

Advances in GaN Dry Etching Process Capabilities

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Gallium nitride (GaN) has become an important compound semiconductor material in the fabrication of an array of optical and electronic devices including light emitting diodes (LEDs), transistors, and laser devices for CD and DVD players. GaN is capable of operating at very high frequencies and power levels, demonstrating excellent thermal tolerance compared to other compound semiconductors such as gallium arsenide and indium phosphide.

Since bulk GaN is not commercially available, it is epitaxially grown on an appropriate lattice matched substrate material such as sapphire or silicon carbide. Variations in the quality of the as grown GaN, coupled with the high bond energies associated with “III- nitride” materials (see Table I), present unique challenges for dry etching processes. As shown in Figure 1, GaN based devices are often comprised of many epitaxial layers, including ternary compounds incorporating different doping types and concentrations. This article presents recent etching results achieved using high density Inductively Coupled Plasma (ICP) technology and chlorine based process chemistries.

Table I: III-nitride Bond Energies

Compound	Bond Energy (eV/atom)
AlN	11.5
GaN	8.9
InN	7.7
GaAs	6.5

Using this technology, bulk, doped and multiple layer epitaxial structures can be etched to meet device geometry and performance requirements. Additionally, some comparisons are made with conventional Reactive Ion Etching (RIE) technology.

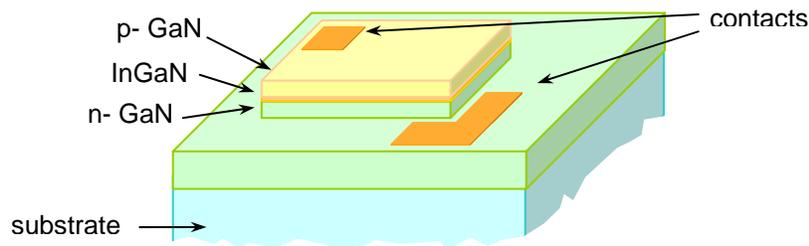


Figure 1. Typical structure for GaN based light emitting diode (LED).

ICP GaN Etching Performance

Successful etching of GaN is characterized by smooth surfaces and appropriate profiles. This requires not only overcoming the strong nitride bond energy but also adjusting the process conditions to deal with inherent defects in epitaxially grown GaN. An un-optimized etching process can result in surface morphologies that include pits and/or pillars. While the GaN etching process produces (volatile) chemical byproducts such as GaCl₃, the etching will not proceed without sufficient energetic ion bombardment due to the high bond strength of the material. Defects in the GaN appear to be particularly sensitive to etching conditions and respond by etching faster or slower than the surrounding material, ultimately forming pits or pillars. Fortunately, ICP systems allow the flexibility to compensate for the material defects through the nearly independent control of the physical and chemical components of the etching mechanism. Two separate power supplies control the plasma density (influencing the chemical component of the etching) and the ion energy (dominating the physical portion of the process). This allows process optimization for a variety of GaN structures and material quality. An example of this optimization flexibility is illustrated in Figure 2. When the ICP power is increased, the process is driven into a more chemical regime through production of higher concentrations of free radical (chlorine) etchant species. At the same time, when the ion energy is maintained by increasing the cathode power the etching results in a smooth surface morphology. Unacceptable pitting or pillar formation will result if the balance between the physical and chemical aspects of the process is not maintained.

Depending on the type of device being fabricated, control of the GaN etching profile is desirable. In the case of a transistor device, a sloped profile can benefit post-etching metalization processes. For an edge emitting laser device, a vertical profile is essential for light guiding and reflecting properties. Over the range of GaN devices currently in use today, the ability to control etching profiles between 45 and 90 degrees may be necessary. To address this requirement, a combination of mask selection (material, profile) and etching chemistry can be used to meet etching profile criteria. Figure 3 illustrates profile control by selecting different masking materials while using fixed process chemistry. While the silicon nitride, silicon oxide and metal are all considered hardmask materials, the selectivity (difference in GaN and mask etching rates) variation and initial mask profile lead to changes in the GaN etching profile. Conversely, for situations where mask selection is limited by process flow, adjustments to etching chemistry can be made to control the selectivity, and hence the resulting slope of the GaN. This capability is shown in Figure 4, where GaN is masked by a silicon dioxide film and a metal film. While the slope of the oxide mask is different from that of the Ni mask, the increased selectivity to the oxide mask (brought about by changes in the process chemistry and conditions) results in the same degree of verticality in the etched GaN.

Process Alternatives – RIE and ICP solutions

Current epitaxy and substrate material technologies produce 2 and recently, 3 inch GaN wafers. These smaller wafer sizes (in comparison to silicon and gallium arsenide), coupled with market pressures to reduce the cost of GaN based devices, demands high throughput capability for dry etching systems. One solution to this issue is to use a RIE based process and run large batches of wafers. A comparison of RIE and ICP performance is shown in Table II. The drawbacks to the RIE approach are obvious,

particularly when the device fabrication requires the etching of several microns of GaN material.

Table II: GaN Etching Mode Comparison

Process Metric	Typical Performance	
	RIE	ICP
Etching Rate (Å/min)	750*	5000
Selectivity (GaN:Hardmask)	≥ 5:1	≥ 10:1
Non-Uniformity %	≤ ± 5 – 10*	≤ ± 3
Etched Surfaces	smooth	smooth

* load dependent

While the deficiencies associated with the RIE approach can be offset by the ability to batch load (six or more wafers can be etched at one time, depending on the size), there is a significant reduction in etching rate associated with the increased loading, as shown in Figure 5.

The concept of batch loading can be extended to the ICP system as shown in Figure 6, provided the “carrier” consists of a process compatible material. Note the substrate (in this case the carrier) must be clamped and actively cooled (i.e., helium backside pressurization) in the ICP system due the high ion flux/energies. For this application, quartz has been successfully utilized and other materials, such as graphite or sapphire, may also prove beneficial. Much like the batch RIE approach, the process performance is affected by the increase in wafer loading as well as the selection of the carrier material. As in the case of batch loading the RIE, there can be changes in etching rates in the ICP as well. Despite these effects, the batch ICP performance is still superior to that of the RIE. However, there are cost factors to consider when deciding the etching technology approach.

GaN Process Solutions – Meeting Technology Requirements

Unaxis’ suite of dry etching equipment and process solutions clearly offers GaN device manufacturers a wide range of options to stay competitive in this growing market segment. While Unaxis still offers a viable RIE GaN etching solution, future efforts will focus on increasing throughput capabilities by increasing ICP etching rates while maintaining the present degrees of process flexibility outlined in this article.

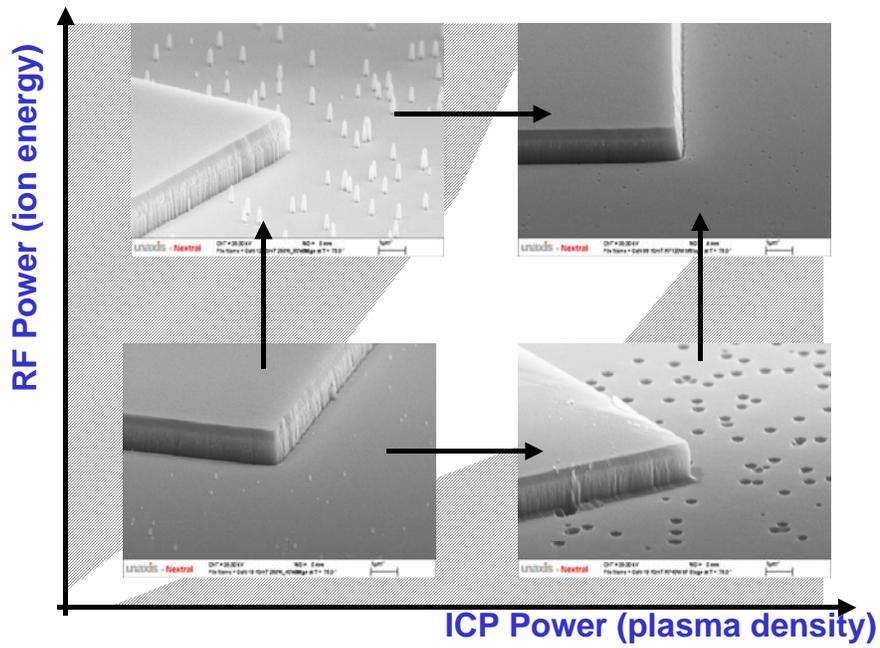


Figure 2. Pit/Pillar Formation Vs RF / ICP Power

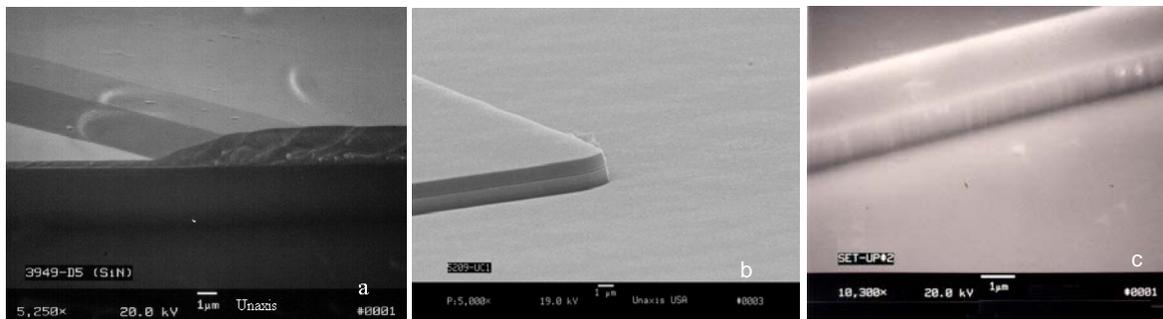


Figure 3. GaN Profile Via Mask Selection (nitride (a), oxide (b), metal (c)), Fixed Process Chemistry

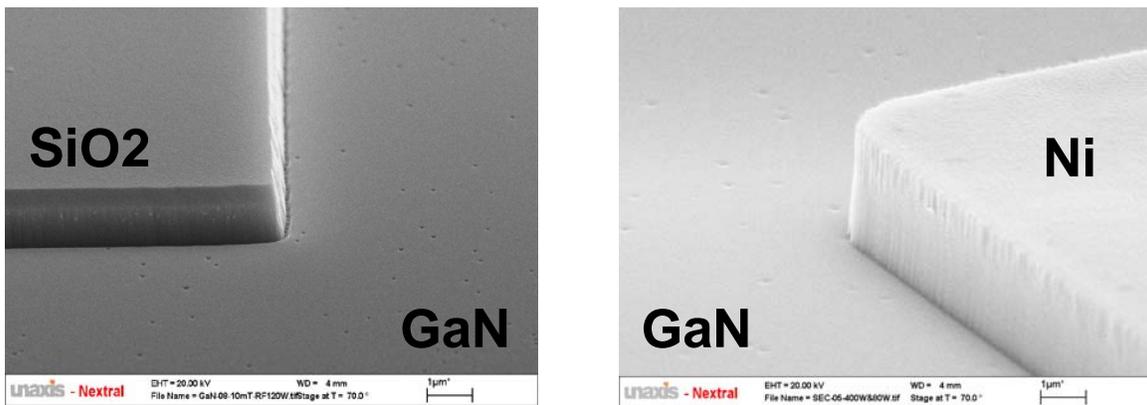


Figure 4. GaN Profile Via Process Chemistry Adjustment

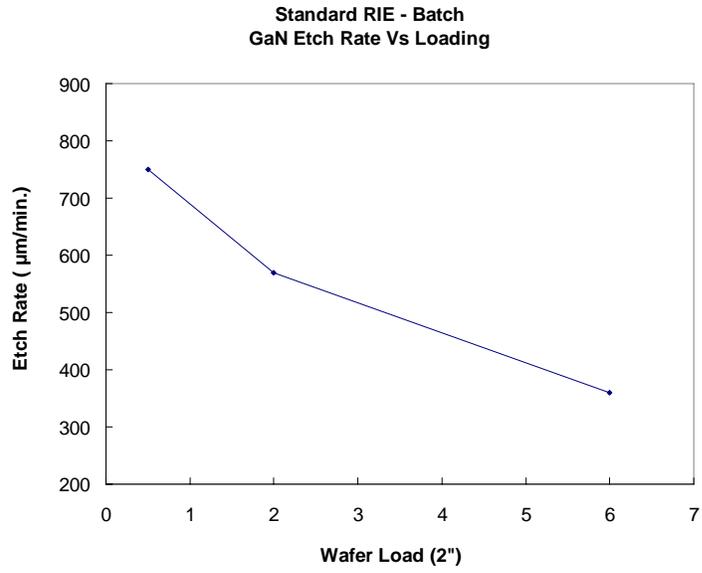
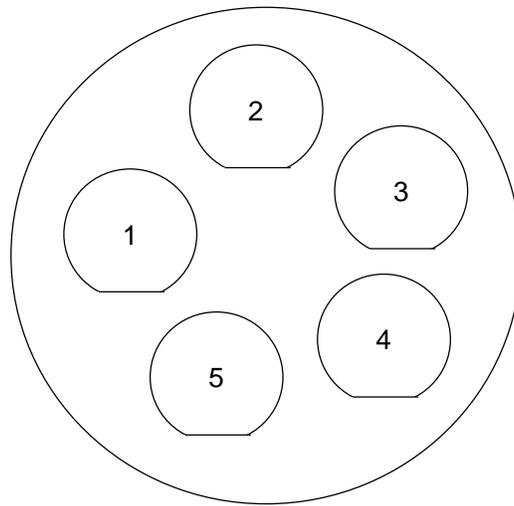


Figure 5. GaN Etching Rate Vs Wafer Loading



Wafer Carrier - Clamped/Cooled

Figure 6. GaN Substrates “Batch” loaded On Single Carrier for ICP Etching