Development of Thin Film Release of GaN using AlN and AlGaN Buffer layers for MEMs Applications

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EE 412 Final

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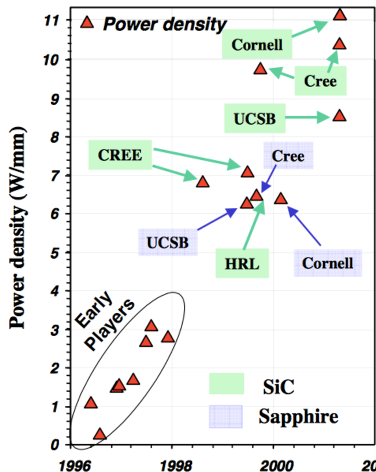
Harsh Environment Sensing and GaN



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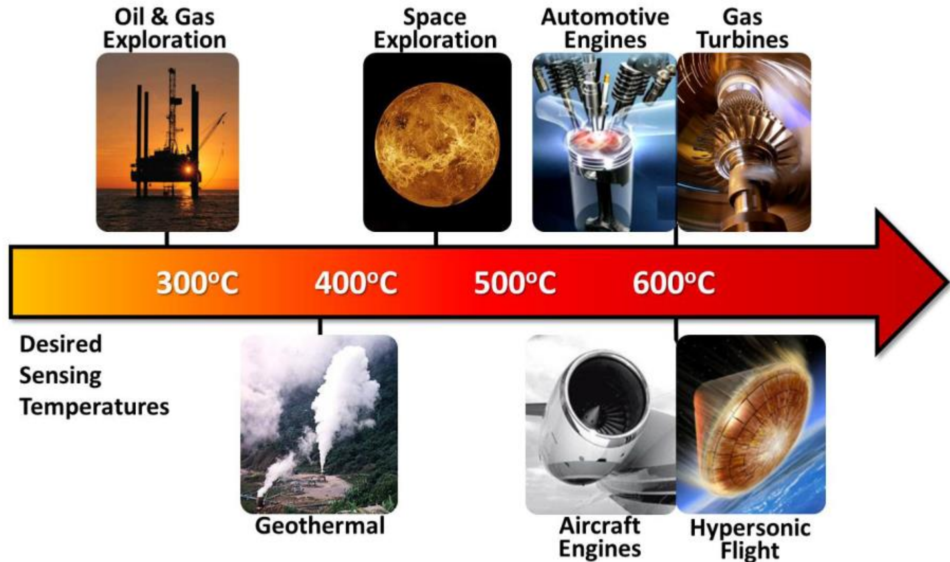
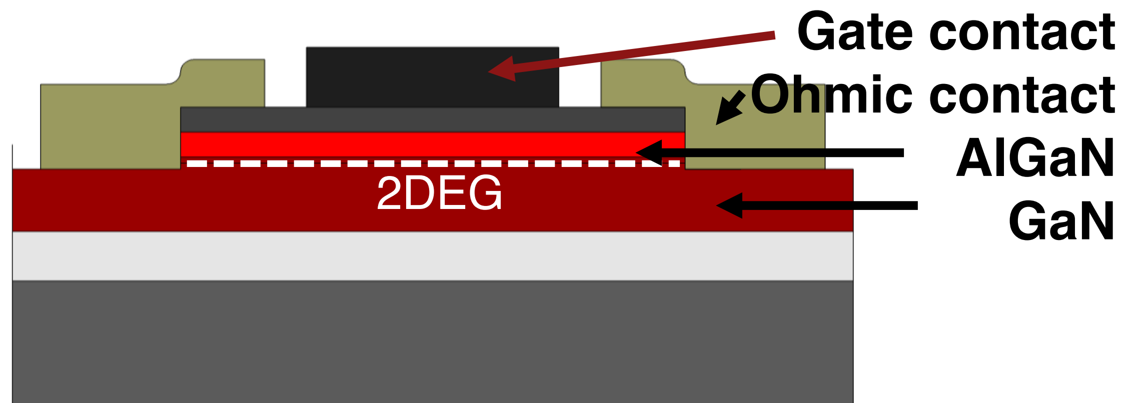


D.G. Senesky, ECS Prime Joint International Meeting (2012)

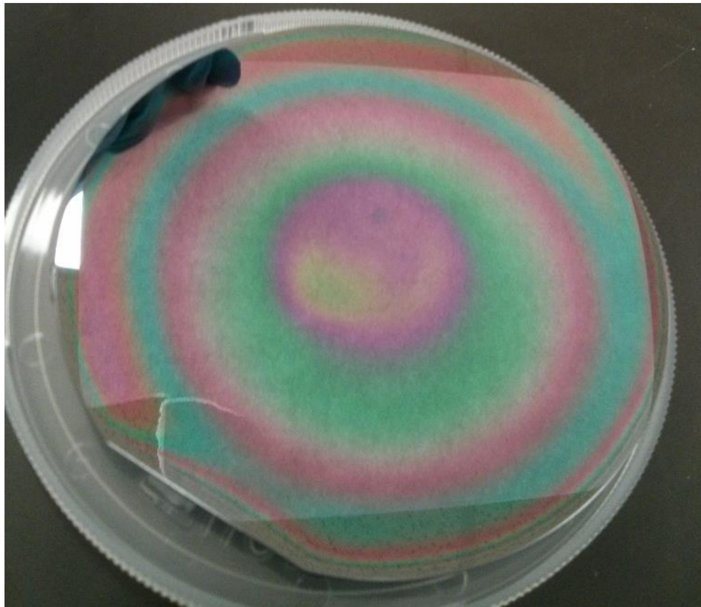
Image: http://physicsworld.com/cws/article/news/2014/oct/07/isamu-akasaki-hiroshi-amano-and-shuji-nakamura-win-2014-nobel-prize-for-physics



Schematic of GaN HEMT

GaN HEMT – New SNF Capabilities

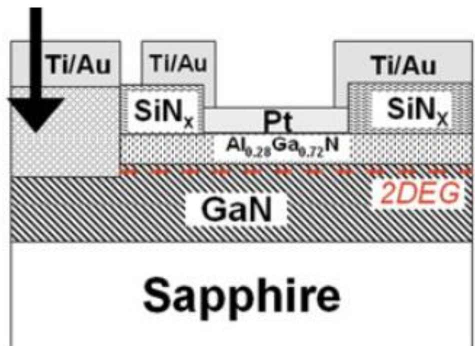
- SNF recently installed III-nitride metal organic chemical vapor deposition system.
- Dr. Xiaoqing Xu established a recipe for growing high electron mobility transistors (HEMTs) last December.
  - Hall mobility: 1590 cm^2/V
  - Sheet carrier concentration: 1.1×10^{13} cm^{-2}

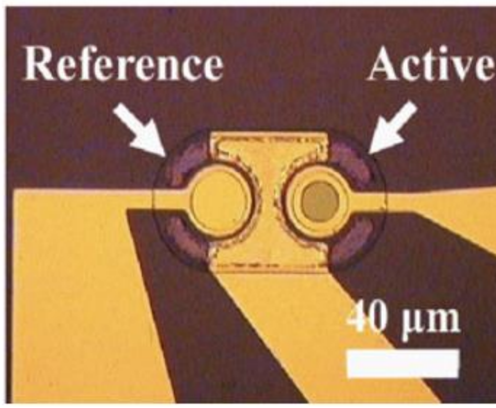


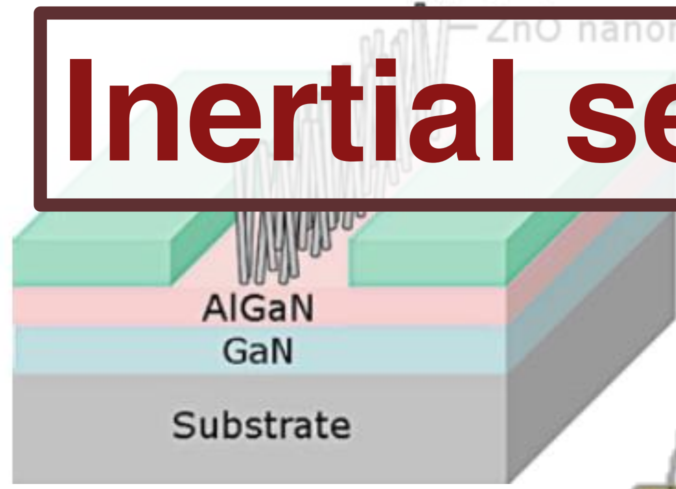
GaN MEMS/NEMS Techniques

Inertial sensing???

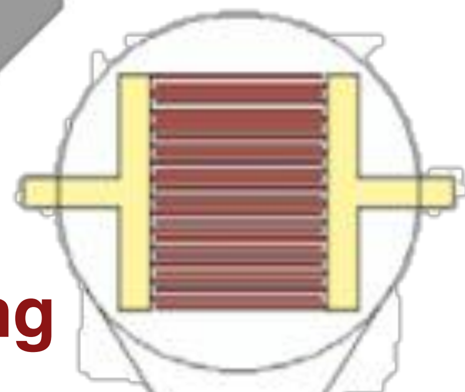
Gas and Chemical Sensing

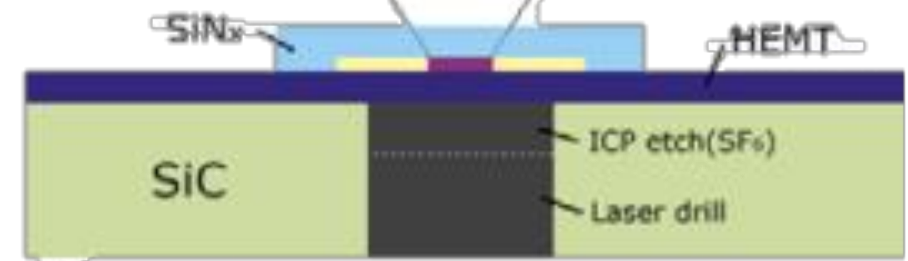






Biological and biomedical sensing

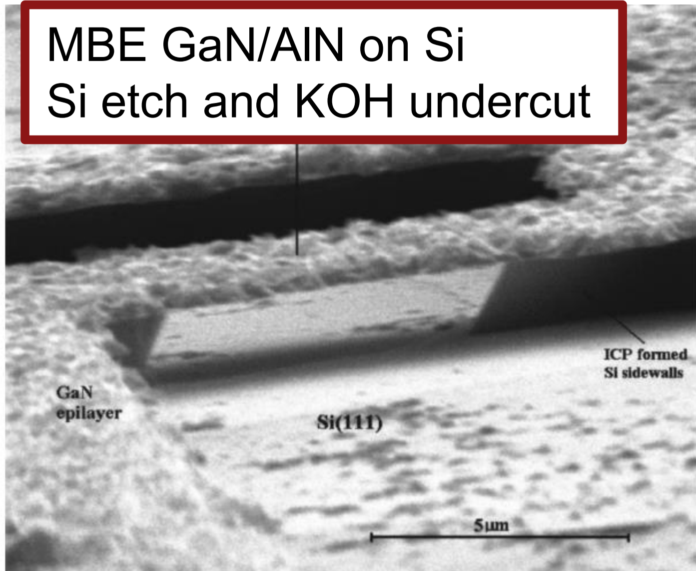




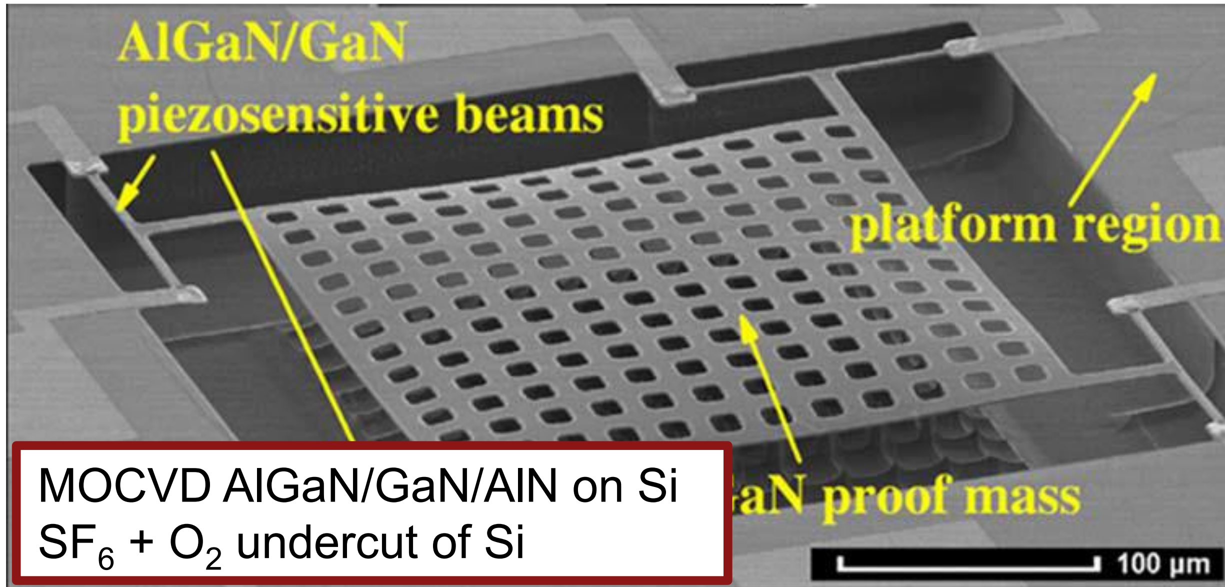
Pressure sensing

1. Pearton, S. J. et al. J. Phys. Condens. Matter 16, R961–R994 (2004).
2. Pearton, S. J. Springer (2012).

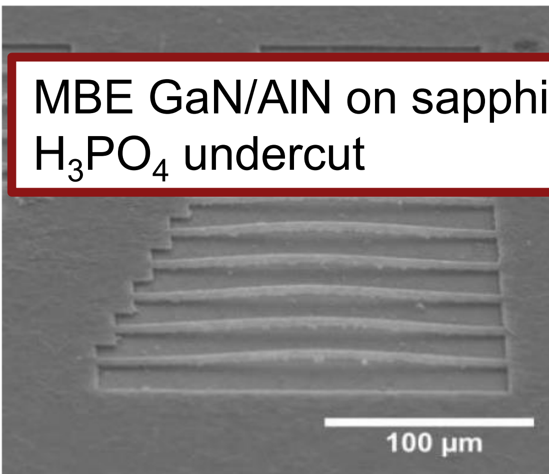
Previous GaN suspension work

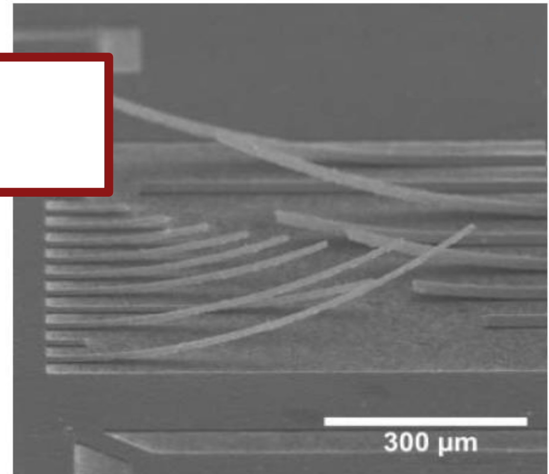


Davies et al. Appl. Phys. Lett., 2004.



Lv et al, IEEE Electron Device Letters, 2009



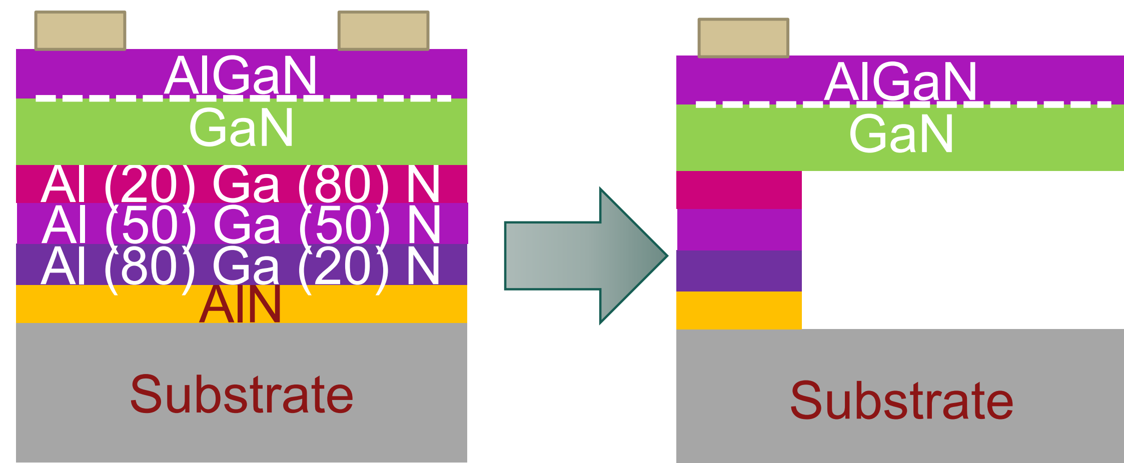


Zaus, E., et al. Phys. Status Solidi-Rapid Res., 2007.

Ansari et al. IEDM12, 2012

Goal & Approach

- Goal: Develop a method for suspending GaN HEMT structures to enable more GaN MEMs.
  - Solid state sensors to suspended sensors!
- Approach: Characterize the etch rate of AlN and AlGaN samples grown with the Axitron-CCS.
  - Measure the wet etch rate and the selectivity between AlN and AlGaN with varying aluminum concentration.
  - Determine perpendicular and lateral etch rates.



Brief Literature Overview of GaN and AlN etching

Material	Chemistry	Temp (°C)	Growth	Etch rate	Source
GaN	Phosphoric acid	155	MOCVD	1 - 0.8 um/min	1998, Stocker
AlN	Phosphoric acid	170	rf-MBE	7-10 nm/min	2001, Ide
GaN	Phosphoric acid	200	MOCVD	1 um/min	2005, Zhuang
GaN	Phosphoric & Sulfuric acid	250	MOCVD		2002, Wen
GaN	Molten KO[illegible]	[illegible]	[illegible]	[illegible]in	1998, Stocker
GaN	KOH & ey[illegible]	[illegible]	[illegible]	[illegible]in	1998, Stocker
GaN	Molten KO[illegible]	[illegible]	[illegible]	[illegible]tion char.	2002, Wehyer
AlN	KOH	[illegible]	[illegible]	[illegible]m/min	2005, Zhuang
AlN	AZ400K (KOH)	25		6-1000 nm/min	2005, Zhuang
AlN	AZ400K (KOH)	20-80	Sputter	1nm - 1um/min	1996, Vartuli
GaN	PEC KOH	RT	MOCVD	500 nm/min	2002, Ko
GaN	PEC phosphoric	RT	MOCVD	300 nm/min	2002, Ko

- Dependent on nitride quality, growth method, growth temperature.
- ***Many are highly anisotropic!***

Anisotropic Etching by Crystal Planes

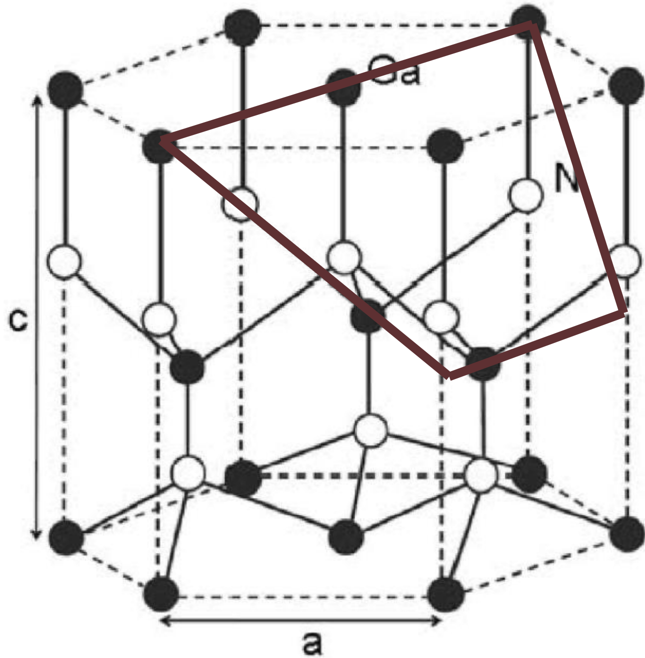
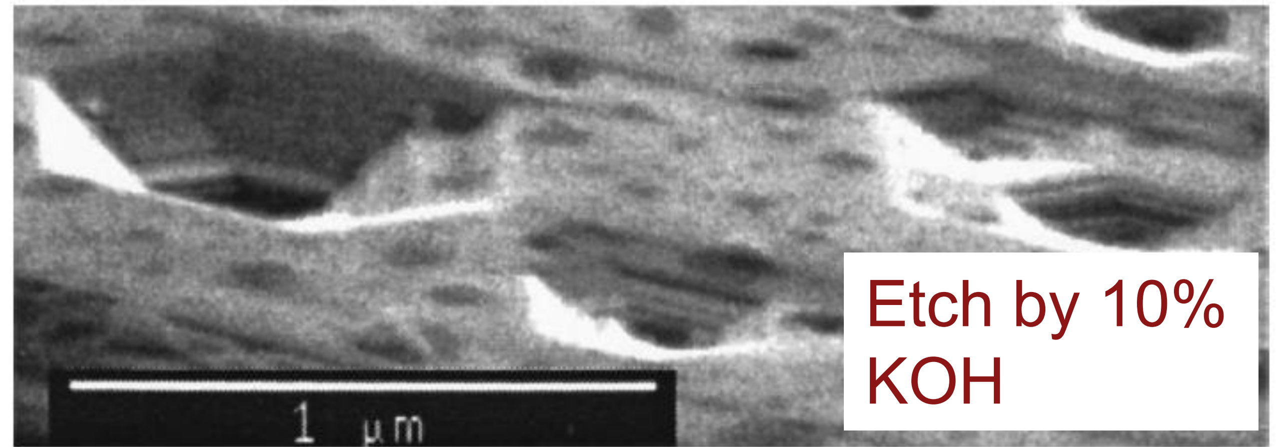
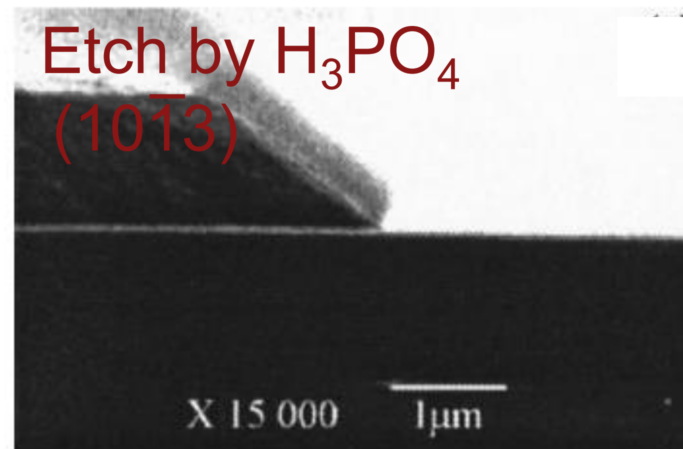
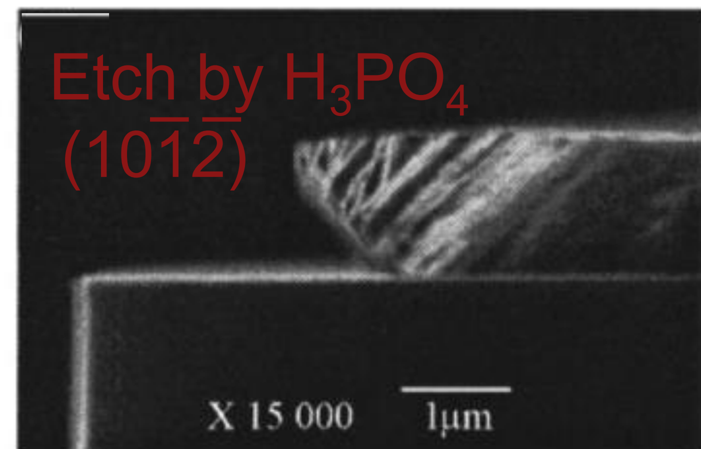


Image Credit: http://m.liudingsheng.cn/ibebuyy/

$(10\bar{1}\bar{2})$ plane



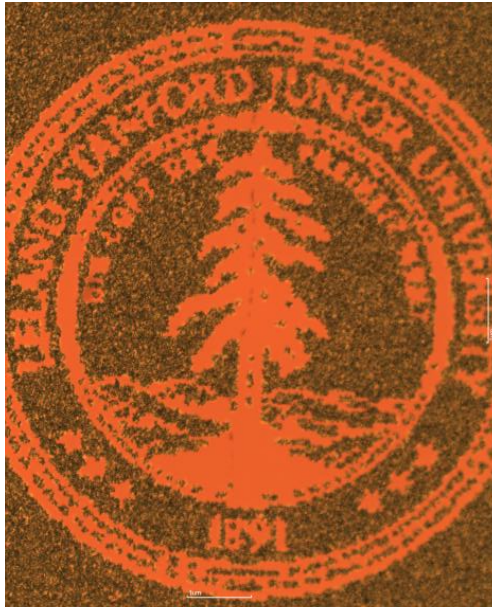


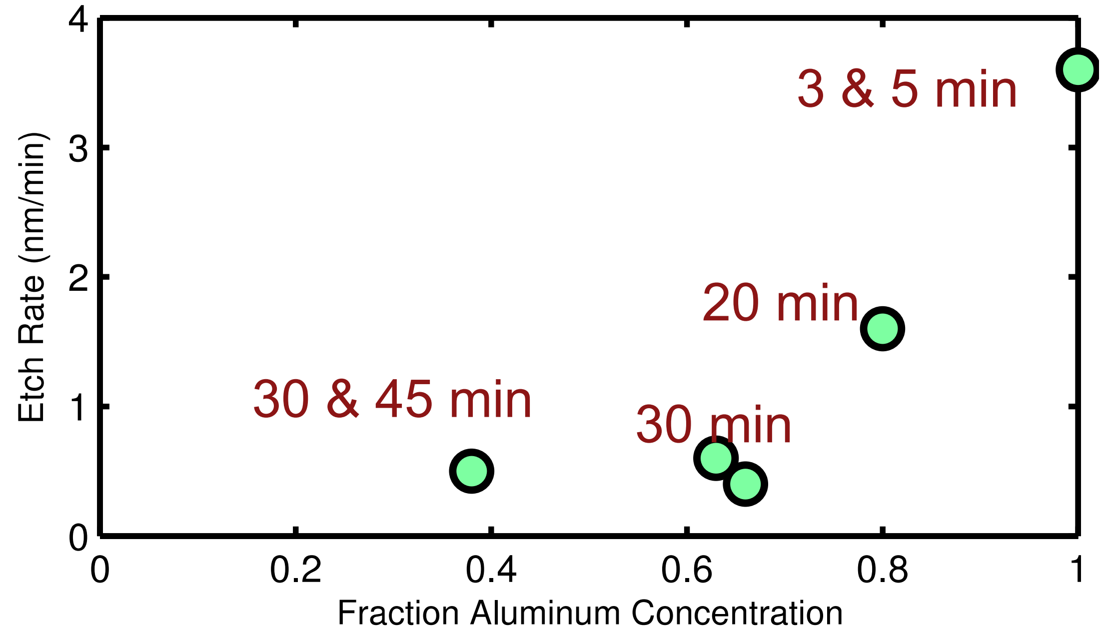


Stocker et al, Applied Physics Letters, 1998

AlN and AlGaN Etched in Phosphoric Acid at 150°C

AlN, 5 min

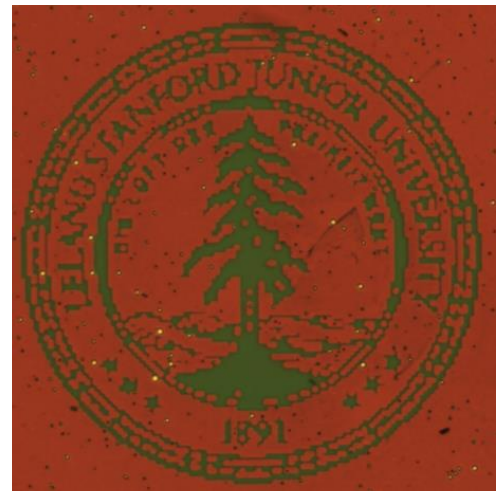




$Al_{0.8}Ga_{0.2}N$, 20 min

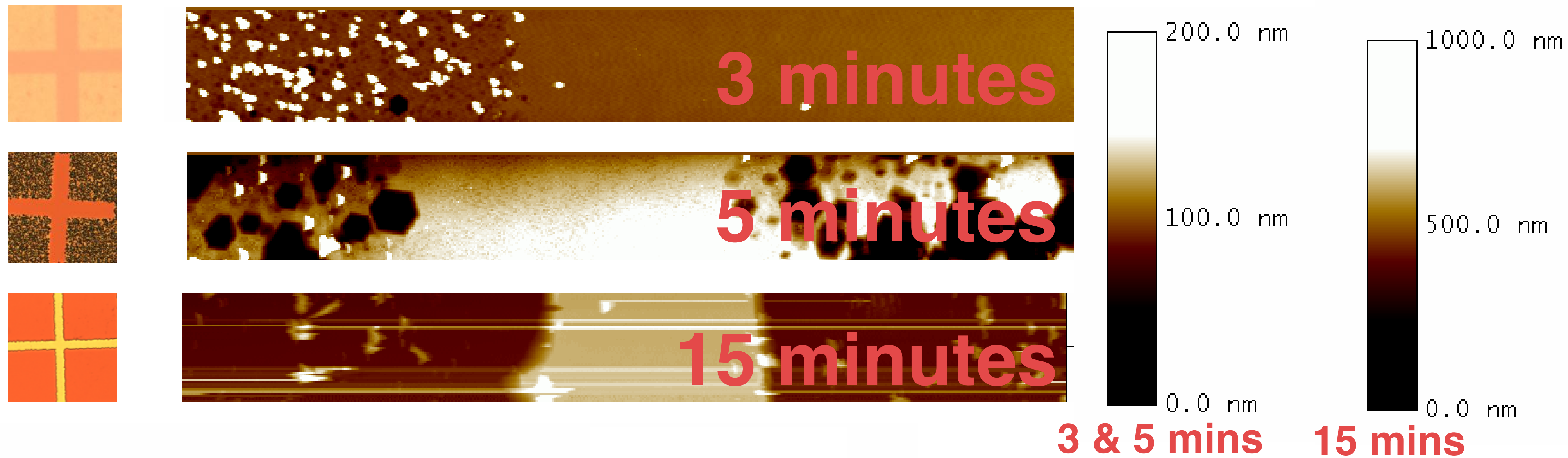
$Al_{0.7}Ga_{0.3}N$, 30 min

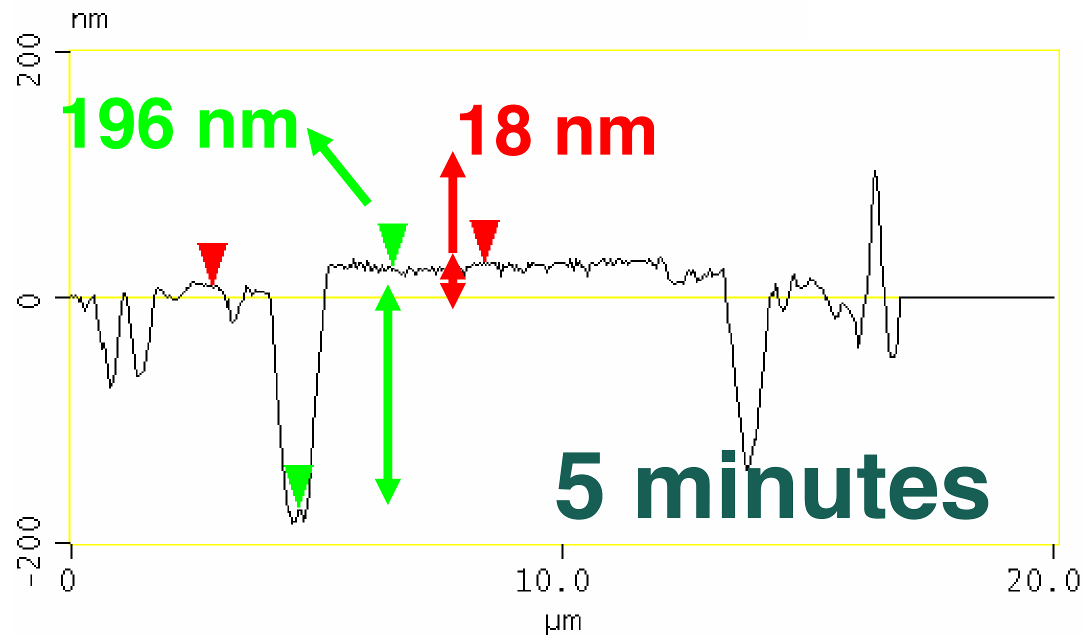
$Al_{0.5}Ga_{0.5}N$, 30 min



$Al_{0.2}Ga_{0.8}N$, 30 min

AlN Etch Evolution at 150°C

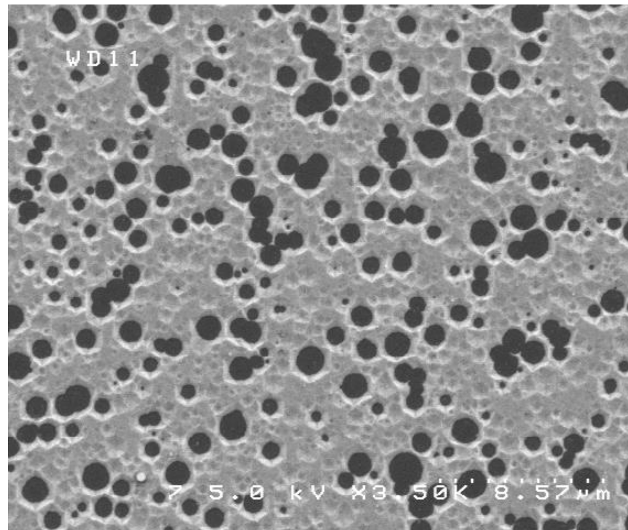


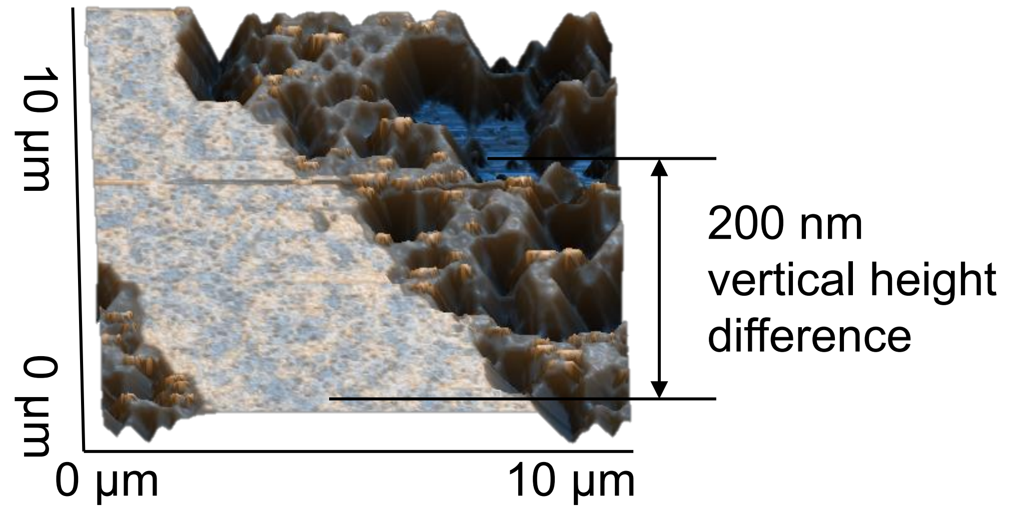


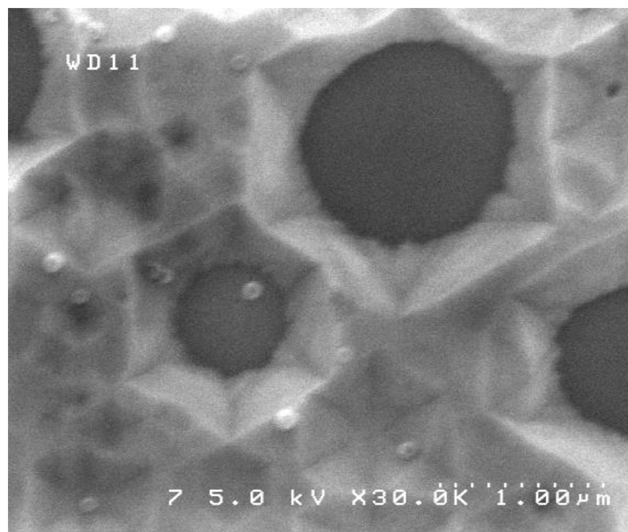
- Etch evolution of AlN in 150°C phosphoric acid for 3, 5, & 15 minutes.
  - Etch rate dominated by defects/dislocations, an order of magnitude different!
    - (0001) etch rate: 3.6 nm/min
    - ($10\bar{1}\bar{2}$) etch rate: 40 nm/min

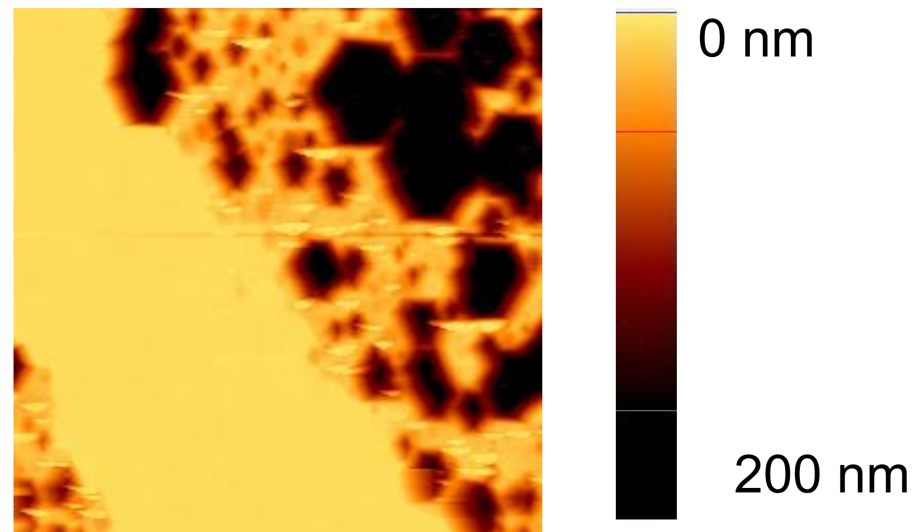
AlN Etch Evolution

- AlN etched at 150°C for 5 minutes

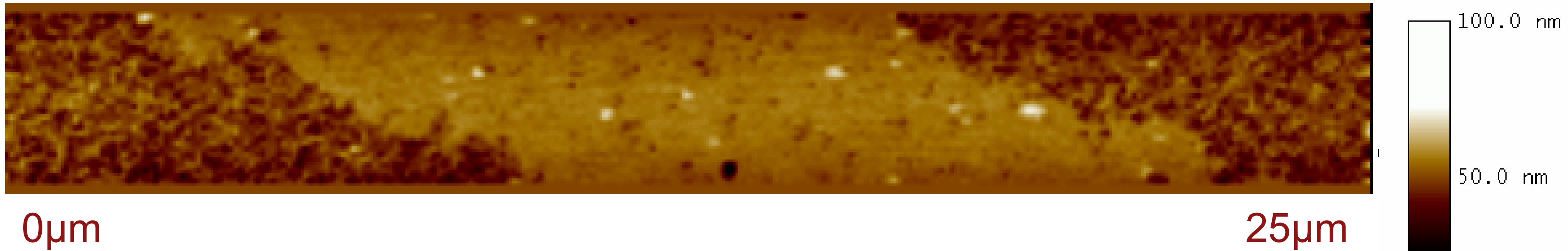






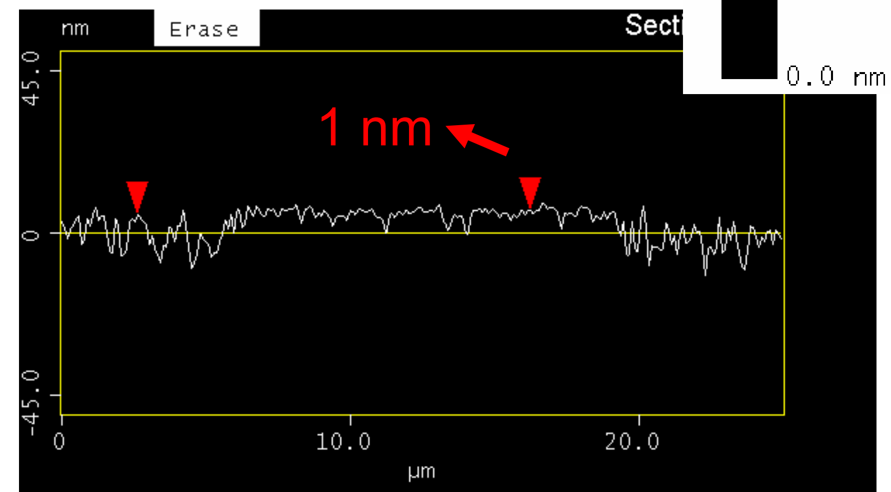


3:1 Sulfuric: Phosphoric Etch > 160°C



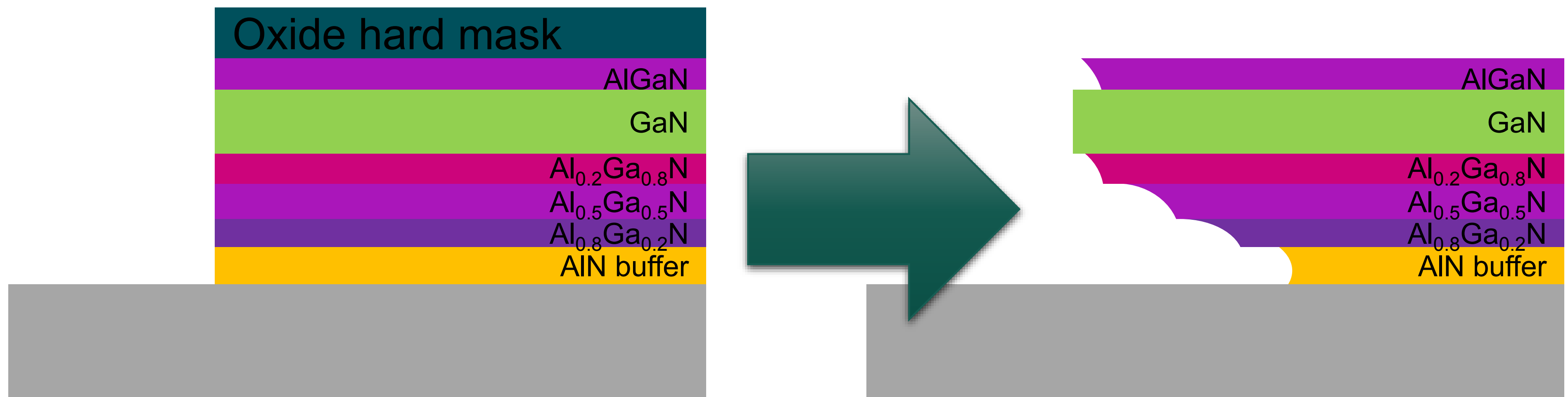
0µm 25µm

- Developed a procedure with the PROM committee to etch III-nitrides in a 3:1 sulfuric to phosphoric bath.
  - Boiling point of phosphoric: 158°C
  - Boiling point of sulfuric: 330°C



- Etched samples at 175°C and 200°C
  - AlGaN's for 10 minutes
    - Couldn't measure with AFM
  - AlN for 2.5 minutes
  - Etch rate much slower than expected, essentially sulfuric acid "diluted" H_3PO_4 acid.

Lateral Etch Rates of AlN, AlGaN & GaN



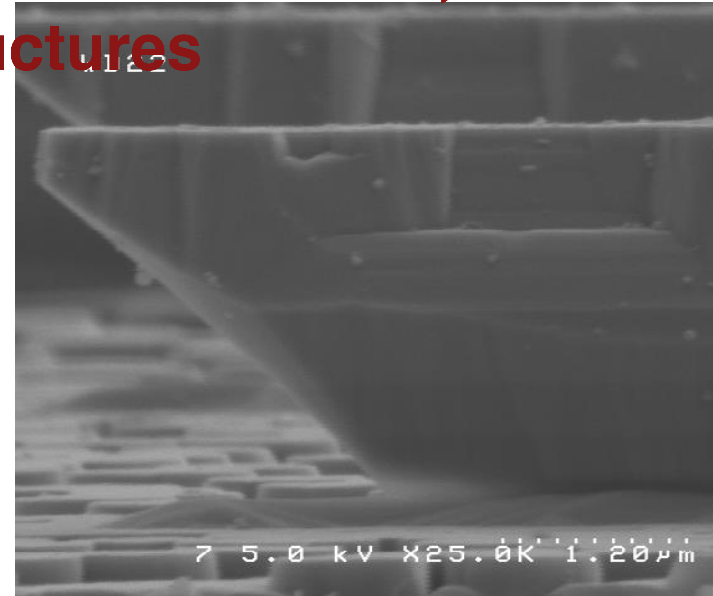
Expose side walls of HEMT structure with dry etch

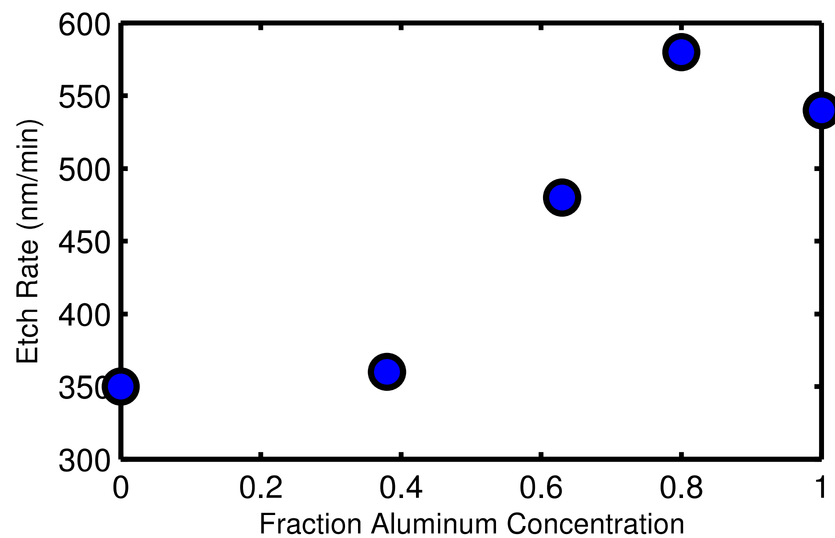
Phosphoric etch to characterize lateral etch

- Used oxford III-V BCl_3/Cl_2 inductively coupled plasma etch to expose all of the side walls
- Measured the lateral etch rates by taking a cross-sectional SEM
  - Preliminary data, measurements dependent on angle of SEM
  - Removed oxide before SEM, determining hard mask location by silicon etched by ox III-V

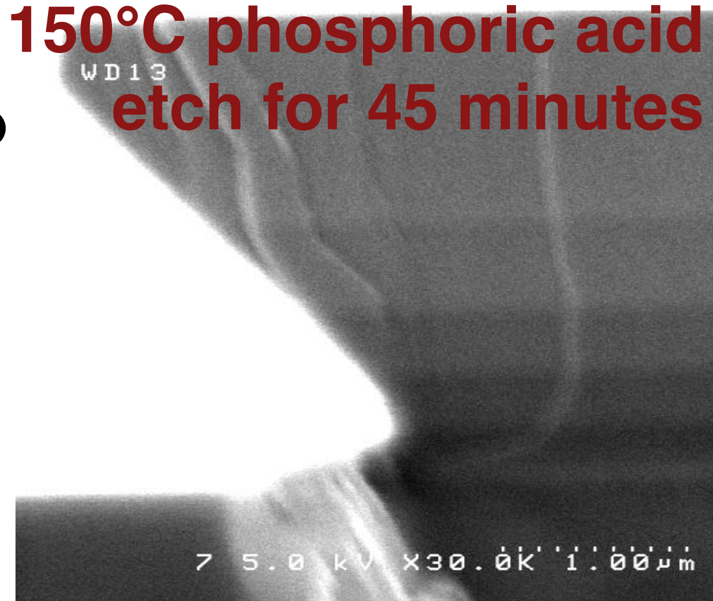
Hot Phosphoric Lateral Etch

150°C phosphoric etch for 5 minutes, cantilever structures

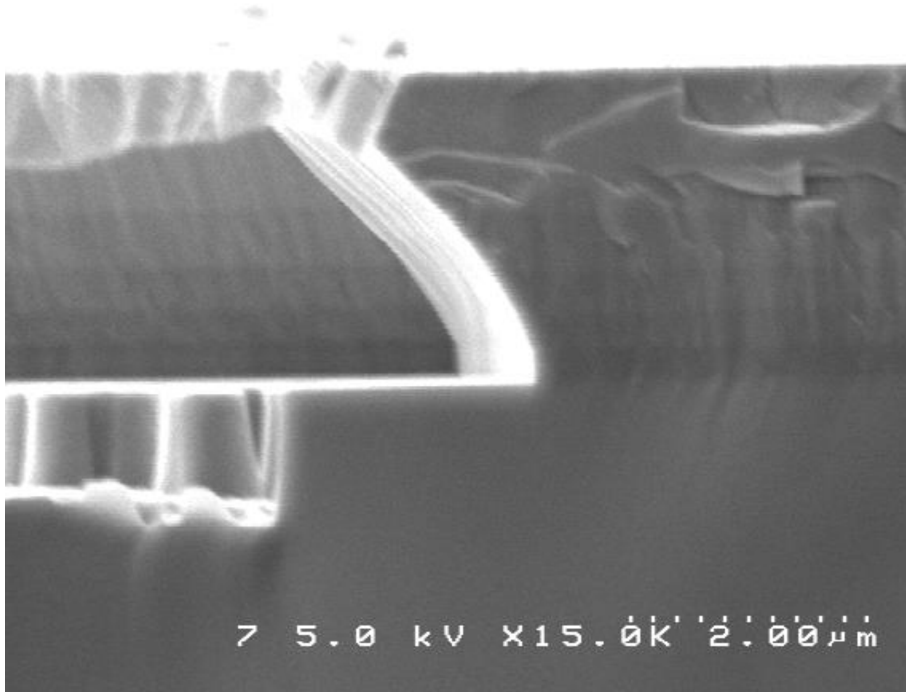


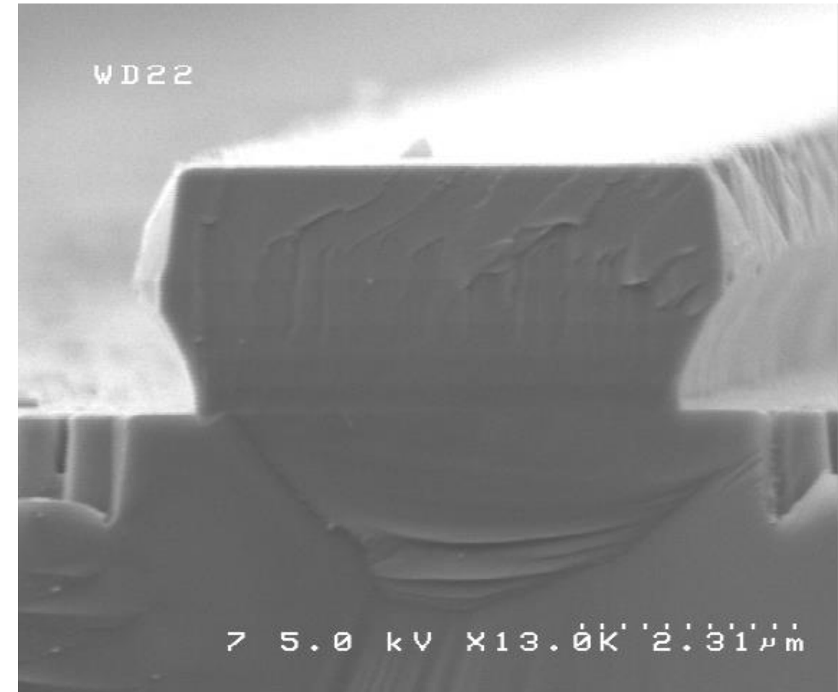


150°C phosphoric acid etch for 45 minutes

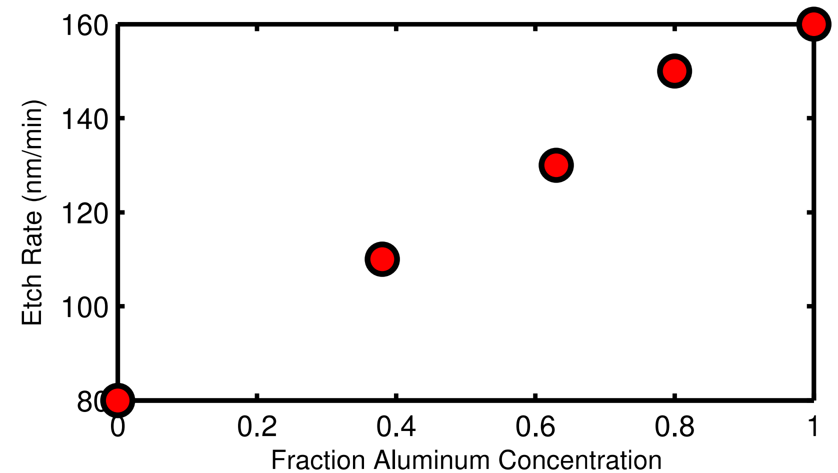


3:1 Sulfuric to Phosphoric Lateral Etch

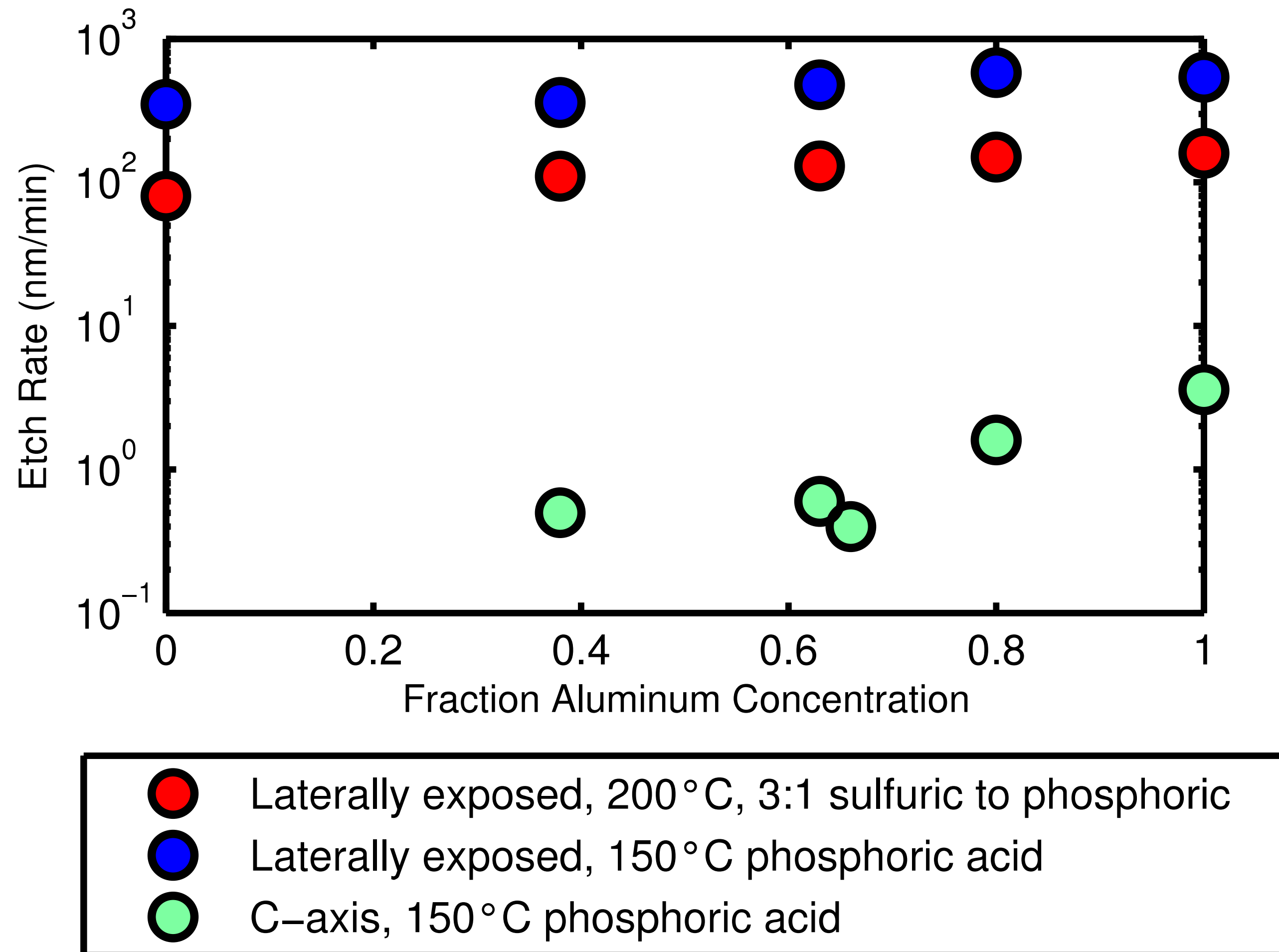




200°C 3:1 sulfuric to phosphoric acid etch for 10 minutes



Overview of Etch Rates



Conclusions

- This is hard!
- This work illustrates that using the AlN buffer layer can be used to release HEMT structures.
  - AlN to GaN selectivity
    - Better selectivity for 3:1 phosphoric acid at 200C
  - Basal plane to lateral planes selectivity
  - Suspended HEMT will still need ALD passivation to protect 2DEG interfaces
- Further efforts are needed for suspension.
  - Can hot phosphoric not only be used for suspension but also fabrication of sensors?
  - Alternatives include photo enhanced chemical etching.
- Stay tuned for more GaN fun!

Acknowledgements

- Xiaoqing!!!
- Robert ☺
- Conway, Usha, Michelle, Uli, Mahnaz, Maurice, Carsen
- Kevah
- Sambahv, Greg, Kim
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