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Advances in Large Batch Gallium Nitride Etching Process for LED Production Solutions

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1. Introduction

Gallium Nitride (GaN) is a wide band gap semiconductor for electronics and optoelectronics applications, including violet laser diodes, detectors, light-emitting diodes (LEDs), high electron mobility transistors (HEMT) and bio-sensors. In particular, with high brightness LEDs (HB-LED) extensively used in large screen display technology and solid-state lighting, there is a drive for the fabrication roadmap to give dramatic acceleration in throughput.

GaN etching is a key part of the HB-LED production process. Plasma dry etching techniques are a mainstream solution to etch GaN epi layers in current manufacture. We report here the advances in large batch technique for GaN etching process, based on leading-edge techniques which provides excellent uniformity over large areas.

2. Experimental and discussion

2.1 Based on a high density ICP source

Our etching experiments were carried out in an *OIPT Plasmalab133-ICP380* (inductively coupled plasma) tool using BCl_3 and Cl_2 as process gases. The lower electrode is 330 mm in diameter and its temperature is able to be actively controlled. A batch of 27 wafers was placed on a silicon carbide (SiC) carrier-plate, as shown in **Figure 1**. These wafers were automatically transferred into process chamber to perform the etch recipe.

A pre-etched wafer was cleaved and checked by field-emission SEM (FE-SEM) tools, as shown in **Figure 2**. As a result, an etch rate of 120 nm/min with a good selectivity of 0.8:1 to photoresist (PR) mask has been achieved. SEM images reveal a near vertical profile and smooth etched surface, as shown in **Figure 3**.

Figure 1 27x2 inch GaN wafer were placed on a SiC carrier-plate for process.

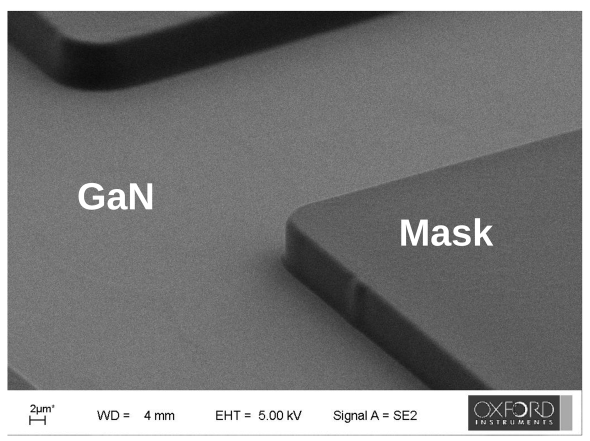

Figure 2 SEM image of pre-etched GaN samples with PR masks.

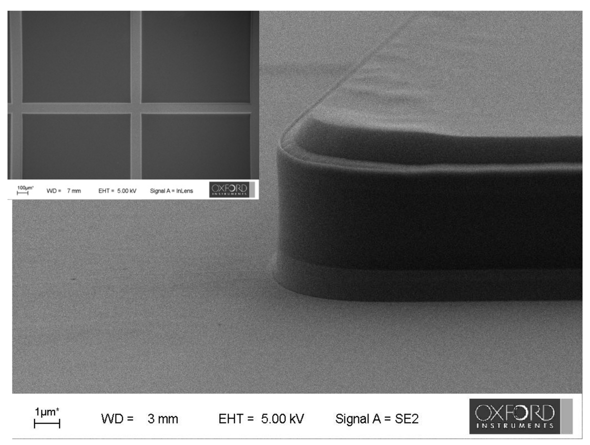

Figure 3 SEM images show a near vertical profile and smooth surface on processed samples. ***Insert:*** a top view of LED Cells.

At the 13.56 MHz frequency used, it is generally considered that the ion energy will mainly depend on the potential difference between the plasma and the lower electrode, which in turn mainly comprises of the easy-to-measure DC self-bias voltage.

After etching, the test GaN wafers were cleaved and examined by FE-SEM in order to measure step height and surface quality. Etch depths were measured across the whole test batch giving the full batch uniformity. A discussion was performed to analyze the effect of key processing parameters on uniformity. These parameters were:

- Process pressure, as shown in **Figure 4**
- RF power, as shown in **Figure 5**
- ICP power, as shown in **Figure 6**
- Gas ratio, as shown in **Figure 7**

Initial experiments were performed without an active spacer; further processes were then performed with the spacer.

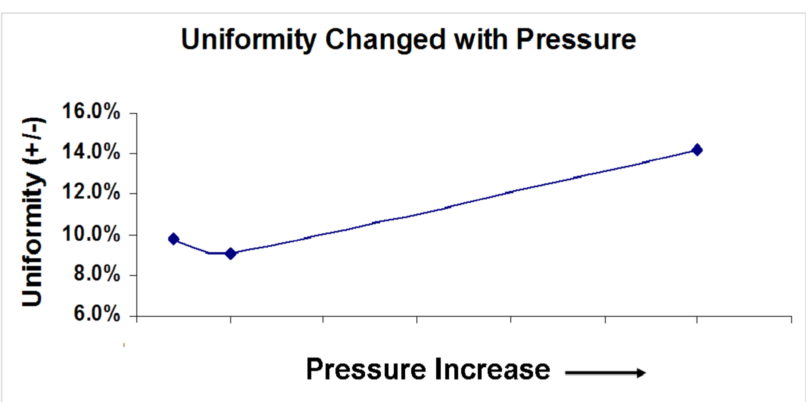

Figure 4 Variation of uniformity with process pressures under a constant BCl_3/Cl_2 chemical ratio of 1:3: at RF power of 400W and ICP power of 400W.

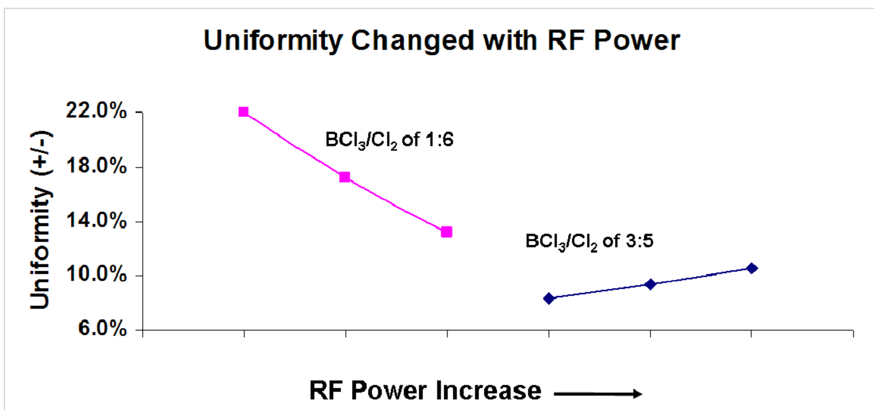

Figure 5 Variation of uniformity with RF power at a constant process pressure of 1.5mtorr: at ICP power of 400W under a constant BCl_3/Cl_2 chemical ratio of 1:6, and at ICP power of 300W under a constant BCl_3/Cl_2 chemical ratio of 3:5.

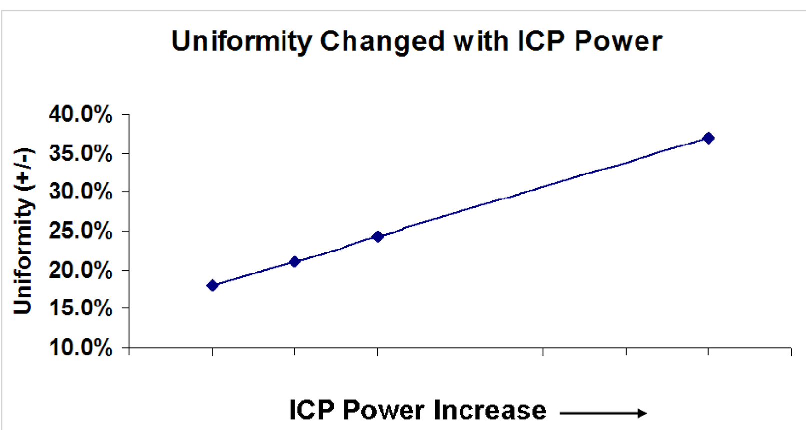

Figure 6 Variation of uniformity with ICP power at a constant process pressure of 4mtorr: at RF power of 200W under a constant BCl_3/Cl_2 chemical ratio of 1:6;

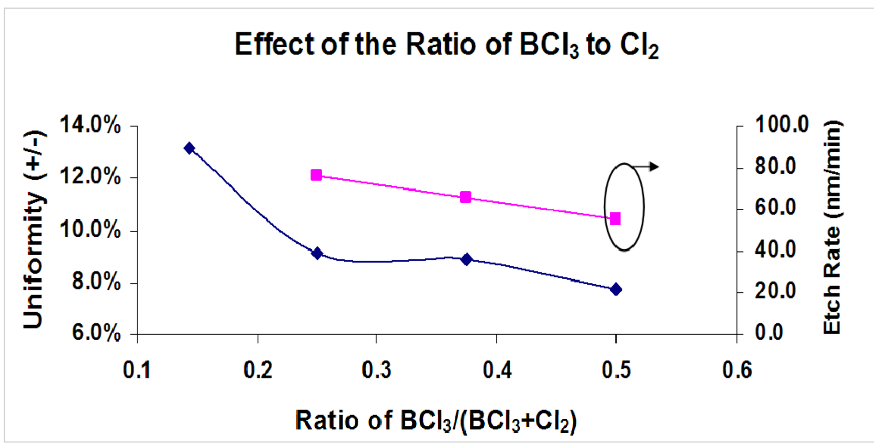

Figure 7 Variation of uniformity and etch rate with the ratio of BCl_3 to Cl_2: at a constant pressure of 1.5mtorr, RF power of 400W and ICP power of 400W.

2.2 Based on a new technique using an active spacer

An special designed active spacer which sits between a ICP source and a main chamber. This is employed giving further control over plasma profile.

Experimental results indicate that etch rate raises with increase of both RF and ICP powers and uniformity is successfully controlled at the range of ±4~5%, based on a variety of chemistries, as shown in **Figure 8**. That means etch rate is able to be independently adjusted while maintaining a good uniformity. As a result, we have achieved an etch rate of 160 nm/min with selectivity of 0.9:1 to PR mask on a 27 × 2 inch batch process.

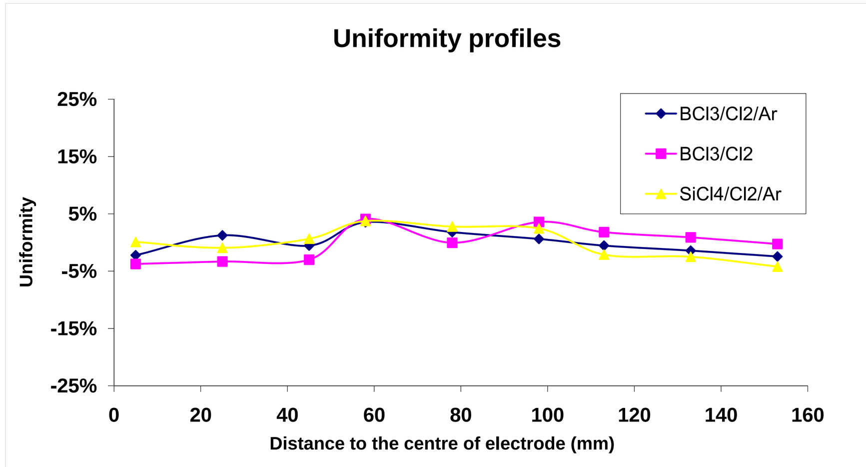

Figure 8 Uniformity profiles of 27 × 2 inch GaN batch processes with a variety of chemistries, including BCl_3/Cl_2, $BCl_3/Cl_2/Ar$ and $SiCl_4/Cl_2/Ar$, based on system133-ICP380 with an active spacer.

2.3 Based on a new tool using VHF plasma source

A GaN batch etching process of 55 x 2 inch wafer has been developed in an *OIPT NGP1000* tool which is shown in **Figures 9** and **10.**

This new tool uses a very-high-frequency (VHF) plasma source. By delivering power in the VHF band this source provides a high plasma density comparable with conventional ICP sources and maintains the benefits of high etch rates but in a low damage environment. Operating at VHF requires careful design of the plasma source hardware and chamber components to minimise undesirable electromagnetic effects, asymmetries and non-uniformities that degrade the process across a batch of wafers.

Figure 9 (left), photograph of NGP1000 system.

Figure 10 (right), 55x2 inch GaN wafer were placed on a SiC carrier-plate for process.

Effect of variable process parameters on uniformity has been studied in order to get an accurate control of uniformity across platen. Influence of parameters like pressure, VHF power and flow have been observed and the results from these parameters is described in **Figure 11**.

This work has demonstrated that pressure and flow are key parameters for uniformity control across platen. Influence on etch rate and selectivity has also been observed and a balance has been found to allow the best process performances. An etch rate of 140 nm/min with selectivity of 1:1 to PR masks and uniformity of <±5% have been achieved.

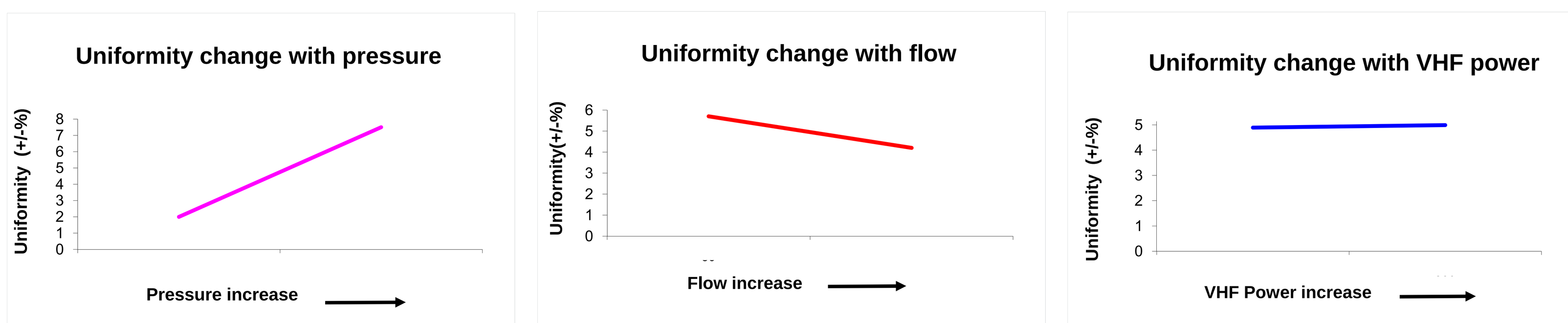

Figure 11 Variation of uniformity with pressure (a), flow (b) and VHF power (c).

3. Conclusions

Large batch etching techniques have been further developed for LED manufacture, based on plasma etching techniques.

An etch rate of 160 nm/min with selectivity of 0.9:1 to PR mask and uniformity of <±5% has been successfully achieved on a 27 × 2 inch GaN batch process, using an active spacer. The process performed an excellent repeatability in LED chip fabrication.

Based on a new tool of NGP1000, we have also achieved an etch rate of 140 nm/min with selectivity of 1:1 to PR masks and uniformity of <±5% on a 55 × 2 inch GaN batch process. This enables throughput to be remarkably and stably increased.

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