Plasma-etching of GaN using (Cl_2, BCl_3) based chemistry and RIE#5 etcher

(November, 2004)

Purpose: To study the etch profile and etched-surface smoothness of GaN material using RIE#5 etcher.

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

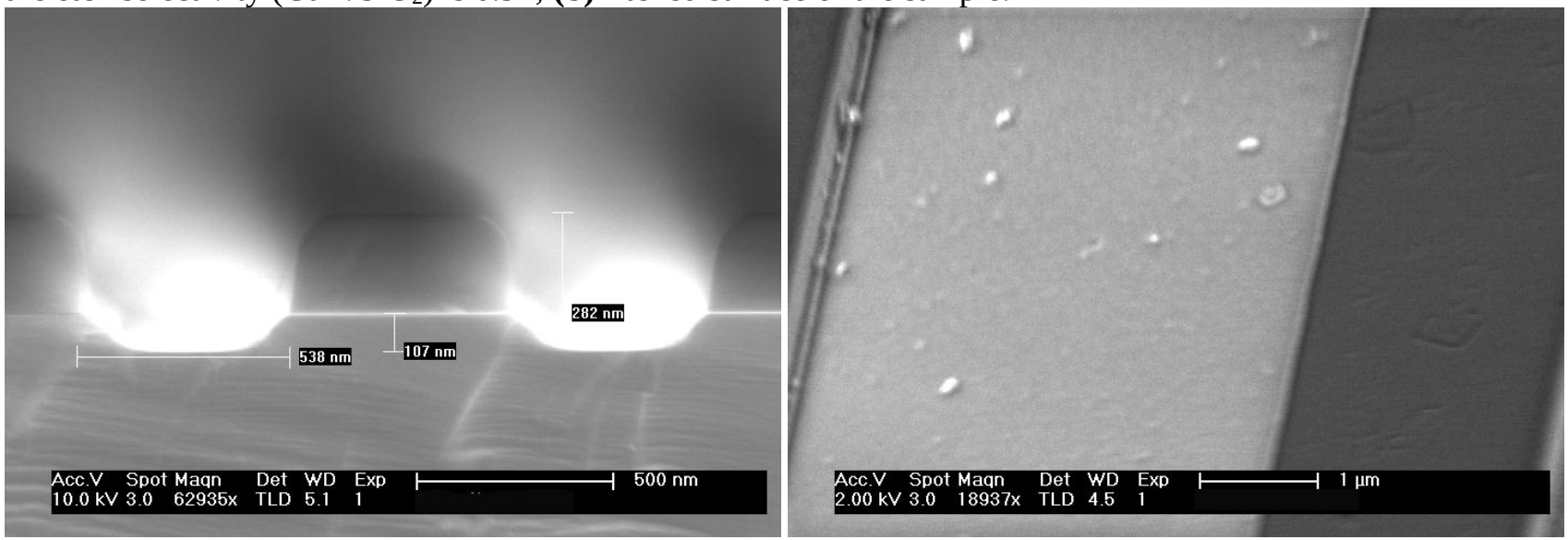
Methods: An 0.4-μm-thick SiO_2 layer was grown on the GaN layer using the Unaxis ICP deposition tool at 250 ^{0}C and, then, was patterned using photolithography with the stepper mask aligner, following by using the Panasonic ICP etcher. Approximate 0.8×0.8 cm^2 samples were diced from the 2" wafer and etched using RIE#5 etcher at room-temperature. The samples were cleaved and examined by SEM.

Results and Discussions:

Table 1. Etch parameters and results of GaN.

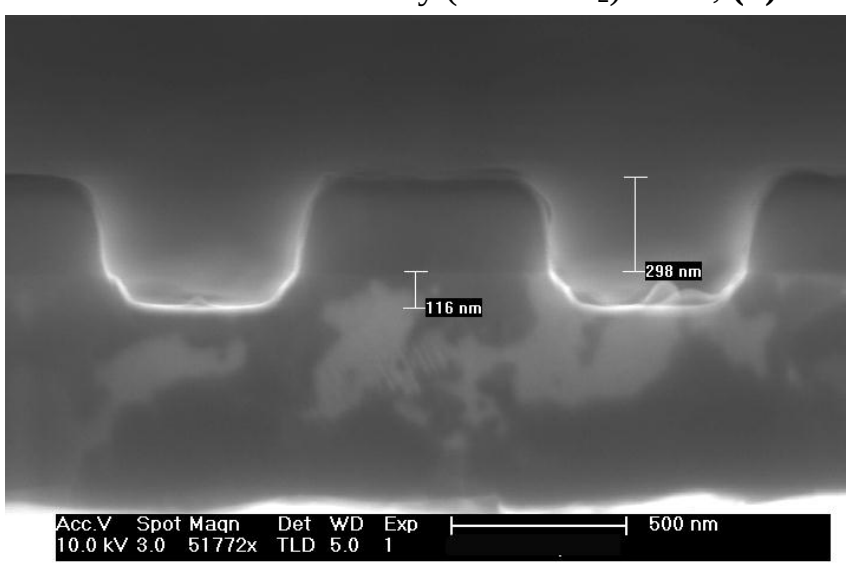
Sample #	Etcher	Gas Flow Rate (sccm)				Pressure (mTorr)	Bias		ICP Power (W)	Substrate Temperature (^{0}C)	Etch Rate (μm/min.)	Etch Selectivity (GaN/SiO_2)
		Cl_2	BCl_3	Ar	N_2		Power (W)	Voltage (v)				
1	RIE-5	0	10	0	0	5	200	520	n/a	R.T.	0.009	0.91
2	RIE-5	0	10	5	0	5	200	526	n/a	R.T.	0.012	1.1
3	RIE-5	2	8	0	0	5	200	522	n/a	R.T.	0.088	5.4
4	RIE-5	5	5	0	0	5	200	531	n/a	R.T.	0.133	8.3
5	RIE-5	10	0	0	0	5	200	561	n/a	R.T.	0.146	5.9
6	RIE-5	20	0	0	0	15	150	375	n/a	R.T.	0.131	10.5

Figure 1. (a) Etch profile of GaN using the RIE#5 etcher with BCl_3 flow rate=10 sccm, pressure=5 mT, bias power=200 W (bias voltage=520 v). The GaN etch rate is 90 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 0.91; **(b)** Etched surface of the sample.

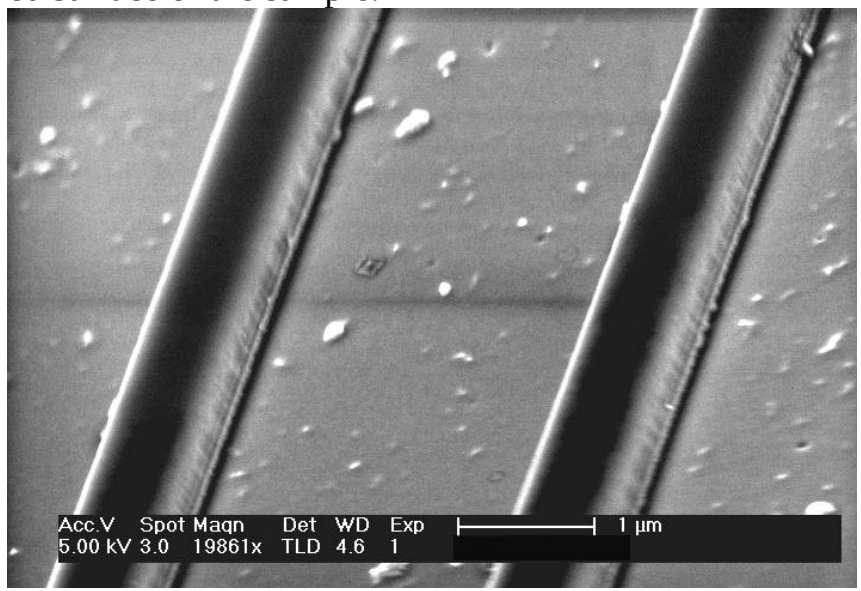


(a) **(b)**

Figure 2. (a) Etch profile of GaN using the RIE#5 etcher with BCl_3/Ar flow rate=10 sccm/5 sccm, pressure=5 mT, bias power=200 W (bias voltage=526 v). The GaN etch rate is 120 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 1.1; **(b)** Etched surface of the sample.



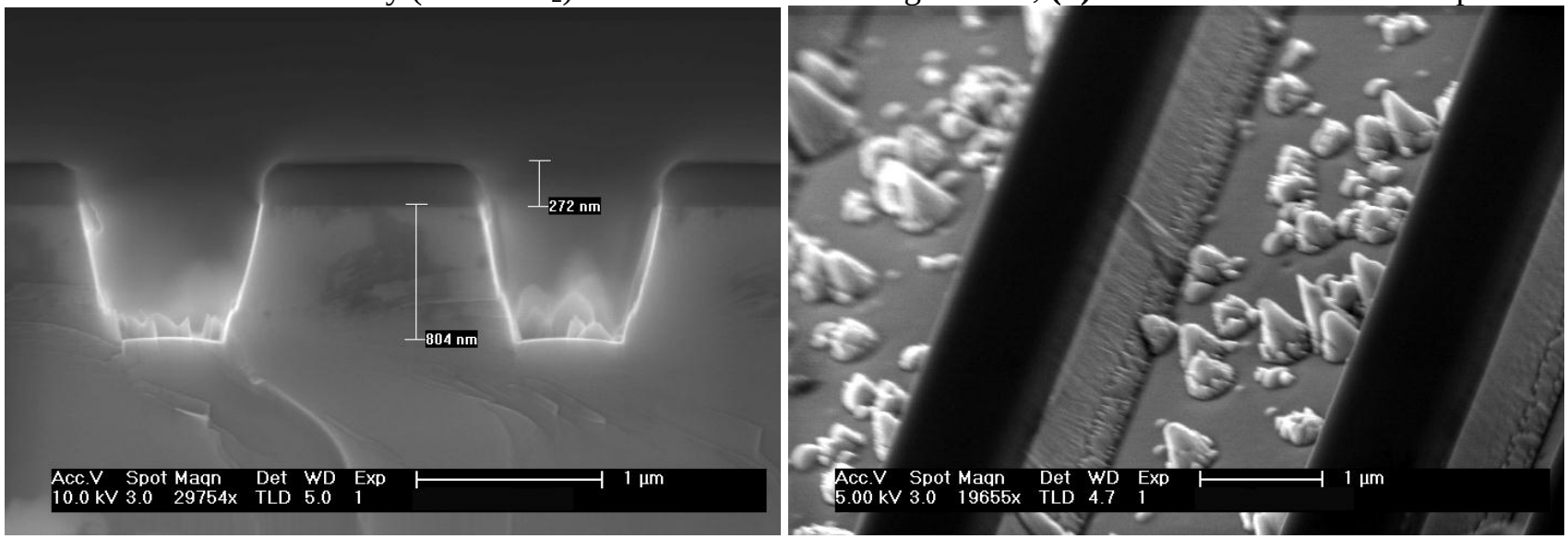
(a)



(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. Also, the etched side-wall slope is ~45º, found typically in an isotropic wet etch. These recipes may be chosen to etch a shallow structure or be used before fast etch using Cl_2-based chemistry (see below).

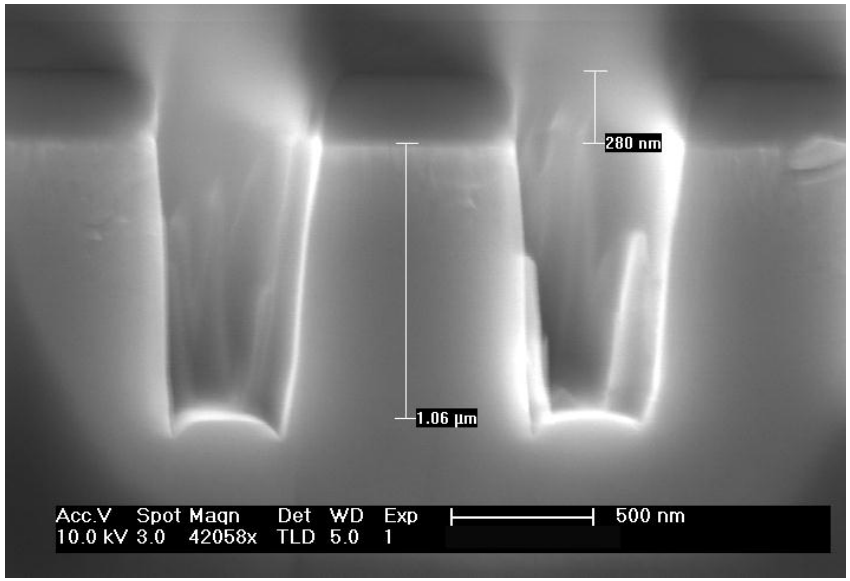
Figure 3. (a) Etch profile of GaN using the RIE#5 etcher with BCl_3/Cl_2 flow rate=8 sccm/2 sccm, pressure=5 mT, bias power=200 W (bias voltage=522 v). The GaN etch rate is 880 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 5.4. The side-wall angle is 76^0; **(b)** Etched surface of the sample.



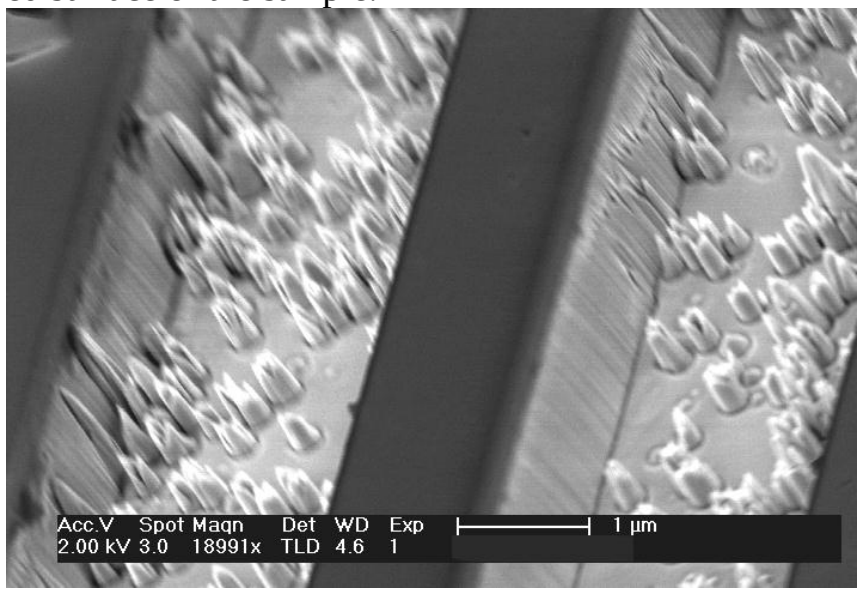
(a) **(b)**

Note: There are a lot of pillars left in the etched trench-bottom-area shown above. These pillars 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 pillars can be suppressed by a pre-etch BCl_3 plasma clean process (see below).

Figure 4. (a) Etch profile of GaN using the RIE#5 etcher with BCl_3/Cl_2 flow rate=5 sccm/5 sccm, pressure=5 mT, bias power=200 W (bias voltage=531 v). The GaN etch rate is 1330 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 8.3; **(b)** Etched surface of the sample.

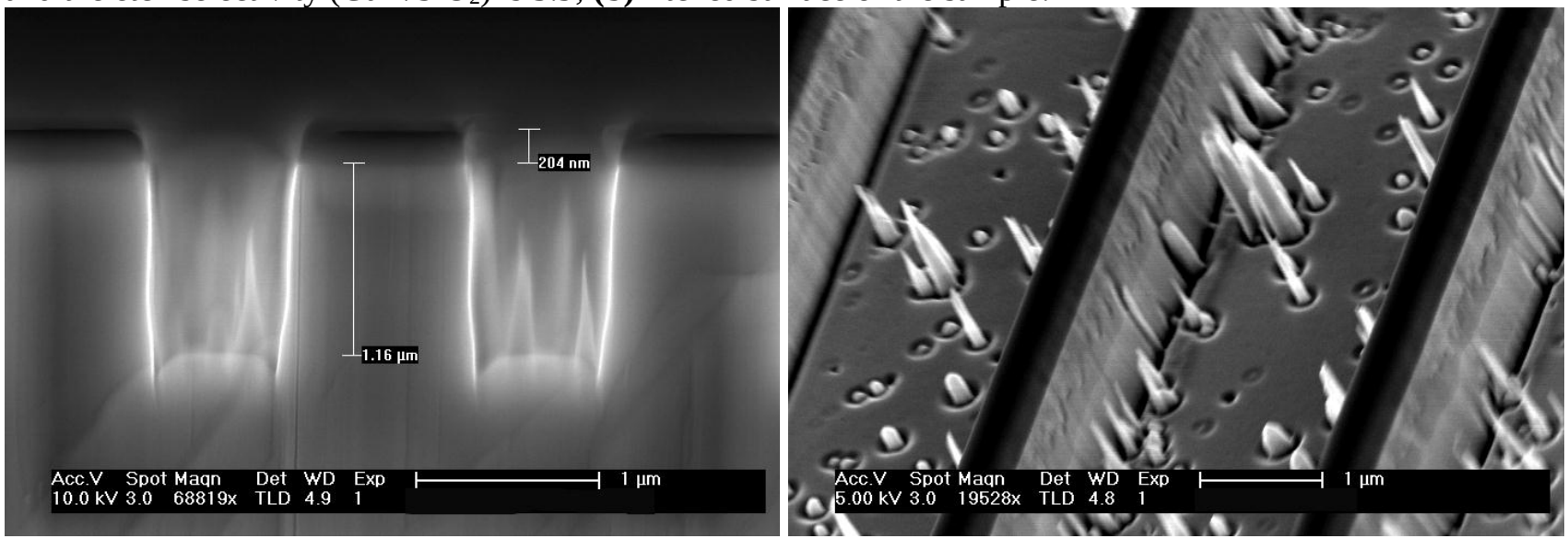


(a)



(b)

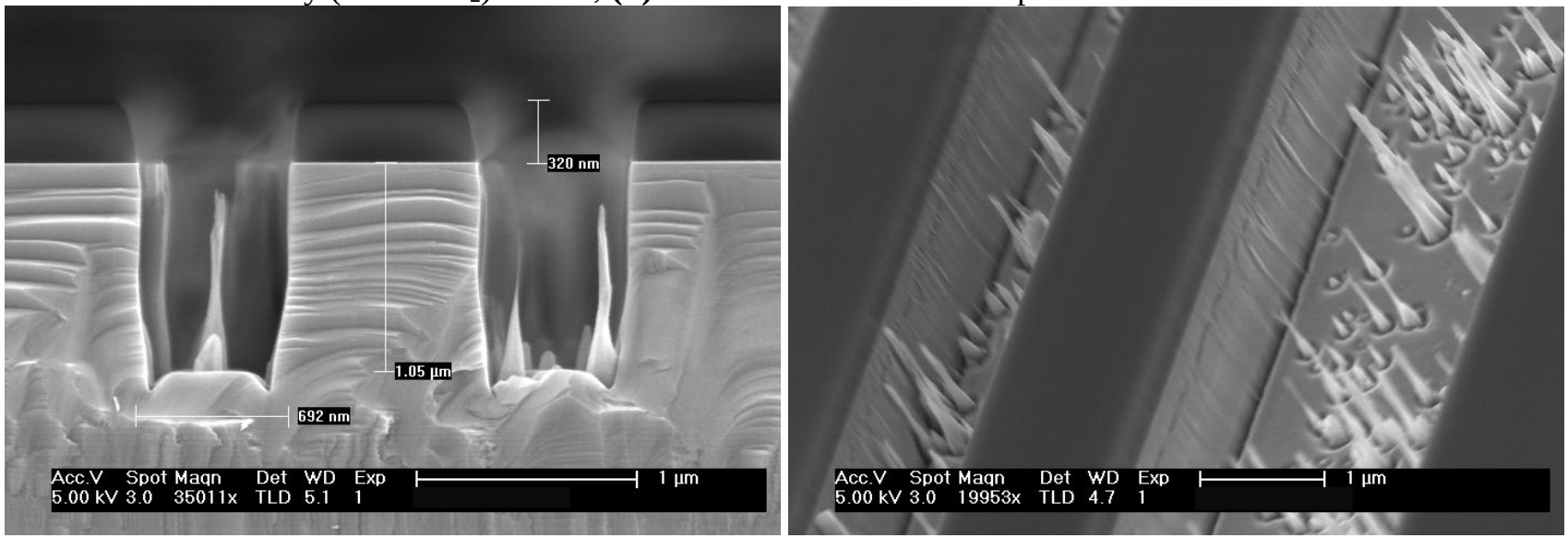
Figure 5. (a) Etch profile of GaN using the RIE#5 etcher with Cl_2 flow rate=10 sccm, pressure=5 mT, bias power=200 W (bias voltage=561 v). The GaN etch rate is 1460 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 5.9; **(b)** Etched surface of the sample.



(a) **(b)**

Note: With the increase of the Cl_2 flow rate from 5 to 10 sccm, while keeping the total flow rate of Cl_2 and BCl_3 as a constant, the GaN etch rate only increases a little (from 1330 to 1460 Å/min), the side-wall angle increases and, the micro-trenches at the bottom corners of ridge become deeper. There are some pillars appearing on the etched GaN surface, which can be suppressed by a pre-etch BCl_3 plasma clean process (see below).

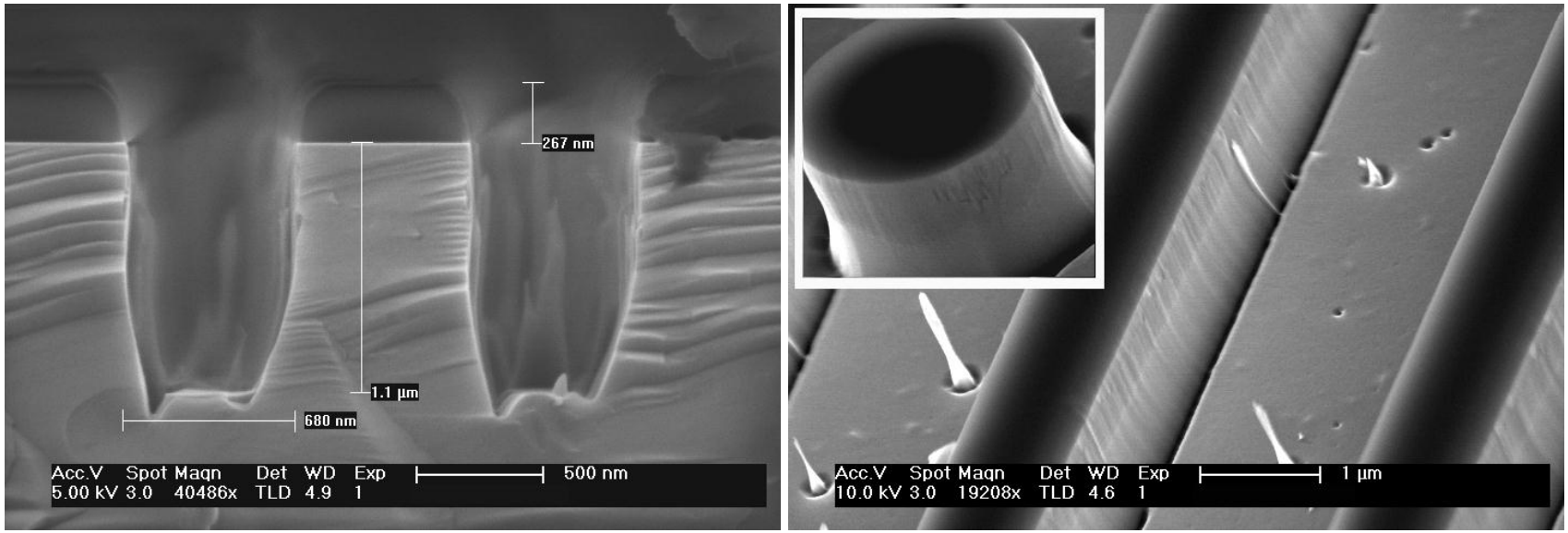
Figure 6. (a) Etch profile of GaN using the RIE-5 etcher with Cl_2 flow rate=20 sccm, pressure=15 mT, bias power=150 W (bias voltage=375 v). The GaN etch rate is 1310 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 10.5; **(b)** Etched surface of the sample.



(a) **(b)**

Note: From Figure 6 (a), the etched side-wall is not straight and there are some micro-trenches at the corners of ridge. From Figures 6 (b), there are some pillars appearing on the etched GaN surface, which can be suppressed by a pre-etch BCl_3 plasma clean process (see below).

Figure 7. Pre-etch BCl_3 plasma clean (BCl_3 flow rate=10 sccm, pressure=5 mT, bias power=200 W, bias voltage=500 v, clean time=6 minutes). **(a)** Etch profile of GaN using the RIE-5 etcher with Cl_2 flow rate=20 sccm, pressure=15 mT, bias power=150 W (bias voltage=380 v). The GaN etch rate is 1310 Å/min. The top layer is the remaining SiO_2 mask and the etch selectivity (GaN/SiO_2) is 10.5; **(b)** Etched surface of the sample. Inset shows the side-wall of an etched dot in detail.



(a) **(b)**

Note: As shown in Figure 7 (a), there are some micro-trenches appearing at the corners of ridge and the etched side-wall is not straight. In comparison with that in Figure 6 (a), the angle of the lower-half side-wall gets larger because of the pre-etch BCl_3 plasma clean [see Figure 1 (a)]. From Figures 7(b), the pillars on the etched surface are suppressed by the pre-etch BCl_3 plasma clean. It may need to do pre-etch plasma clean a little longer to eliminate them completely. This recipe gives the smoothest side-wall among recipes in this report, as can be clearly seen from the inset of etched dot.

Conclusions: The GaN samples were etched using RIE#5 with the Cl_2 and BCl_3 chemistry. With the increase of Cl_2 flow rate, while keeping the total flow rate of Cl_2 and BCl_3 as a constant, the etch rate and etched side-wall angel increase. There are some pillars appearing on the etched GaN surface when using Cl_2 and BCl_3 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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