at the conference.

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