PLASMA ETCH AND STRIP IN MICROTECHNOLOGY
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ETCH DEVELOPMENT FOR E-MODE GaN POWER HEMT FABRICATION

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* S.C. ETCH TECH SOLUTIONS, STR. OANCEA 3 B1 D10 APT. 2, IASI, ROMANIA

BACKGROUND

GaN has a wide band gap:
3.4 eV vs 1.1 eV for Si
GaN has a higher e- mobility:
2000 vs 1450 (cm2/V-sec) for Si
GaN is **quite inert** and **wet etching is limited**

Applications:

- consumer electronics
- telecommunication
- AC/DC converters
- solar/wind power systems

Why GaN instead of Si ?

- High electron velocity
  → devices @ **high speed**
- High breakdown field
  → devices @ **high voltage**
- High thermal conductivity
  → devices @ **high temperature**

OUTLINE

- ☐ background GaN etch
- ☐ GaN high power transistor
- ☐ concept 1: MISHEMT
  - Controlled barrier recess: concept + results
- ☐ concept 2: pGaN HEMT
  - Selective pGaN/AlGaN etch: concept + results
- ☐ Conclusions

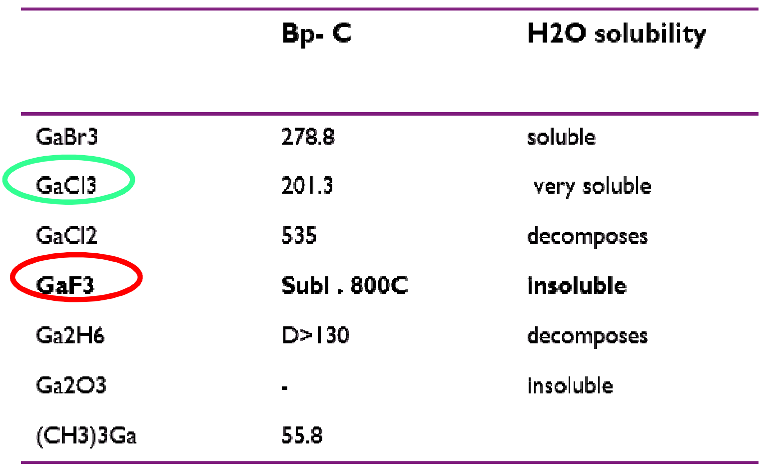
BACKGROUND
- GaN ETCH

	Bond Strength
Ga-Ga	33+-5 kcal/mol
Ga-O	14.7eV
Ga-N	8.9 eV
Ga-As	6.5 eV
Al-N	11.52 eV
Al-O	21.2 eV
In-N	7.72 eV

- Bond strength:

Ga-O/Al-O >> Ga-N

→ Important for selective etch



	Bp- C	H2O solubility
GaBr3	278.8	soluble
GaCl3	201.3	very soluble
GaCl2	535	decomposes
GaF3	**Subl . 800C**	**insoluble**
Ga2H6	D>130	decomposes
Ga2O3	-	insoluble
(CH3)3Ga	55.8	

- $GaCl_3$ mainly formed during etch:

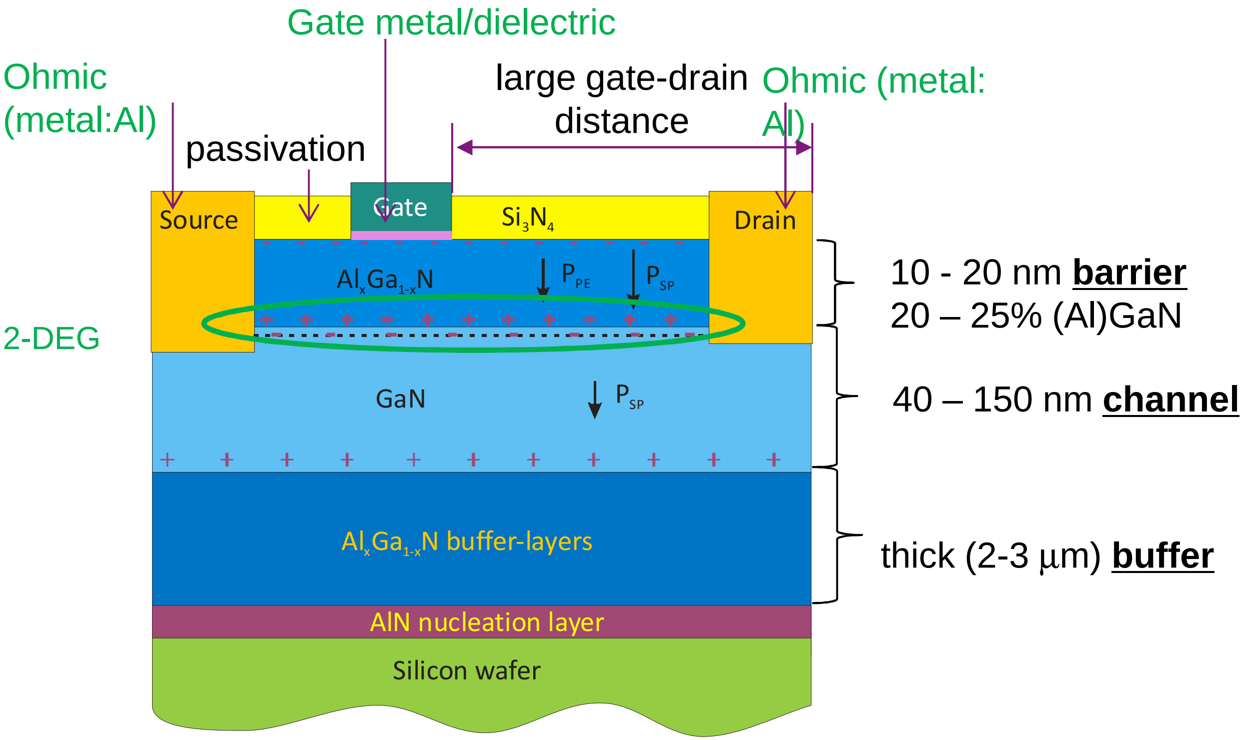
→ $GaCl_3$ more stable than $GaCl_2$

- GaF_3 is very non-volatile

Etch tool: LAM Versys2300 TCP (ICP) reactor

GaN POWER (E-MODE) TRANSISTOR - ZOOM IN

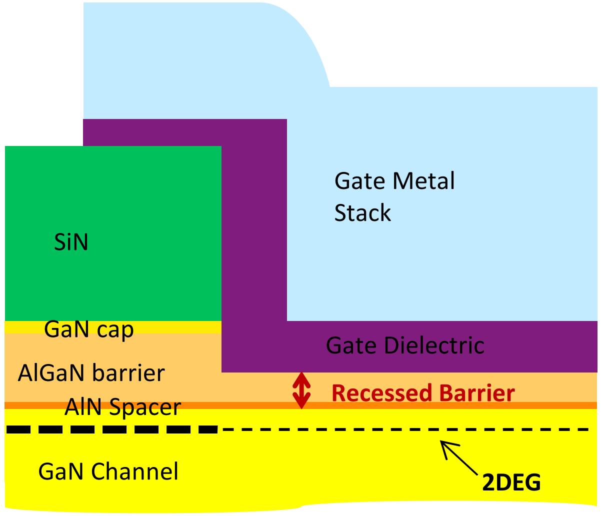
Gate dielectricum: SiN/Al2O3
Gate metal: Ti/TiN – Al- Ti/TiN



HEMT: High Electron Mobility transistor
MISHEMT: Metal-Insulator-Semiconductor High Electron Mobility Transistor

CONCEPT 1: MISHEMT

Concept 1: Barrier Recess



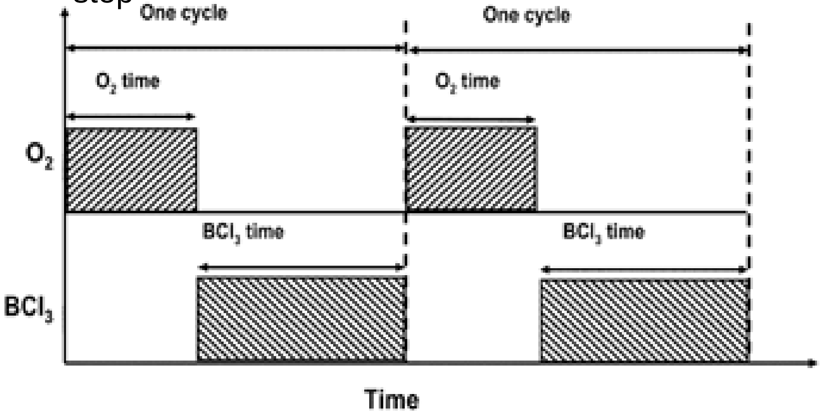
Principle: **suppressing 2-DEG formation** below gate area by **recessing the barrier** → E(nhancement)-mode device if Vth > 0 is applied to the gate electrode

Etch requirements:

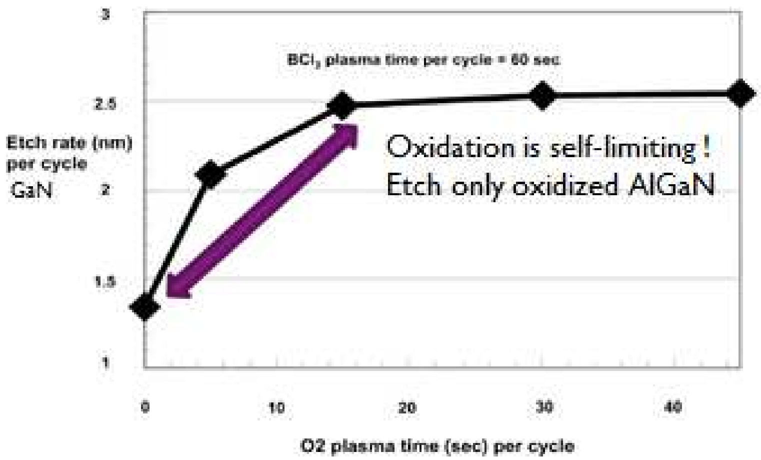
- Very low/controllable AlGaN barrier etch rate
- Minimal surface roughness
- Clean Surface
- Low non-uniformity

CONTROLLED BARRIER RECESS - ALE (ATOMIC LAYER ETCH)*

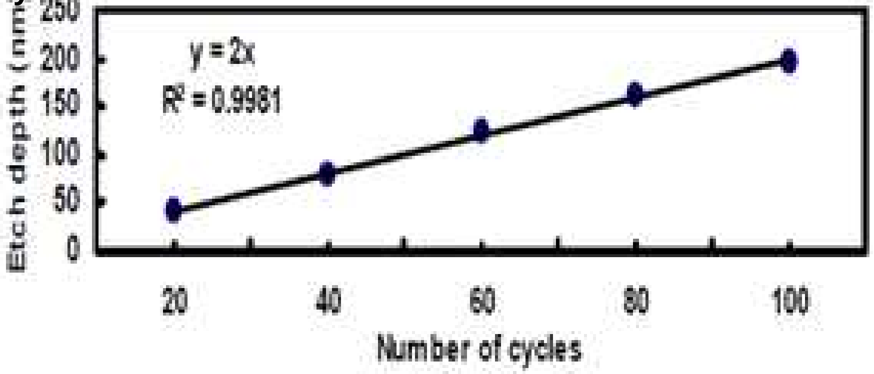
Alternating self-limiting **oxidation** and **etch** step



- **BCl_3 etches oxidized AlGaN almost 2 times faster than the non-oxidized layer.**
- GaN and AlGaN etches substantially identically because the Al does not prevent the oxidation or the etching by BCl_3.
- **The thickness of the oxide layer in the AlGaN/GaN material depends on the plasma power used to oxidize the material.**



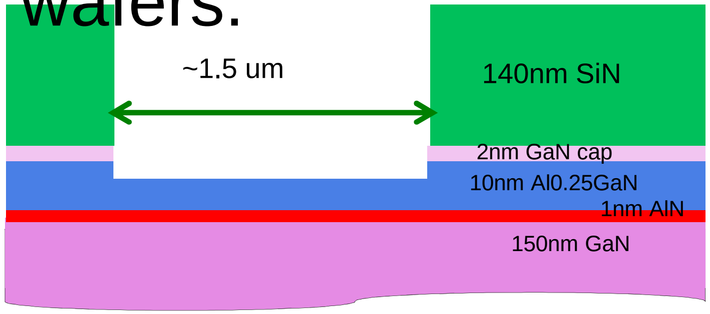
Linear behaviour of the ALE **etch depth** vs**. number of ALE cycles**

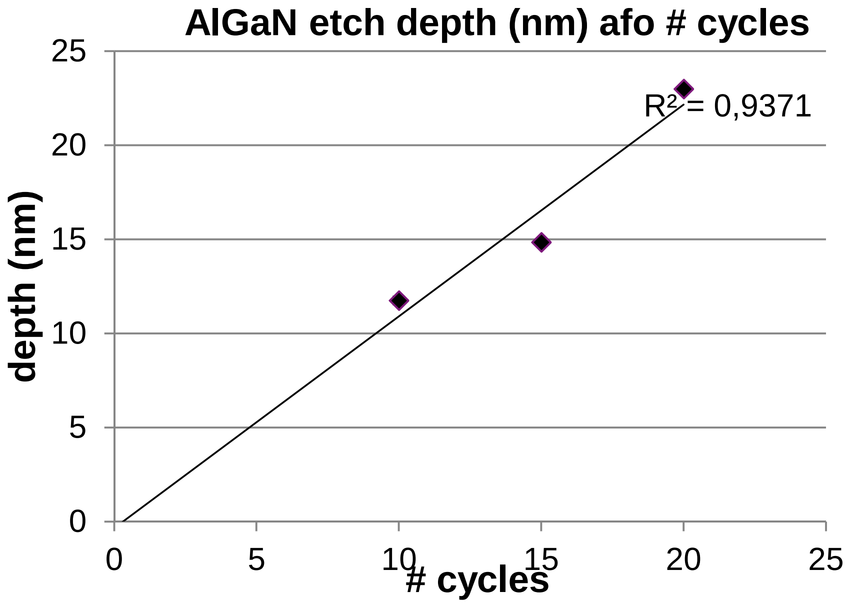


*reference: US patent 8.124.505: Two stage plasma etching method for E-mode GaN HFET

CONTROLLED BARRIER RECESS - RESULTS

Test wafers:

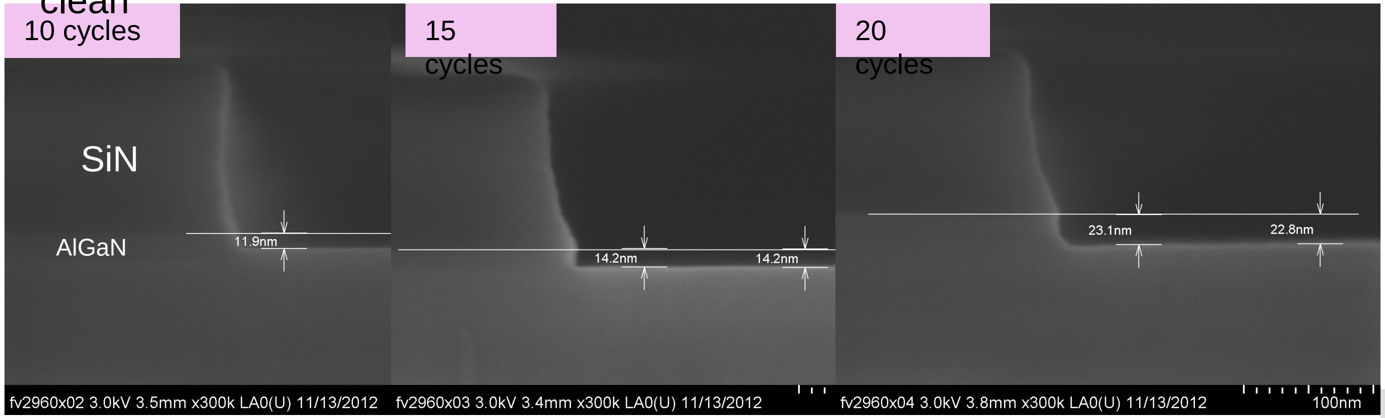


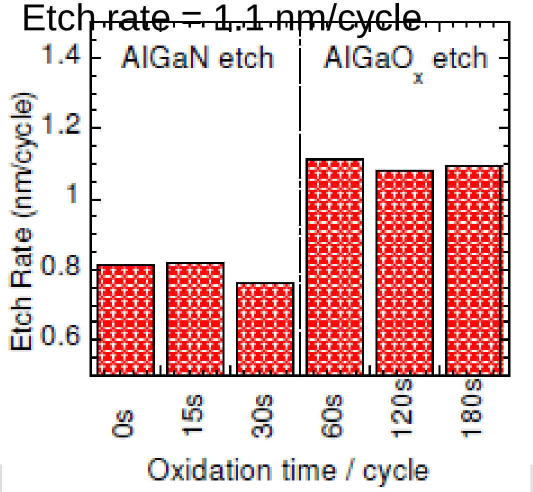


Minimum oxidation time = 60 s

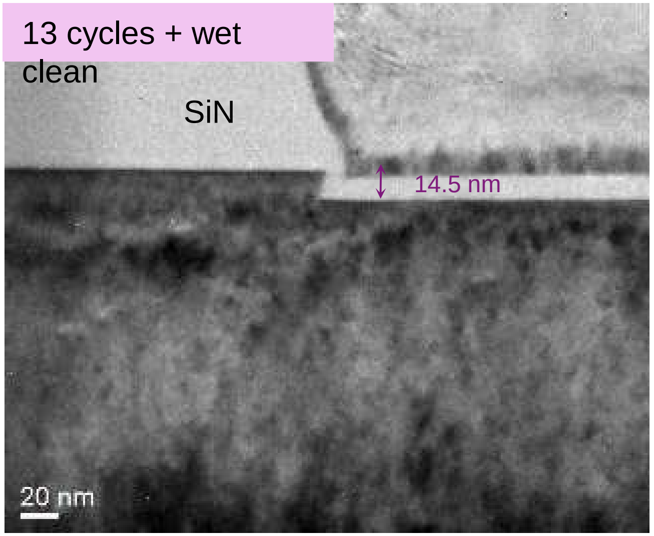
Etch rate = 1.1 nm/cycle

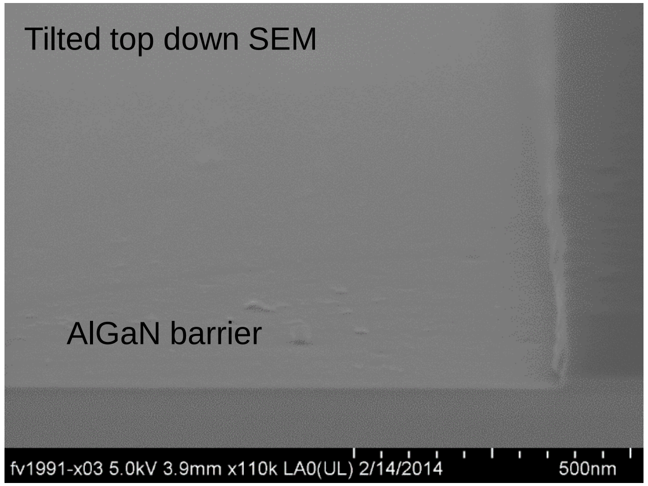
SiN etch (SF$_6$) + **PR strip** + #cy**(90” oxidation** (O$_2$) / 30” **BCl$_3$ etch**) + wet clean



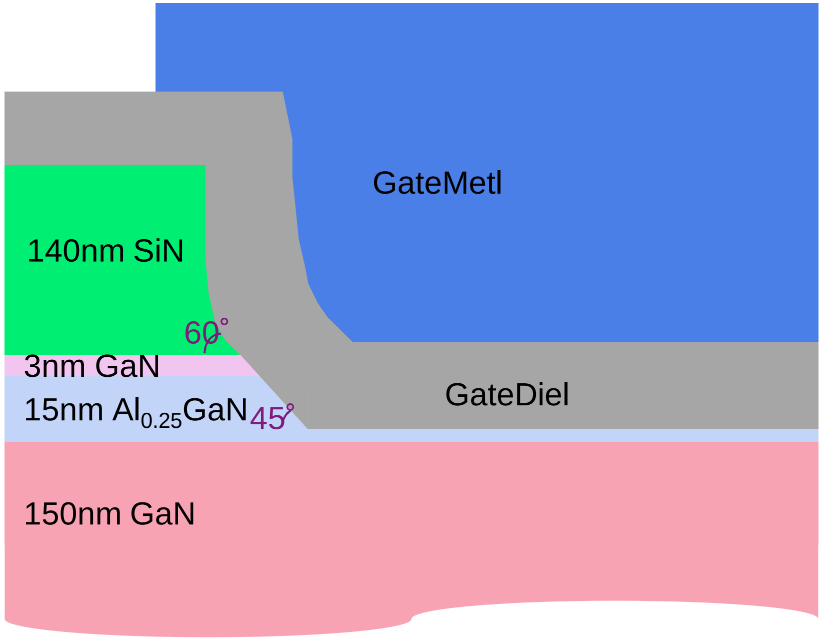


CONTROLLED BARRIER RECESS - INTEGRATED RESULTS





Sloped

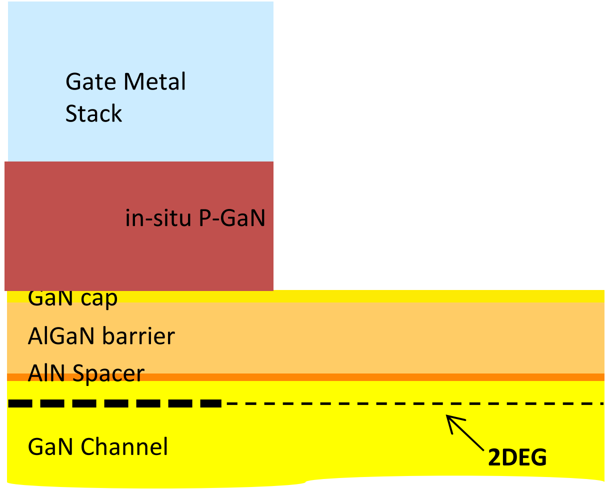


To be investigated:

- Effect of wet clean
- Effect of pressure in dry etch
- Effect of gas additive Cl_2, SF_6, CH_3F

CONCEPT 2: P-GaN HEMT

Concept 2: p-GaN etch
(stacked etch)

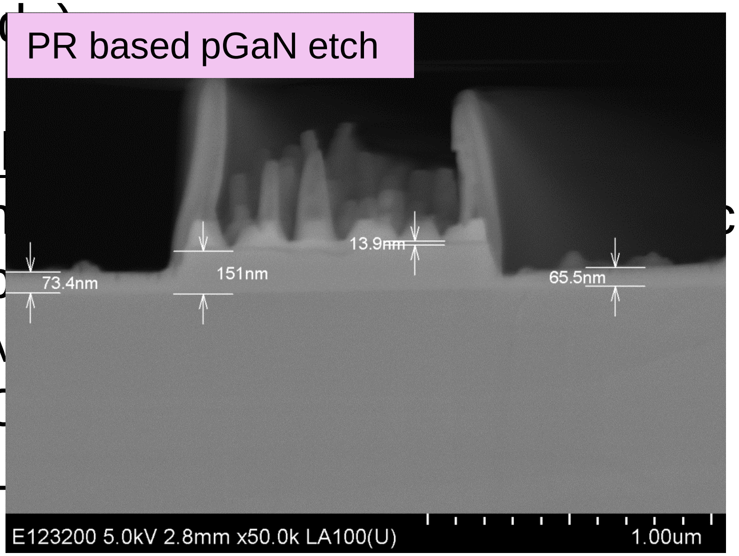


Principle: **Mg-doped** GaN locally **lifts up conduction band below gate area** unless Vth >0 is applied to the gate electrode (E-mo

Etc

- h ch
- p
- M
- C
- L

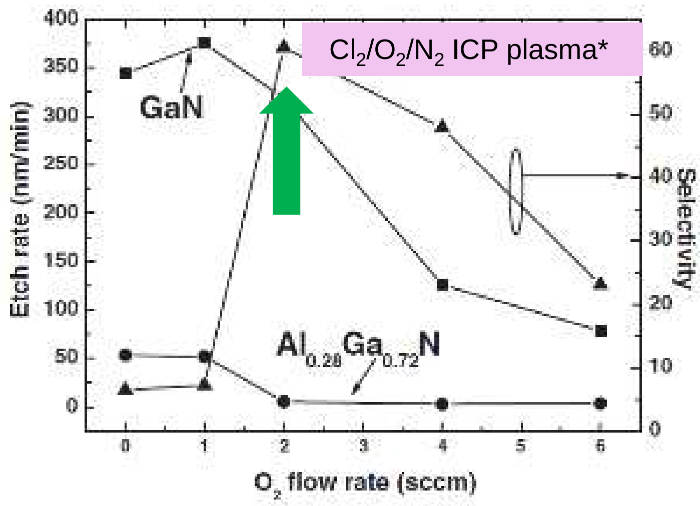
PR based pGaN etch



Parameters that affect the etch result:

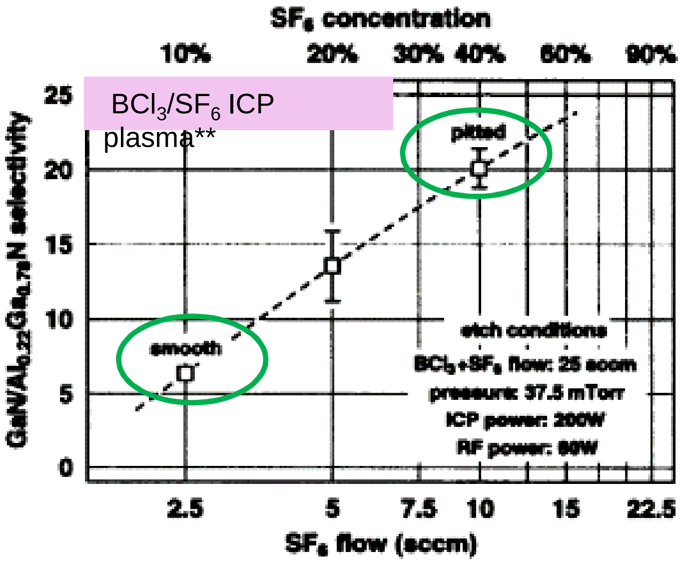
- presence of photoresist
- HM nature (oxide or nitride)
- % of Al in AlGaN barrier
- Chamber conditioning (CWAC)

HIGHLY SELECTIVE PGaN ETCH - LITERATURE*/**



$Cl_2/O_2/N_2$ ICP plasma*

	$Cl_2/O_2/N_2$ Chemistry
Selectivity layer	Formation of Al_xO_y
Critical parameters	• Cl_2 flow • O_2 flow • Pressure • ICP power • V_{bias}



BCl_3/SF_6 ICP plasma**

	$Cl_2/O_2/N_2$ Chemistry
Selectivity layer	Formation of AlF_3
Critical parameters	• SF_6 flow • Pressure • ICP power • V_{bias}

*Highly Selective Dry Etching of GaN over AlGaN Using Inductively Coupled Cl2/N2/O2 Plasmas
Jpn. J. Appl. Phys. Vol. 42 (2003) pp. L 1139–L 1141
Part 2, No. 10A, 1 October 2003
The Japan Society of Applied Physics

**SELECTIVE DRY ETCHING OF GaN OVER AlGaN IN BCL3/SF6 MIXTURES
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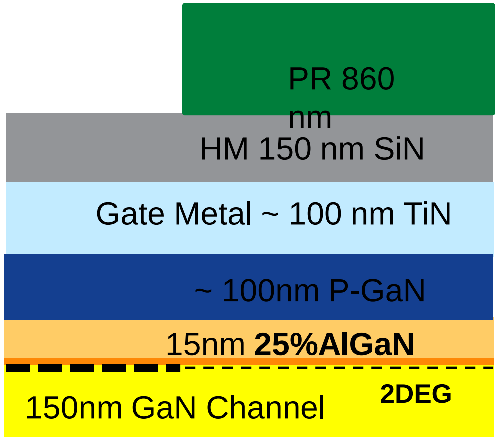
University ofCalifornia Santa Barbara, Santa Barbara, California 93106, U.S.A.

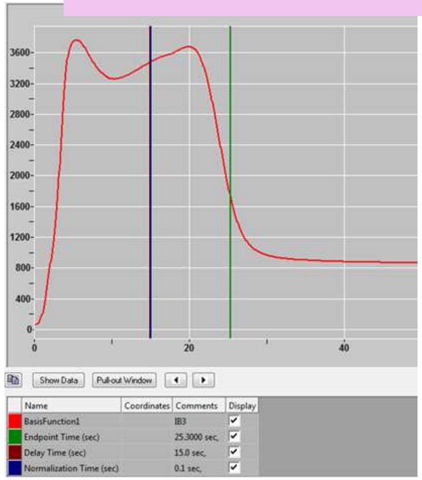
$Cl_2/O_2/N_2$ PLASMA - 1-STEP RESULT



	$Cl_2/O_2/N_2$ Chemistry
Tool(s)	LAM Alliance A6, TCP9600 (SiN+TiN) LAM Domino, Versys 2300 (p-GaN)

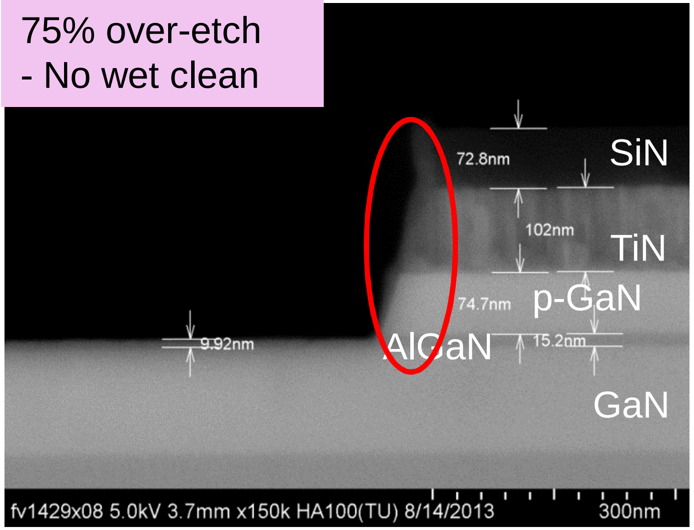
Sequence	1. Lithography
	2. SiN+TiN etch
	    1. SiN HM etch: SF6/O2
	    2. TiN Etch stop on p-GaN: SF6/O2
	3. Resist strip – AlGaN covered
	4. P-GaN etch (1 step)
	    a) Breakthrough (BCl3/Cl2)
	    b) Selective etch (Cl2/O2/N2) – on EP

IB3 = $GaCl_3$ = 335 nm

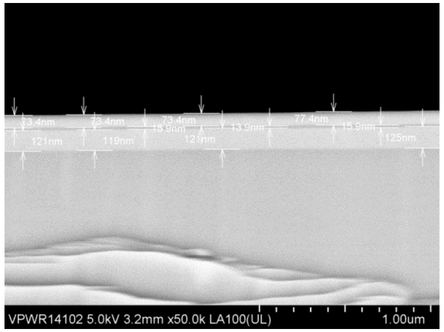


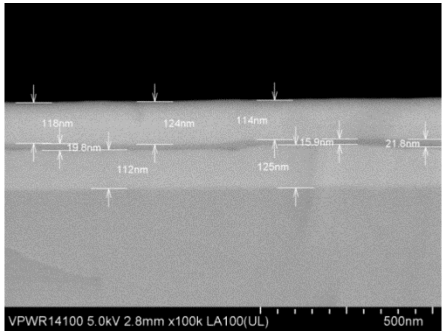
	Name	Coordinates	Comments	Display
🟥	BasisFunction1		IB3	☑
🟩	Endpoint Time (sec)		25.3000 sec.	☑
🟥	Delay Time (sec)		15.0 sec.	☑
🟦	Normalization Time (sec)		0.1 sec.	☑

75% over-etch
- No wet clean



$Cl_2/O_2/N_2$: PROCESS WINDOW - OVER ETCH VARIATION

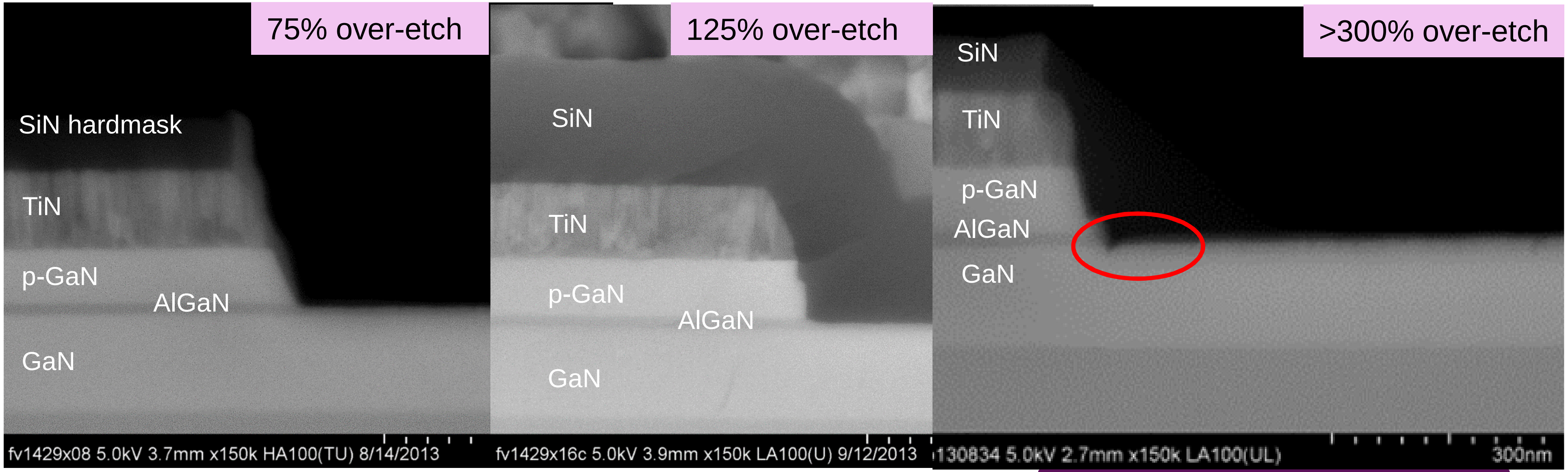




huge p-GaN thickness variation:

- 73 nm to 124 nm

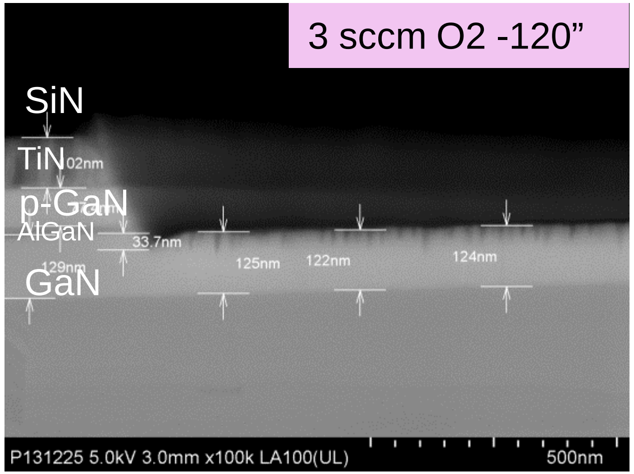
→ Target 100 nm

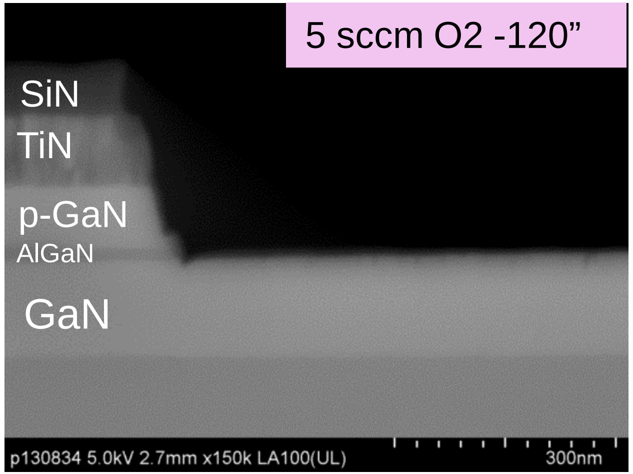


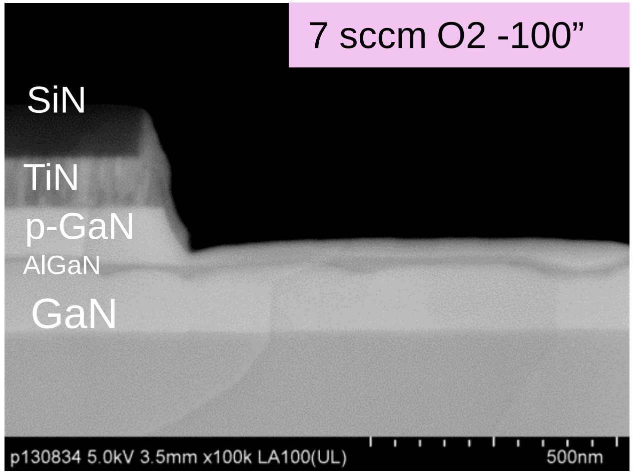
→ P-GaN removed everywhere
Etch rate pGaN:AlGaN = 21:1

- Micro-trenching
- pitting

$Cl_2/O_2/N_2$: PROCESS WINDOW - OXYGEN FLOW VARIATION


3 sccm O2 -120”


5 sccm O2 -120”


7 sccm O2 -100”

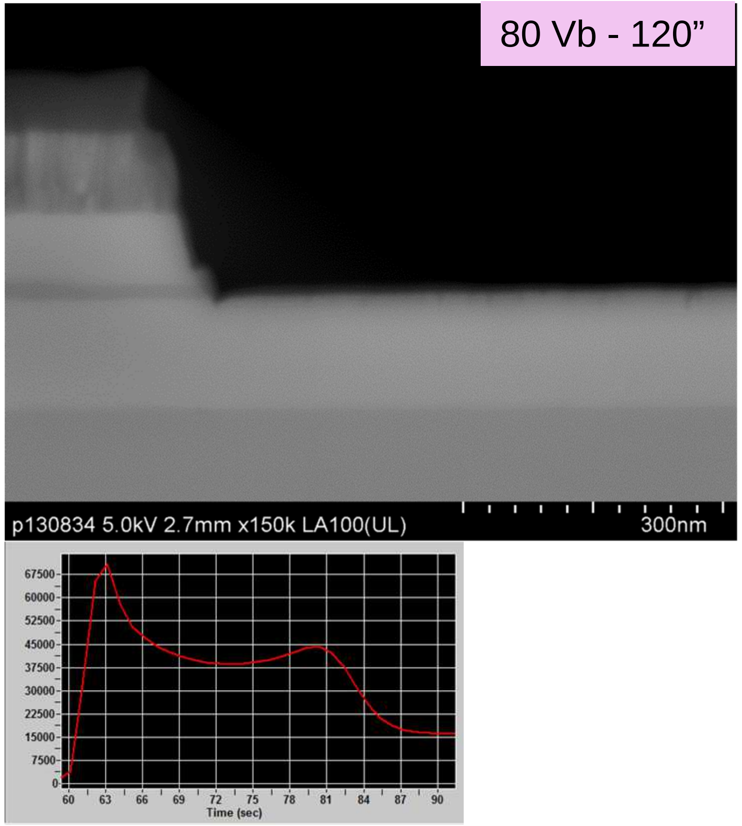
- No selectivity
- Micro-trenches/pitting

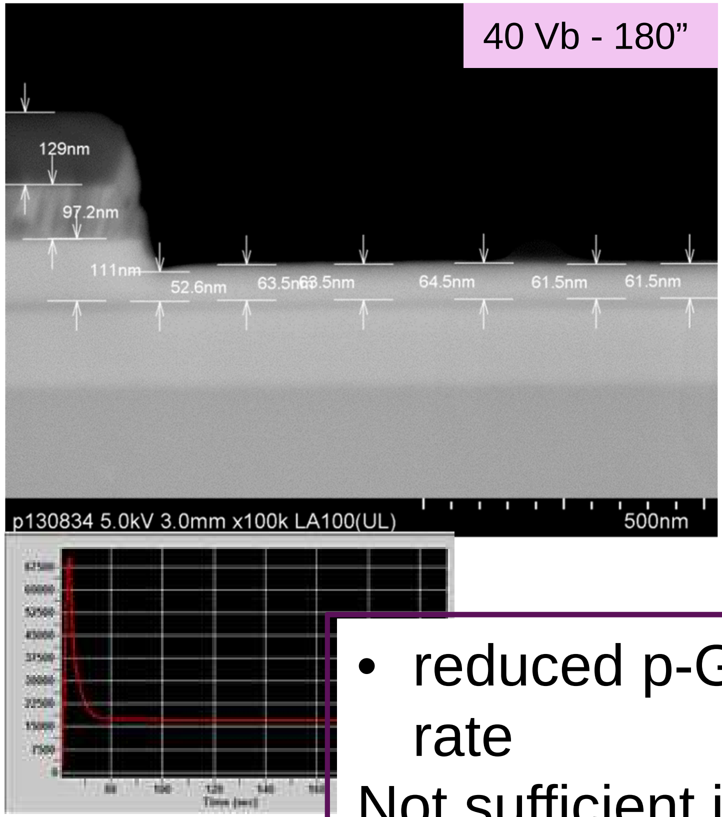
- Improved selectivity
- Some micro-trenches
- p-GaN etch rate ~ 192nm/min

- Lower p-GaN etch rate ~ 30 nm/min

Ga-O bond formation:
bond strength Ga-O >> Ga-N (etch stop !)

Cl$_2$/O$_2$/N2: PROCESS WINDOW - BIAS VOLTAGE VARIATION


80 Vb - 120”


40 Vb - 180”

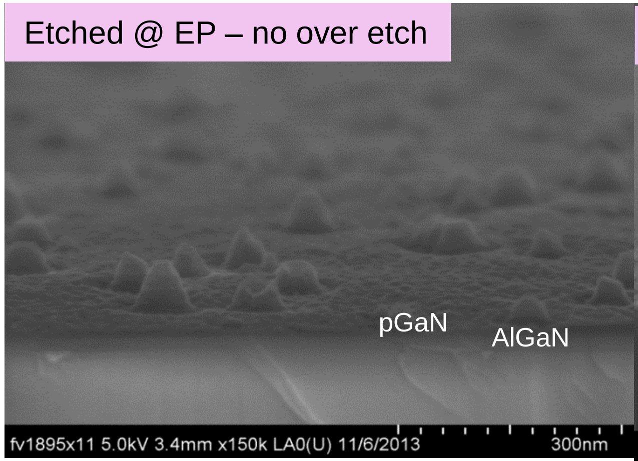
- reduced p-GaN etch rate

Not sufficient ion E to brake the Ga-O and Ga-N bond resulting in Etch stop !

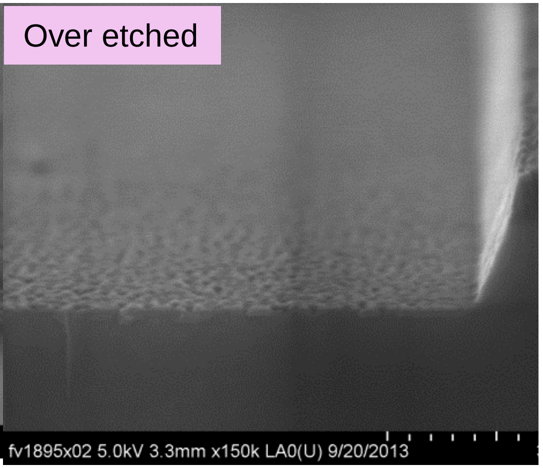
$Cl_2/O_2/N_2$ PLASMA
- MICRO-MASKING/ROUGHNESS

Our observation:

Etched @ EP – no over etch



Over etched



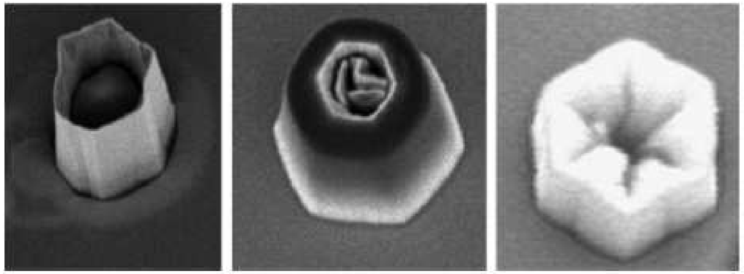


FIG. 15. SEM image columnar defects observed at the etched surface.

Mechanism*

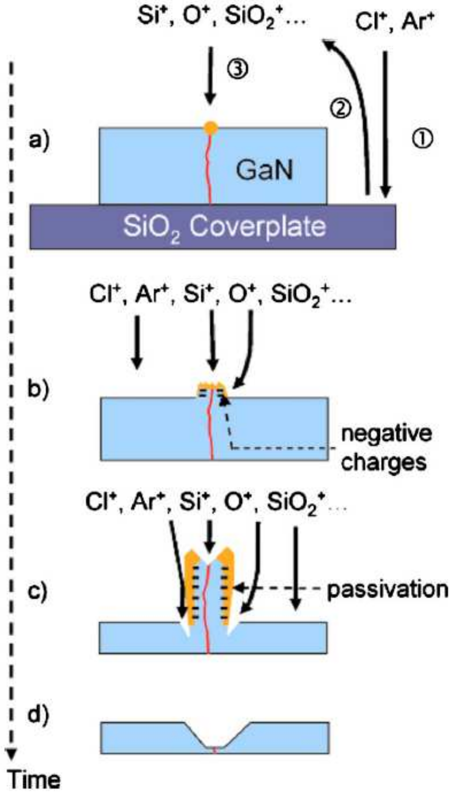


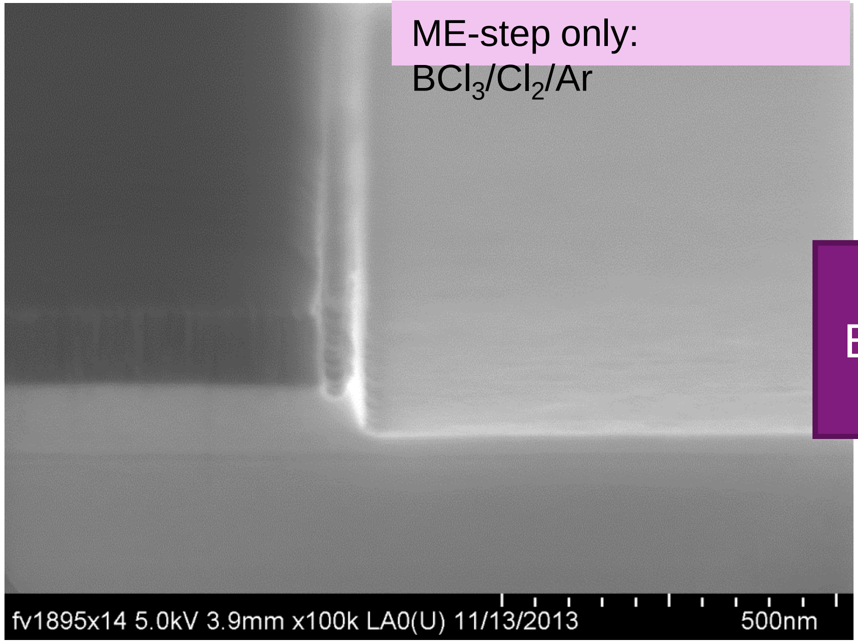
FIG. 14. (Color online) Schematic of a possible mechanism of formation of columnar defects. (a) Preferential decoration of dislocation, (b) column creation and passivation layer, (c) cavity at the top of the columnar defect and trenching at the bottom, and (d) column removed leaving a cavity.

*J. Ladroue, et al., “Deep GaN etching by ICP and induced surface defects”, J. Vac. Scie Technology A28 (5), Sep/Oct 2010 p1226

$Cl_2/O_2/N_2$ PLASMA
- MICRO MASKING / ROUGHNESS OPTIMIZATION

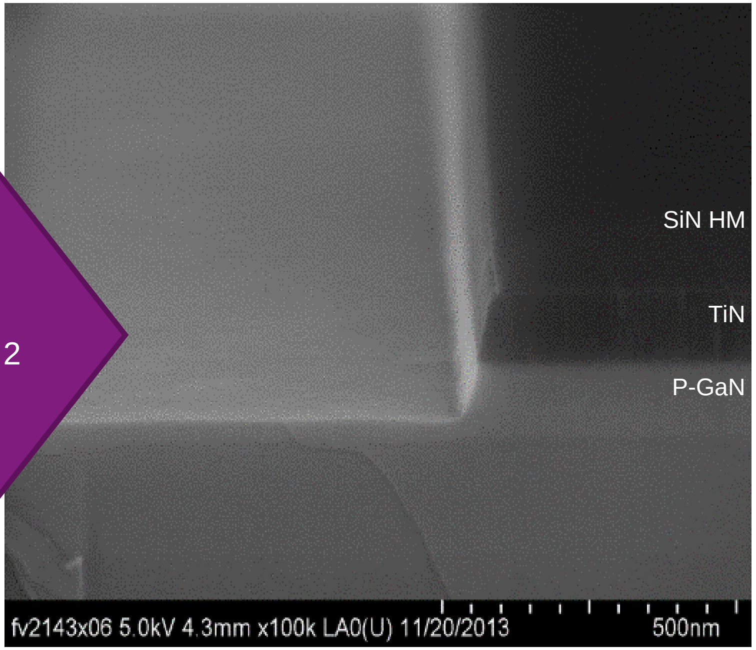
☐ Introduce main etch + selective over etch:

☐ introduce CWAC !



ME-step only:
$BCl_3/Cl_2/Ar$

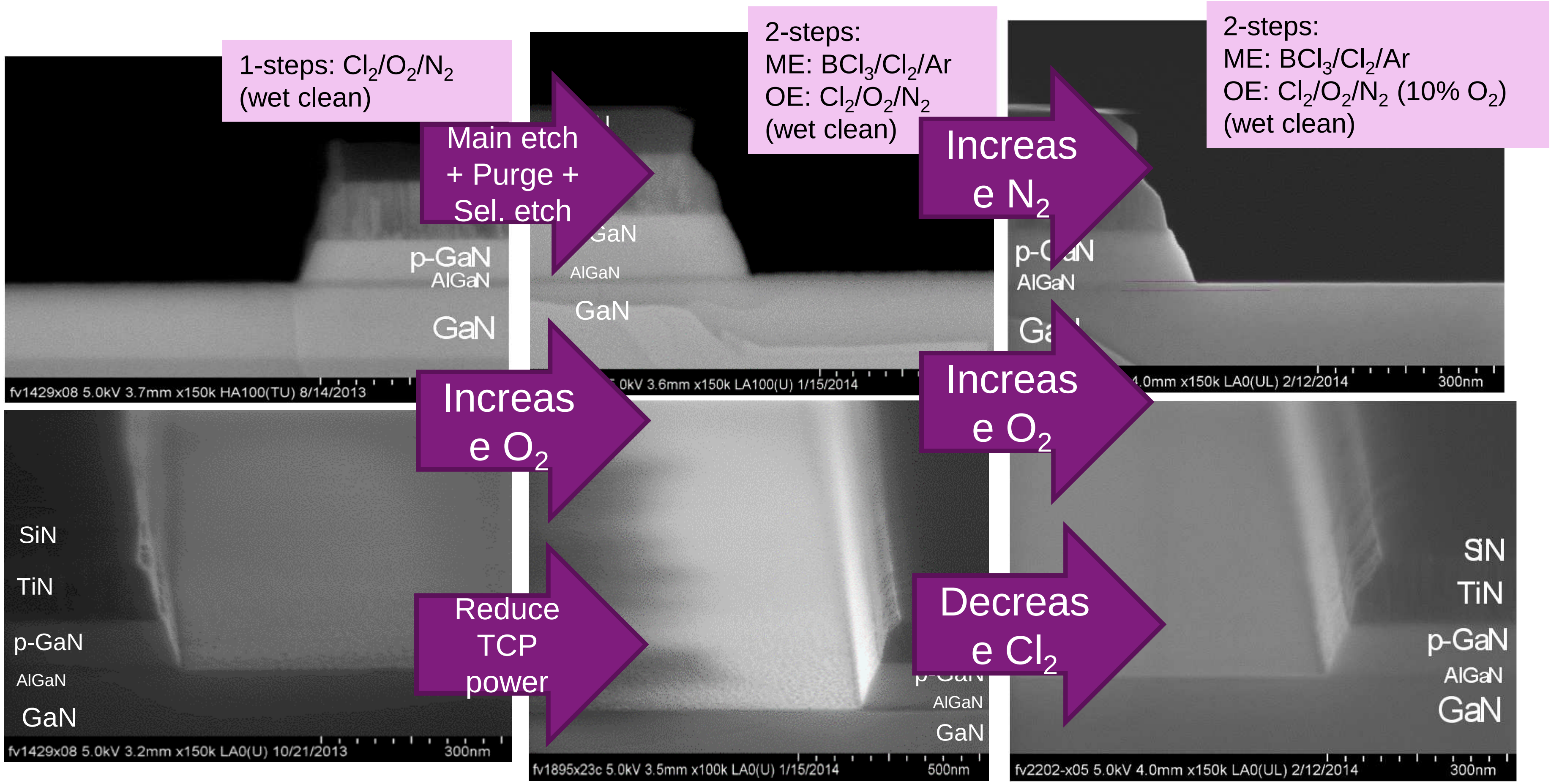
Tune
BCl_3/Cl_2
ratio



- Remove TiN residue's
- De-oxidize GaN

- Improved side wall protection
- avoid micro-trenching
- reduce lateral TiN attack
- Etch rate ~ 29.5 nm/min

$Cl_2/O_2/N_2$ PLASMA SURFACE ROUGHNESS - MAIN ETCH + SELECTIVE OVER ETCH



1-steps: $Cl_2/O_2/N_2$
(wet clean)

Main etch + Purge + Sel. etch

2-steps:
ME: $BCl_3/Cl_2/Ar$
OE: $Cl_2/O_2/N_2$
(wet clean)

Increase N_2

2-steps:
ME: $BCl_3/Cl_2/Ar$
OE: $Cl_2/O_2/N_2$ (10% O_2)
(wet clean)

Increase O_2

Increase O_2

Reduce TCP power

Decrease Cl_2

- Ar Purge step after main etch to remove BCl_3

→ BCl_3 reduces available oxygen

- reduce active Cl content

- Increase O_2 flow for improved selectivity
- Decrease Cl_2 / increase N_2 flow for improved surface morphology
- AlGaN loss observed 2 to 4 nm

CONCLUSIONS

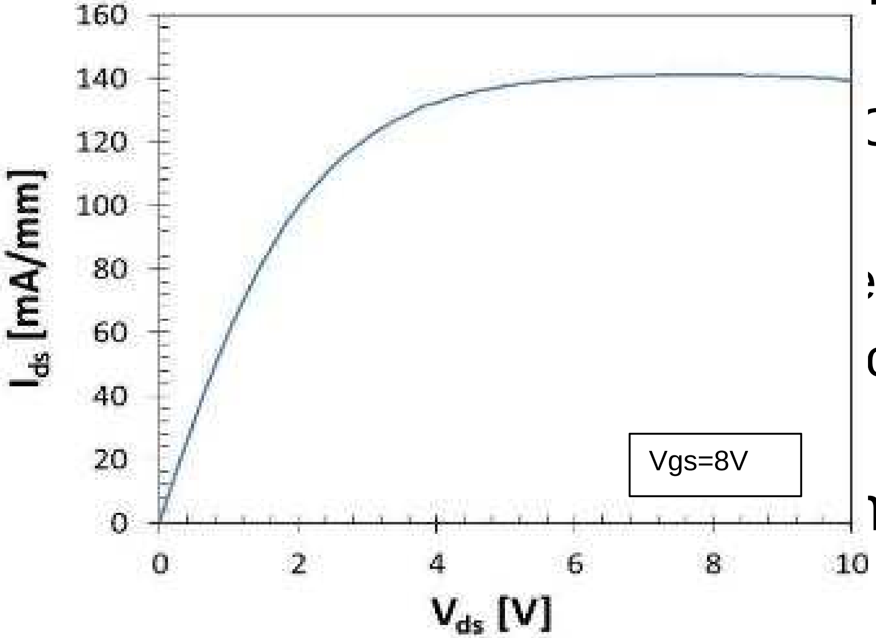
❑ 2 E-mode device concepts have been proposed

❑ both concepts require particular etch development:

- ALE approach: slow, very controllable etch rate based on
  alterna
- Select
  $_2$ (or SF_6)
  sma
  AlGa
  roughness
  ce (effect of Si
  sputterin

❑ both co
node power
transist

I_{ds}-V_{ds} Power transistor



THANKS FOR YOUR ATTENTION !