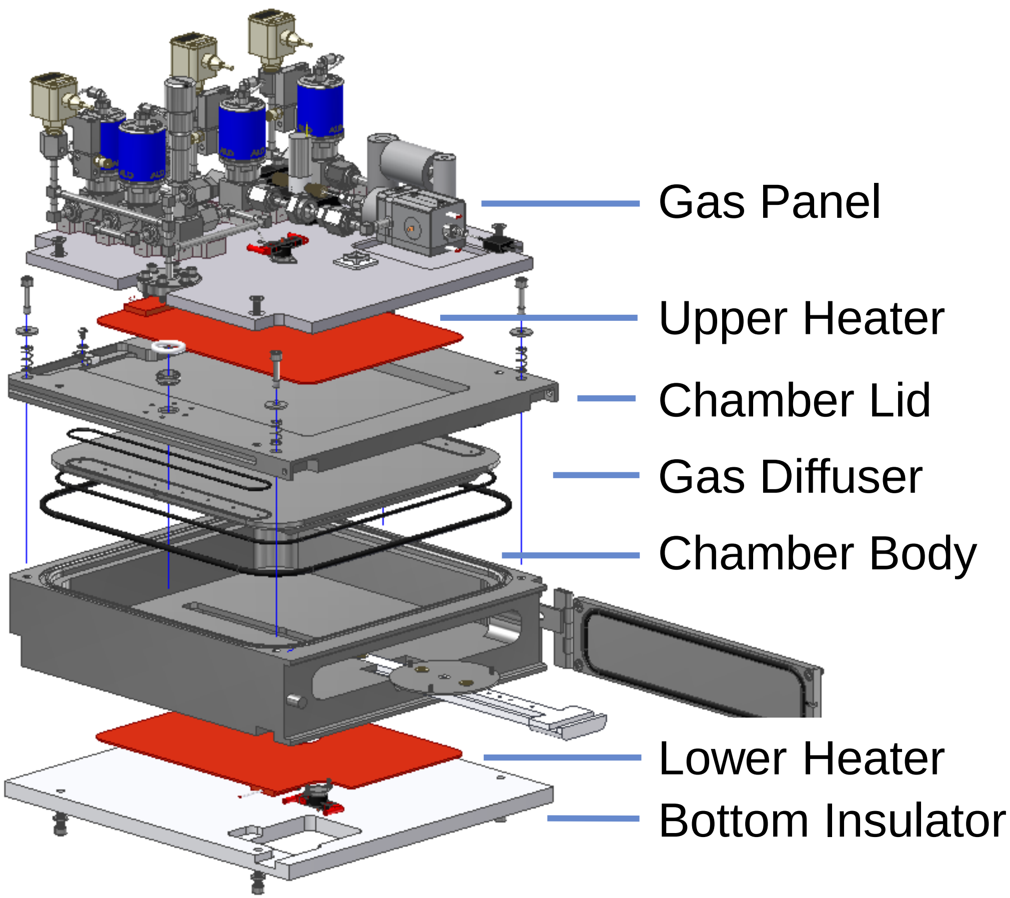
Temperature Control

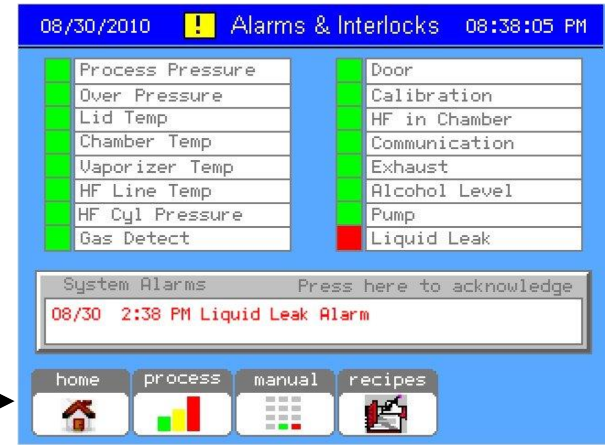


- Dual zone with resistive element heaters heats the entire system
- 24V resistive heaters
- Top heater provides heating to gas panel and chamber lid
- Bottom heater provides heating to chamber body
- PID controller with software enables setting control temperature and out of range trip points

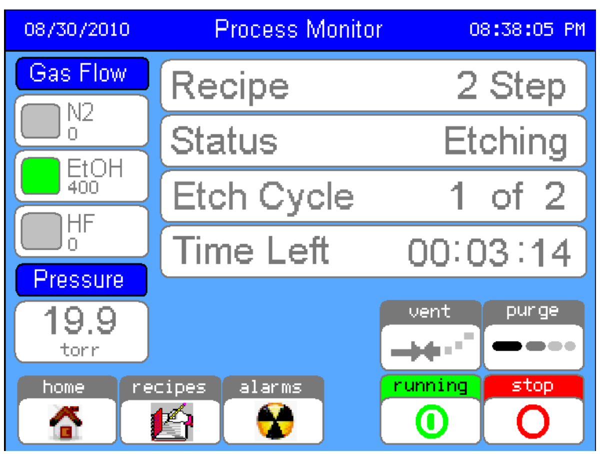
Software/Process Control

Home Screen

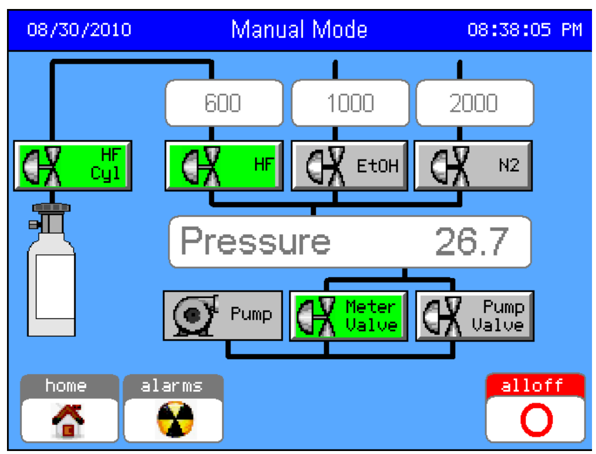
Alarm Screen



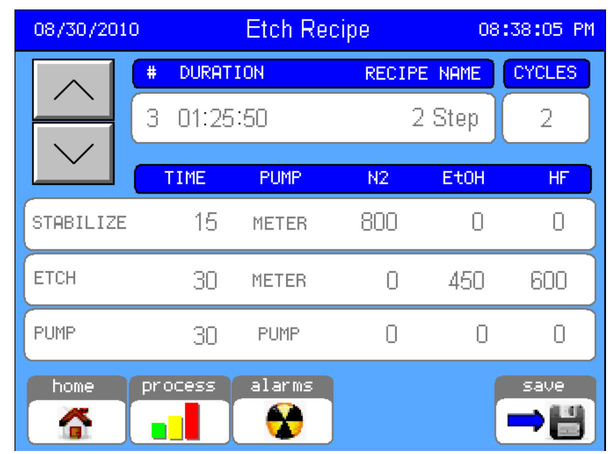
Main Process Screen



Manual Valve Control Screen



User Recipe Create Screen

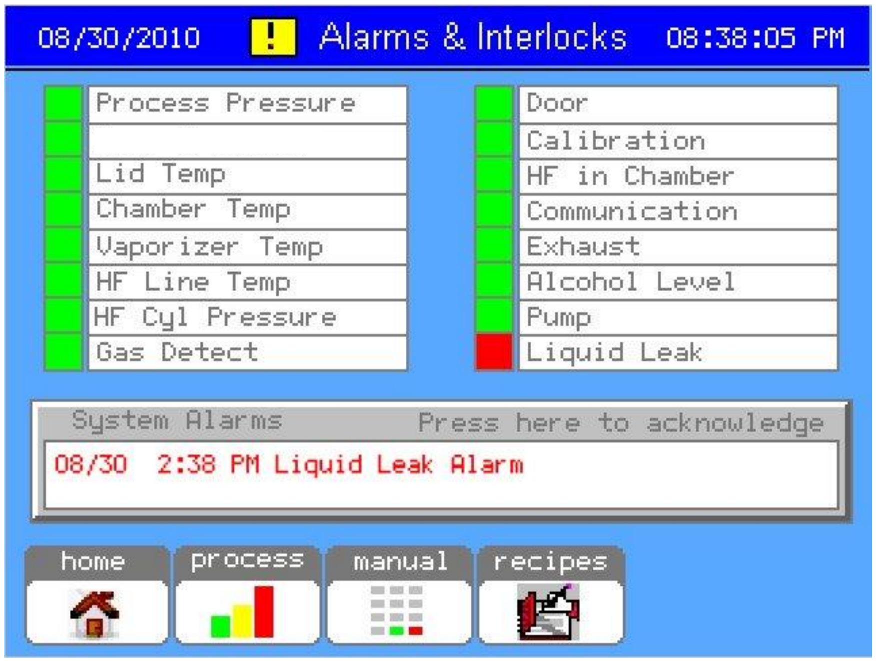


Interlock/Safety Features

Process Pressure – detects pressure < 300 torr to enable HF/EtOH delivery valves to operate

Door or Lid – gas panel lid open

Exhaust – extraction hood exhaust sufficient (SYSTEM only)



Temperatures – detects out of range for critical components (Chamber, Vaporizer, HF line option)

Pump – foreline vacuum detect (SYSTEM only)

Liquid Leak – Detects Alcohol Leak (SYSTEM only)

Calibration – checks for system calibration

System Features for Multiuser Facilities

- Password Protected Advanced Screens
  - Critical settings are password protected from a “standard” user – who has limited access to the etch portion of the recipe relating to the etch length (etch rate * etch time)
- Hidden Manual Mode Feature
  - Manual Mode Screen can be configured to be hidden (only available to tool owner) to prevent manual valve operation
- Recipe Lock Feature
  - Parameters on the Recipe Editor Screen can be locked independently allowing tool owner to create, test and then “lock” any parts of the recipe. The standard user will only be able to edit parameters made available by the tool owner.
- Interlock (Door)
  - Can be used to enable/disable tool to limit use through a host computer. Has been used to log and bill time on tool.

Maintenance

- Chamber body and gas diffuser plate slide forward and can be removed for easy cleaning

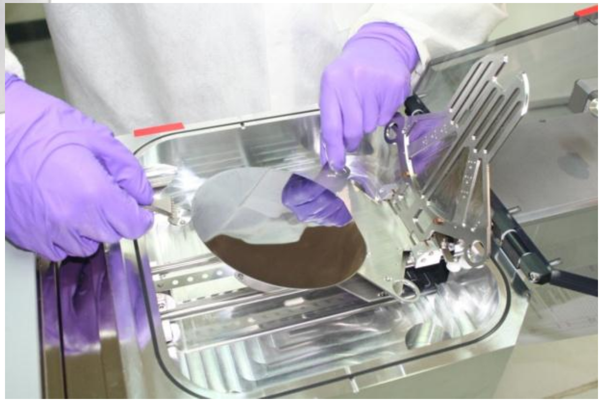
PRIMAXX® uEtch SYSTEM

- Integrated system with built-in HF gas cabinet, reduced pressure regulator and heated delivery line to uEtch module
- Facilities bulkhead for easy connections
- 27” x 27” footprint, 69” high
- Requires 125 mm exhaust connection, electrical power, dry vacuum pump, process nitrogen and Compressed Dry Air

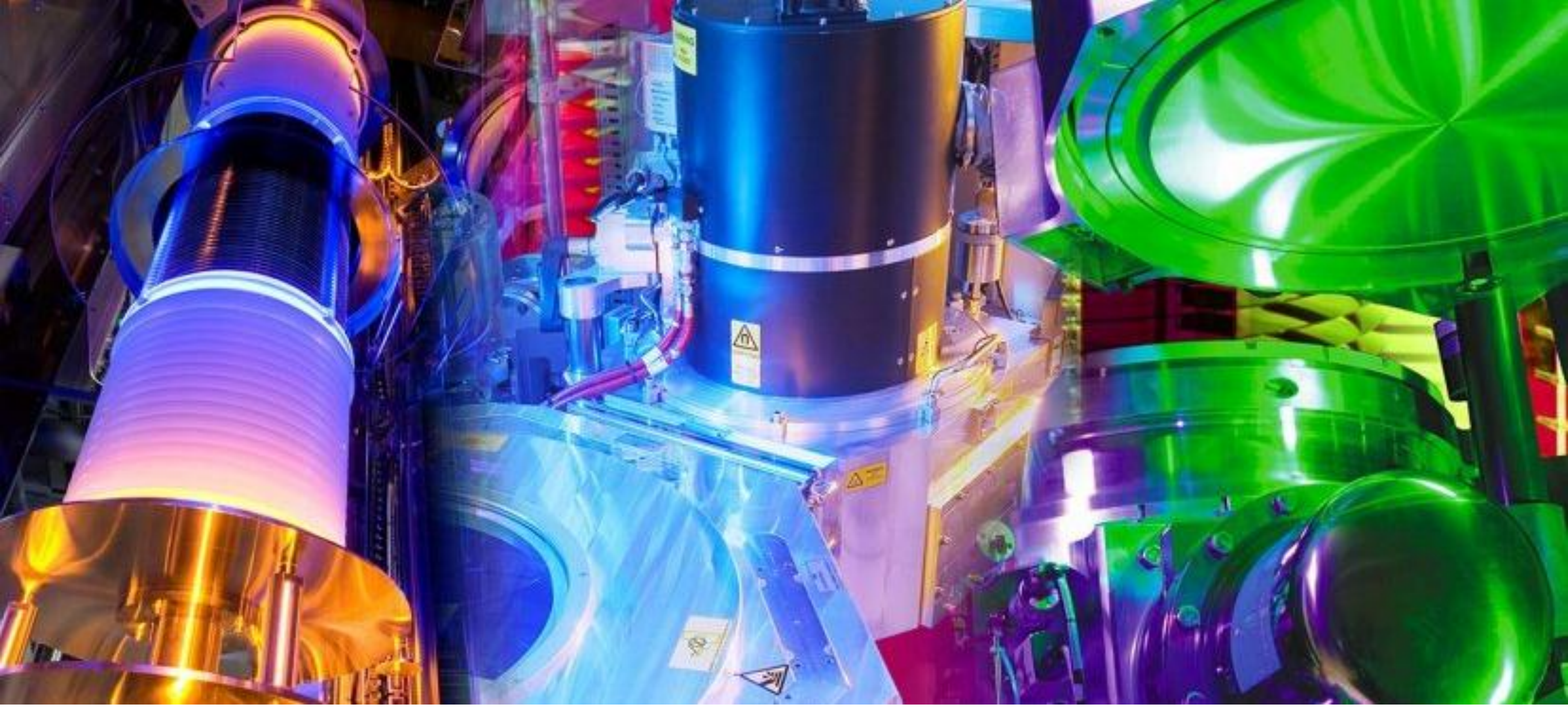
Scalable – from R&D to Production

- uEtch process regime is similar to SPTS HF production configurations
- Process transfer from uEtch to Monarch3/25 platforms readily achievable

Monarch 3 with auto-loader



Monarch25 process module

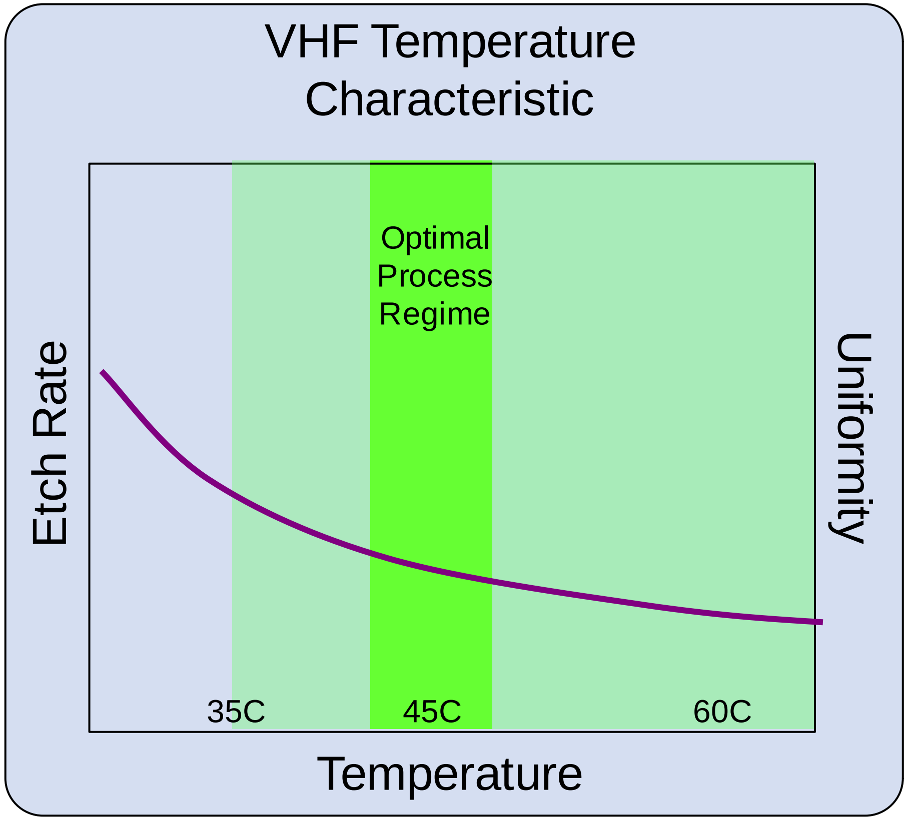


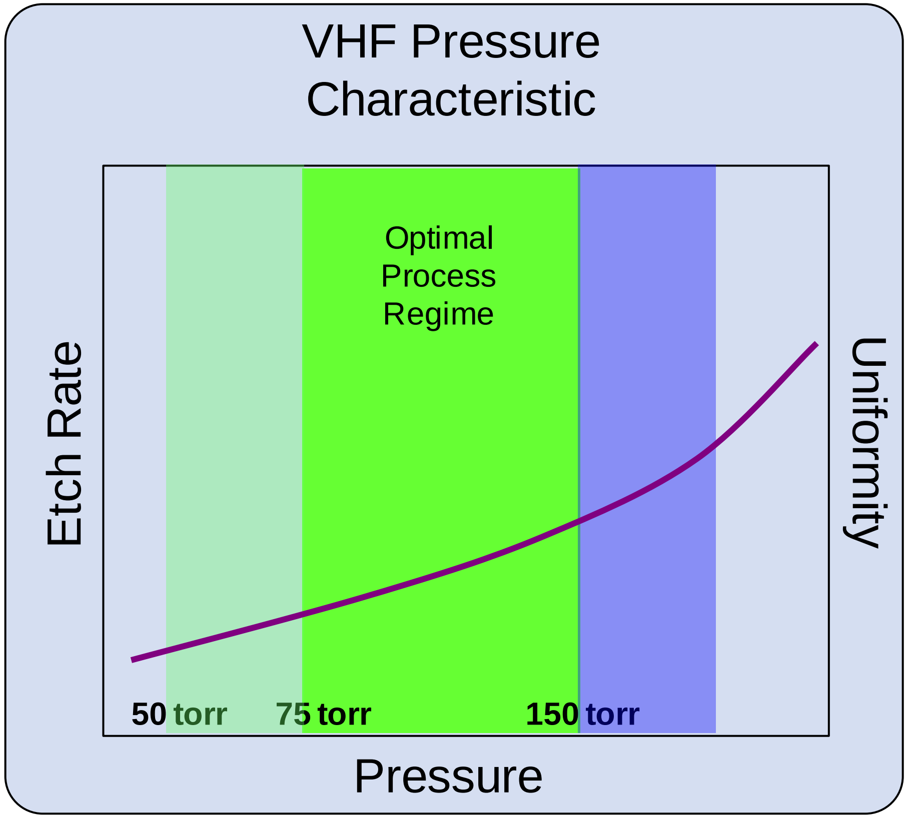
PRIMAXX® VHF Etch Release Technology

Performance – Basics

PRIMAXX® VHF Etching – Rate Control

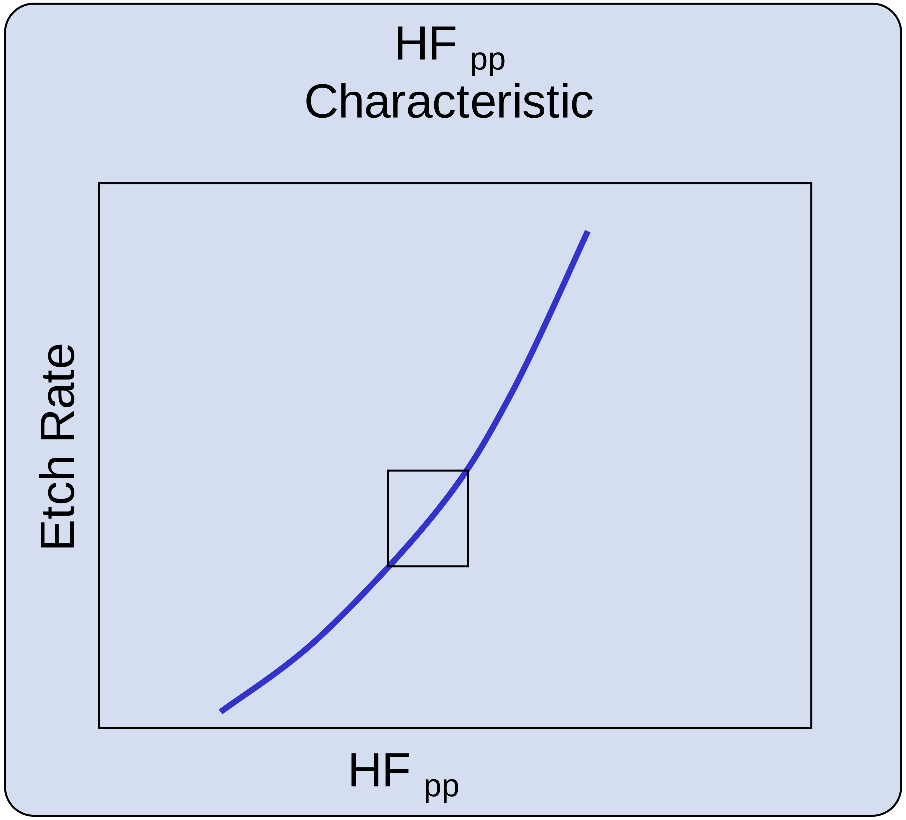
- Etch Rate dependencies
  - ***Increases*** with lower temperature and higher pressures
  - ***Decreases*** with higher temperature and lower pressures
  - Uniformity degrades as etch rate increases





Etch Rate Control – HF_{pp} using HF Flow

- HF_{pp} is the dominant parameter used to control etch rate
- Increasing Total Gas Flow (and Total N_2) without changing HF flow rate reduces etch rate because HF_{pp} is reduced



HF Partial Pressure =

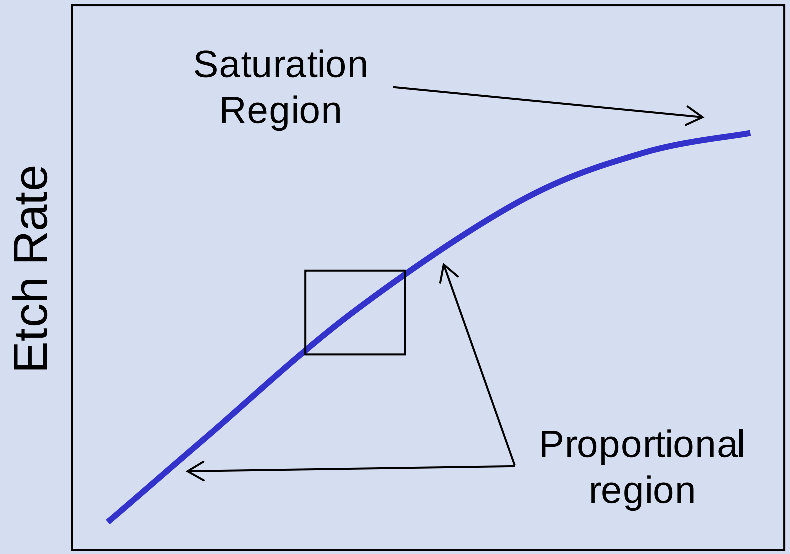
$$\frac{\text{HF Vapor Flow * Pressure}}{\text{Total Gas Flow}}$$

20% increase in HF_{pp} = 40% increase in etch rate when in a controlled regime

Alcohol in the PRIMAXX® VHF Process

- Alcohol is **<u>required</u>** to ionize the HF and activate etching
- Alcohol influences within wafer etch uniformity
- Ethanol vapor pressure most compatible with VHF

Alcohol $_{pp}$
Characteristic



Alcohol $_{pp}$

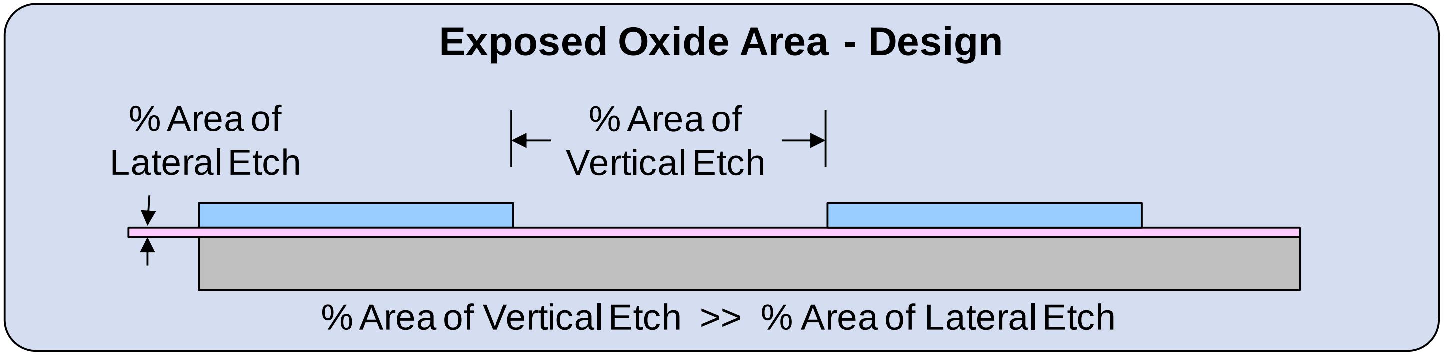
Alcohol Partial Pressure =

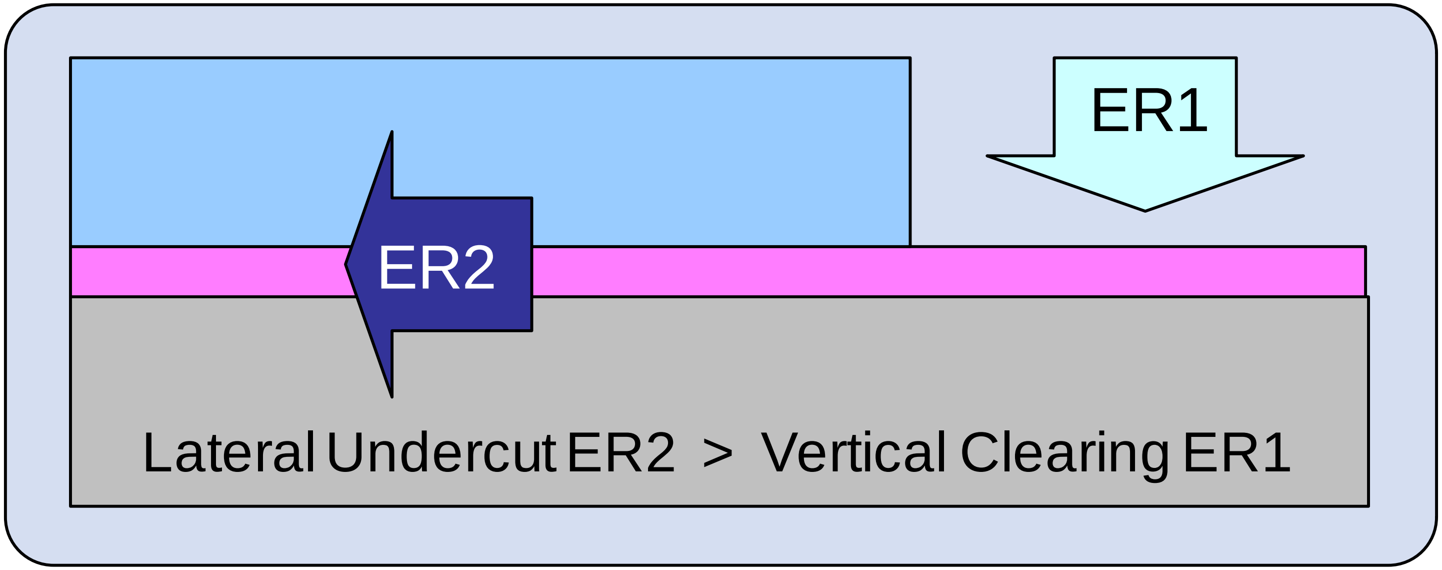
$$\frac{\text{Alcohol Vapor Flow * Pressure}}{\text{Total Gas Flow}}$$

+ 1% Alc$_{pp}$ ~ + 1% etch rate (up to saturation)

Typical Two Step Etch Approach

- Initial oxide loading often high (field oxide, exposed BOX)
- Once etched to handle wafer (ER1), exposed area small



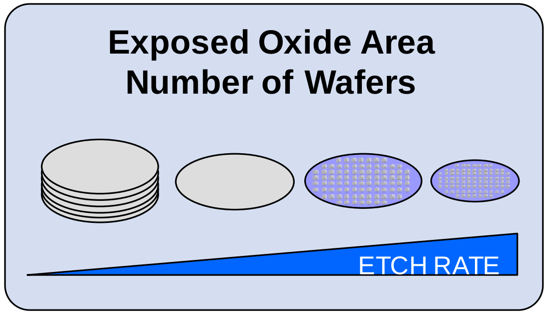


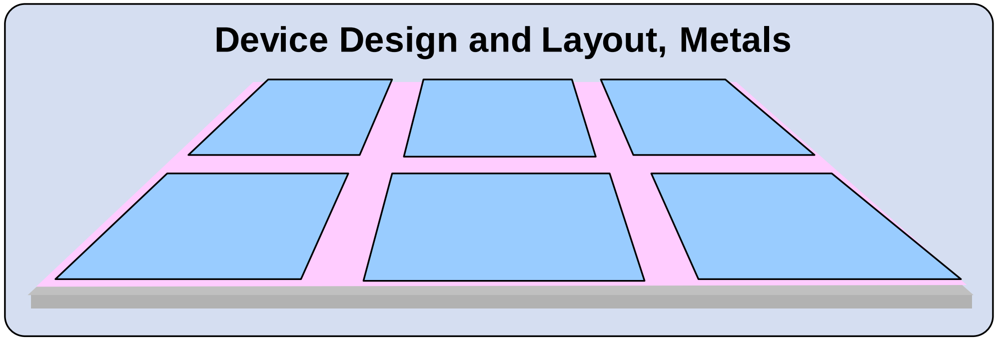
Process Regimes for Two Step Etching

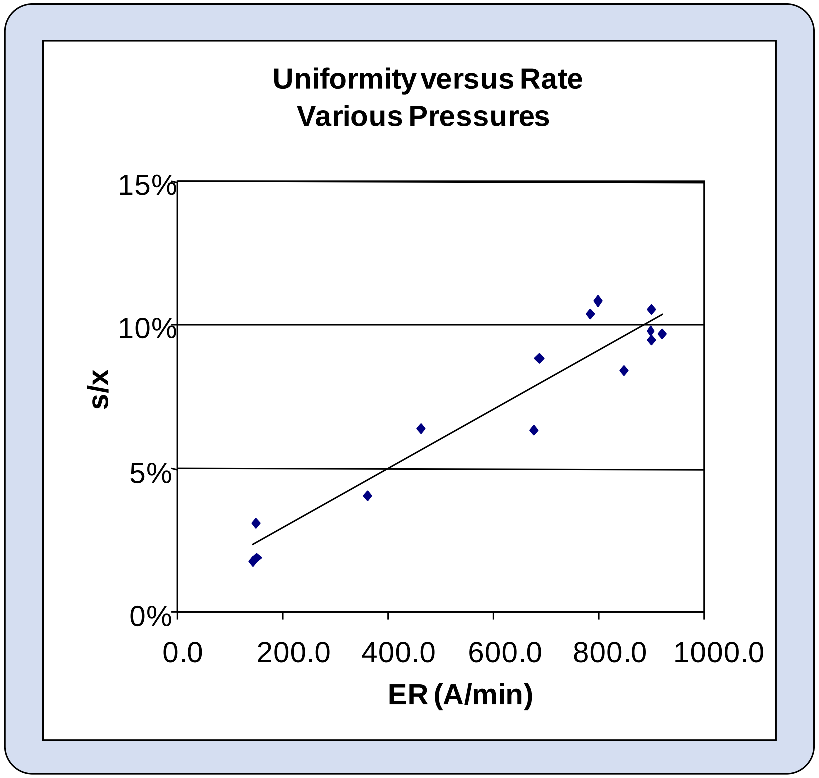
		Clearing Step – ER 1	Undercut Step – ER 2	
Slow	High oxide %	< 350 A/min	< 0.12 um/min	High Stiction Probability
Fast	Low oxide %	300 - 750 A/min	0.15 - 0.25 um/min	Low Stiction Probability

Process Loading Effects

- Amount of exposed oxide is the biggest loading factor
  - Device/wafer layout, # of wafers, presence of back side oxide
- Uniformity degrades with increasing etch rate
- Presence of exposed metals limits maximum etch rates

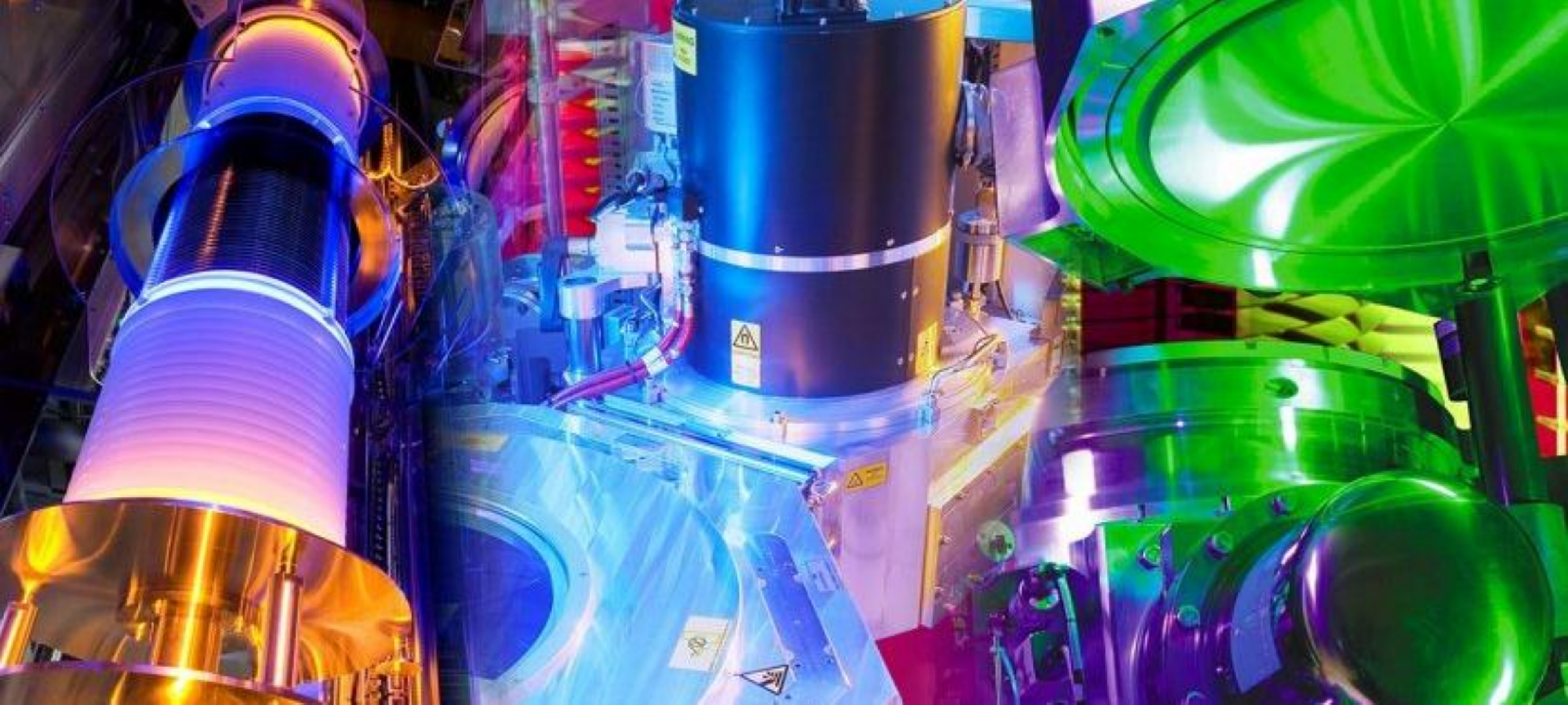






Materials Compatibility with VHF

Material	Sacrificial Oxide	Protective Layer	Metal/Electrode /Adhesion
Thermal Oxide, TEOS	🟢		
SOI bonded oxide	🟢		
Quartz	🟢		
PECVD oxide	🟡		
Spin on oxide	🟡		
Doped oxides BPSG, PSG	🔴		
Doped glass, Pyrex	🔴		
Low temperature spin on glass	🔴		
PECVD oxide (SiH_4 +N_2O)	🔴		
Silicon (poly, amorphous, single crystal)		🟢	
Alumina (thick)		🟢	
ALD alumina (1000A)		🟢	
Aluminum		🟢	🟢
Silicon Carbide		🟢	
Si-Rich LPCVD silicon nitride (low stress)		🟡	
Stoichiometric PECVD nitride		🔴	
Photoresist		🔴	
Gold			🟢
Copper			🟡
Ti			🔴
TiO2			🔴
TiW			🟢
Nickel			🟢

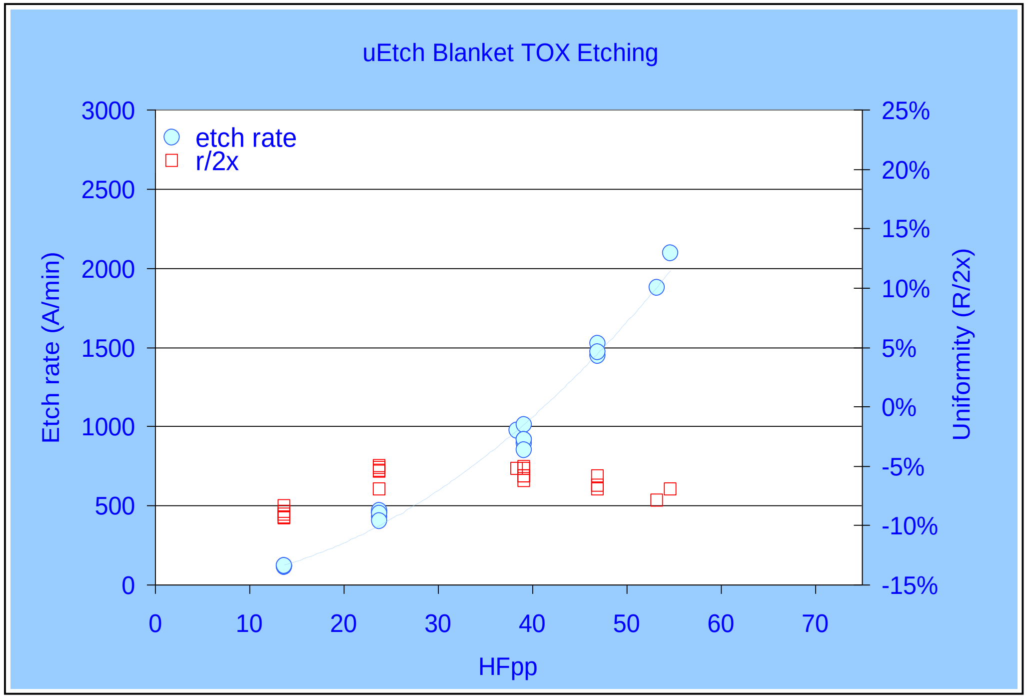


PRIMAXX® VHF Etch Release Technology

Performance – Wafer Processing

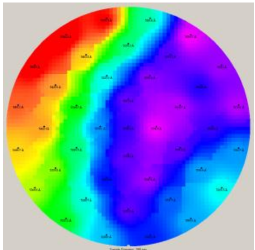
uEtch Performance Specifications

- Processes up to 1 x 200mm wafer per run
  - Or silicon wafer carrier/optional “pocket” carrier for die level
- Etch Specifications (200 mm blanket TOX etching)
  - Etch rate range : 100 A/min - 1000 A/min
  - WIW ≤ 12%, R2R ≤ 15% (r/2x at 100 A/min, ER dependent); device wafer uniformities are typically better



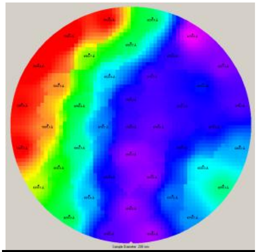
uEtch Results – TOX Wafers

Run 1



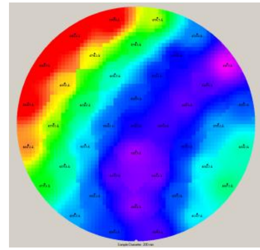
260.76	**average**
7.76	**SD**
-2.98%	**s/x**
26.72685	**range**
-5.12%	**r/2X**

Run 2



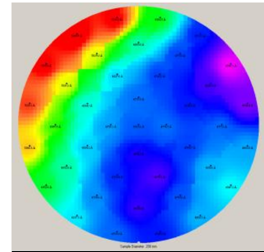
241.54	**average**
6.58	**SD**
-2.72%	**s/x**
22.363	**range**
-4.63%	**r/2X**

Run 3



231.65	**average**
7.57	**SD**
-3.27%	**s/x**
27.52245	**range**
-5.94%	**r/2X**

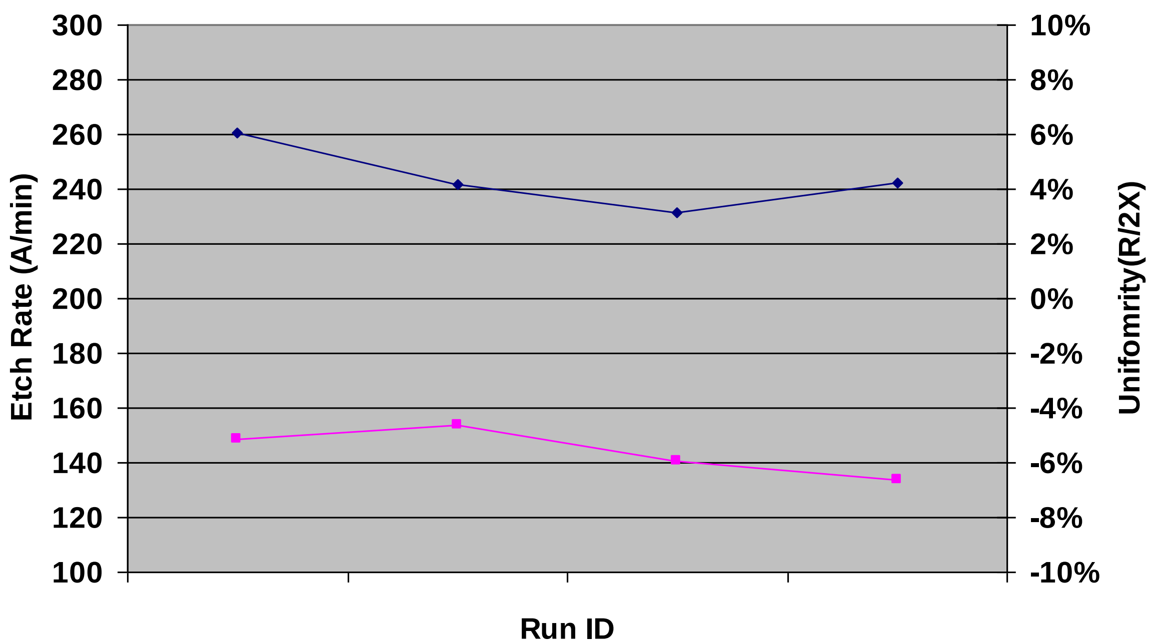
Run 4



242.15	**average**
7.71	**SD**
-3.18%	**s/x**
31.9858	**range**
-6.60%	**r/2X**

R2R statistics

average	244.03
sd	12.152039
s/x	4.98%
r/2x	5.97%



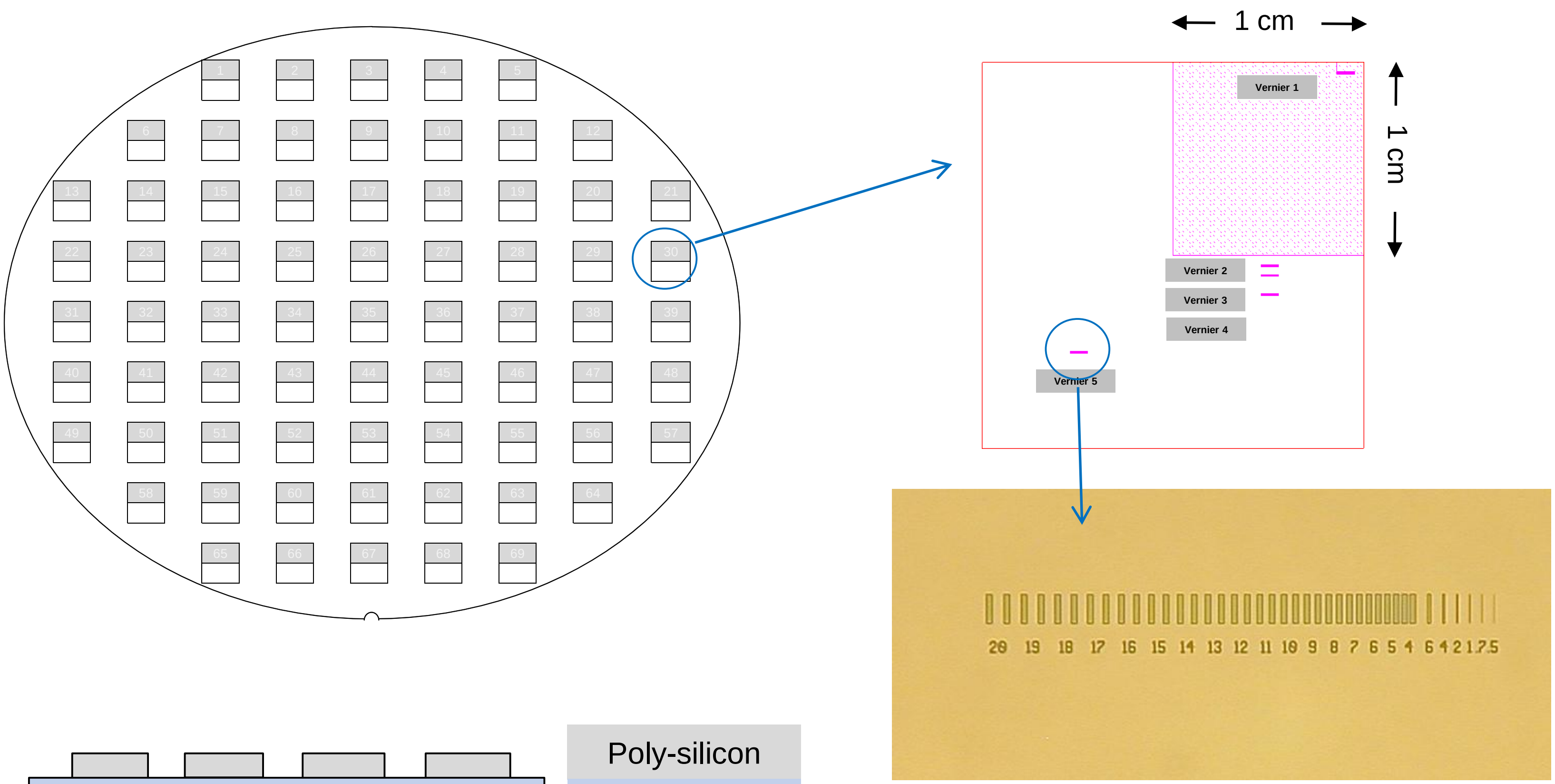
uEtch Patterned Wafers – Methodology

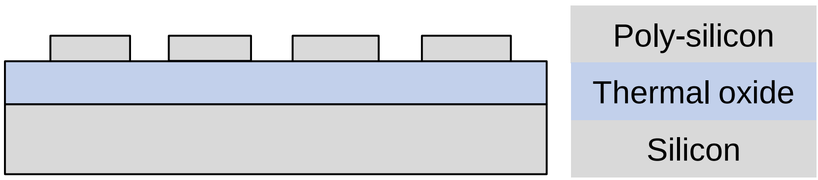
- Use TWO "patterned" test wafers to establish WIW% and R2R repeatability
- Use standard etch methodology:
  - Clearing Step – remove exposed oxide using a slow to moderate etch rate to control uniformity under high loading conditions
  - Undercutting Step – use a higher etch rate since the exposed oxide percentage has been reduced by an order of magnitude
- Etch test on each wafer (FOUR tests total)
  - Etch ~ 50% of exposed vertical thickness of BOX layer ($ER_{CL}1$)
  - Etch remaining exposed oxide, confirm clearing rate ($ER_{CL}2$)
  - Etch laterally (undercut) using higher etch rate ($ER_{UC}1$)
  - Repeat for a second lateral etch ($ER_{UC}2$)

uEtch Patterned Wafers – Description

200 mm wafer – 69 test die with 20% exposed oxide to simulate “typical” MEMS wafer

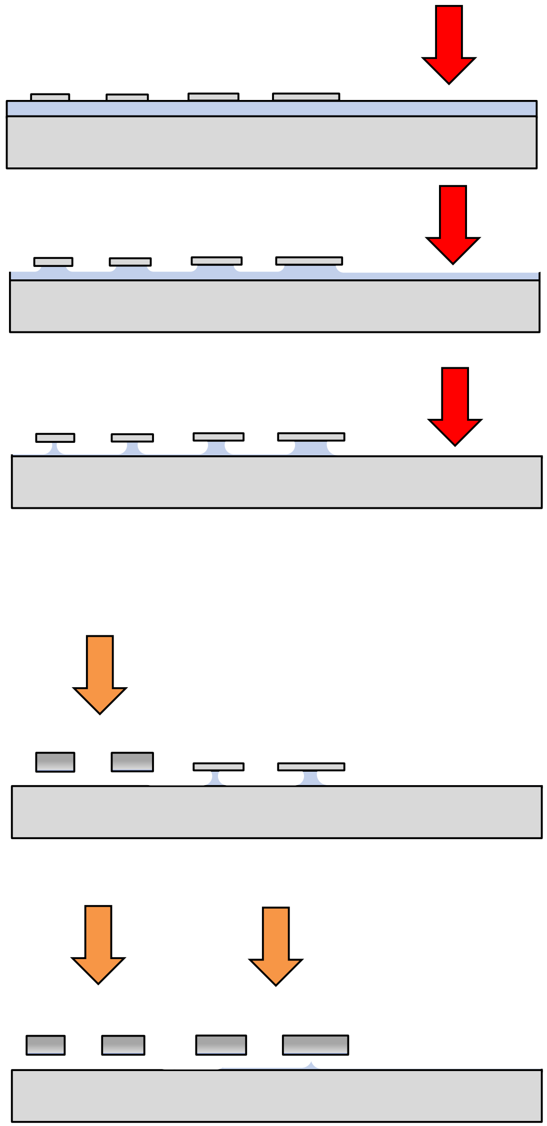
Each die consists of 5 identical test verniers and a 1 cm^2 oxide pad





Each vernier has equispaced trenches with varying separations up to 20 um

uEtch Patterned Wafers – Etch Runs



Pre-measure 69 oxide pads with thickness mapping tool

VHF Run 1

Etch 50% exposed pads and calculate $ER_{CL}1$ with thickness mapping tool

VHF Run 2

Etch to substrate and calculate $ER_{CL}2$ with thickness mapping tool **(NOTE THAT SOME UNDERCUT OCCURS - ISOTROPIC ETCH)**

VHF Run 3

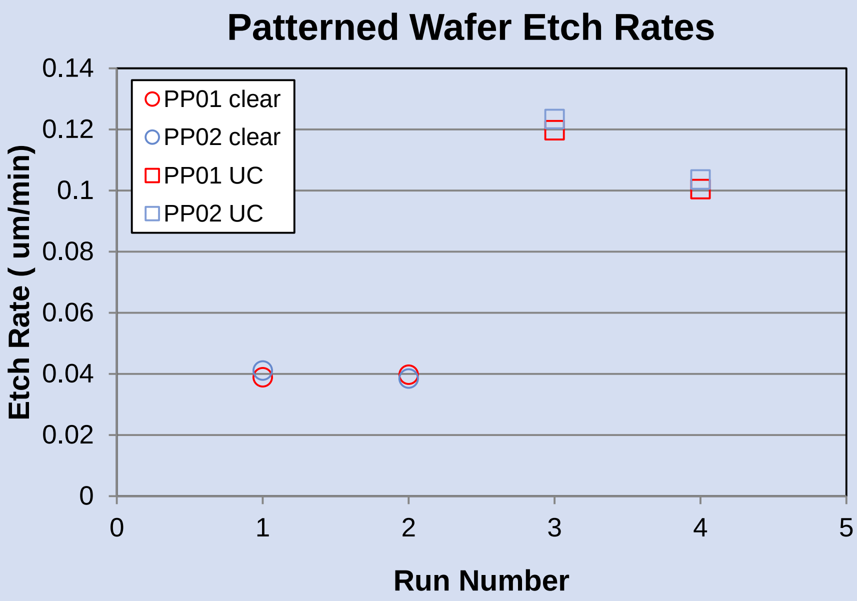
Etch laterally by time and calculate $ER_{UC}1$ with optical inspection of vernier deflection

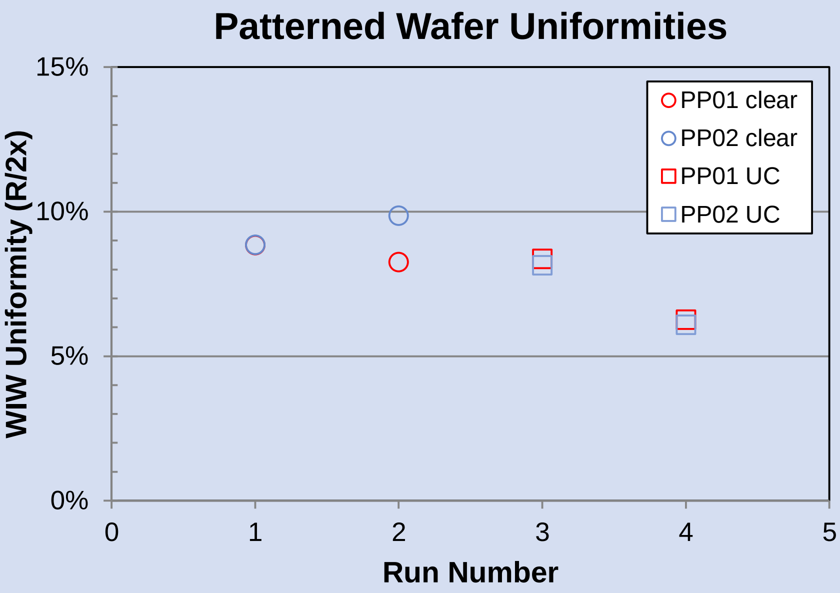
VHF Run 4

Etch laterally by time and calculate $ER_{UC}2$ with optical inspection of vernier deflection

uEtch Patterned Wafers – Data Summary

Sequential chart of Etch Rate and R/2x U % for each step (TWO patterned wafers)

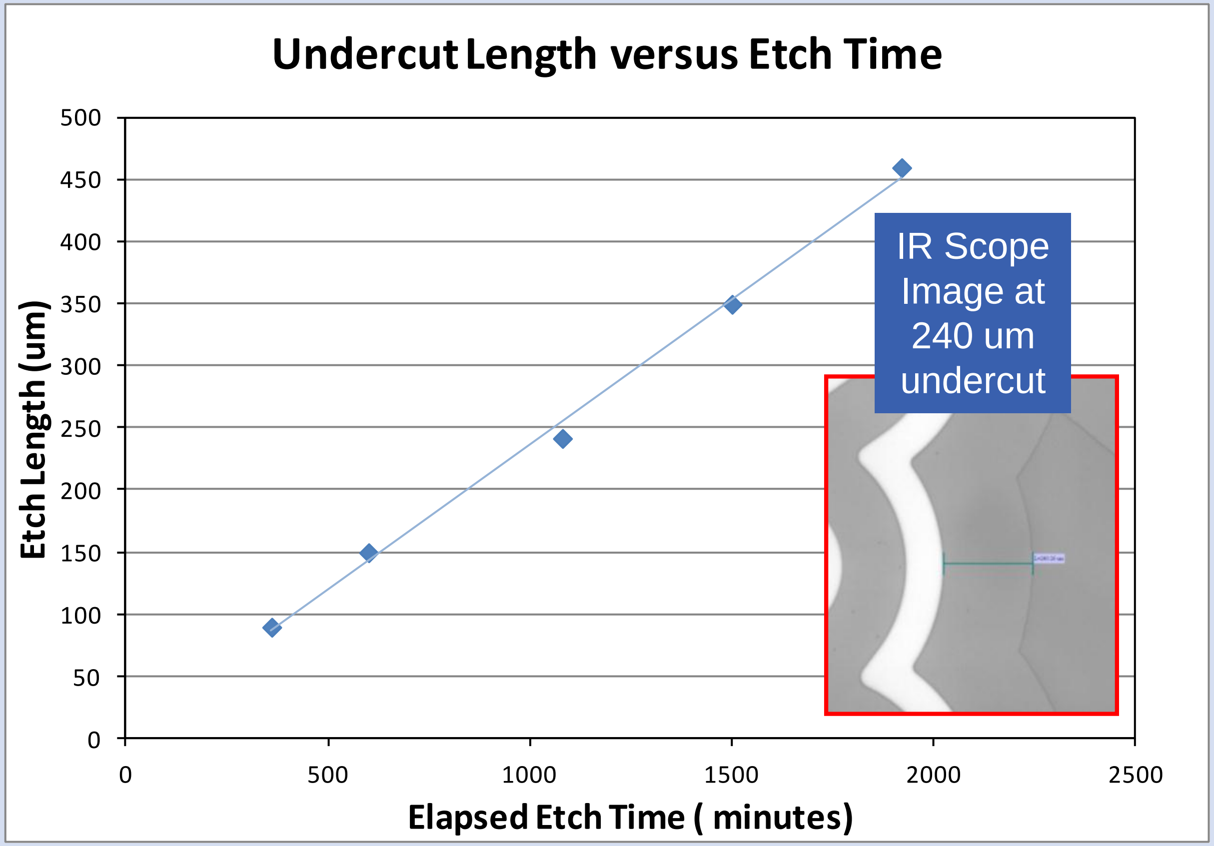




- Total Etch Time = 90 minutes (excludes overhead time)
- Average Total Etch Length = 8.1 um
- Average Etch Rate = 0.090 um/min

Etch Stability – Very Long Undercuts

- SOI based sample, full removal of BOX layer with mm length undercuts



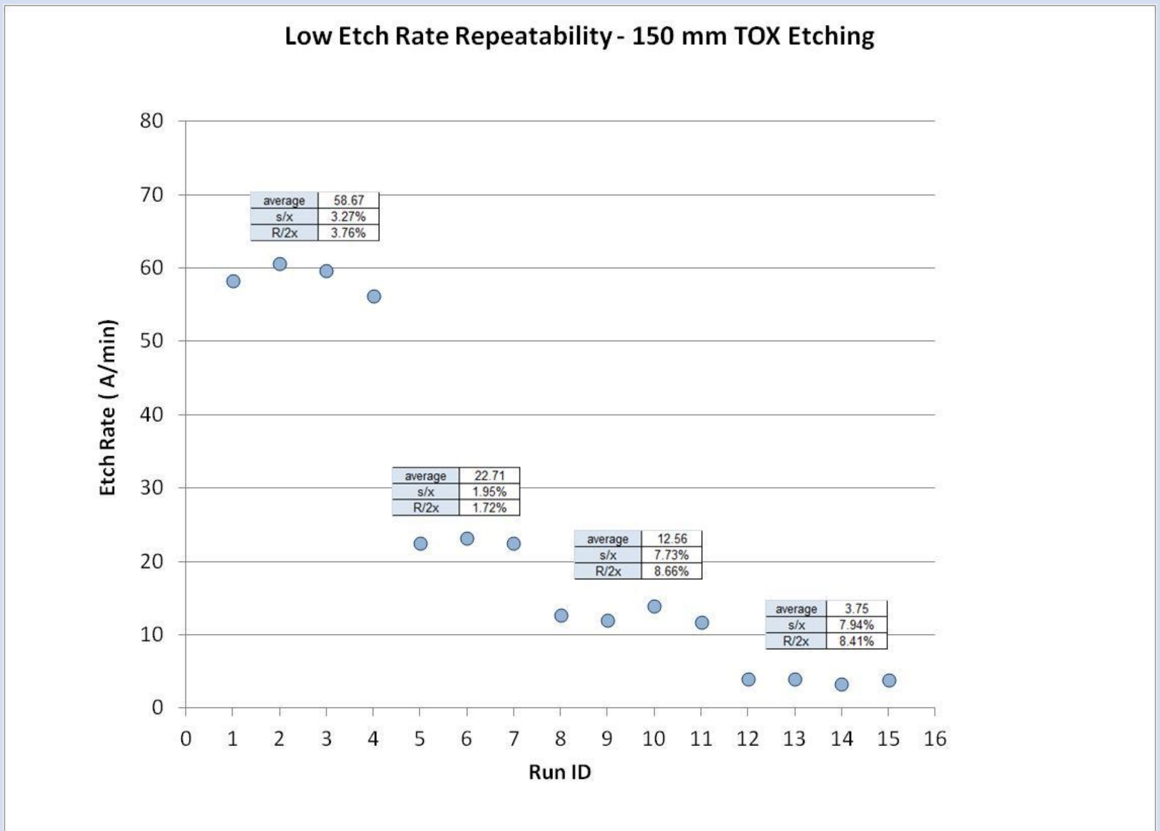
Etch Uniformity

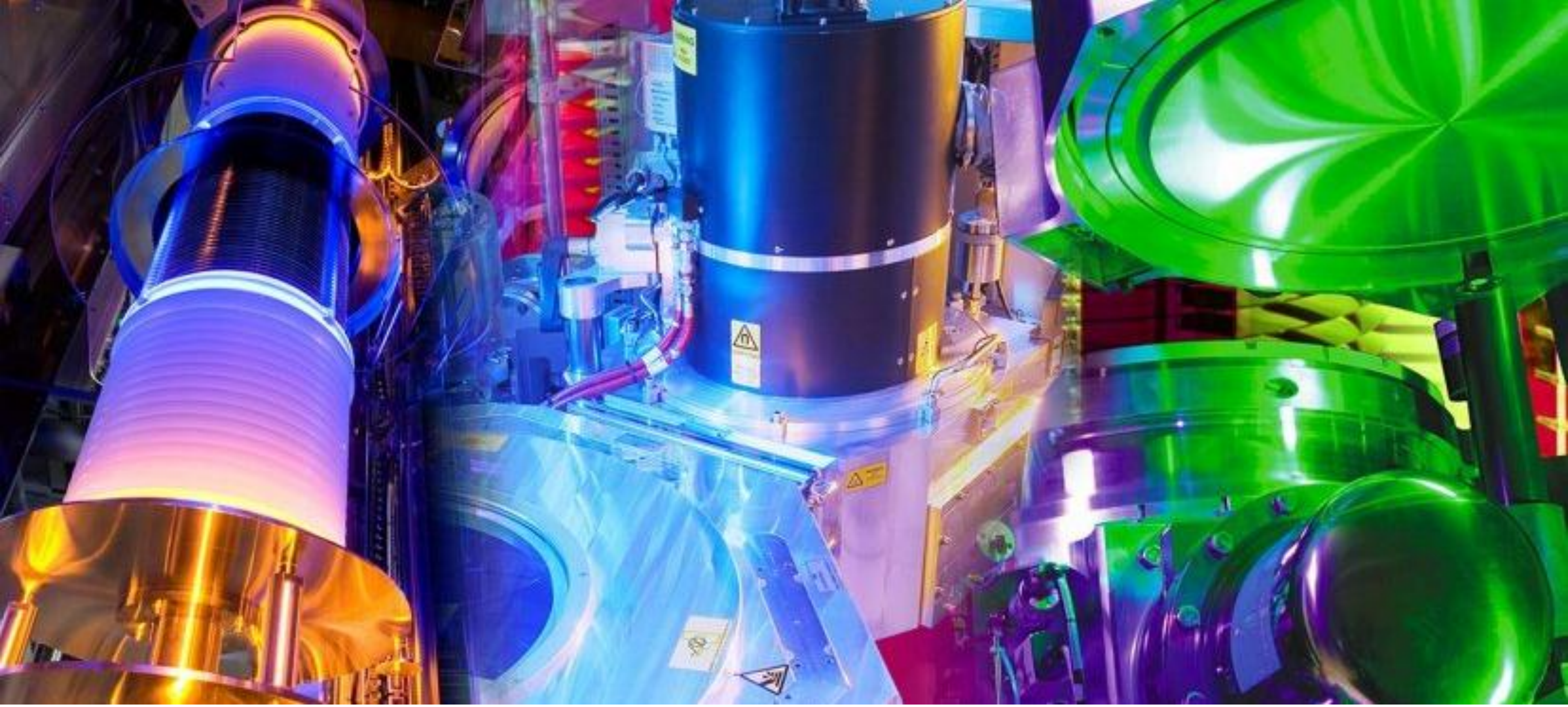
POSITION	UNDERCUT (um)
Top	244
Center	240.1
Bottom	241.2
Left	242.1
Right	241.2
AVERAGE	241.7
WIW% (SD)	0.6%

Devices are cleared at 1080 minutes. Only the frame remains bound.

Etch Stability at Ultra Low Etch Rates

- Controlled, repeatable etching on 150 mm blanket TOX wafers at ultra low etch rates from 60 A/min to 3 A/min



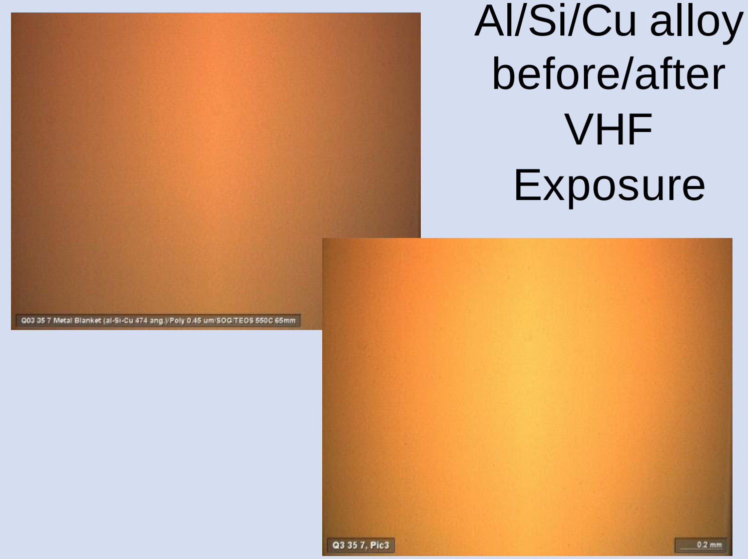


PRIMAXX® VHF Etch Release Technology

Conclusions

Competitive Processes that Use Water

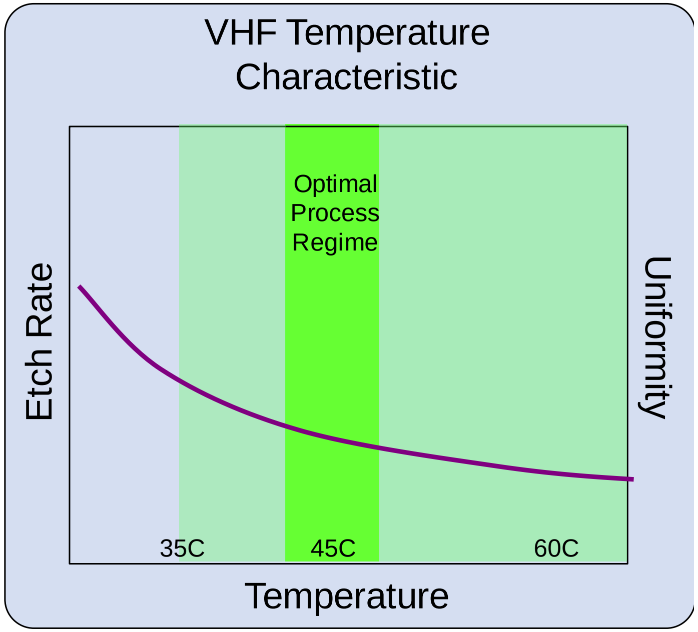
- PRIMAXX® VHF technology with no water added has a significant advantage in terms of corrosion/surface degradation (water is more aggressive)
- Silicon nitride selectivities are similar
- Materials such as Al, Al/Si/Cu and Al_2O_3 typically show **<u>NO</u>** attack at viable production etch rates in the PRIMAXX® VHF process – compared to some limitations in an etch environment with more water present



Al/Si/Cu alloy before/after VHF Exposure

Ambient versus Elevated Temperatures

- Etch rate versus temperature curve has a steep slope at typical ambient temperature – so small changes in T have a very significant effect on etch rate
  - At 35 - 60 C this curve is much flatter (SPTS temperature range)
  - Heated chamber gives within wafer temperature uniformity of +/- 0.2C **AND IS VERY REPEATABLE** giving excellent run to run performance)
- Elevated temperature helps by-product desorption directly into the gas phase
- Silicon nitride selectivity is generally better at lower temperature



Conclusions

- PRIMAXX® VHF
  - Dry, reduced pressure, gas phase oxide etch release process
  - Proven, patented technology eliminates stiction, increases yields
- Compatible with exposed Al/alloy features (mirrors, bond-pads) and common MEMS materials (NO CORROSION)
- Tools have high uptimes and low cost of ownership
  - **NO** consumables, low power , simple routine maintenance
  - HF/alcohol/gases are low cost
- SPTS provides worldwide sales/service coverage
- Product range for R&D through low, medium, high volume production
- 80+ VHF process modules shipped to 60+ customers
- 100's of successful customer demonstrations means VHF "process knowledge base" second to none