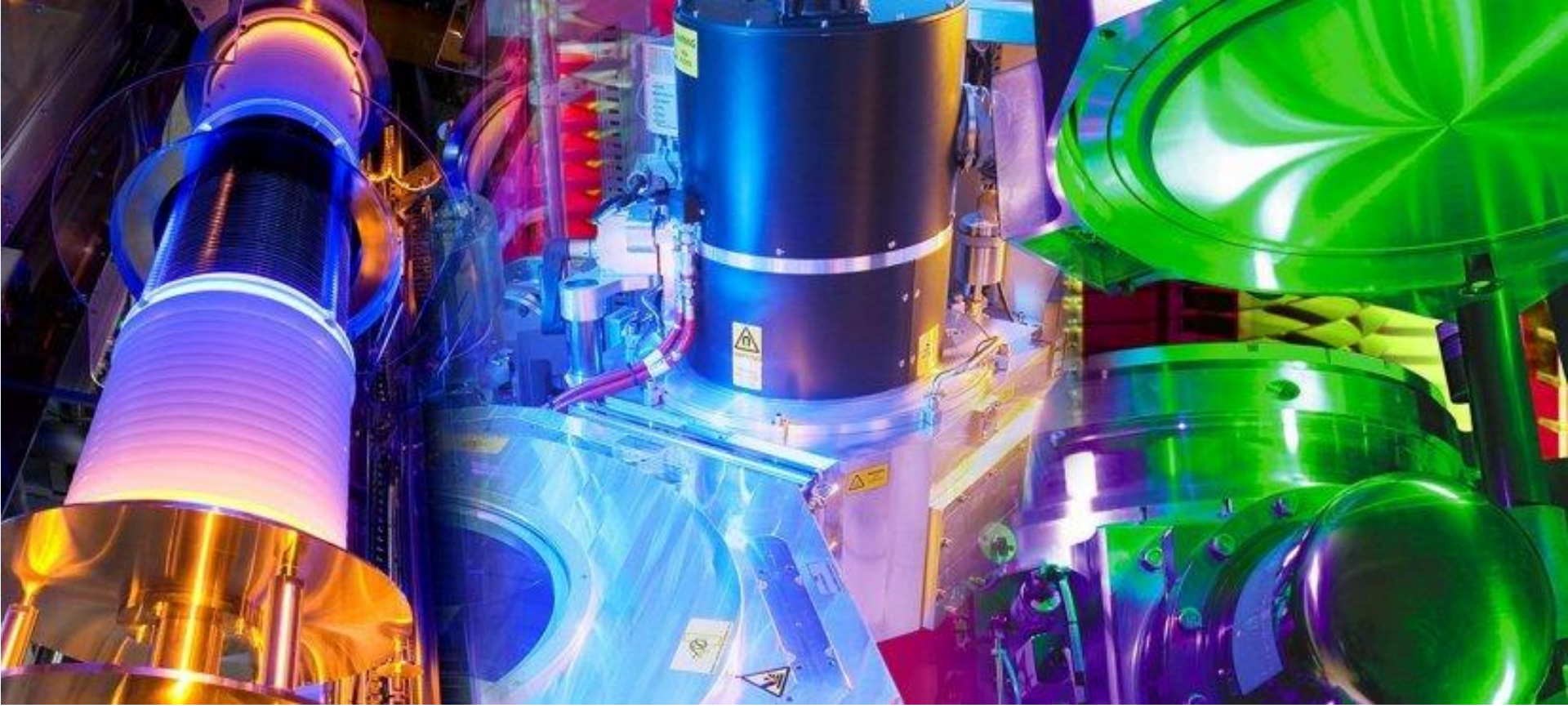


SPTS APS PM Overview Prepared for Customers

August 2013

Contents

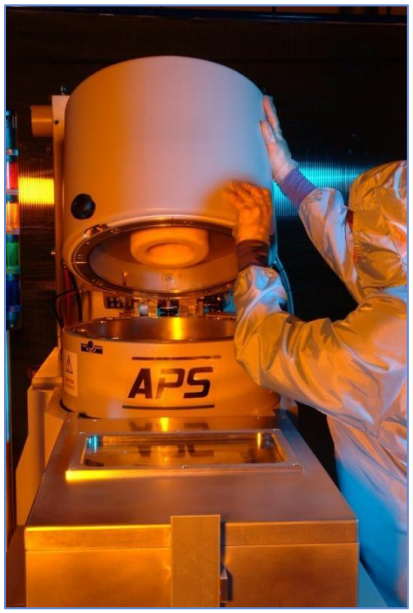
- Details on APS applications
  - Oxide & nitride
  - Deep oxide
  - Glasses
  - Sapphire
  - SiC/GaN
  - PZT/Pt
  - Endpoint Capability
- Summary

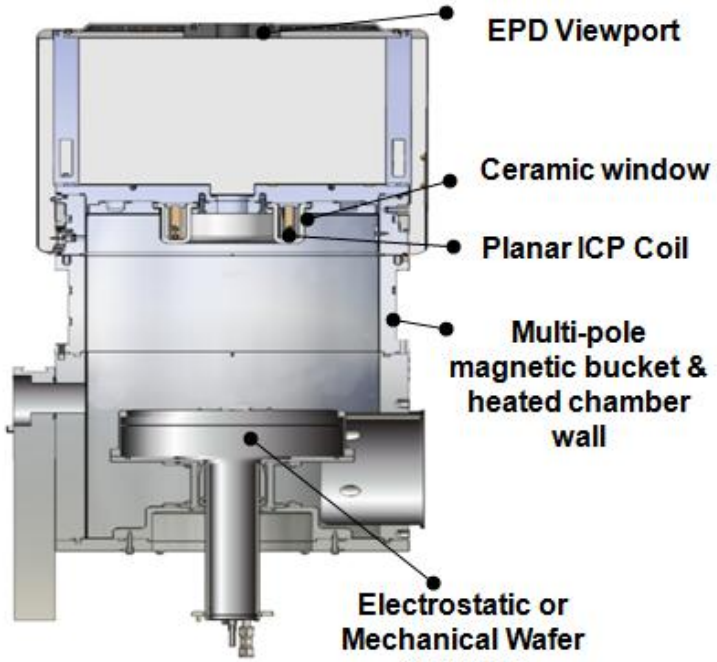
Strongly Bonded Materials & Markets

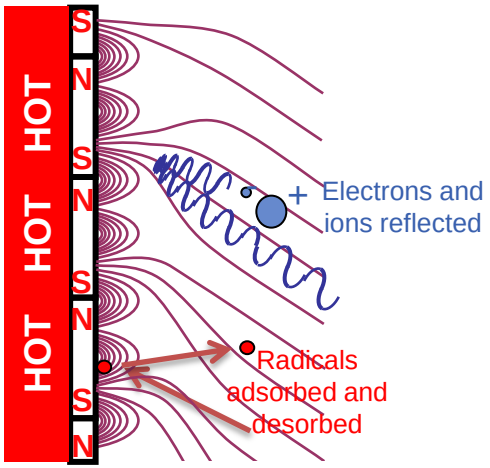
Etched Material	End Market				
	MEMS	**Optical**	**Compound Semi**	**Power Semi**	**Adv Packaging**
Deep oxide		Waveguides			
Glass	Fluidics Biomedical	Waveguides			Through glass vias?
Sapphire			Pre-patterned substrates		
SiC	High temp (engine mgt)		GaN power	FETs	
PZT	Piezoelectric (inkjet)				
$LiNbO_3$		Modulators			

- Requirement to etch strongly bonded materials across multiple end markets

APS Module – Good Fit to Requirements





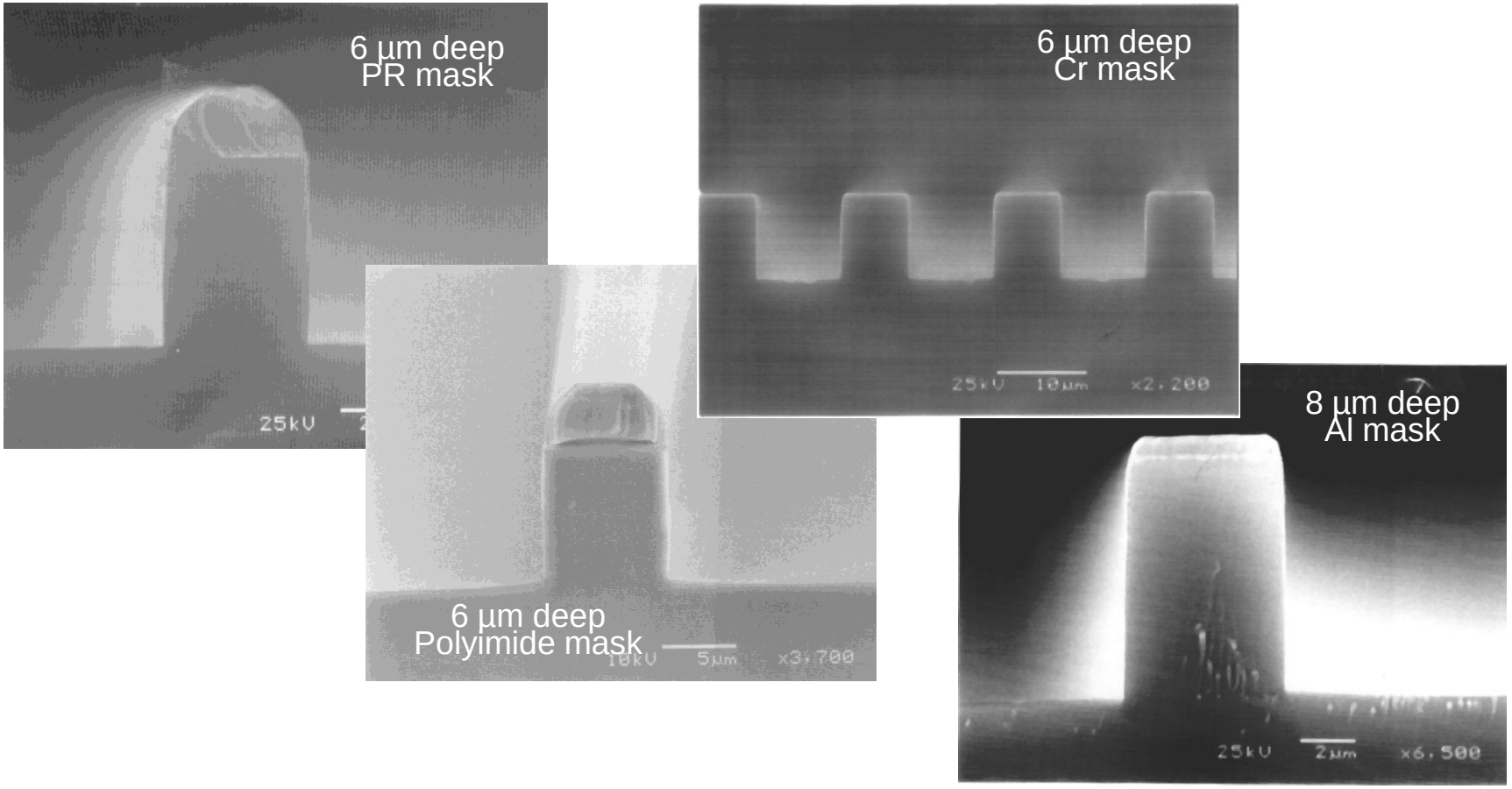


- Magnetic confinement reduces electron & ion losses to walls/lid
- Heated chamber reduces radical losses
- Small, multi-turn planar coil & ceramic
  - Inductively coupled plasma
- Higher ion and radical densities

Best suited to <u>strongly</u> ion driven chemical etching

~100x AOE/APS modules installed

Waveguide Core Etching

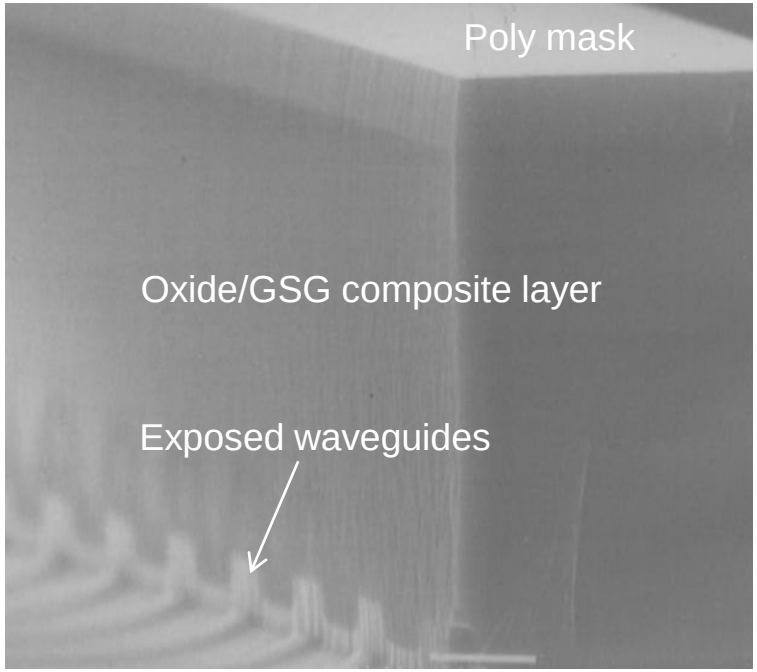


- Typical etch rate 0.3-0.5 µm/min depending on oxide type & doping

Waveguide Termination Etch

- Cladding layer etch

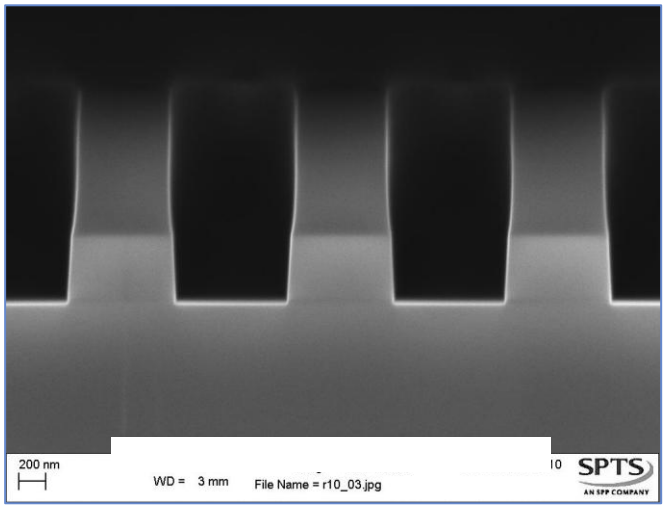
  - 200 mm quartz wafer
  - Poly Si mask
  - Etch depth ~40µm
  - Etch rate 6000 Å/min
  - Profile 90º
  - Selectivity to mask >30:1
  - Uniformity ±4%

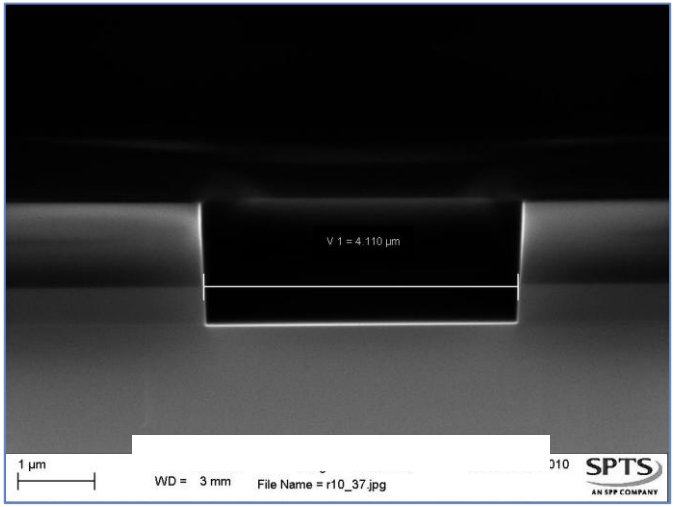


Deep Oxide Etching Challenges

- Range in etch depths depends on end market
  - ~6µm for waveguide cores
  - 10's of µm for waveguide termination (cladding etch)
  - 100's of µm for lenses & through wafer applications
- 3 types of mask used
  - PR – lowest selectivity, limited on depth
  - Si (amorphous or poly) – medium selectivity, deeper etches
  - Metals (Al, Cr, Ni) – highest selectivity, for deep etching and HAR
- Glass etching behaviour depends on glass type
- Pure quartz & fused silica etch like thermal oxide
  - Smooth etching, lower bias powers
- Pyrex contains impurities – B, Na, Al, Fe, Ca, Mg ..
  - Rougher surfaces, higher bias powers
- SPTS has large install base
  - >40x Etch PMs for waveguide & related applications

Silicon Oxide Etch

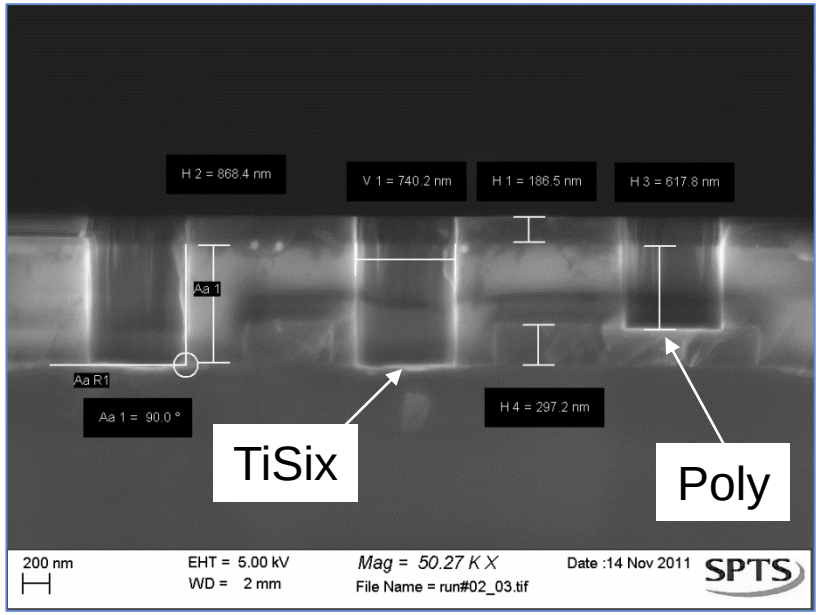




- Etch depth 0.5 µm
- Etch rate 0.3 µm/min
- Uniformity <±4%
- S_{PR} ~4:1
- S_{Si} ~14:1
- Profile ~80-88°
  - Feature dependant

Oxide Contact Etching

- ~0.7µm diameter x 0.87µm deep contact etch

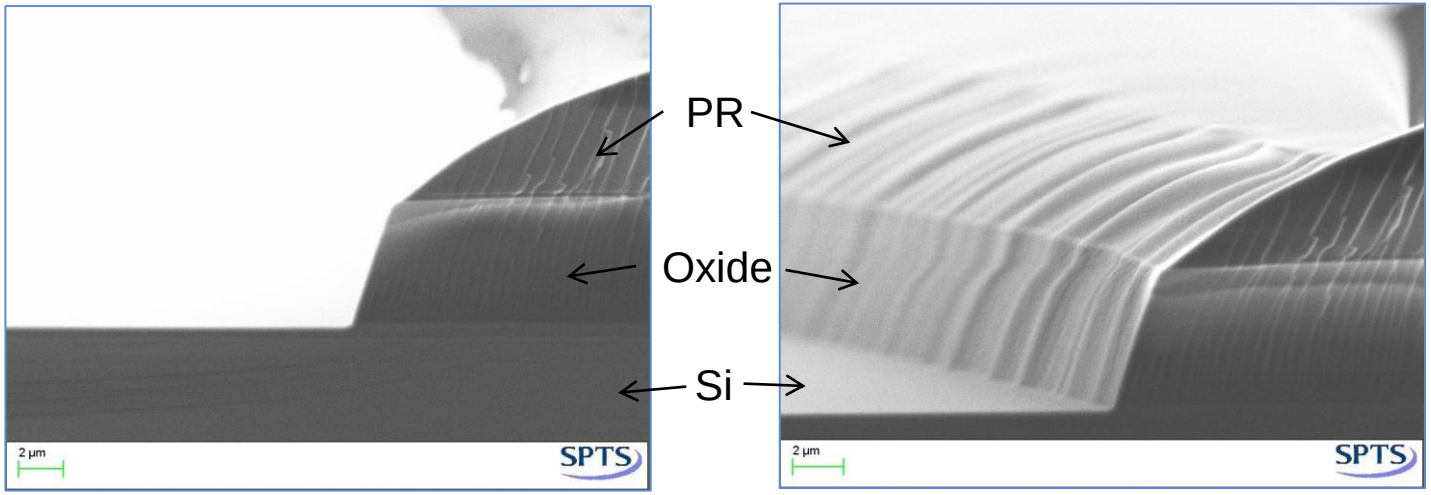


- C_4F_8/He/H_2 chemistry
- Etch rate 0.33µm/min
- S_{PR} ~3:1
- S_{Poly} >10:1
- S_{TiSix} >8:1
- Profile ~90°

1.6µm PR
TEOS/BPSG stack
Poly & TiSix stop layers
<1% open area
150mm Si wafer

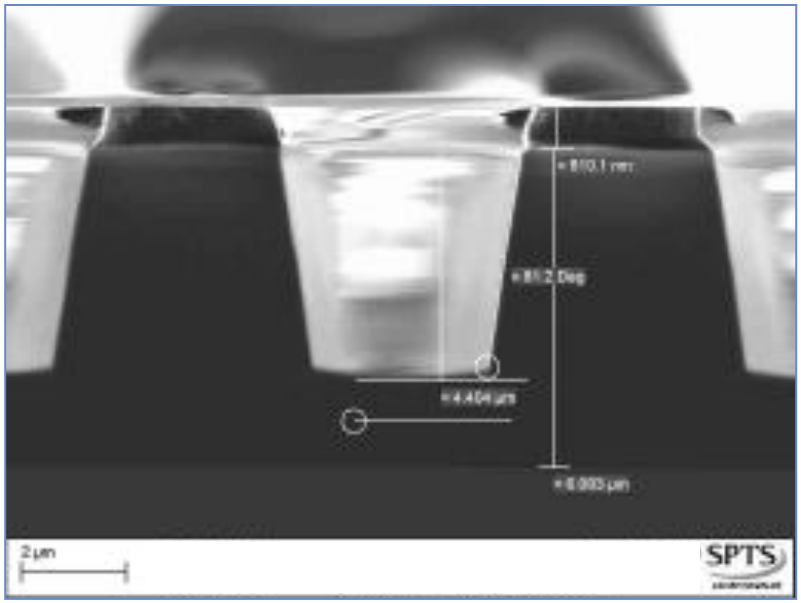
Tapered Oxide Contact Etching

PR mask
5µm silicon oxide
Si wafer



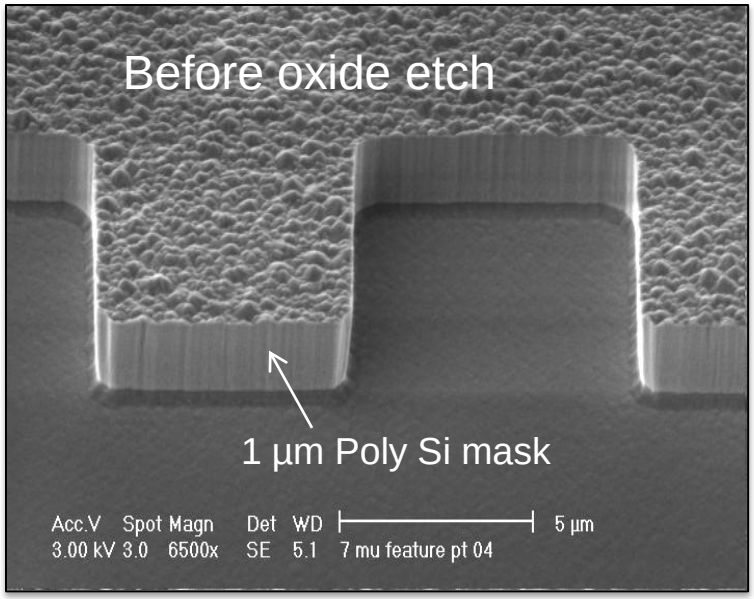
- Etch rate 0.65µm/min
- Uniformity ±3-4%
- Profile ~69°
- S_{PR} ~1.5:1
- Si loss <0.5µm

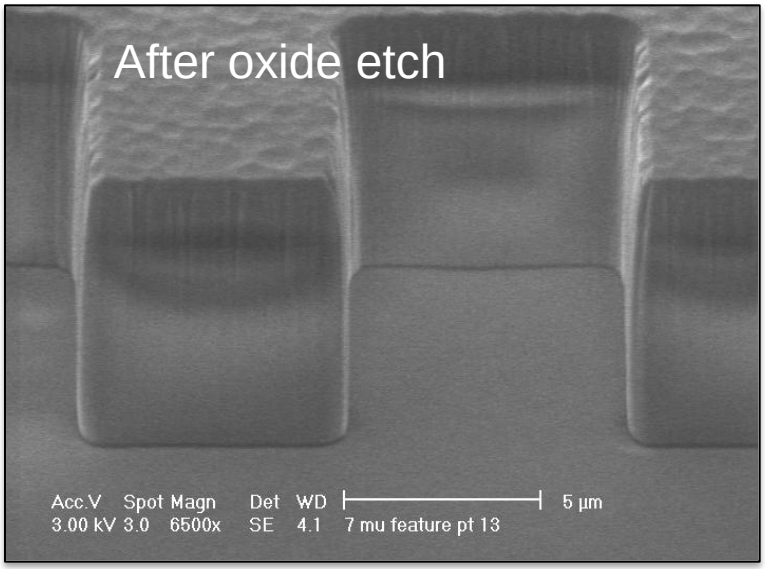
Silicon Oxide Etch



- Etch depth 4.3 µm
  - Partial etch
- Etch rate 0.53 µm/min
- Uniformity <±3%
- S_{PR} ~2.7:1
- Profile ~80°
  - Mask dependant

Silicon Oxide Etch

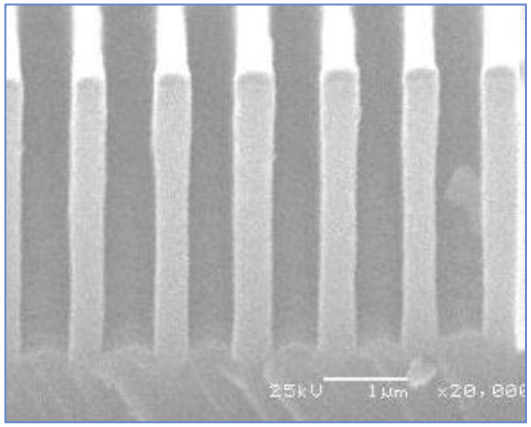




- Etch depth 7µm
- Etch rate 0.54 µm/min
- Uniformity ±1%

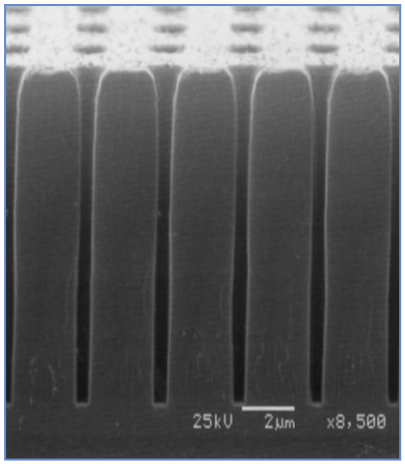
Sub-Micron HAR Oxide Etching

Metal mask
0.5µm features
3.5µm deep
~7:1 AR



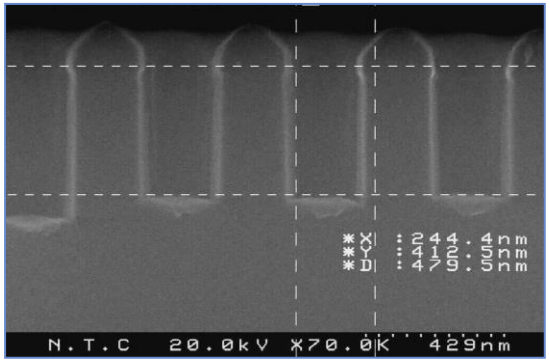
- Etch rate 0.5µm/min
- Selectivity >50:1
- Profile 89-90°

Metal mask
0.6µm features
12.0µm deep
~20:1



- Etch rate 0.28µm/min
- Selectivity >50:1
- Profile 89-90°

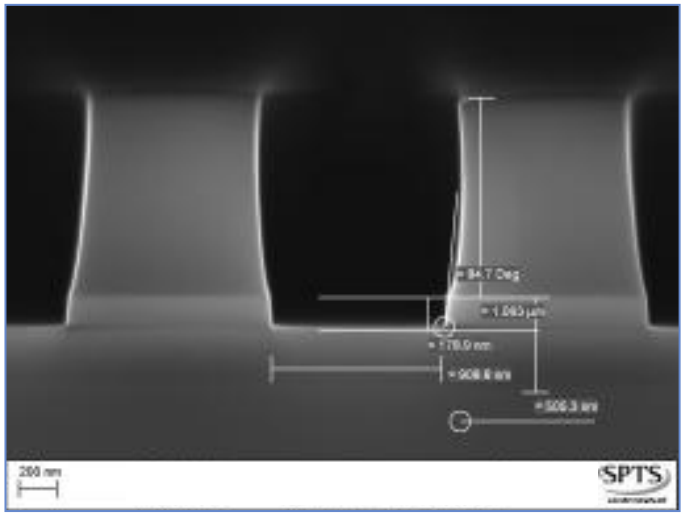
Si mask
0.24µm features
0.5µm deep

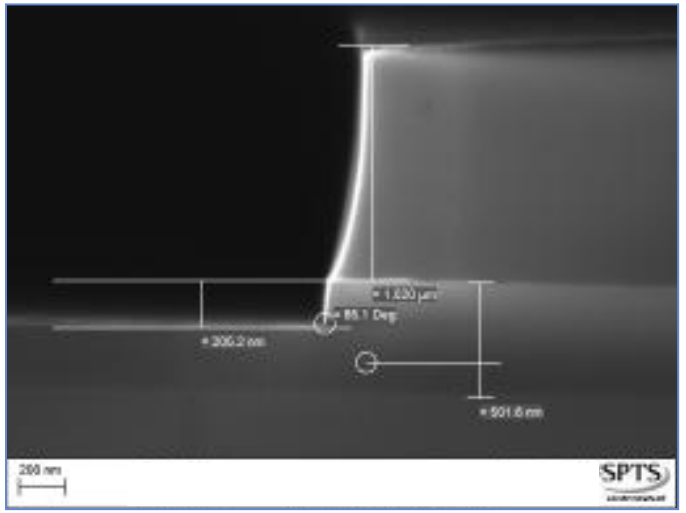


- Etch rate 0.3µm/min
- Selectivity >5:1
- Profile 86°

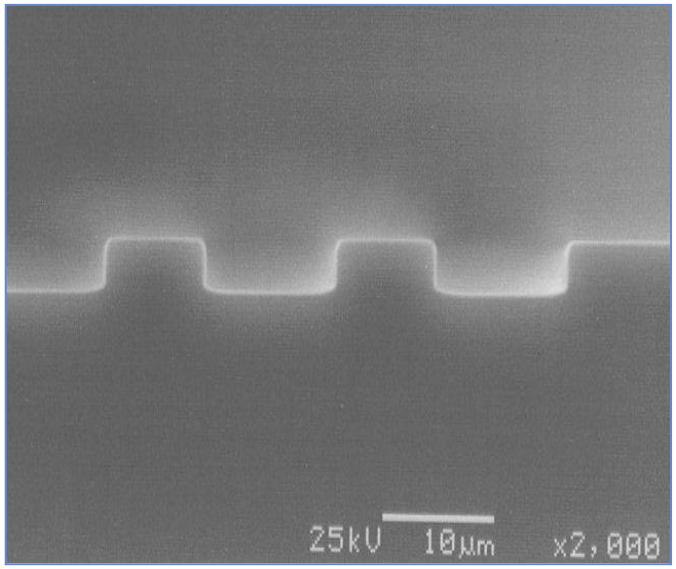
Silicon Nitride Etch

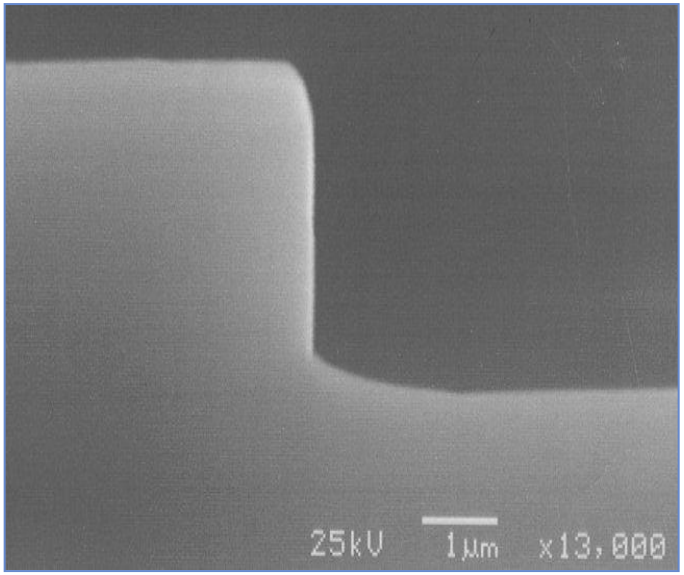
- Etch depth 0.2 µm
  - Partial etch
- Etch rate 0.35 µm/min
- Uniformity <±3%
- S_{PR} ~2.9:1
- Profile ~84°
  - Mask dependant





Silicon Nitride Etch

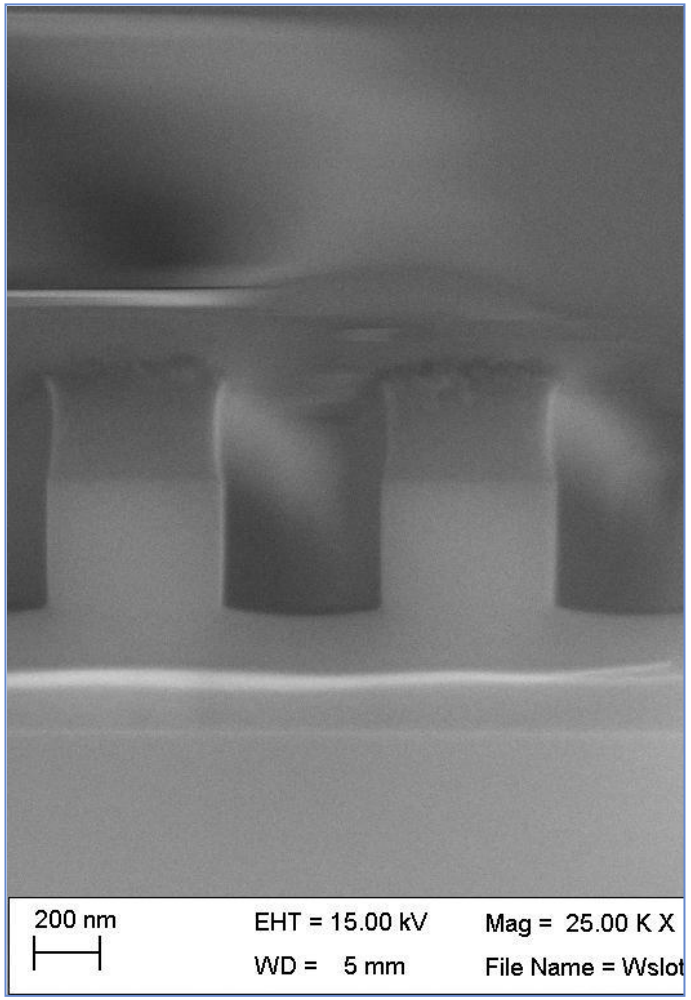




- PR mask
- Etch depth ~2.5 µm
- Etch rate ~0.5 µm/min
- S_{PR} >3:1
- Uniformity <±3%
- Profile ~89°

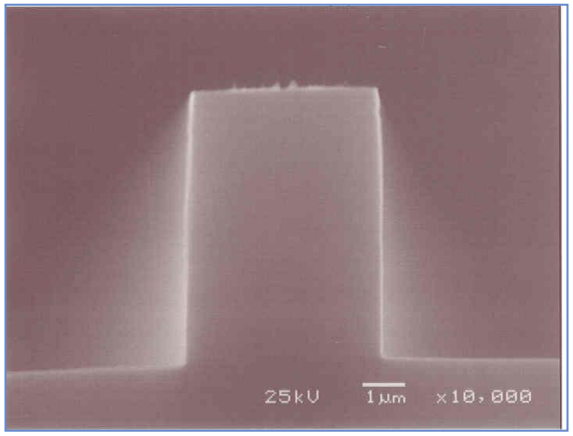
Sub-Micron Silicon Nitride Etch

- 500nm features
- PR mask
- Etch rate ~0.42 µm/min
- S_{PR} 1.3:1
- Profile angle 90.5°

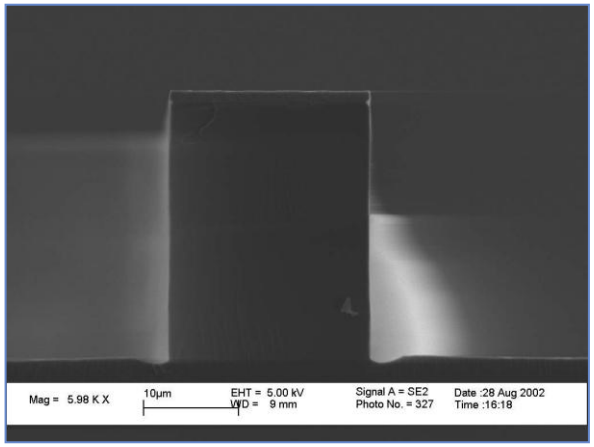


Quartz Glass Etching

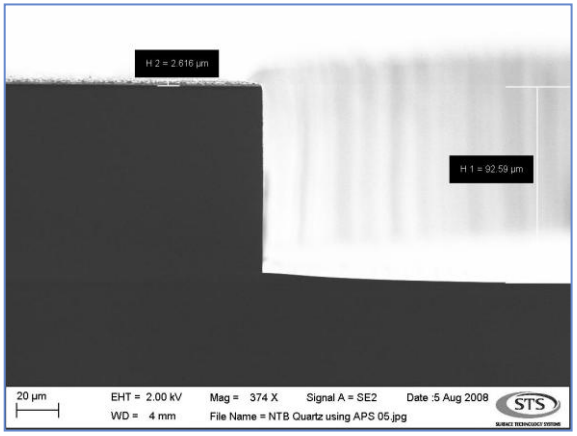
- Depth, etch rate & selectivity depend on mask type



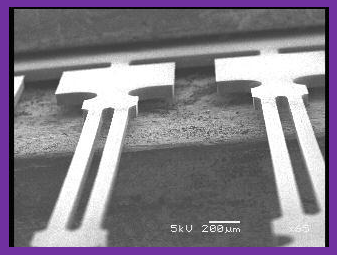
PR mask
Etch depth ~8µm
Etch rate ~0.29µm/min
Profile ~89°
S_{PR} ~5:1

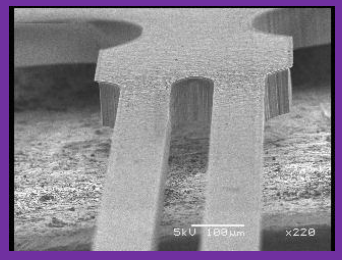


Si mask
Etch depth ~20µm
Etch rate ~0.49µm/min
Profile ~89.8°
S_{Si} ~18:1



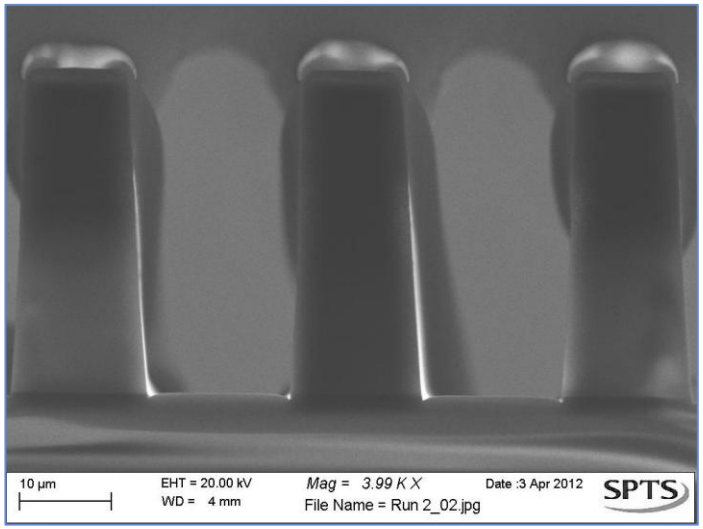
Al mask
Etch depth ~90µm
Etch rate ~0.60µm/min
Profile ~90.5°
S_{Al} ~40:1



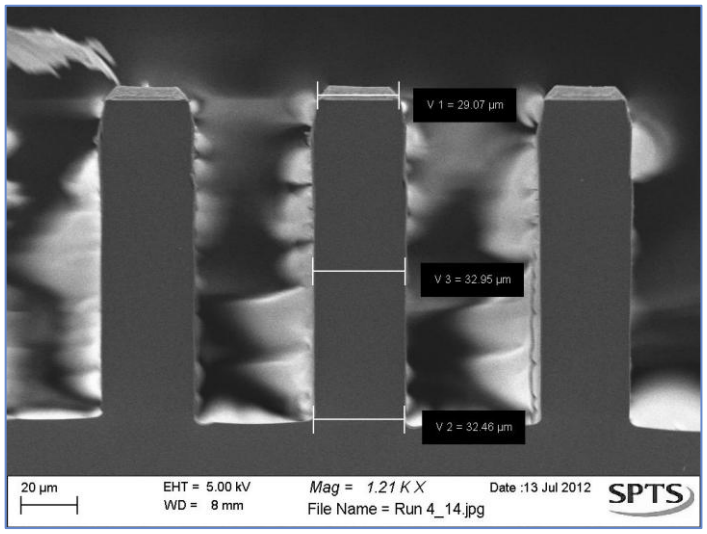


Quartz tuning forks
Ti/Ni/Au mask
Etch depth ~80µm
Etch rate ~0.32µm/min
Profile ~91.5°

Fused Silica Glass Etching



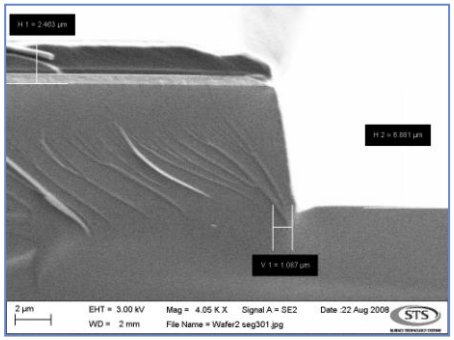
20µm trenches
Al mask
Etch depth ~37µm
Etch rate ~0.58µm/min
Profile ~85°
S_{Al} ~27:1



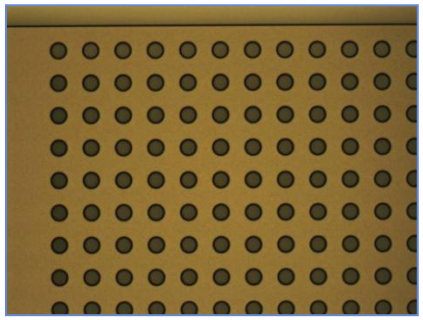
40µm trenches
Ni mask
Etch depth ~100µm
Etch rate ~0.64µm/min
Profile ~88.8°
S_{Ni} ~15:1

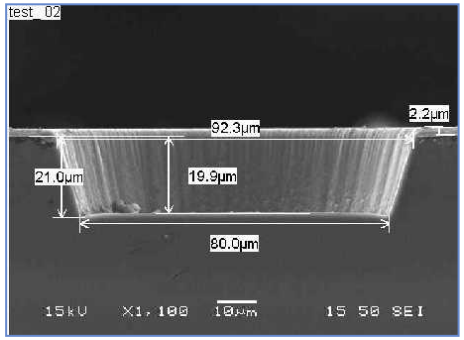
Pyrex Glass Etching

- Depth, etch rate & selectivity depend on mask type

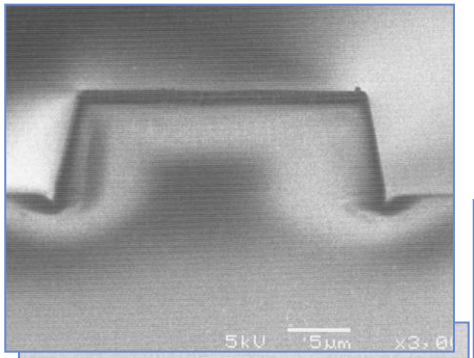


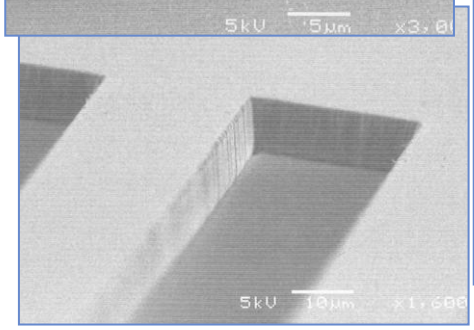
4 µm SU8 PR mask
Etch depth ~7µm
Etch rate ~0.34µm/min
Profile ~81°
S_{SU8PR} ~4.7:1



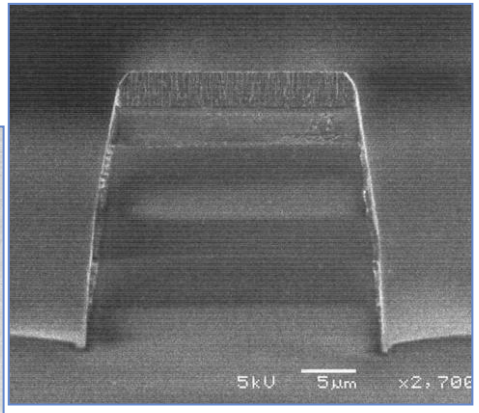


4µm Al mask
Etch depth ~20µm
Etch rate ~0.65µm/min
Profile ~73.0°
S_{Al} ~11:1



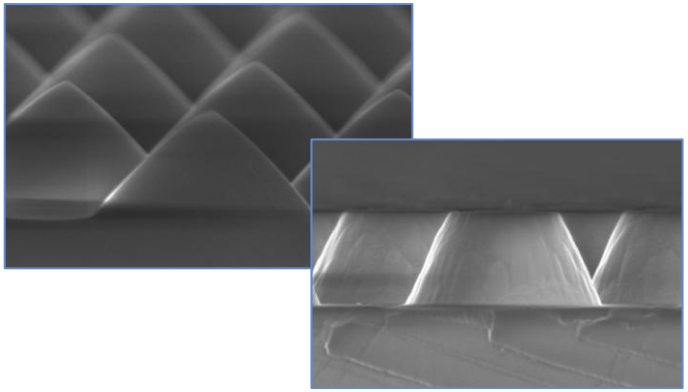


1.5µm Cr mask
Etch depth ~6µm
Etch rate ~0.80µm/min
Profile ~80.0°
S_{Cr} ~19:1

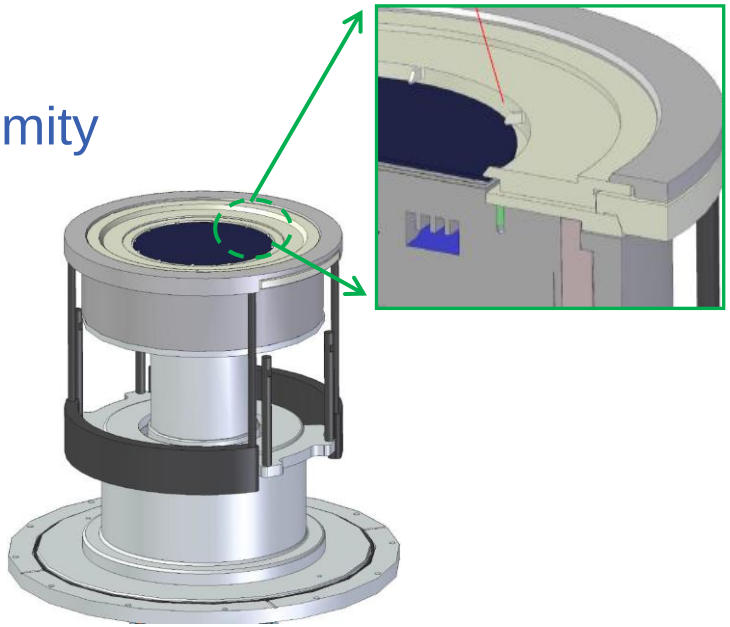


4µm Cr mask
Etch depth ~20µm
Etch rate ~1.4µm/min
Profile ~83.0°
S_{Cr} ~20:1

Pre-patterning Sapphire for LEDs

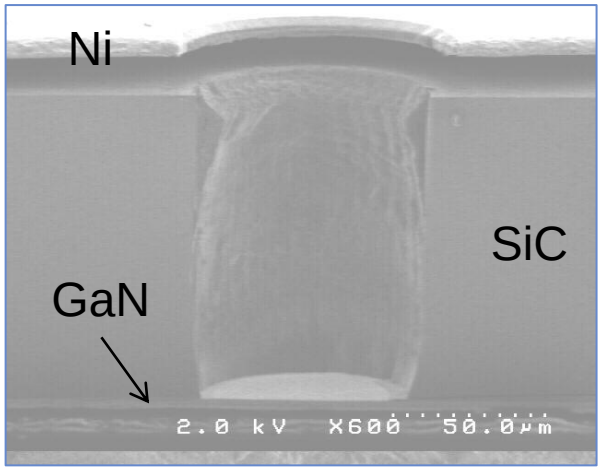


- Pre-forming features in sapphire
  - Improves GaN dislocations
  - Increases light efficiency by reflection
- Wet etching is crystallographic
  - Doesn't offer shape flexibility
- Dry etching requires mechanical clamping (combo with ESC)
  - Minimal wafer overlay for best uniformity
- Etch rate ~150 nm/min
- Profile ~55°
- S_{PR} ~0.3-0.7:1 (controls shape)
  - Peaked or flat topped cones
- Smooth sidewalls

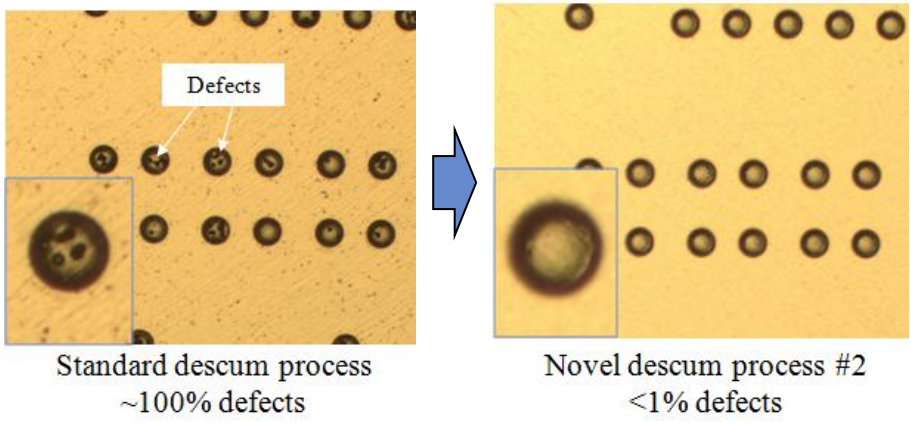


SiC Via Etching for GaN Power

- Compound Semi Fab activity
  - High power from wide band-gap materials
- A challenging application
- Issues wrt clamping & cleanliness
  - Mechanical clamping preferred
  - Low volatility of etch by-products
  - Bonded wafer temperature
- Industry leading capability
  - Proprietary descum minimises pillar defects
  - Etch rate ~1.3µm/min
  - Selectivity to Ni mask ~35:1
  - Profile ≤90°
  - Wafer temp <116°C



80 x 100µm Via

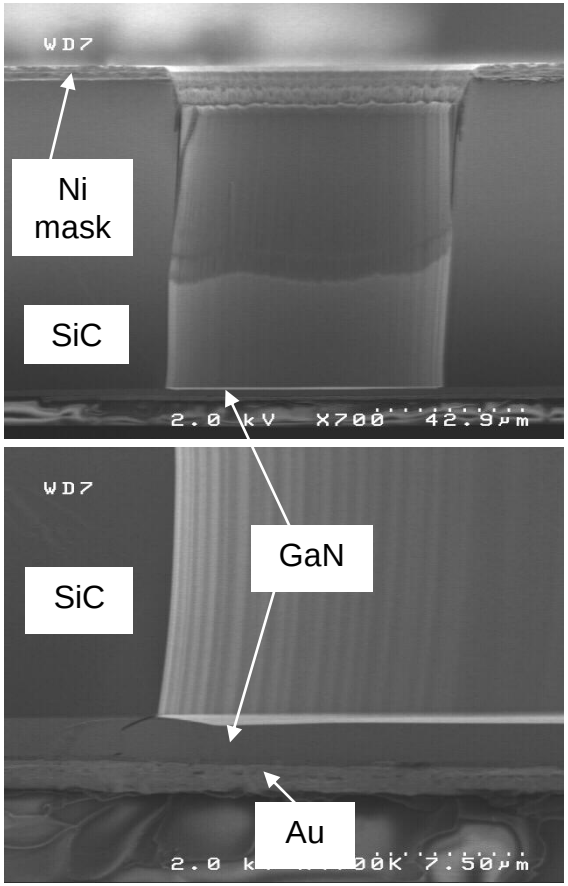


Standard descum process
~100% defects

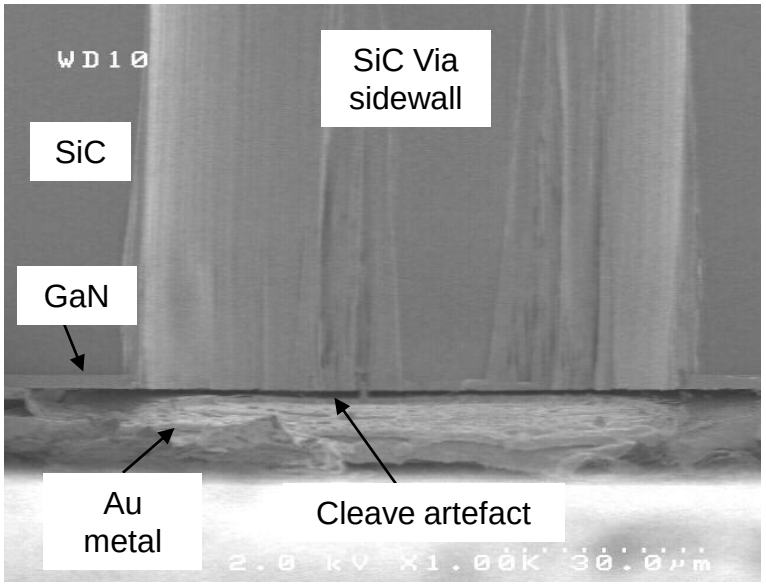
Novel descum process #2
<1% defects

GaN Etch at Via Base

- 100µm deep SiC via etched to GaN stop layer
  - GaN loss <0.35µm

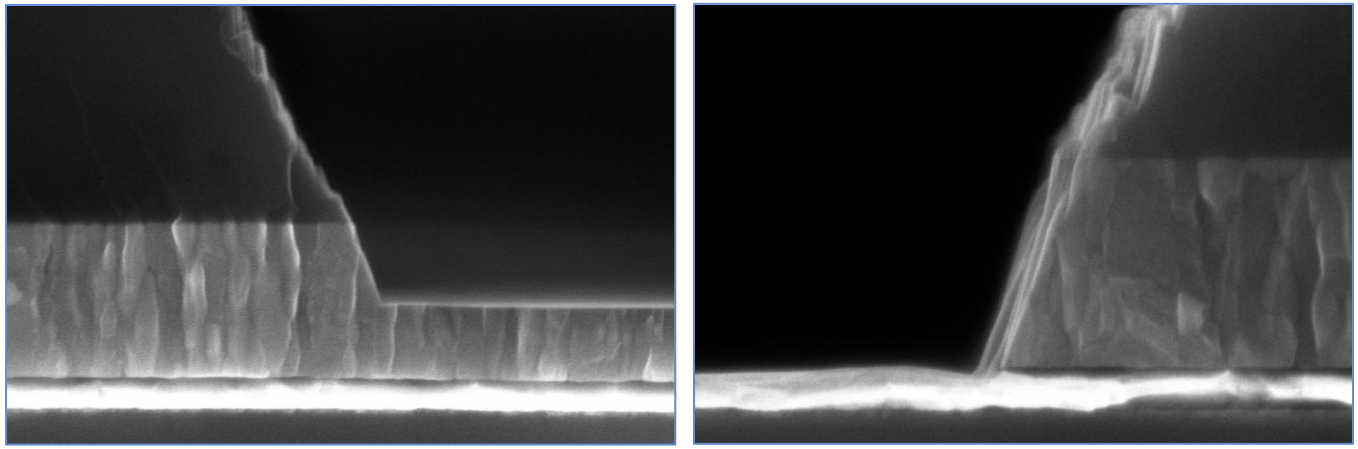


- Base of SiC via after GaN etching



- GaN etch rate ~0.49µm/min
- Profile <90°
- Metal loss <0.6µm

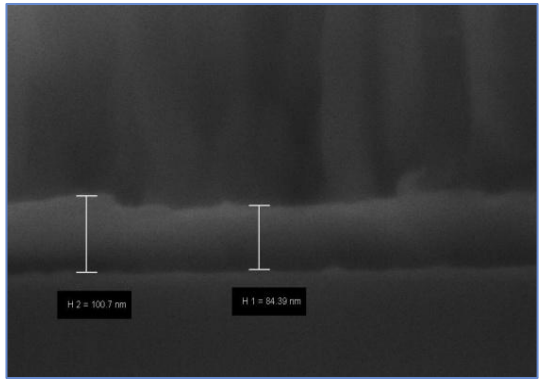
PZT Etch – Single Step Process



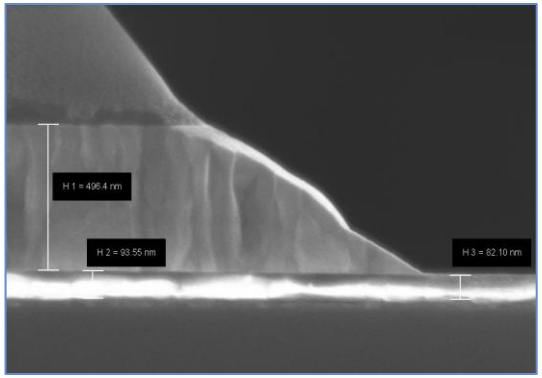
- Etch depth 0.5µm
- Etch rate 0.18µm/min
- S_{PR} ~1.2:1
- S_{Pt} ~1:1
- Profile ~70°

PZT Etch – 2 Step Process

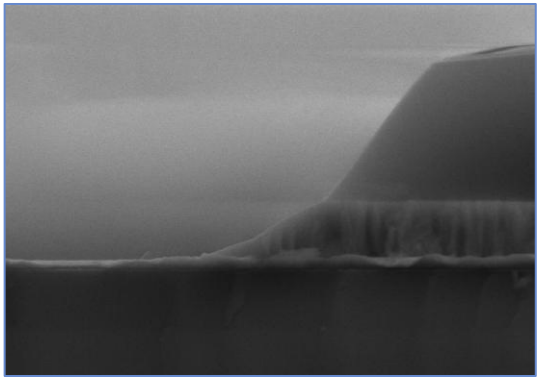
Un-etched Pt



10 % overetch



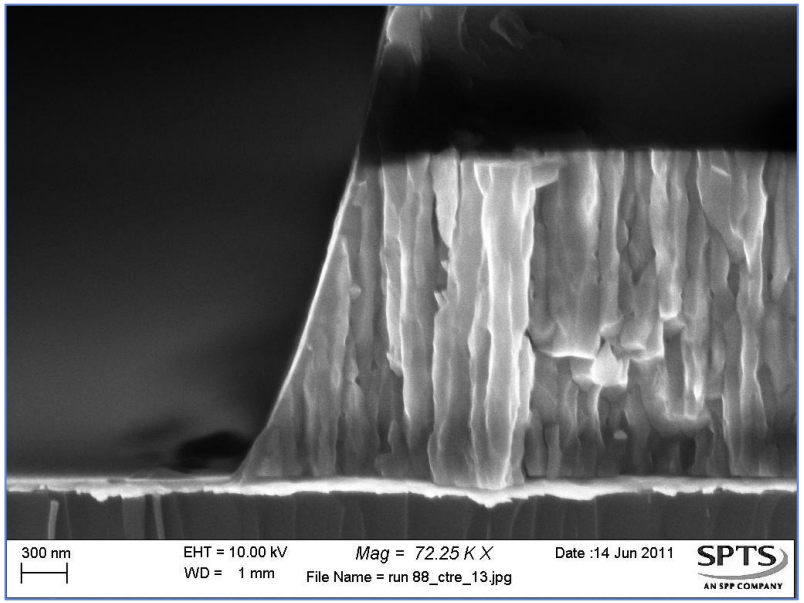
30 % overetch



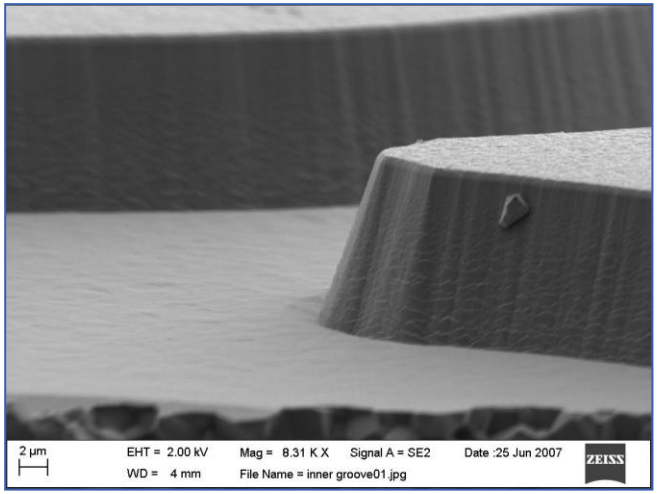
- High selectivity over-etch
  - Etch rate 27nm/min
  - S_{PR} ~0.24:1
  - S_{Pt} ~12:1
  - Profile ~70°

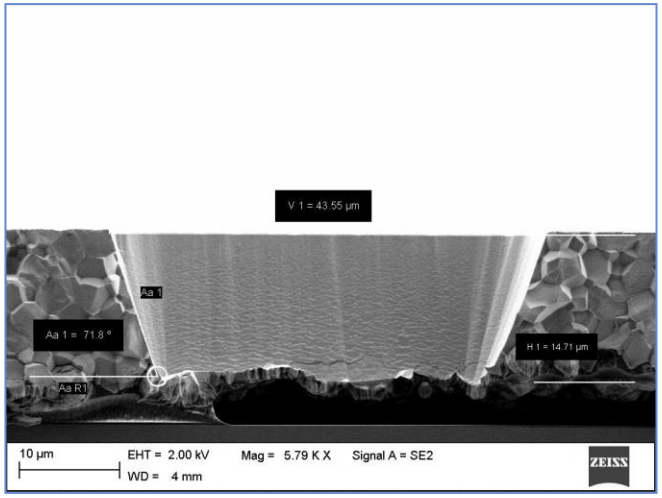
Deep PZT Etch – PR Mask

- Etch depth ~2µm
- Etch rate 0.2µm/min
- S_{PR} ~2:1
- S_{Pt} ~4:1
- Profile ~72°



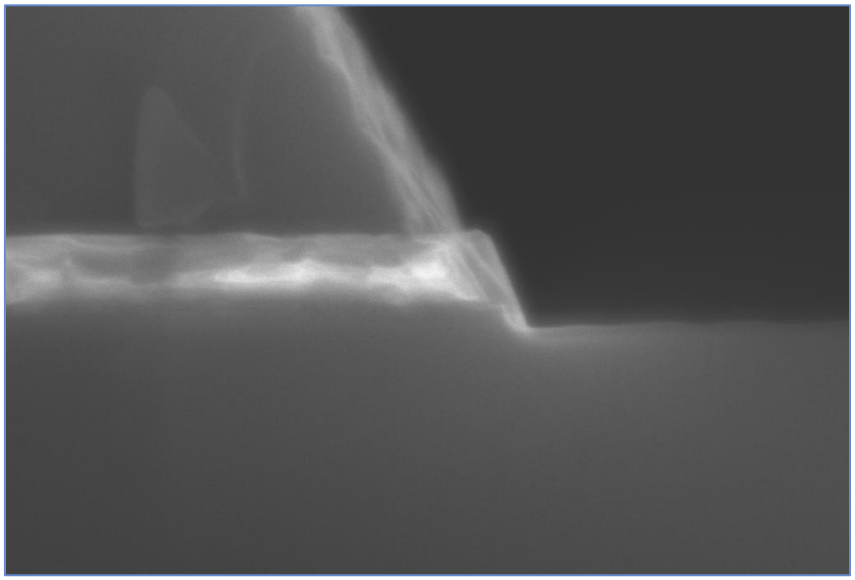
Deep PZT Etch – Ni Mask





- Etch depth up to 15µm
- Etch rate 0.2µm/min
- S_{Ni} ~8:1
- Profile ~72°

Pt Etch

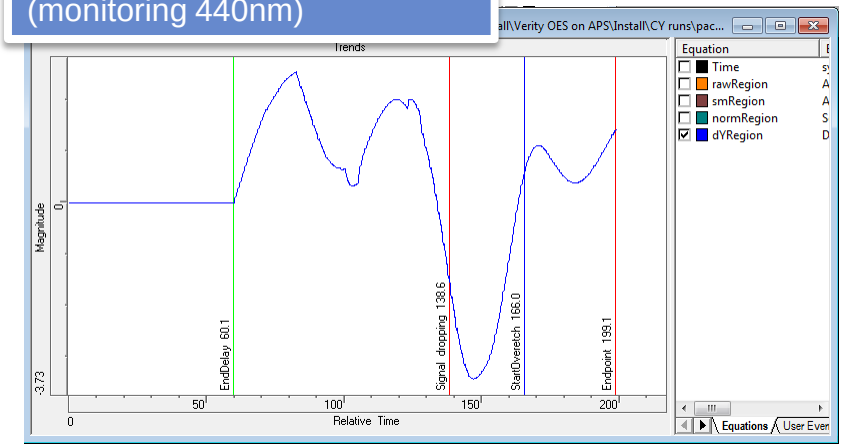


- Etch rate 0.18µm/min
- S_{PR} ~1.3:1
- S_{Pt} ~1.6:1
- Profile ~70°

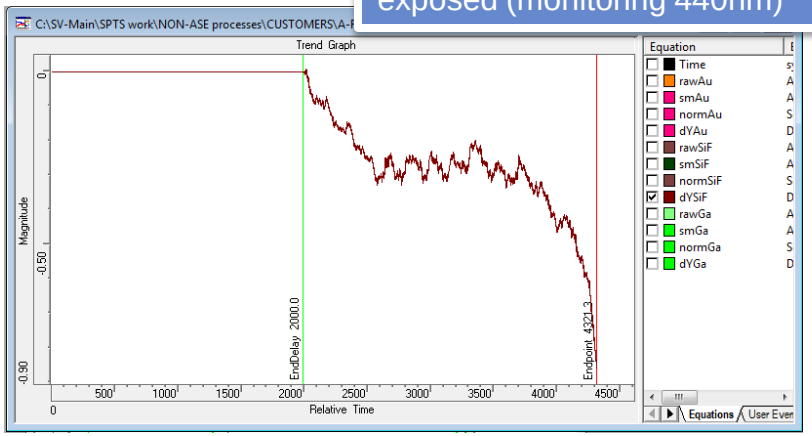
Endpoint Capabilities for APS

- Verity OES hardware utilized for endpoint monitoring and control (mounted to chamber viewport):
  - On-wafer etching, on-chamber cleaning, etc. (200-800nm)
  - Integrated to software, recipe control, can be field upgraded
- Applications with endpoint:
  - SiO2, SiN, SiC, GaN (for various exposed areas/patterns)
  - Select regions of interest, control with overetch features

Oxide etching, 0.4% exposed area pattern to Si etch stop (monitoring 440nm)



SiC etching, main etch process, stopping before GaN exposed (monitoring 440nm)



Summary

- Strongly bonded materials are used extensively within SPTS's target markets
  - MEMS, waveguides, compound, power & advanced packaging
- APS is well suited to etching strongly bonded films
  - High ion & radical densities
- APS applications capability includes:
  - Dielectric etching
  - Deep oxide etching for waveguides & related
  - Glass etching
  - Sapphire etching
  - SiC/GaN
  - PZT/Pt
- APS endpoint capabilities for various applications