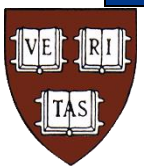
Etching Facility and Capability
at
Center for Nanoscale System
Harvard University

Dr. Ling Xie

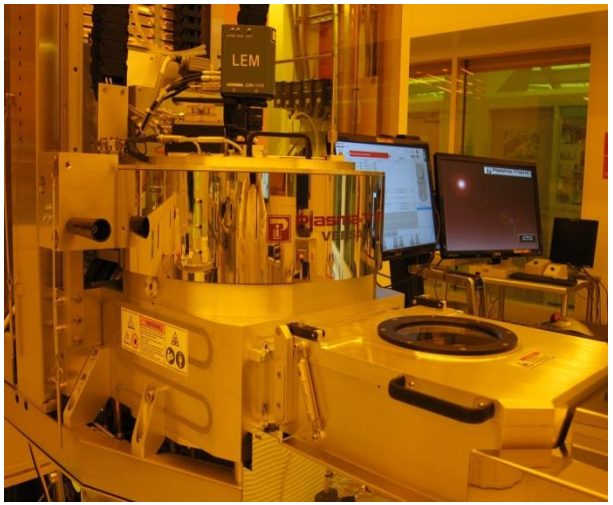


Center for
Nanoscale
Systems
Harvard University

Dry Etching Systems

1. **Plasma Thermal Versaline**
2. **SPTS Rapier DRIE**
3. **STS Lpx ICP RIE**
4. **Unaxis Shuttline ICP RIE**
5. **Nexx ECR RIE**
6. **SouthBay RIE**
7. **XeF_2 Etcher**
8. **Technics and Anatech Strippers**
9. **Matrix Plasma Asher**

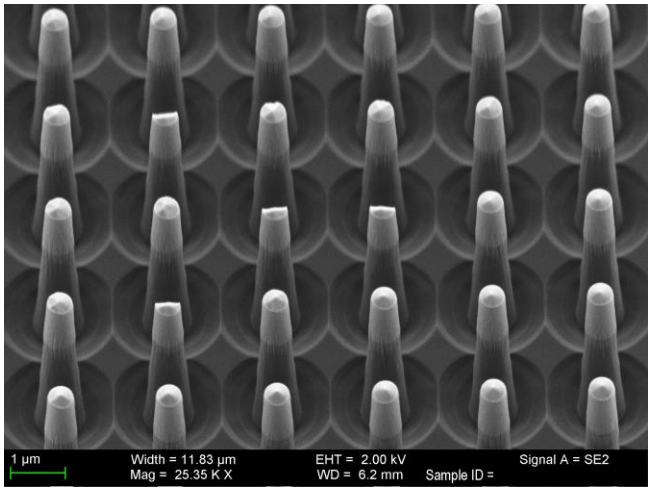
Plasma-Thermal Versaline



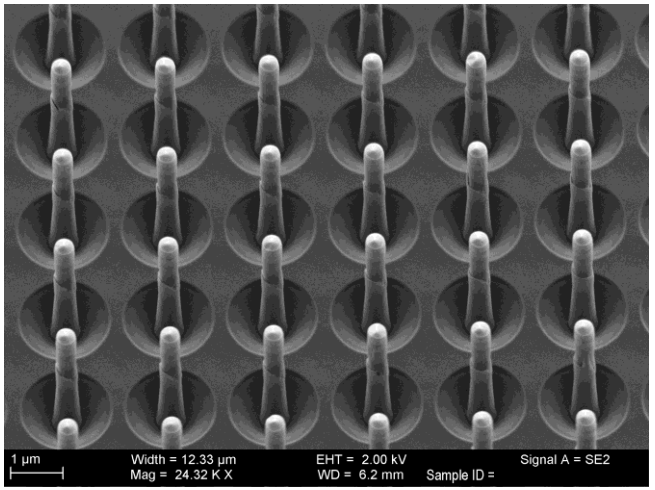
- **ICP power 1.2 kW**
- **Substrate RF power 600 W**
- **Chuck temperature 10°C – 180°C**
- **Primary gases: BCl_3, Cl_2, HBr, CH_4, O_2, Ar**
- **Single wafer loadlock up to 4” wafer**

Diamond Pillars Etch

460 nm



350 nm



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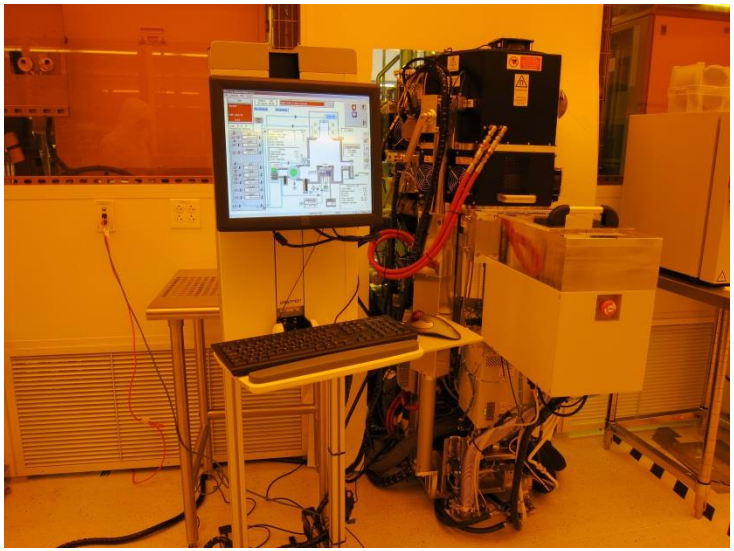
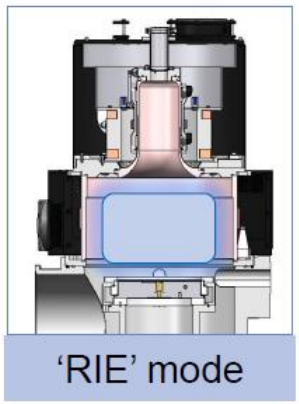
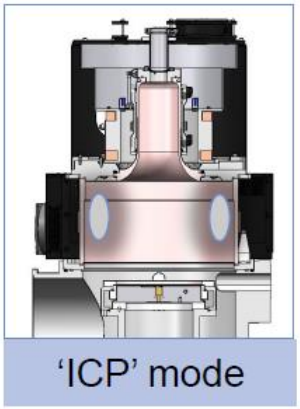
SPTS Rapier DRIE



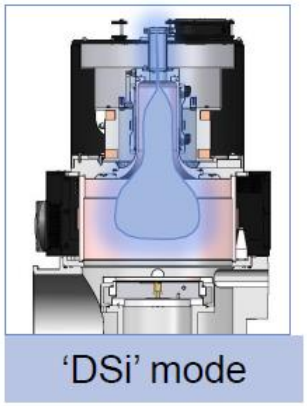
- Primary source power 5.0 kW
- Secondary source power 5.0 kW
- Pulsed HF substrate power 300 W
- ESC chuck, temperature range -20°C – +40°C
- Primary gases: C_4F_8, SF_6, O_2, Ar, N_2
- Secondary gases: C_4F_8, SF_6, O_2
- Single wafer loadlock up to 6” wafer

SPTS Rapier Operation Modes

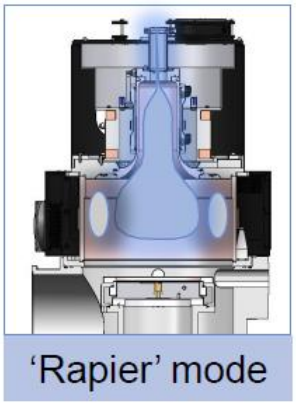




Original technology



Std decoupled source
Newer technology

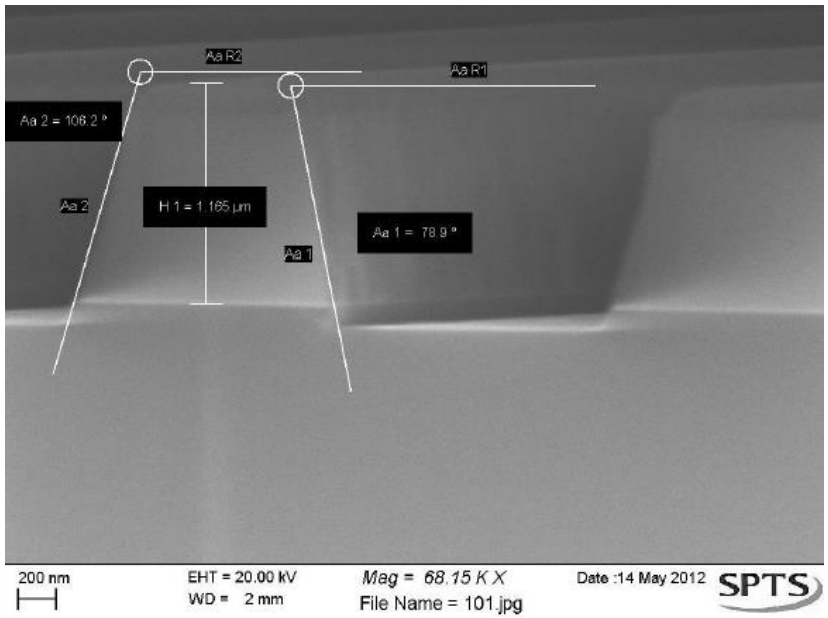


Dual source
Newest technology

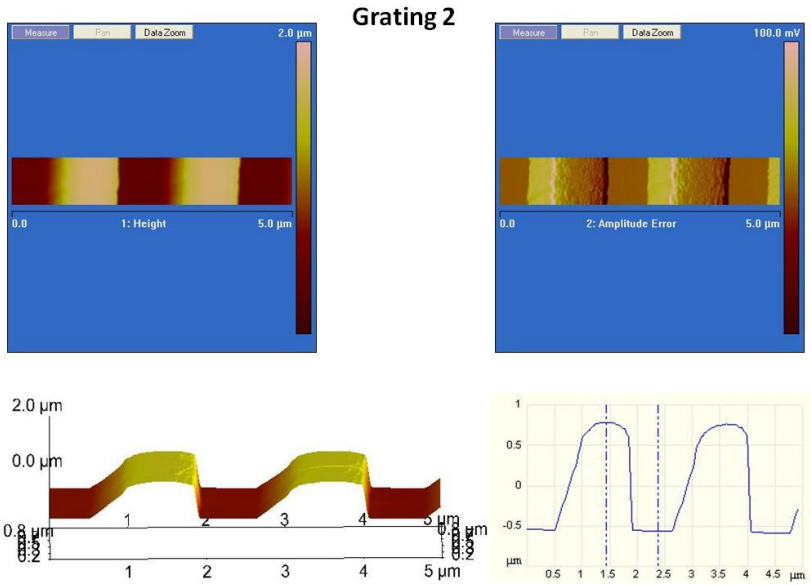
- **Unique 'Dual Source' capability**
  - Dual RF sources
  - Dual gas inlets
- **Multiple operating modes**
- **Average ICP power of 3.5kW**
- **Maintenance intervals**
  - >6000 rf hours for cavity etches
  - >1000 rf hours for mixed processes
  - Wet clean recovery 6 – 8 hours

Pre Etch Mask for Grating Wafers

- Mask material: thermal oxide
- Thickness: 1.0 μm
- Bottom opening width: 0.8 – 0.9 μm



SEM by SPTS



AFM measurement at CNS before sent out

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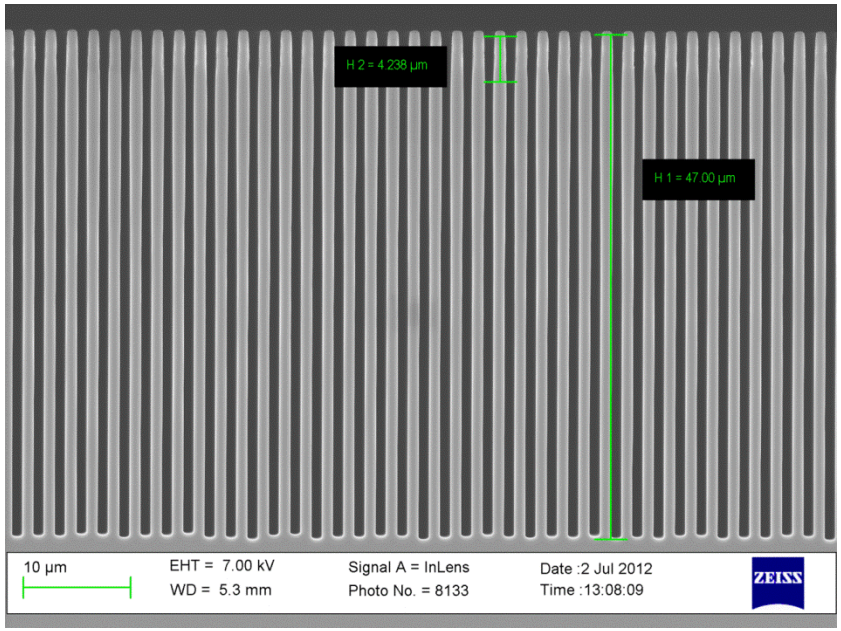
Grating

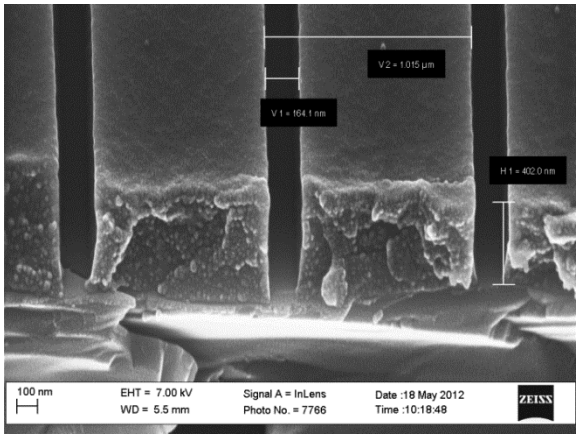
2 μm in pitches, 50 μm in depth
1.0 μm SiO_2 etching mask

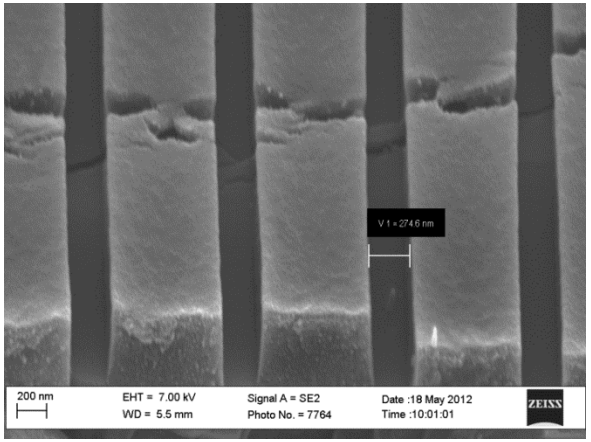


Characteristic	Achieved
Etch profile angle	90±0.1°
Scallop depth	38nm @ top
CD Loss (nm)	30nm
Mask Undercut (nm)	0
Selectivity to thermal oxide	53:1
Etch rate	1.27
Uniformity	1.3%
Depth (μm)	47 μm

Nano Features - Pre Etch Mask

ZEP450A

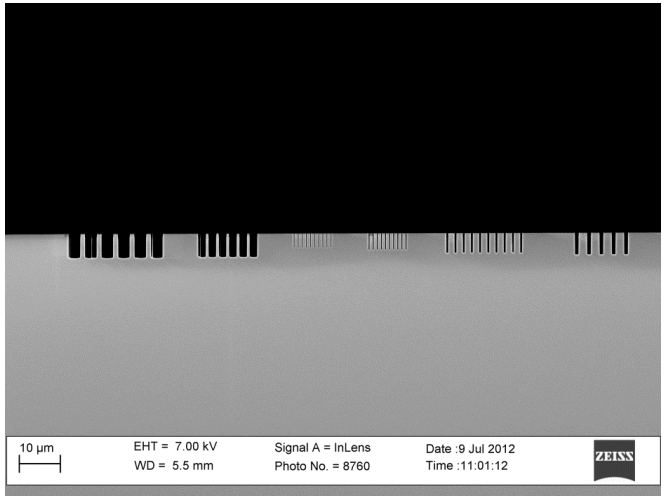


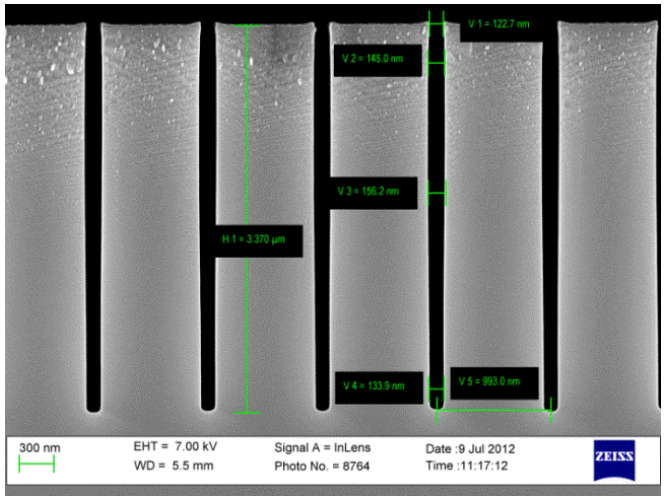


These are images of the e-beam resist etch mask of 100nm trenches. The top width is 144nm, 44nm off the design value, but became narrower at the bottom as shown on the cross section image.

The top width for 200nm trenches is 223nm.

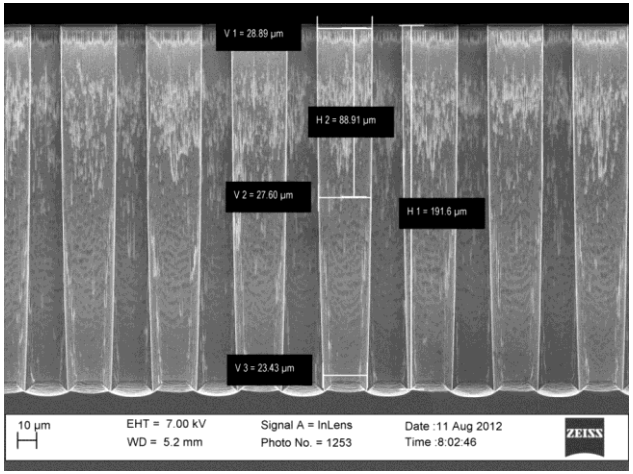
Nano Features

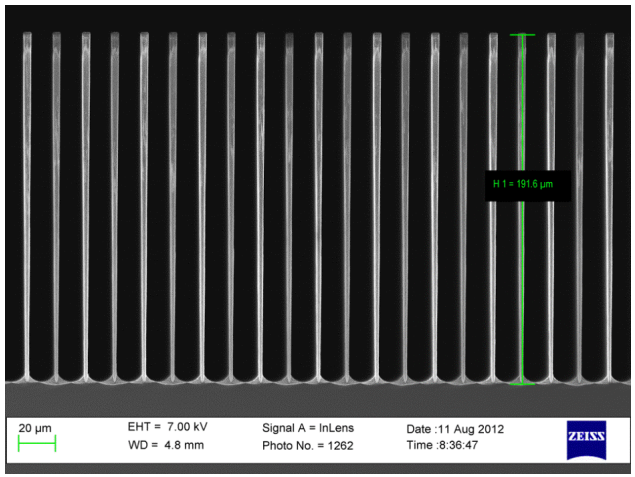




Characteristic	Achieved
Etch Profile	89.85
Scallop Depth	< 6 nm
CD Loss (nm)	6 nm
Mask Undercut (nm)	0
Selectivity to e-beam resist	9:1
Etch Rate	1.1 um/min
Uniformity	4.3%
Etch Depth (µm)	3.4

Micro Fins



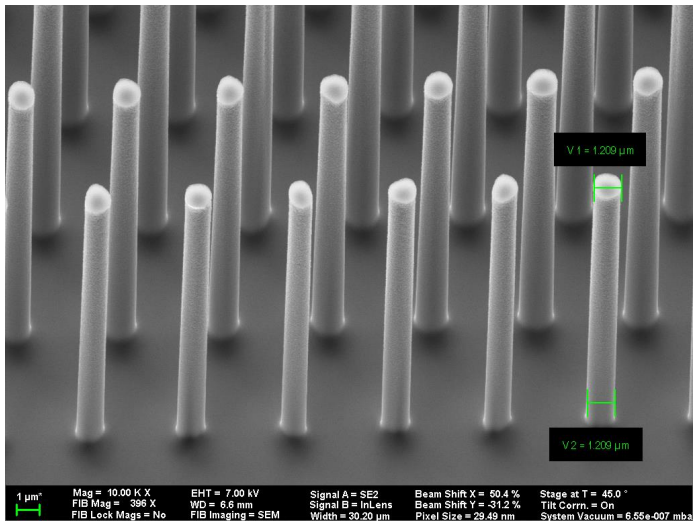


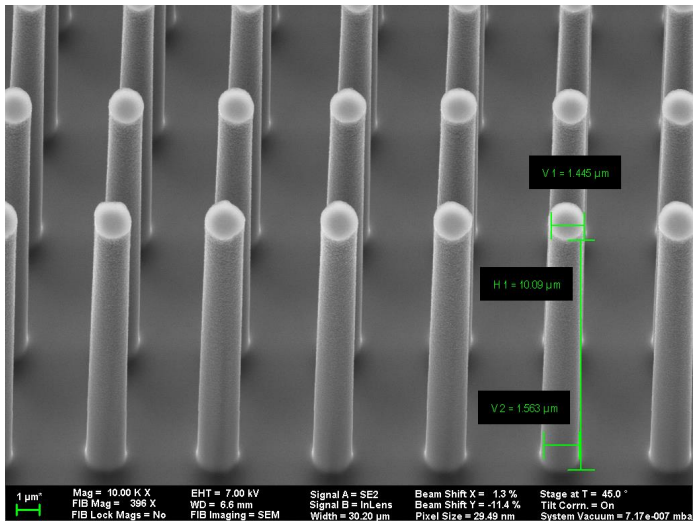
Characteristic	Achieved
Etch Profile	90.7° long side 90.3° short side
Scallop Depth	< 100 nm
CD Loss (nm)	N/A
Mask Undercut (nm)	0 long side 0 short side
Selectivity to photo resist	52:1
Etch Rate	4.4 um/min
Uniformity[1]	4.4%
Etch Depth (µm)	191µm

STS Lpx ICP RIE

- ICP assembly upper electrode 1500W
- rf biased lower electrode, chilled to 15 – 30°C, 300 W
- Available gases: C_4F_8, SF_6, CF_4, CHF_3, Cl_2, HBr, BCl_3, H_2, Ar
- Single wafer loadlock up to 6” wafer

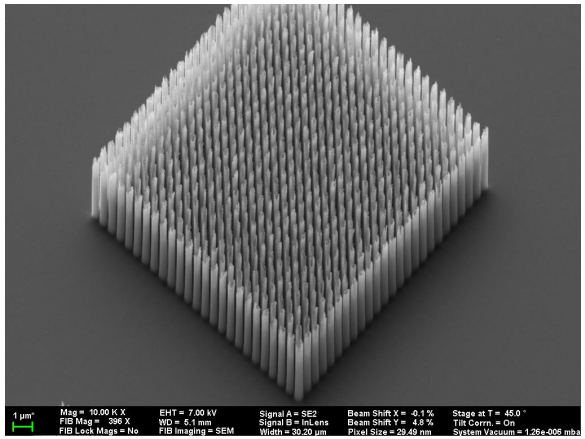
Si Pillar Etch with none-Bosch Process



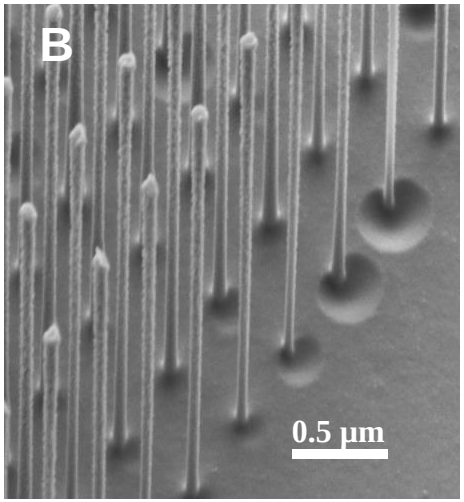


C_4F_8/SF_6 etching gases, Al etching mask
Pillars: 1.0 - 1.5 µm in diameter, 10 µm in etch depth

Si Nanowire Etch with STS ICP

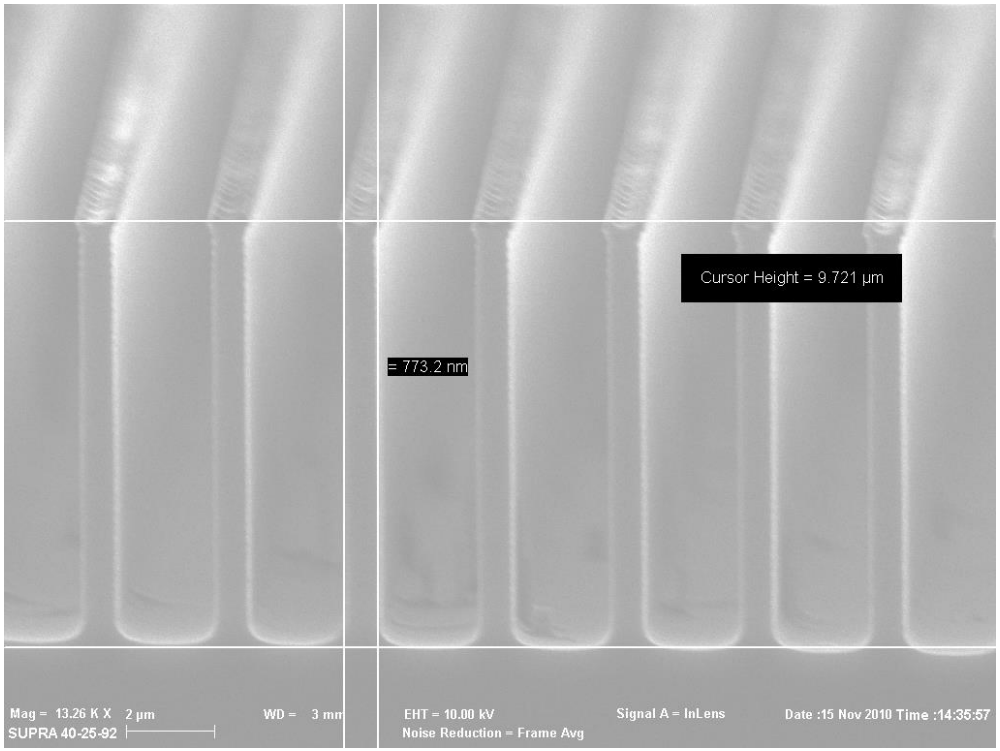


Reactive ion etch to obtain NWs length 300nm in diameter and 5 microns in depth Si NW arrays



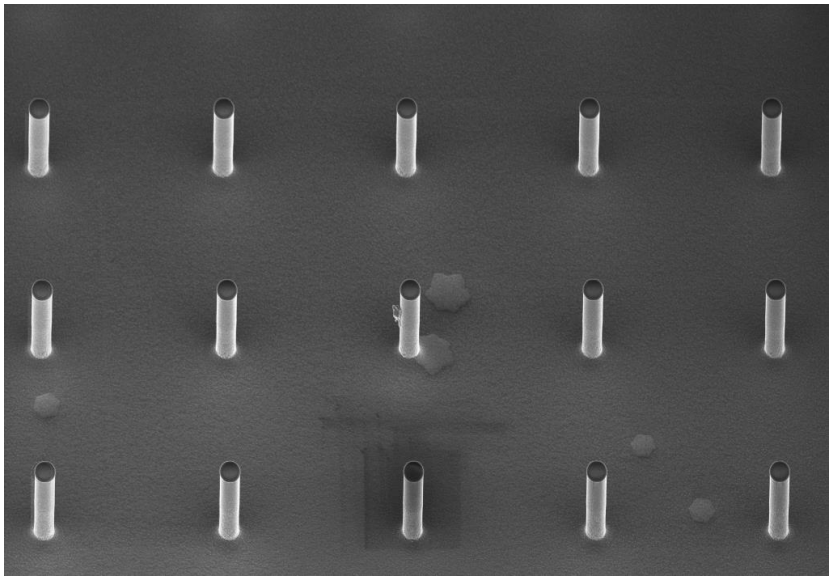
FESEM image of Si NW by RIE
The rough surface was possibly the fluoropolymer layer formed during etch.

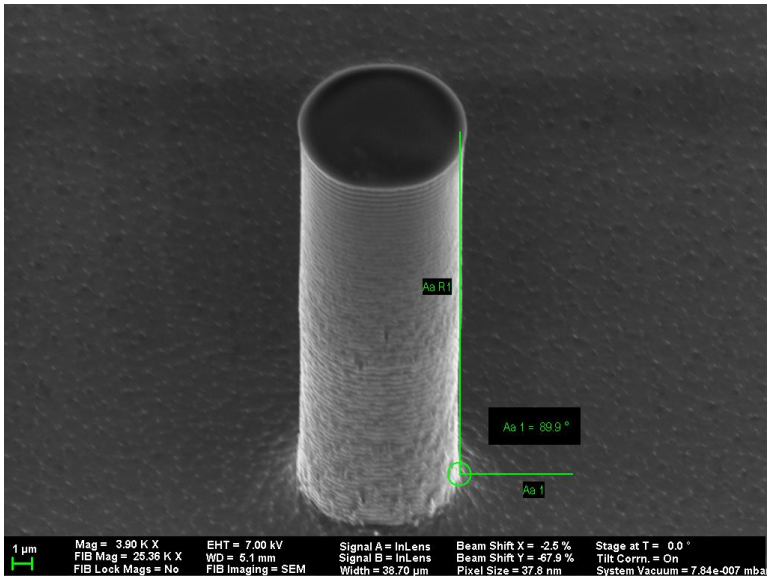
Si Ridge Etch with Bosch Process



Ridges with 770 nm in width, 2 µm in space, and10 µ m in etch depth

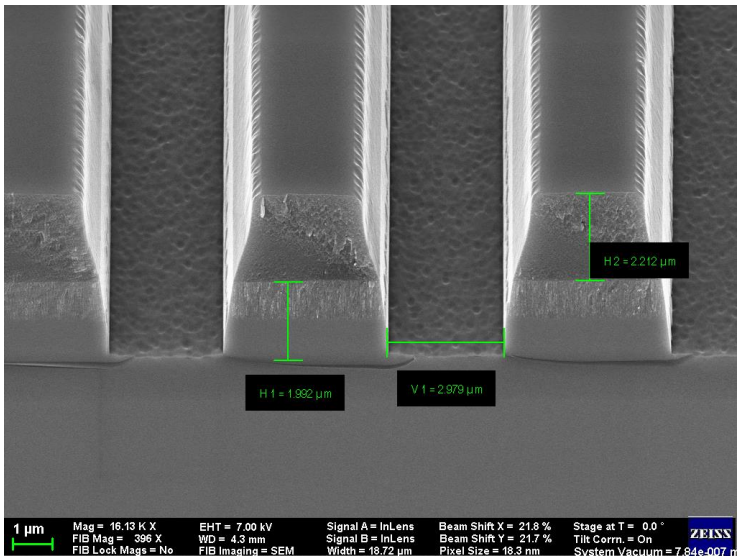
Si Pillar Etch with Bosch Process





C_4F_8/SF_6 etching gases, resist etching mask
Pillars: 8.0 µm in diameter, 50 µm in etch depth

SiN_x/SiO_2 Etching with STS ICP



- **Gases:** C_4F_8, SF_6, H_2
- **Etch depth:** 2.0 µm deep
- **Mask:** Photoresist
- **Etch Rate:** 0.5 µm /min
- **Selectivity:** 1.5:1
- **Profile:** 82°
- **Uniformity:** +/- 1.4%

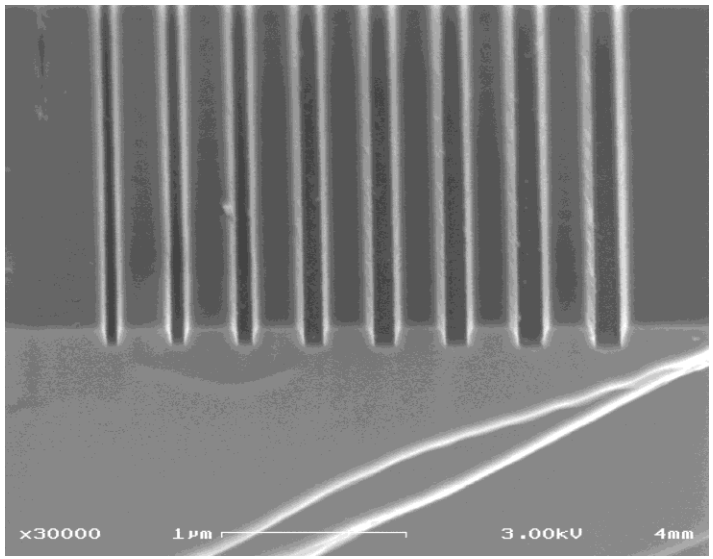
Unaxis Shuttline™ System

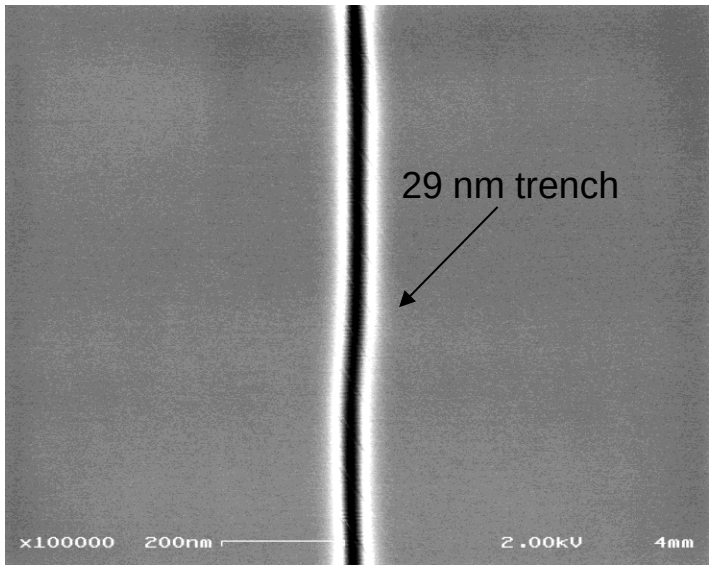
Specification:

- Inductively Coupled Plasma Etching (ICP)
- 2.5 kW ICP source power supply @ 2 MHz
- RF generator up to 300W @ 13.56 MHz
- Substrate clamping with backside helium thermal control
- Substrate heating system up to 180°C
- Available gases: HBr, Cl_2, BCl_3, CH_4, H_2, Ar, N_2, O_2
- Laser endpoint detector
- Loadlock equipped
- Computer control

GaAs Nanotrenches with Unaxis

Chemistry:	BCl3, Ar, N2
Mask:	PMMA
Selectivity:	1.22
Etch rate:	0.5 um/min

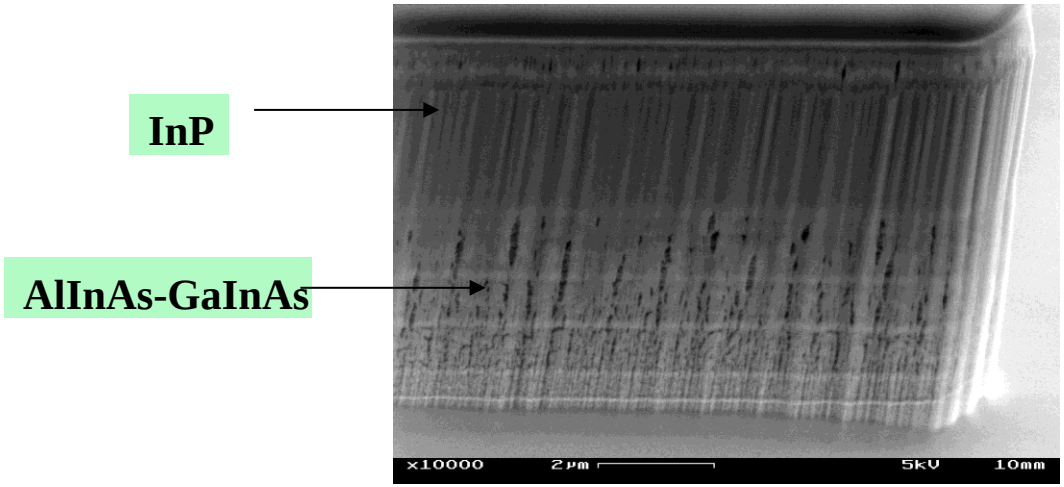




This process was used to etch nano-trenches and -holes and resulted in clean & smooth etch surface, good selectivity to PMMA, and 85 degree side wall.

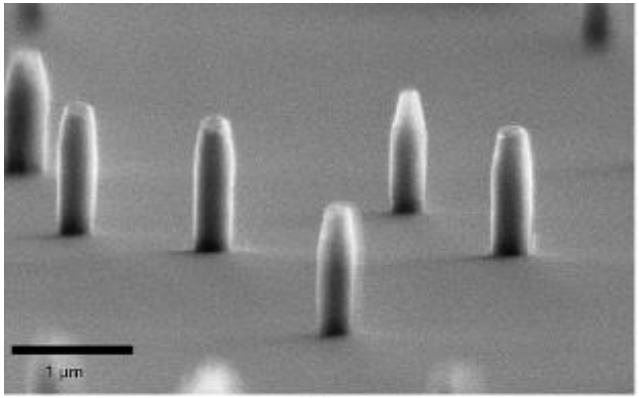
InP/(AlInAs-GaInAs multi-layers)/InP

Chemistry:	HBr, N2
Mask:	SU-8
Selectivity:	> 10:1
Etch rate:	~ 2.0 um/min

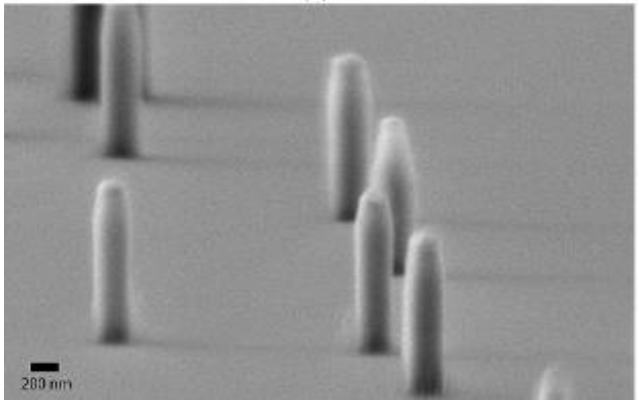


This process resulted in uniform etching along the depth for different materials. For multi-layer-different materials etching, the big challenge is the jags or roughness along the sidewall caused by selective etching or varying lateral etch rates of different materials. This process overcomes this problem and also demonstrated clean & smooth etch surface.

Diamond Etch

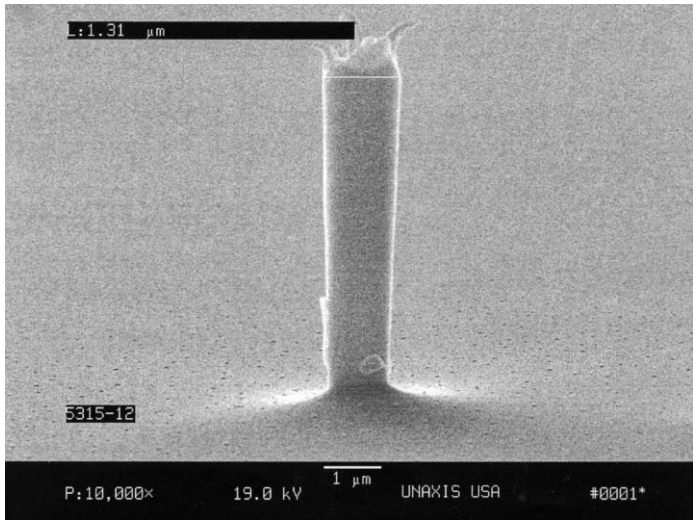


(b)



Birgit J. M. Hausmann, etc.
School of Engineering and Applied Sciences, Harvard University, McKay Lab 219, 9 Oxford Street

GaN Etch with Unaxis ICP



Provided by Dr. Y. Lee, etc, from Unaxis

Chemistry: BCl_3, N_2, **and Ar**

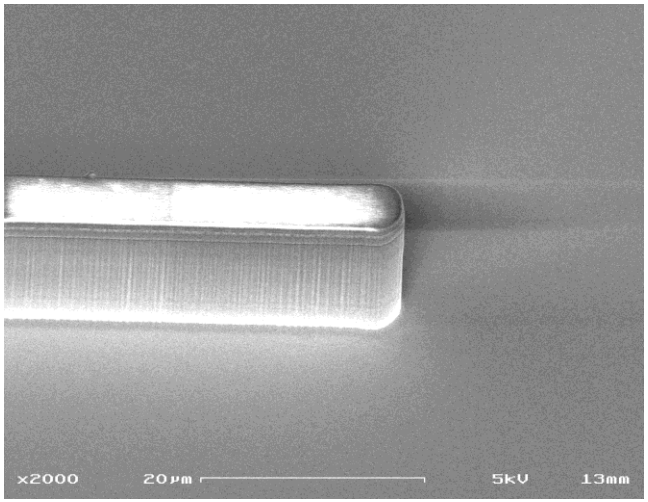
Characteristics: Vertical wall, smooth sidewall and floor surfaces

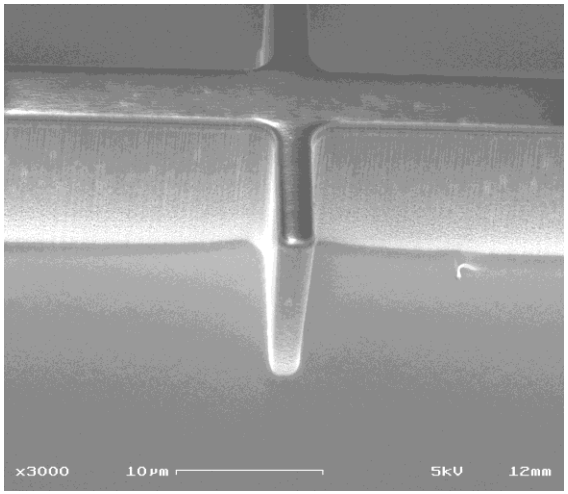
Etch Rate: 0.5 µm/min

Selectivity: 40:1 to Ni

InP Etch with Unaxis

Chemistry:	HBr, N2
Mask:	SU8
Selectivity:	> 10:1
Etch rate:	~ 2.0 um/min





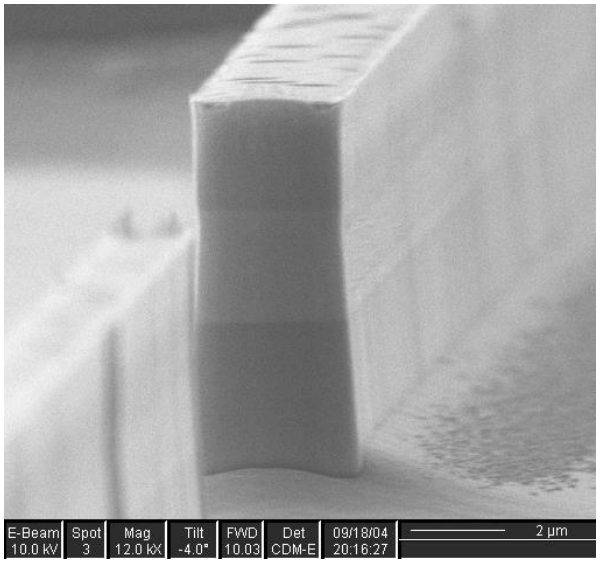
Clean & smooth etch surface, 10 – 15 um deep etch, vertical side wall, greater than 10:1 selectivity to Si3N4 or SU-8

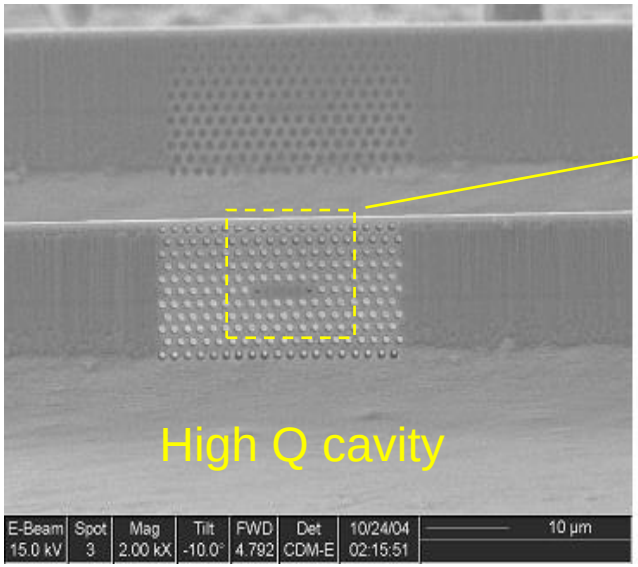
Nexx Systems Cirrus 150

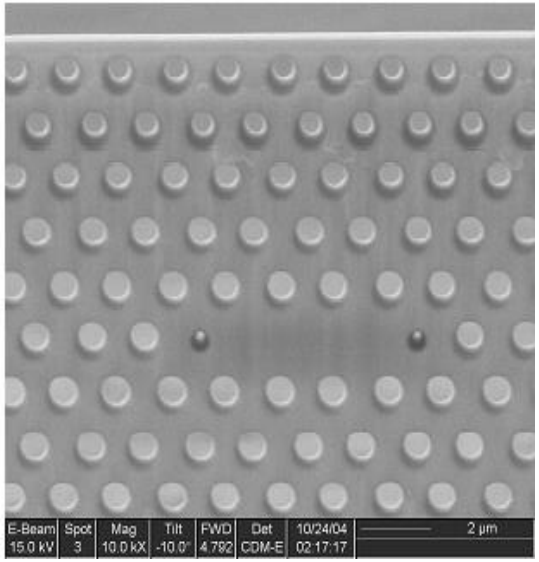
Specifications:

- Electron Cyclotron Resonance Reactive Ion Etch
- ASTeX 1500 W microwave power supply
- RFPP 13.56 MHz 500 W RF generator
- Stainless reactor, 12.75 in O.D, process up to 6” wafers
- Balzers turbo pump
- Substrate clamping with backside helium cooling
- Available gases: Cl_2, CF_4, CHF_3, CH_4, H_2, Ar, O_2, and He
- Loadlock equipped
- Computer control

Deep InP Etch with Nexx ECR

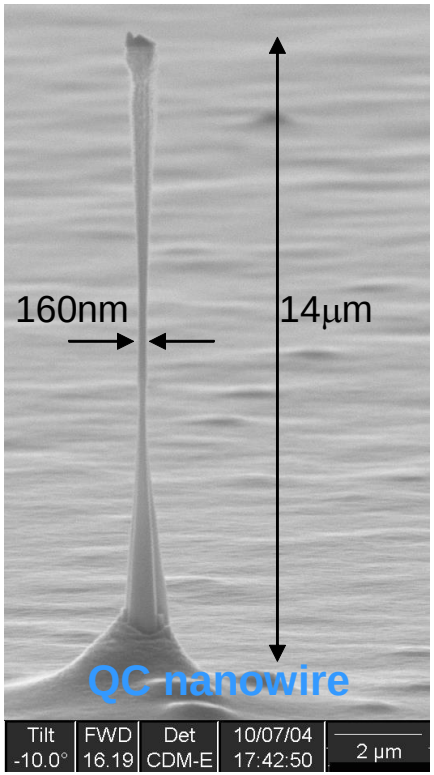


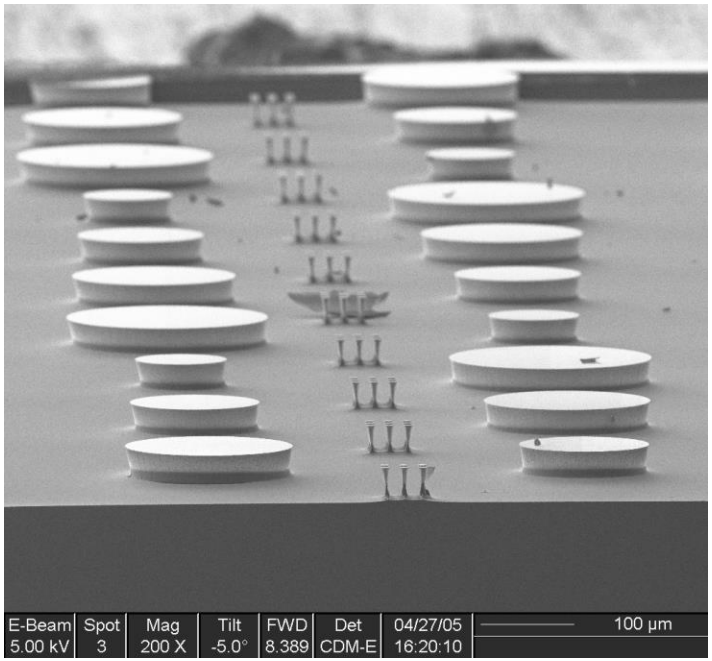




Chemistry : Cl_2 and H_2; Etch rate: 1 µm/min
Provided by Dr. M. Loncar in Prof. F. Capasso's group

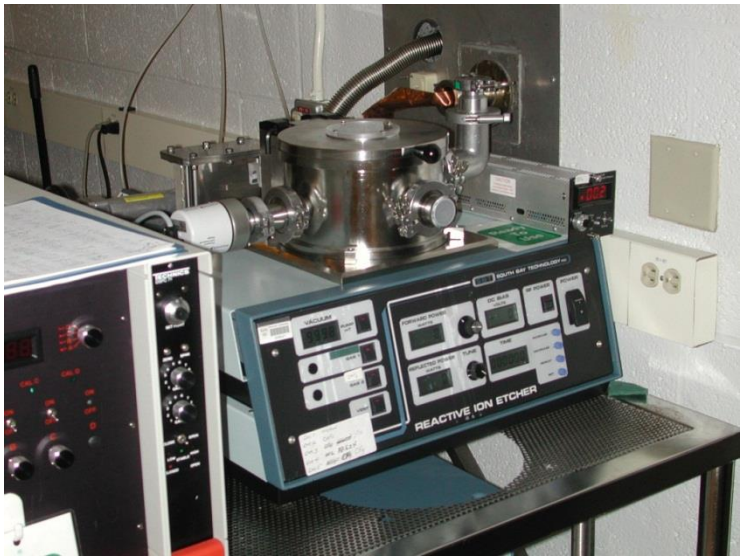
Deep InP Etch with Nexx ECR





Nanowire and disk laser
Provided by Dr. M. Loncar in Prof. F. Capasso's group

SouthBay RIE 2000



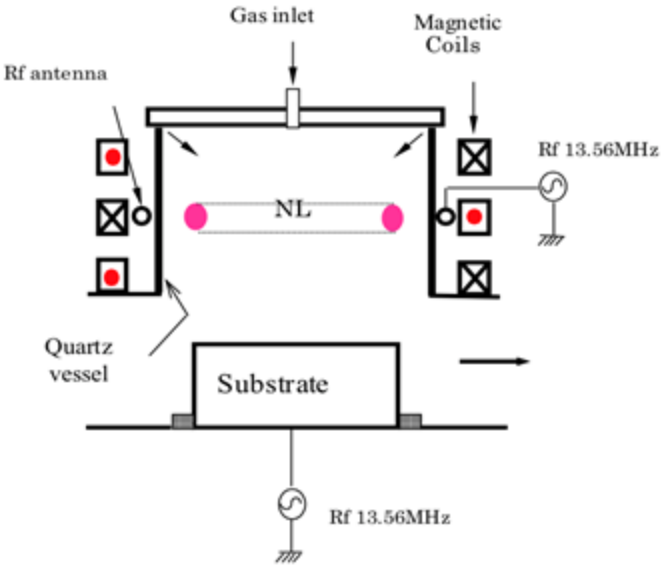
Specification:

- Standard parallel-plate rf plasma
- 13.56 MHz RF power up to 200 W
- 8” chamber diameter
- Water cooled sample stage
- Sample size up to 6”
- Turbo pump to10^{-6} Torr base pressure
- Available gases: SF_6, CHF_3, CF_4, Ar, O_2
- Manual controls

Upcoming System

- **ULVAC Deep Oxide Etcher**
- **Intlvac IBE System**

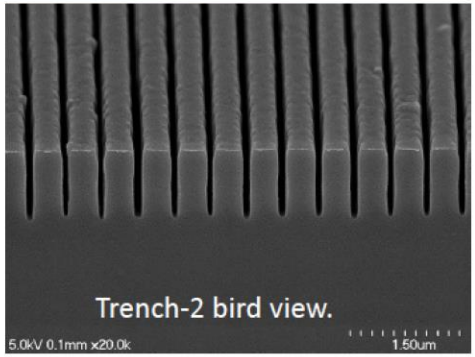
Deep Oxide Etcher – Ulvac -570

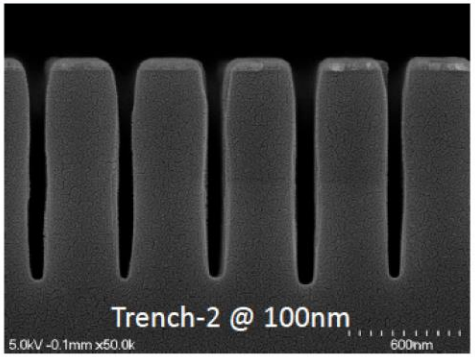


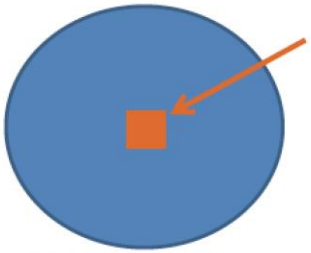
- NLD (Neutral Loop Discharge) plasma is generated by charging an electric field at Neutral magnetic points.
- The plasma can be controlled spatially by adjusting the electro-magnetic coil current.
- Achieves ideal anisotropic structural profile by generating low pressure and high density plasma.

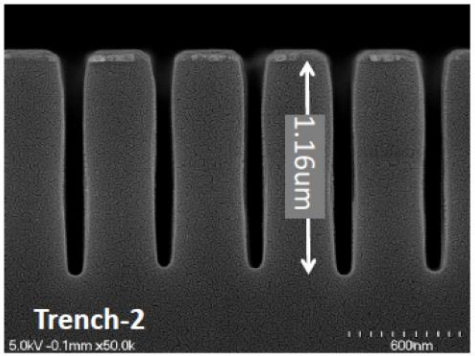
ULVAC High Aspect Ration Oxide Etch

SiO2 Etch at NLD-570EXa



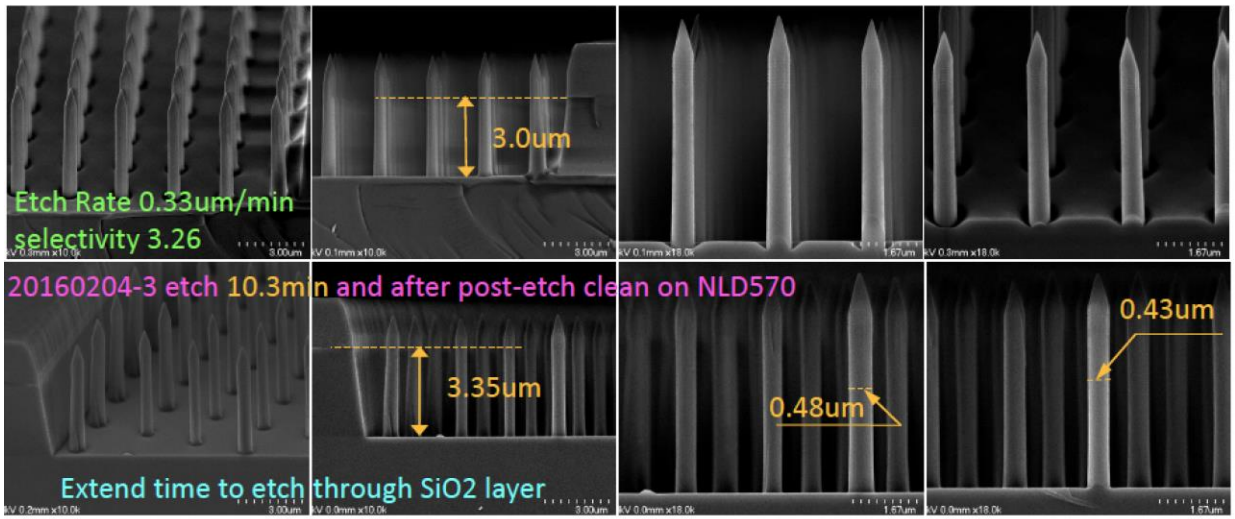






ULVAC Pillar Oxide etch results

2016-0203-2 and 0204-3 (wafer 2-piece)



Center for Nanoscale Systems Harvard University

IBE : Intlvac SiO2

Wafer 6-6

6" fused silica. Performed on October 15, 2015.

Note: Normal to beam is 90° and parallel is 0°

Etch Angle	Time (min)		Total Removed	148	nm
85°	40		Etch Rate	3.7	nm/min
Beam Parameters	200V, 70mA				
Process Pressure	3.3×10^{-4} Torr