Plasma-etching of GaN using (Cl_2, BCl_3) based chemistry and Unaxis ICP Tool

Purpose: To study the etch profile and etched-surface smoothness of GaN material using Unaxis ICP etcher.

Material: Undoped, GaN epitaxial layer (2-μm in thickness) on a two-inch sapphire substrate.

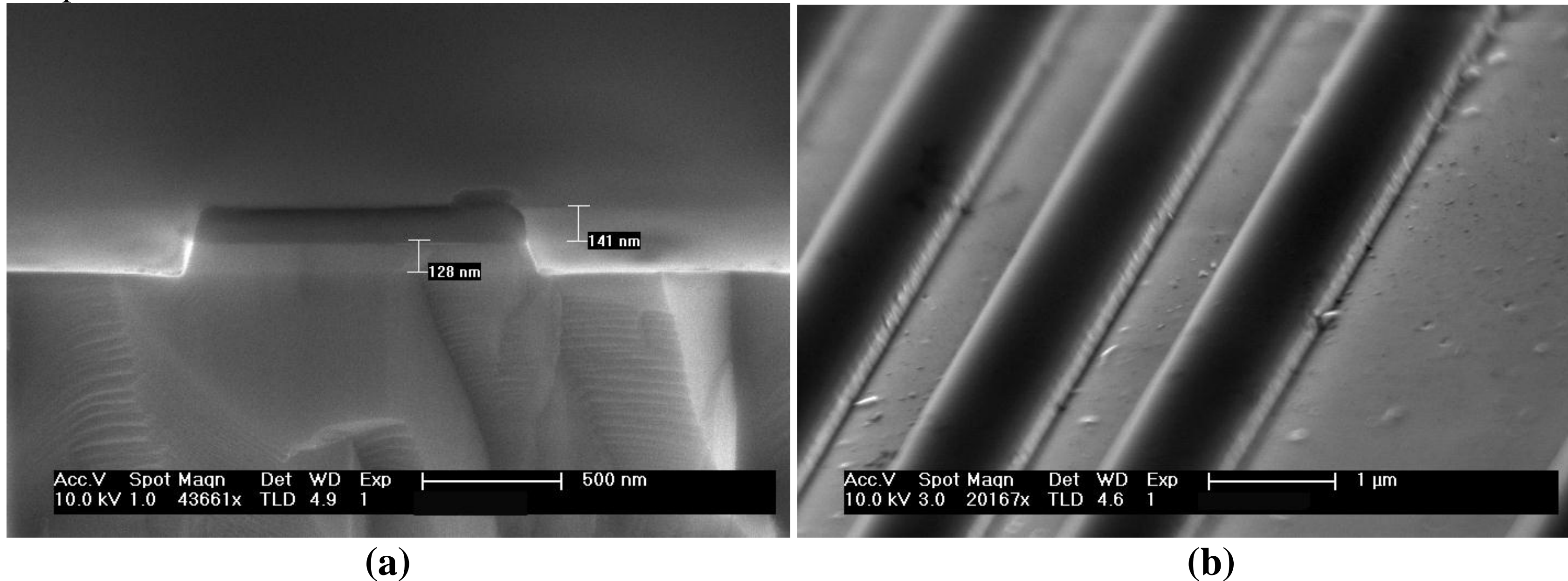
Methods: An 0.4-μm-thick SiO_2 layer was grown on the GaN layer using the Unaxis ICP deposition tool at 250 ^{0}C and, then, was patterned using photolithography with the stepper mask aligner, following by using the Panasonic ICP etcher. Approximate 0.8×0.8 cm^2 samples were diced from the 2” wafer and etched using the Unaxis ICP etcher at 85 ^{0}C. The samples were cleaved and examined by SEM.

Results and Discussions:

Table 1. Etch parameters and results of GaN using Unaxis ICP tool at 85°C.

Sample #	Gas Flow Rate (sccm)				Pressure (mTorr)	Bias		ICP Power (W)	Etch Rate (μm/min.)	Etch Selectivity (GaN/SiO_2)
	Cl_2	BCl_3	Ar	N_2		Power (W)	Voltage (v)			
1	0	25	25	0	10	100	122	1000	0.043	0.5
2	25	25	0	0	5	100	121	500	0.215	3.4
3	25	0	0	25	5	100	142	500	0.34	4.4
4	25	0	25	0	5	100	112	500	0.406	8.6

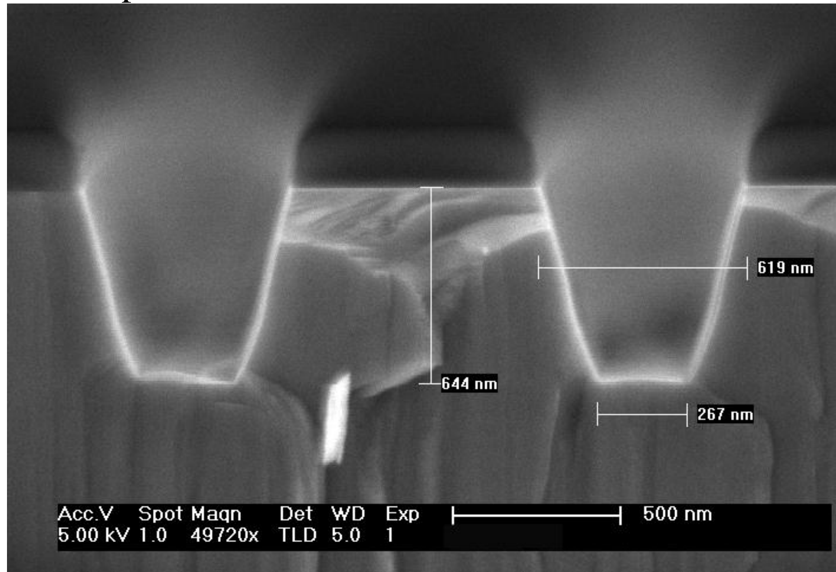
Figure 1. **(a)** Etch profile of GaN using the Unaxis ICP etcher with BCl_3/Ar flow rate=25sccm/25 sccm, pressure=10 mT, bias power=100 W (bias voltage=122 v), ICP power=1000 W. The GaN etch rate is 430 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 0.5; **(b)** Etched surface of the sample.

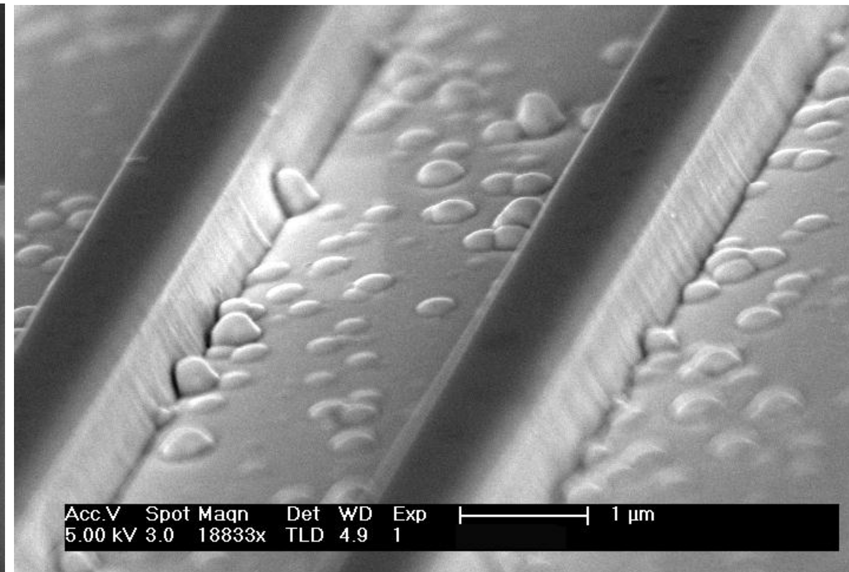


(a) **(b)**

Note: Generally speaking, the etch rate of GaN material is slow and the etch selectivity between GaN and SiO_2 mask is low when using a pure BCl_3 or a combination of BCl_3 and Ar. There are few defects appearing on the etched GaN surface, shown in Figure (b) above. Also, there is a slope of the etched side-wall slope, shown in Figure 1 (b). This recipe may be chosen to etch a shallow structure or be used before fast etch using Cl_2-based chemistry (see below).

Figure 2. (**a**) Etch profile of GaN using the ICP etcher with BCl_3/Cl_2 flow rate=25 sccm/25 sccm, pressure=5 mT, bias power=100 W (bias voltage=121 v), ICP power=500 W. The GaN etch rate is 2150 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 3.4. The side-wall angle is 75^0; **(b)** Etched surface of the sample.

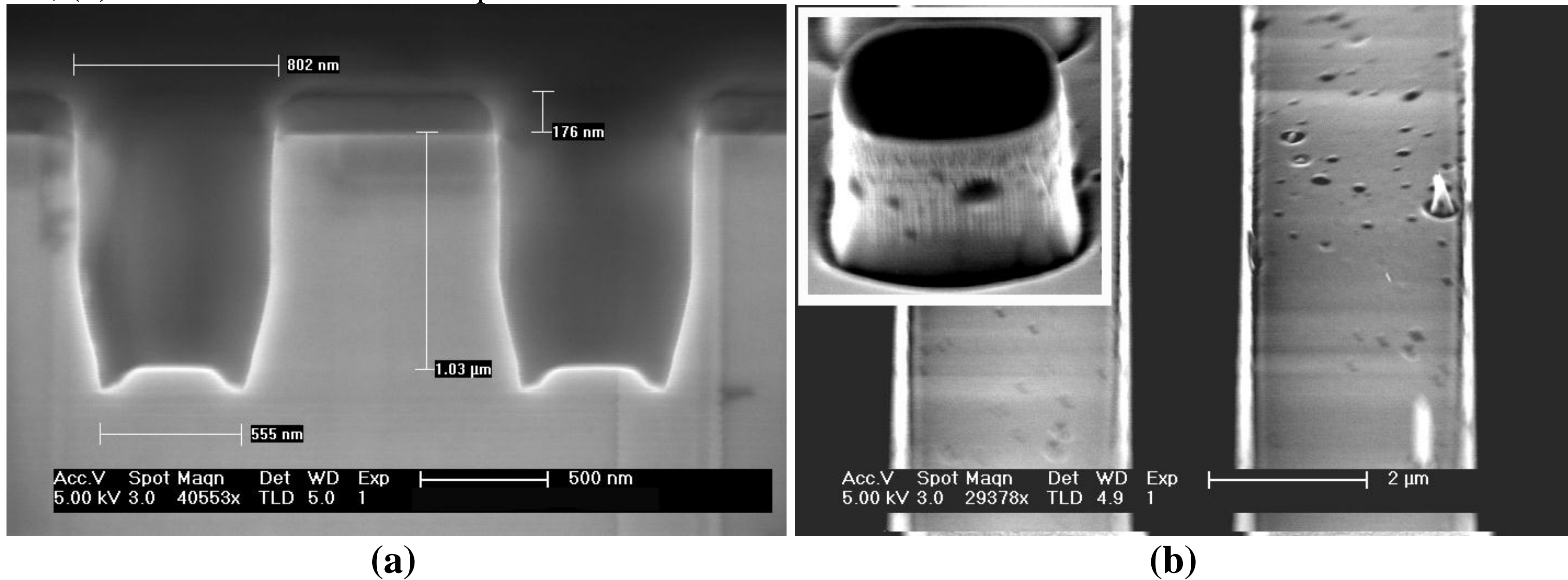




(a) **(b)**

Note: There are a lot of spots left on the etched area shown in Figure 2 (b). These may be caused by sputtered oxide debris off the side-wall of the mask to the opening areas during the SiO_2 mask patterning process using the Panasonic ICP etcher (BCl_3 etches metal oxides, but, Cl_2 doesn't). These spots can be suppressed by a pre-etch BCl_3 plasma clean process (see below).

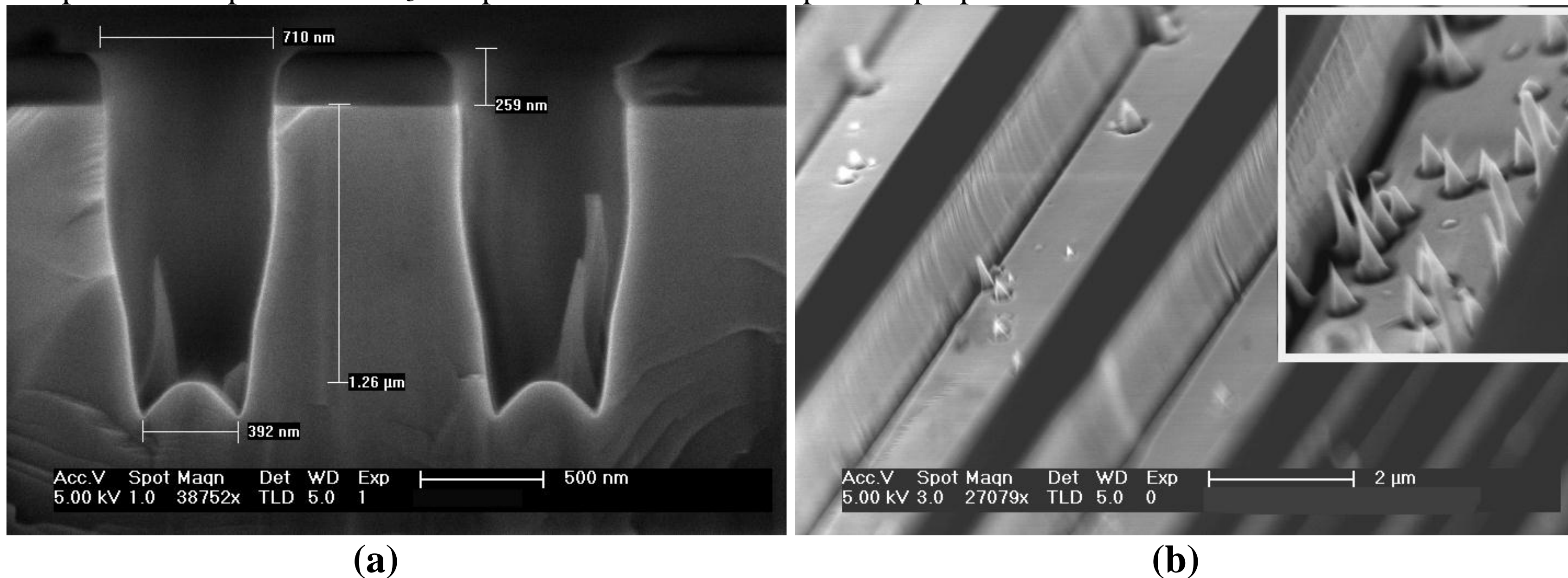
Figure 3. Pre-etch BCl_3 plasma clean (BCl_3 flow rate=25 sccm, pressure=5 mT, bias power=100 W, bias voltage=137 v, ICP power=1000 W, clean time=1 minute). **(a)** Etch profile of GaN using the ICP etcher with Cl_2/N_2 flow rate=25 sccm/25 sccm, pressure=5 mT, bias power=100 W (bias voltage=142 v), ICP power=500 W. The GaN etch rate is 3400 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 4.4; **(b)** Etched surface of the sample. Inset shows the side-wall of a dot in detail.



(a) **(b)**

Note: The spots on the etched GaN surface are suppressed by pre-etch BCl_3 plasma clean. It may need to do pre-etch plasma clean a little longer to eliminate them completely. There are micro trenches appearing at the corners of ridge and there is a slope along the lower part of the etched side-wall.

Figure 4. Pre-etch BCl_3+Ar plasma clean (BCl_3/Ar flow rate=25 sccm/25 sccm, pressure=10 mT, bias power=100 W, bias voltage=123 v, ICP power=1000 W, clean time=1 minute). **(a)** Etch profile of GaN using the ICP etcher with Cl_2/Ar flow rate=25 sccm/25 sccm, pressure=5 mT, bias power=100 W (bias voltage=112 v), ICP power=500 W. The GaN etch rate is 4060 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 8.6; **(b)** Etched surface of the sample with pre-etch BCl_3+Ar plasma clean. Inset shows the etched surface of the sample without pre-etch BCl_3+Ar plasma clean for a comparison purpose.



(a) **(b)**

Note: From Figure 4 (a), as similar to the etched sample 3, there is a slope along the lower part of the etched side-wall and there are the micro-trenches at the corners of ridge. Both the etch rate and etch selectivity are high. From Figures 4 (b), the pillars on the etched surface are suppressed by the pre-etch BCl_3+Ar plasma clean (it may need to do the clean a little longer to eliminate them completely).

Conclusions: The GaN samples were etched using Unaxis ICP etcher with the Cl_2 and BCl_3 chemistry. The etch rate of the ICP etch is as high as ~0.41 μm/min. There are some pillars appearing on the etched GaN surface when using Cl_2 chemistry, which, we believe, are due to the sputtered oxide from the side-wall of SiO_2 mask to the opening areas during mask patterning process. These pillars can be suppressed by using the pre-etch BCl_3-based plasma clean process.

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