

Applications of SF₆/Cl₂/BCl₃ ALE for III-Nitrides

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Primary CNF Tools Used: Takachi ALE, FlexAL ALD, Odd hour evaporator, MLA maskless lithography

Abstract:

This study demonstrates the successful atomic layer etching of aluminum nitride and gallium nitride using sequential exposures to SF₆ plasma for surface fluorination, followed by Cl₂/BCl₃ plasma to remove the altered layer at or below 100 °C. We investigated the applications of this ALE recipe in achieving improved ohmic contacts to highly doped 71% n-AlGaIn, especially when compared to other plasma based etching techniques. Several techniques were performed, including AFM, XPS, in-situ ellipsometry and probe station measurements for TLM analysis.

Summary of Research:

Gallium nitride (GaN) and aluminum nitride (AlN), both belonging to the III–V semiconductor group, play a pivotal role in modern electronic and photonic technologies. Their wide bandgaps, strong thermal stability, and intrinsic piezoelectric properties make them particularly suitable for fabricating high electron mobility transistors (HEMTs), which are commonly used in radio-frequency (RF) and power electronics applications^{1–3}. Additionally, due to their outstanding optical characteristics, GaN and AlN are also emerging as key materials for photonic integrated circuits and light-emitting diodes (LEDs)^{4,5}.

Atomic Layer Etching (ALE) operates on the principle of dividing the etching process into a series of self-limiting, sequential steps. This separation allows for precise control over the formation and transport of reactive species, enabling improved process uniformity and avoiding the surface damage typically associated with reactive ion etching. The ALE cycle generally comprises two distinct phases: a surface modification step that lowers the material's surface binding energy, followed by a removal step^{6,7}.

Utilizing SF₆ plasma for surface modification and Cl₂/BCl₃ plasma for removal, we achieved etch rates of 4.47 Å/cycle and 5.92 Å/cycle for AlN and GaN respectively,

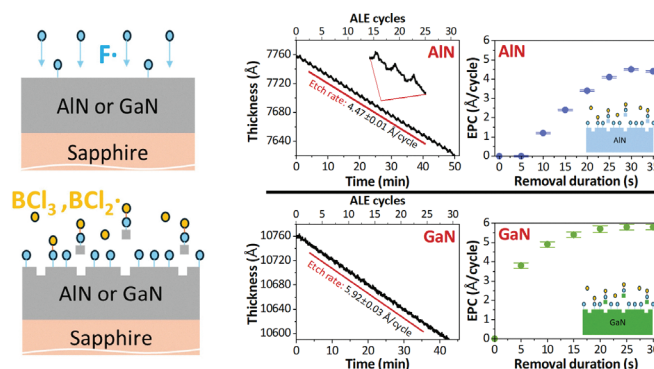


Figure 1: Etch rates and saturation behavior for AlN and GaN.

which correspond approximately to one unit cell per cycle. Etch rate was monitored with in-situ ellipsometry as seen in Figure 1. This approach displayed very controlled results, achieving ALE at temperatures significantly lower than thermal ALE, down to even 40°C (Figure 2). Furthermore, this technique was used to treat n-AlGaIn surfaces prior to ohmic contact metallization. The Si doped AlGaIn samples were grown on single crystal AlN substrate by plasma-assisted molecular beam epitaxy (MBE) with a Si density of $9 \times 10^{19} \text{ cm}^{-3}$. 10 nm of n+AlGaIn were etched on 3 samples with ALE, high etch rate Cl₂/BCl₃/Ar ICP-RIE and low etch rate BCl₃ ICP-RIE. Ti/Al/Ti contacts were deposited by e-beam evaporation and annealed at 900°C for 30 s in N₂ atmosphere. ALE leads to increased linearity in the I–V characteristics of the contacts. Current dependent TLM analysis showed that ALE led to the lowest contact resistivity and highest uniformity with $\rho_c = (2.50 \pm 0.14) \times 10^{-4} \Omega \text{ cm}^2$ at 0 A (Figure 3). Atomic Force Microscopy (AFM) was utilized to study the effect of etching on surface morphology (Figure 4). These results render ALE a great alternative to conventional ICP-RIE to improve performance in high Al composition AlGaIn devices.

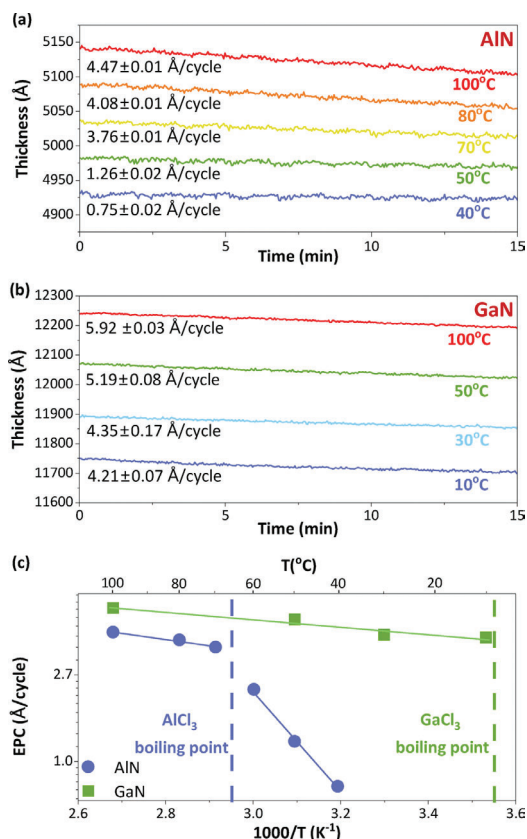


Figure 2: Temperature dependence of ALE.

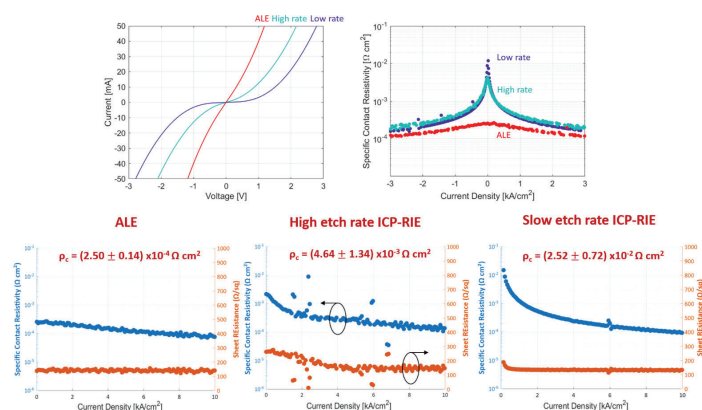


Figure 3: I-V characteristics of ohmic contacts and current dependent linear TLM analysis

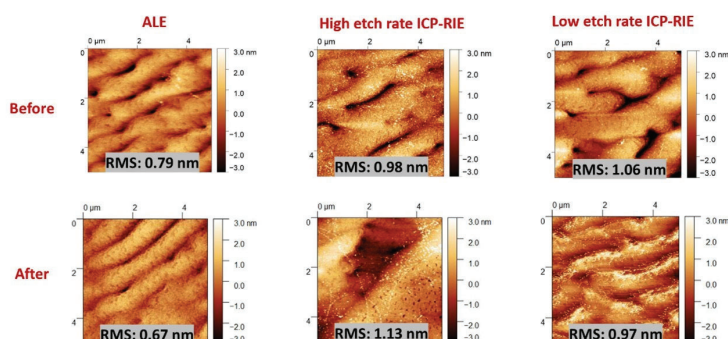


Figure 4: 5 x 5 μm^2 AFM scans of n^+ AlGaIn surface before and after etching.

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