Dry Etch at UCSB

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Nanofab Facility, UCSB

Present at Etch-Workshop
Cornell University
May 21-22, 2013

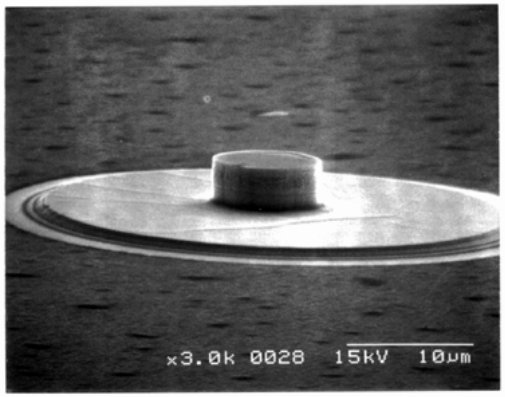
Etcher 1 (RIE#1)– Chlorine Based

UCSB Nanofabrication Facility

RIE #1

Homebuilt System -1987

- *500 W Power supply. Power or Cathode V control. Automatic Tuning*
- *Stainless Steel Housing. Vertical Mounting on thermally bonded silicon carrier. Load Locked*
- *RT – 80 C, 6" electrode, no He cooling*
- *HeNe Laser monitoring*
- *Mid 1e-7 Torr base Pressures*
- *Cl_2, O_2, Ar, N_2*
- *Primarily AlGaAs etching for Vertical Cavity Lasers*
- *Masks: PR, SiN_x, SiO_2, SrF_2, Ni*



GaAs – AlGaAs VCL,
Cl_2 10 sccm, 1-2 mTorr,
60W, 200nm/min

Double-mesa by using
Silicon sacraficial mask

Ni Mask

B. Thibeault

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Etcher 2 (RIE#2)– MHA Based

UCSB Nanofabrication Facility

RIE #2

1980s Vintage MRC etch system

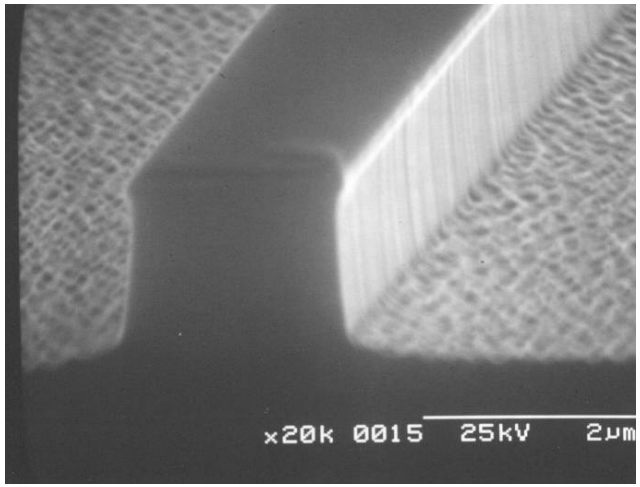
- *Methane/Hydrogen/Argon system Non-Load-Locked*
- *500 W power supply. Control of DC cathode voltage or power. Automatic Tuning*
- *Variable anode-cathode separation*
- *Pyrex inner liner*
- *RT – 80 C, 6" Aluminum Electrode*
- *Laser monitoring – IR & Vis.*
- *CH_4, H_2, Ar, O_2*
- *III-V As-P materials, II-VI materials.*
- *Diffusion Pumped*
- *SiN_x, Si, PR, metal masks used*

Oxygen plasma clean and polymer pre-coat is used to ensure system stability before each run. Typical O_2 clean: 125mT, 20sccm, 500V, 30 minutes.

Electrode Temperature kept at 60 C for best results – related to polymer formation

High bias etching (> 700V) affects InP results if a thorough wet-clean and condition not done after the high bias etch.

MHA Etching-InP – Parallel Plate



Above: InP Etching.

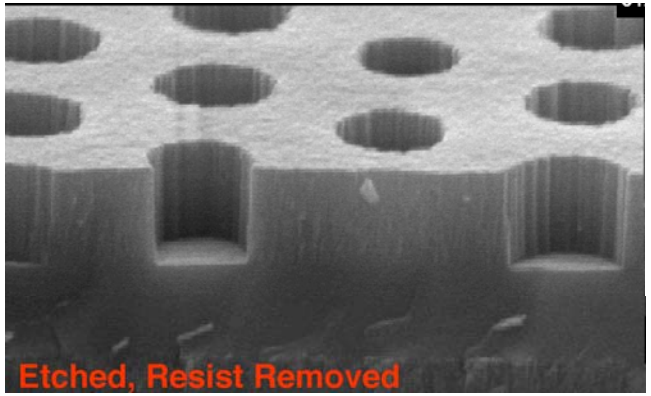
$CH_4/H_2/Ar$ 4/20/10sccm, 75 mTorr, 450V, 43nm/min, SiN mask.

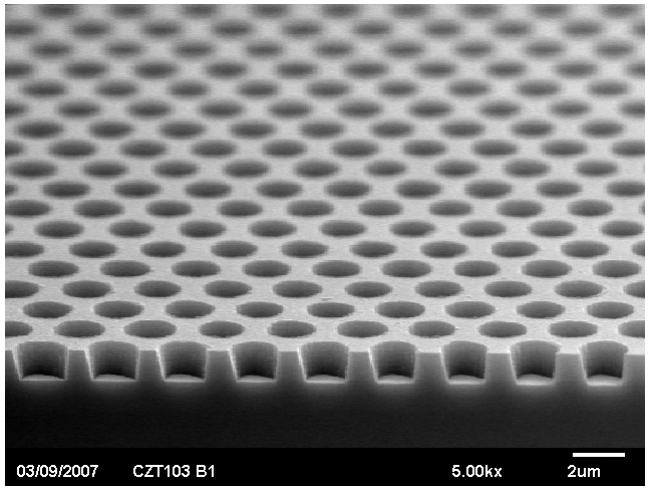
O_2 clean for 5 min at 300V at end to remove polymers from sample

Polymer formation on sidewall leads to vertical profile

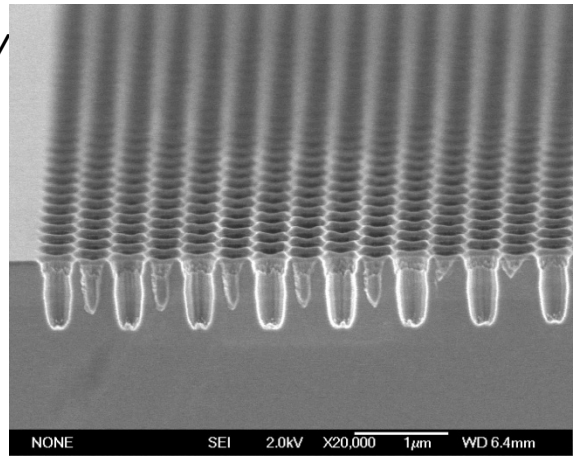
E. Skogen

Below: ZnS Etching
CH4/H2/Ar: 4/32/4sccm, 45 mT, 900 V (~400 W), 30min. Etch Rate ~46 nm/min





Above: CdZnTe Etching: 6 CYCLES OF (MHA 3/24/3 SCCM, 45mT, 500V, 10min + O2 20 SCCM, 50mT, 200V,5min). Net Etch Rate ~ 25nm/min
N. Cao



Above: InGaAsP Photonic Crystal Etching

7 CYCLES OF (MHA 4/20/10sccm, 75mT, 500V, 2min + O2 50SCCM, 125mT,180V,1min)

Cyclic Etch required for submicron hole work.

Net Etch Rate ~ 80nm/min for 300nm wide holes

Etcher 3 (RIE#3) – Fluorine Based

UCSB Nanofabrication Facility

RIE #3

1980s Vintage MRC etch system

- *Fluorine-based Non-Load-locked System, turbo-pumped*
- *500 W power supply. Control of DC cathode voltage or power. Automatic Tuning*
- *Variable anode-cathode separation*
- *Pyrex inner liner*
- *RT – 80 C, 6" Aluminum Electrode*
- *Laser monitoring –Vis.*
- *SF_6, CHF_3, CF_4, Ar, H_2, O_2, N_2*
- *SiO_2, SiN_x, BCB, Polymers, W, Other materials possible.*
- *PR, metal masks primarily used*

Oxygen plasma clean is used to ensure system stability before each run. Typical O2 clean: 125mT, 20sccm, 450V, 30 minutes.

Wet cleans done on as-needed basis.

Some low pressure sensitive processes for SiN_x etching require wet-clean before runs.

Low etch rates for SiN_x, SiO2

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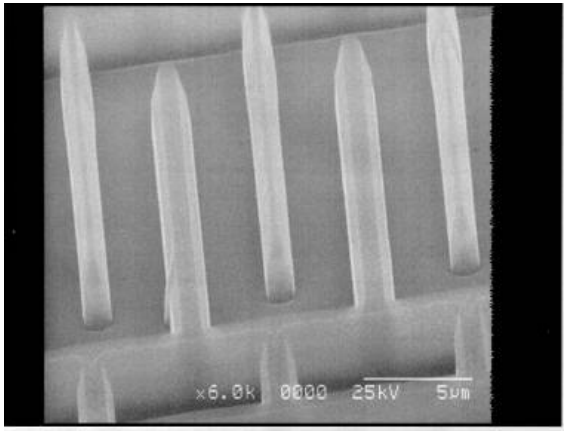
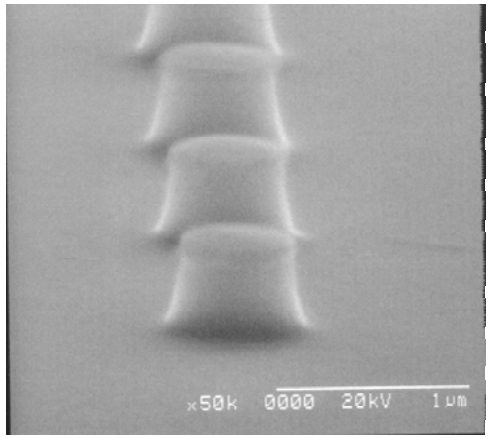
Flourine Etching – Parallel Plate

SiO_2 Etching



CHF_3 (20sccm)@8.8mT for 1 hr 15 mins, 550V, 120W
Oxide thickness: 2μm
~ 27nm/min. PR etch ratio ~1:1
Sloping Sidewalls
Cannot get vertical using this system

Si Etching

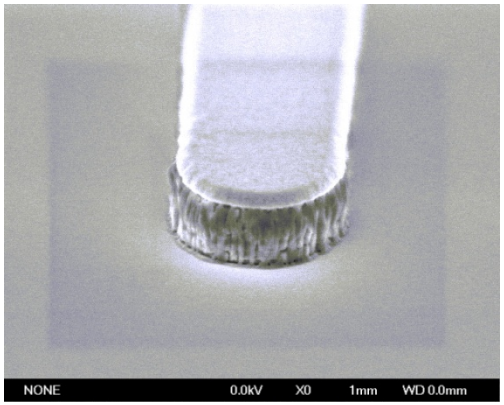


SF_6/O_2 20/2 sccm, 6mT, 100V
~130 nm/min. > 2:1 selectivity w/PR
Undercut ~ 10nm/min.

Strong Loading Effect

SiN_x etching faster than SiO_2 under all gases and conditions in this system

Tungsten Etching



SF_6/O_2 7.5/10 sccm, 7mT, 300V

~44 nm/min. > 50 selectivity w/Nickel

Etcher 4 (RIE#5)- Chlorine Based

UCSB Nanofabrication Facility

RIE #5

Plamsa Therm 770 SLR system

- *500 W Power supply.*
- *Stainless Steel Housing. No liner. Ceramic clamp (Alumina)*
- *RT – 80 C, 4" electrodes with clamp and He cooling*
- *Variable Upper Electrode Height*
- *HeNe Laser monitoring*
- *Cl_2, BCl_3, $SiCl_4$, O_2, Ar, N_2*
- *AlGaAs, AlGaN, Ti, Al, Si, Other materials*
- *Masks: PR, SiN_x, SiO2, SrF2, Ni*

Oxygen cleans often used before runs to clean chamber

System needs wet clean ~ every 2 months. Cleaned at first signs of arcing

System is down for 3 days minimum after wet clean

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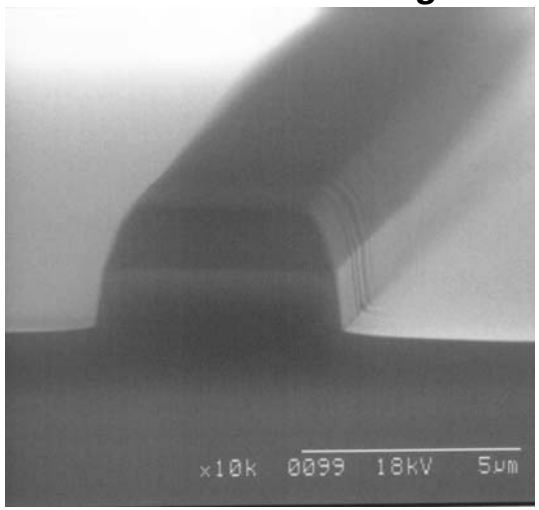
Chlorine Etching – RIE#5

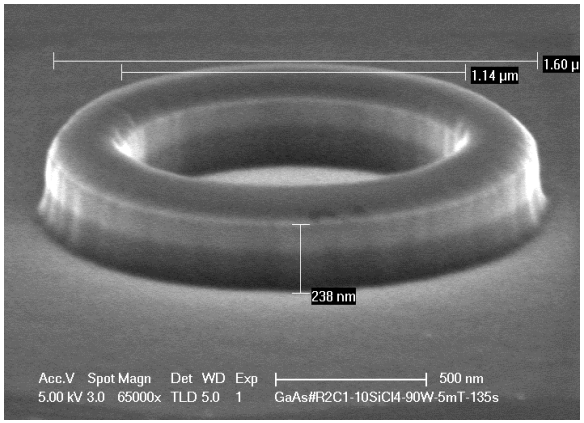
UCSB Nanofabrication Facility

GaAs/AlGaAs Etching



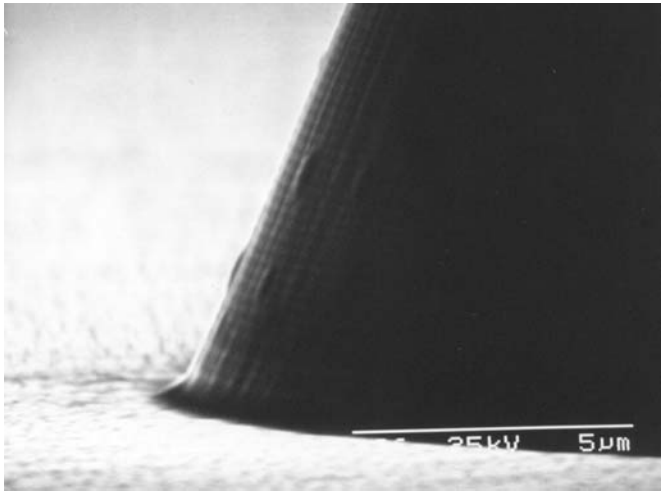
GaAs –Mesa $SiCl_4/BCl_3$ 10/15sccm, 15 mTorr, 115W, 200nm/min, PR mask

GaAs/AlGaAs Etching

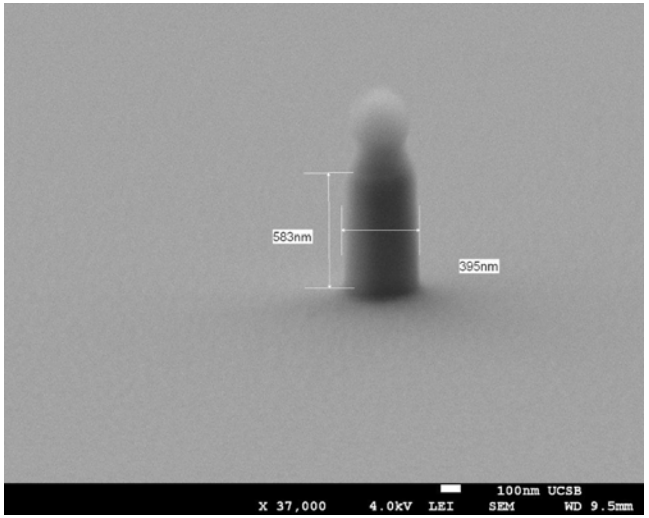


GaAs/AlGaAs Ring Etch: 5mT, 90W, $SiCl_4$=10sccm, 125 nm/min.

AlInGaAs Etching

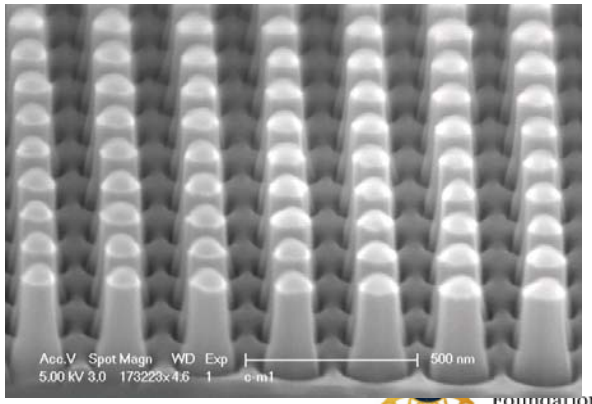


InAs/GaAs Mesa Cl_2/Ar 10/10sccm, 20 mTorr, 250W, 160nm/min. SrF_2 mask. 60 C High bias with Ar required due to In. Physical removal of $InCl_x$



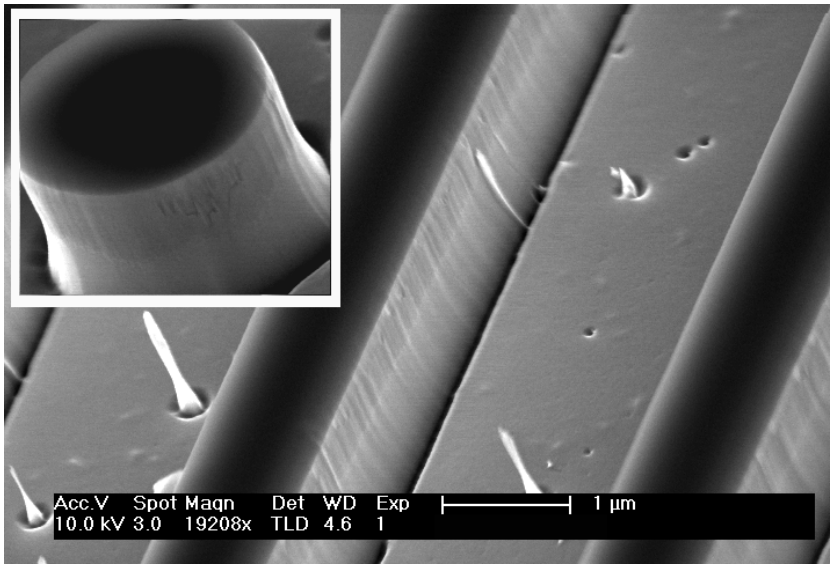
Left: GaAs/AlGaAs Post Etch: *5mT, 110W, $SiCl_4$=10sccm, Etch rate: ~90 nm/min. (PR mask remaining on the top) B. Thibeault*

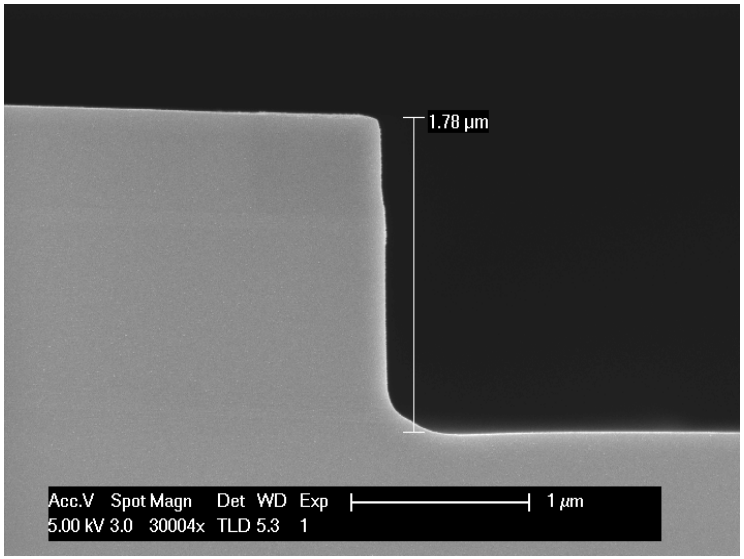
Right: Si Etch for imprint mask *Cl_2 10sccm, 5 mTorr, 100W, 50nm/min, SiO_2 mask. C. Nuefeld*



Chlorine Etching – RIE#5

GaN/AlGaN Etching





GaN Mesa, Cl_2 :20sccm, 15mT, 150W(380 v), Etch Rate:131 nm/min.

Laser Facet Etch: 5mT,Cl_2:10sccm, 200W. Bi-Resist-layer etch masks. BCl_3 surface clean reducing defects.

R.M. Farrell (Ph. D. Thesis)

Etcher 5 (Si-DRIE ICP#1)-Fluorine Based

Si- DRIE

Plasma-Therm 770 SLR

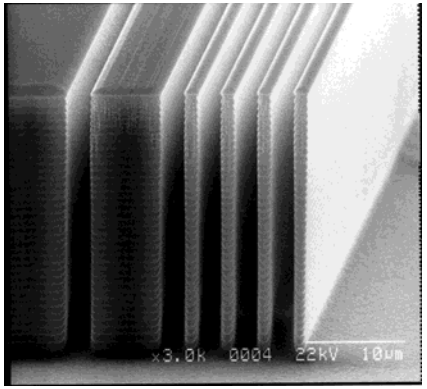
- *Fluorine-Based Bosch Process (Cyclic etch/dep process)*
- *1kW, 2 MHz ICP source, 4" wafers, 500 W Sample Bias*
- *Pieces mounted with Diff Pump Oil: Santovac 5 (Polyphenyl Ether) or thermal tape*
- *He cooling, ceramic clamp*
- *Si-deep etching for MEMS*
- *> 3um/min etch rates possible*
- *SF_6, C_4F_8, O_2, Ar, N_2*
- *PR, SiN, SiO_2, AlN masks*
  - *Selectivity up to 300:1 with oxide*
  - *Up to 80:1 with PR*

30-minute O_2 plasma clean run done before etch to remove polymer left in previous run.

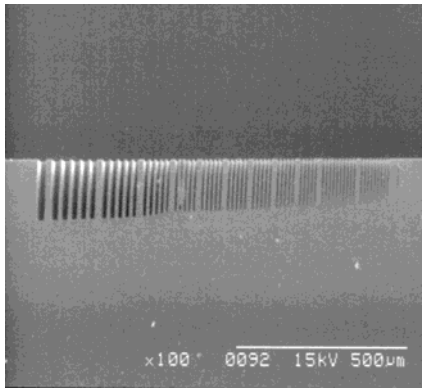
Wet cleans done on as-needed basis.

SF6/Ar release etches also done in the system.

Si Etching (Bosch Process) – ICP



Typical Standard Bosch Process ~ 2um/min etch rate

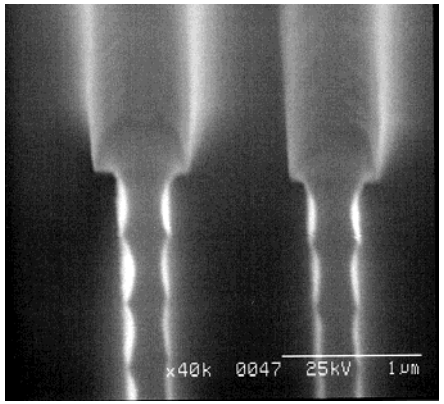


ARDE of Bosch Process

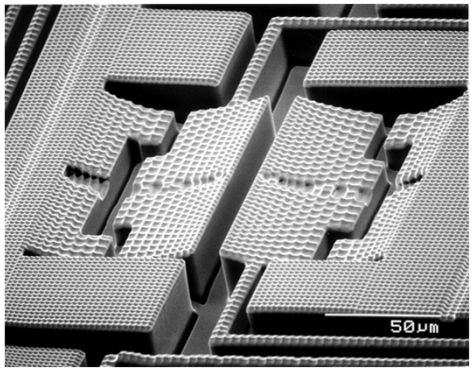
Standard Recipe: ICP power 825 W, 23 mTorr, Coil Temp: 40 C, Sub Temp 10C

EtchA: SF6/Ar 50/40, Bias 9W, 2 sec.
EtchB: SF6/Ar 100/40, Bias 9W, 6 sec.
Dep: C4F8/Ar 70/40, Bias 0W, 5 sec.

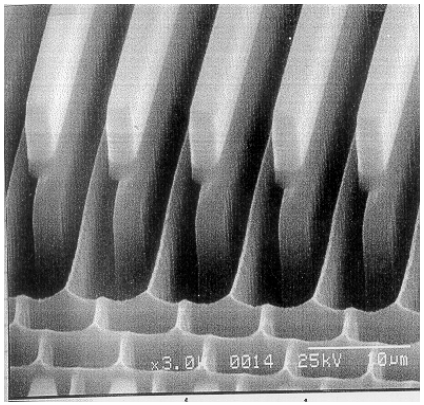
Lots of In-house parameter characterization



Bosch Scalloping due to Cyclical Process

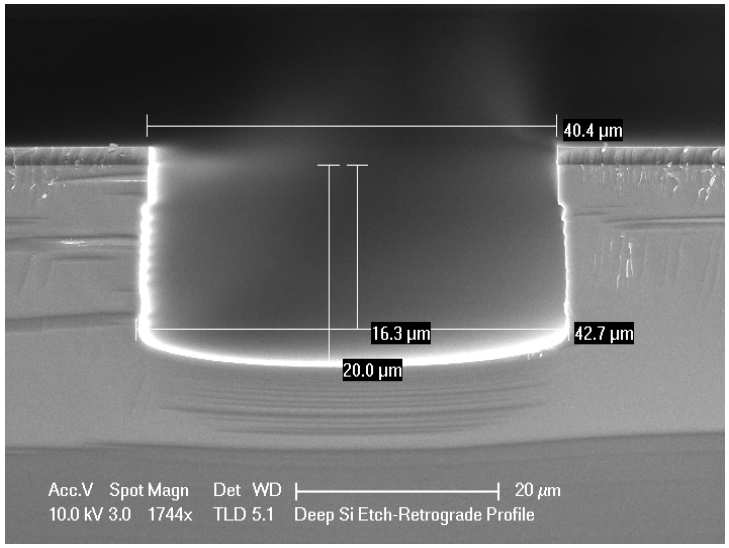


Single-Step-3D Micromachining by Controlling ARDE through parameter adjustment and hole opening



Release

Si Deep RIE (ICP) - Si Etching



This work was done with a help of Dr.Shouliang Lai from Oerlikon USA Inc. N. Cao

Deep Si Etch with Retrograde Etching Profile (Side-wall Angle=94º)

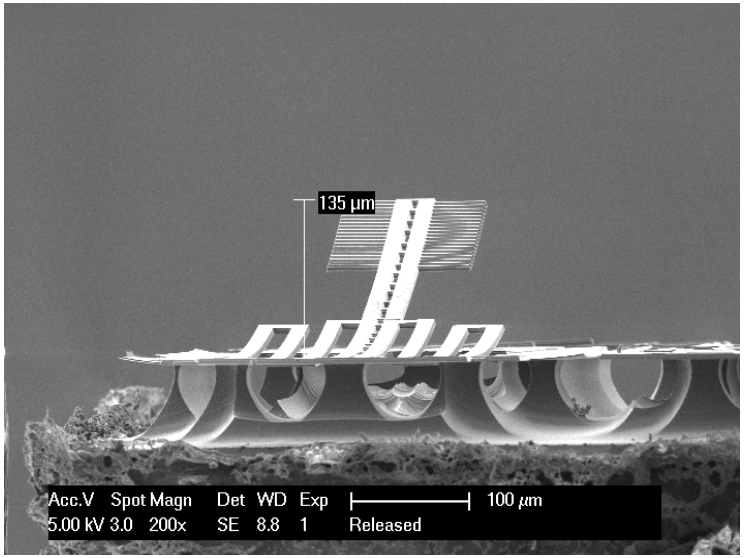
Step#1:Standard Bosch Recipe: ICP power=825 W, 23 mTorr, Coil Temp=40 C, Sub Temp=10C, ∆t=3.5min

Etch A: SF6/Ar=50/40, Bias=9W, 2 sec.
Etch B: SF6/Ar=100/40, Bias=9W, 6 sec.
Dep: C4F8/Ar=70/40, Bias=0W, 5 sec.

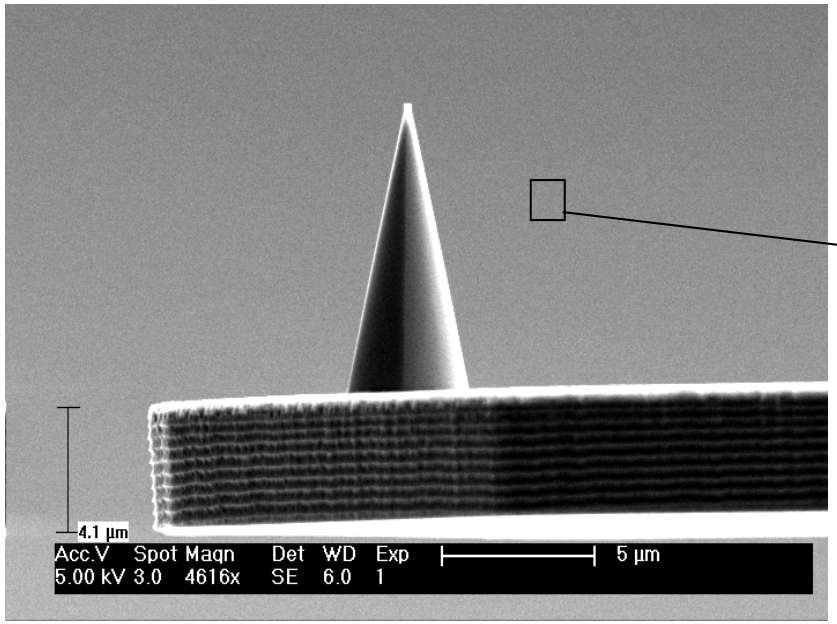
Step#2: Modified Bosch Recipe: ICP power=825 W, Coil Temp=40 C, Sub Temp=10C, ∆t=6min
Etch A: 23 mTorr, SF6/Ar=65/40, Bias=12W, 5 sec.
Etch B: 30 mTorr, SF6/Ar=130/40, Bias=8W, 20 sec.
Dep: 23 mTorr, C4F8/Ar=85/40, Bias=0W, 5 sec.

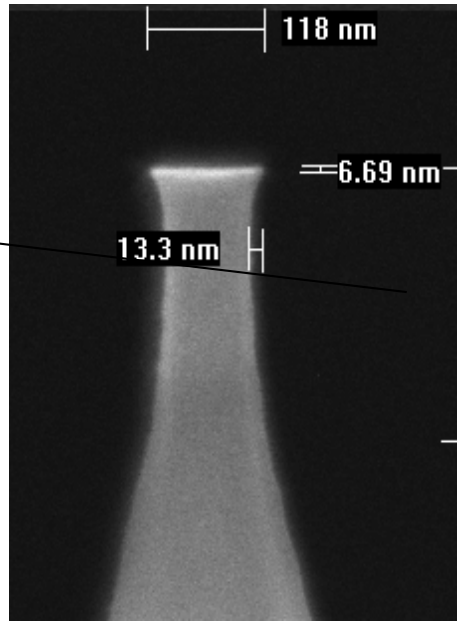
Release Etching standard CMOS process MEMS structures

ICP power=825 W, Bias Power=9W, 23 mTorr, Coil Temp=40 C, Sub Temp=10C, SF6/Ar=100/40sccm, ∆t=9min. B. Thibeault



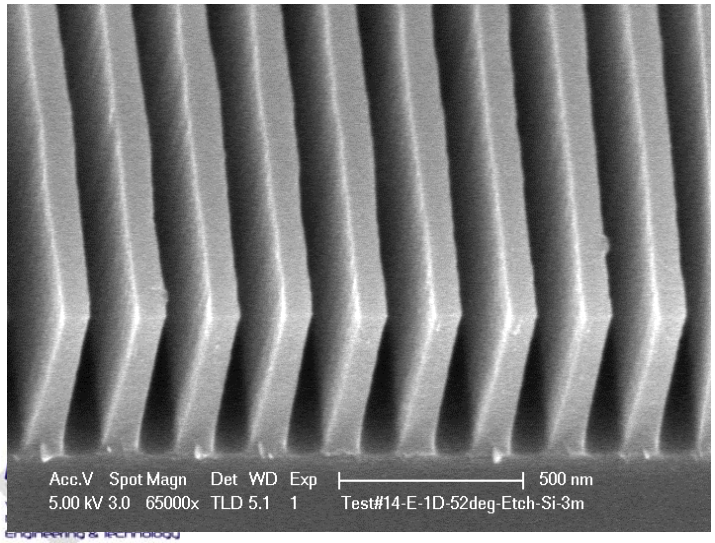
Si Etching– ICP

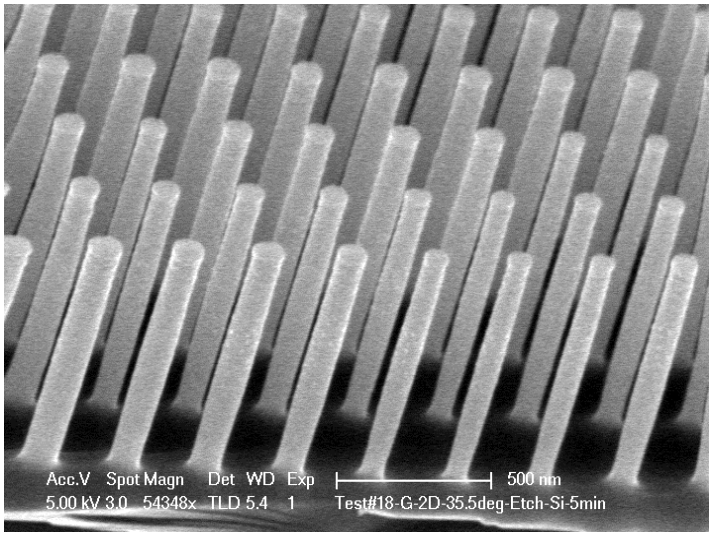




Another Example of Etching done in the system

Tapered tip for Cross-sectional AFM measurements



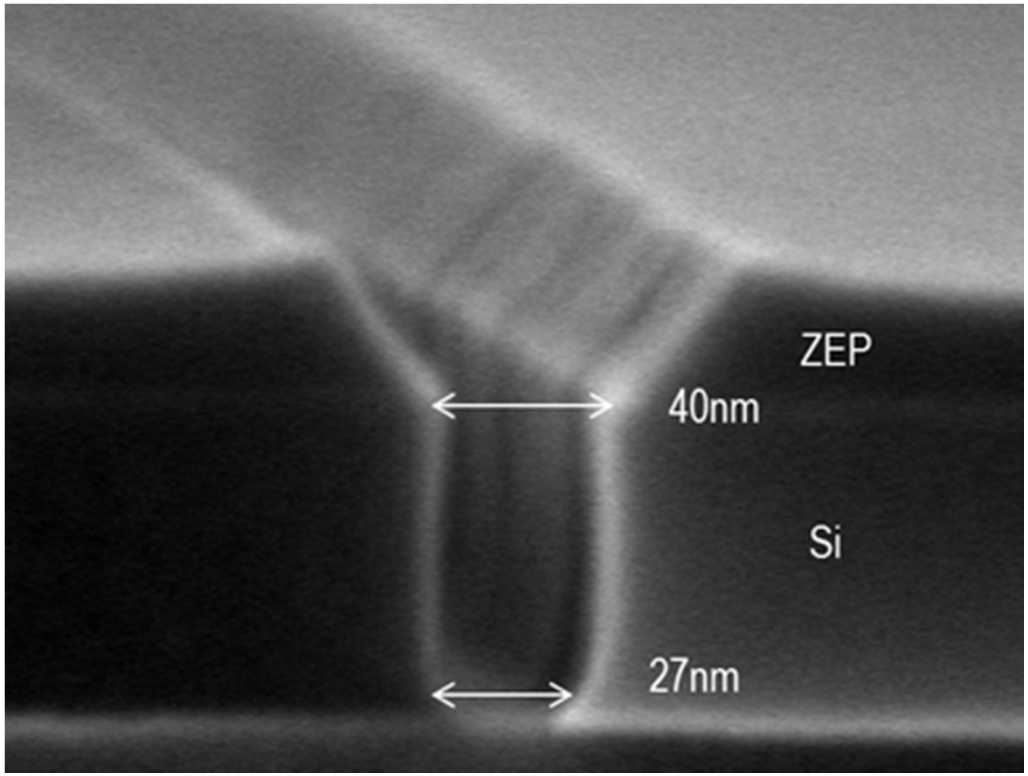


One-step Etch (none Bosch process)

Scalloping Free

Si Etch-ICP

One-step amorphous Si etch



Etcher 6 (ICP#2)-Fluorine/Chlorine Based

ICP #2

Panasonic E640 ICP Etcher

- *Multi-Purpose ICP etcher*
- *1kW ICP, Pancake style, 13.56 MHz. 500 W substrate power.*
- *RT – 80 C, 6" Electrode, Electrostatic Chuck, 6" silicon carrier wafers*
- *Pieces mounted with Diff Pump Oil (Santovac 5)*
- *Integrated 2kW ICP Asher*
- *Cl_2, BCl_3, CF_4, SF_6, CHF_3, N_2, Ar, O_2*
- *III-V As/N. Ceramics, Dielectrics, Metals, Silicon.*
- *Various Masks used depending on chemistry*
- *Maximum etch pressure ~ 37.5 mTorr*

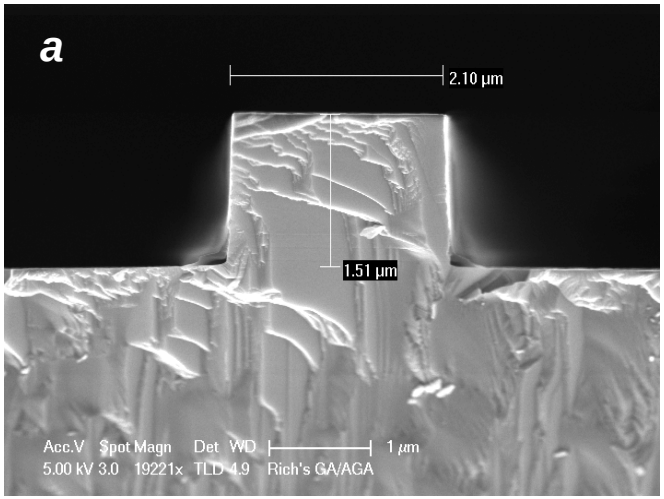
Work horse of the lab. Used for many purposes.

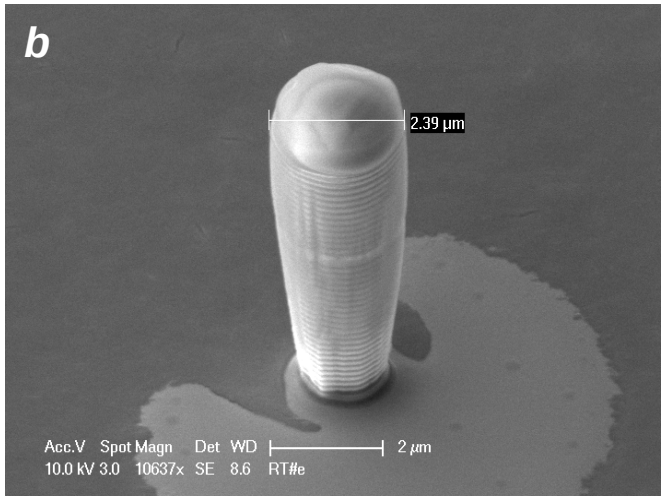
Dry cleans done after every run to "reset" system. System precoats are often recommended

Biggest Issue – Tool Availability – 2nd one is available, ease load on this system

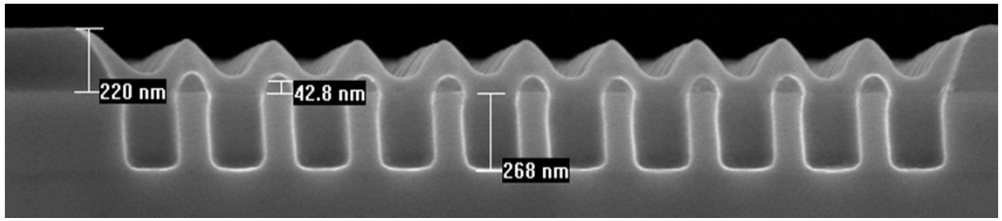
System wet-cleaned on a two-week cycle due to heavy use (up to 18 hours a day)

ICP#2-GaAs-Based Etching

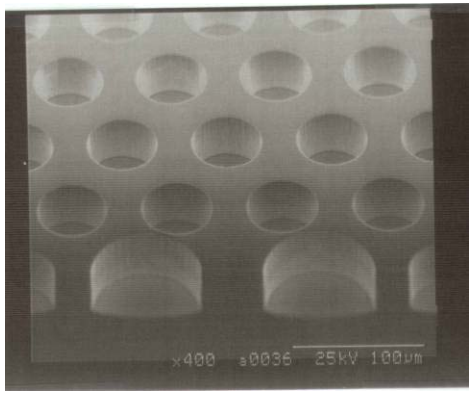




AlGaAs/GaAs Etching with a Vertical Side-wall
Cl_2/N_2:20/10sccm, 0.2Pa, 75/900W,
Etch rate: 600nm/min. (a)AlGaAs/GaAs Ridge;
(b) AlAs/GaAs DBRs. N. Cao

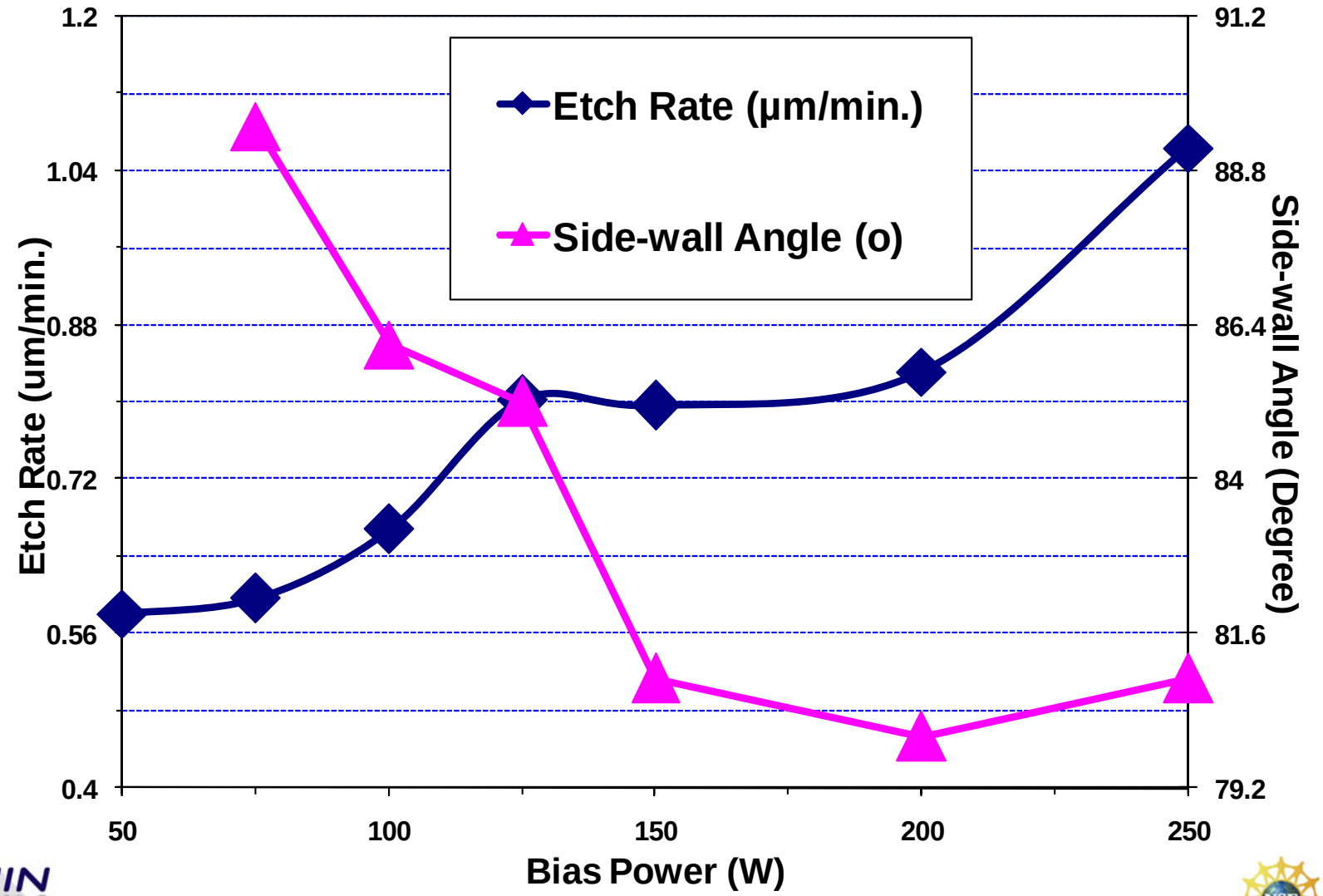


GaAs Photonic Crystals $BCl_3/Cl_2/Ar$, Ebeam Resist Mask, no hard mask, Feature shape well controlled
K. Hennessy



GaAs Deep Via Etching for Terahertz Photonic Crystal $BCl_3/Cl_2/Ar$, 24.5mT, ICP/Bias=900/100W ~8um/min. N. Jukam

ICP#2: AlGaAs/GaAs Etch (Cl_2/N_2:20/10sccm, 0.2Pa, and ICP=900 W)

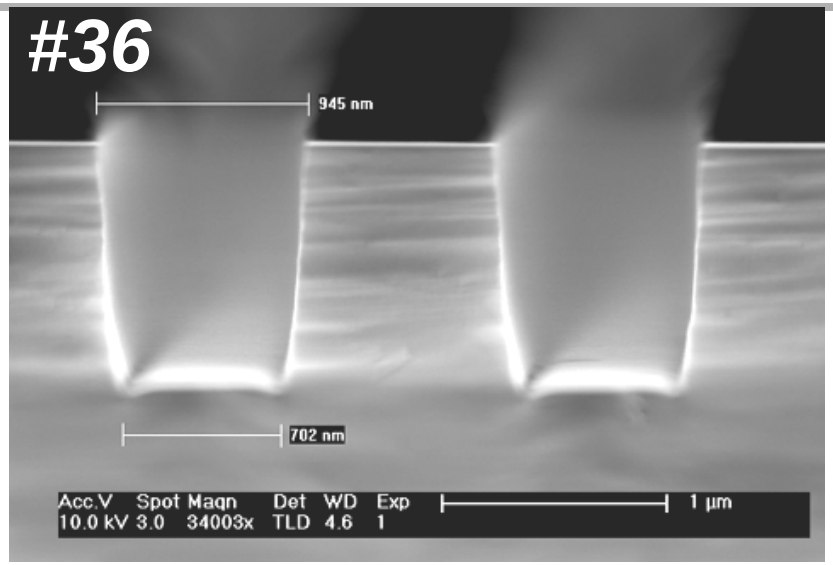


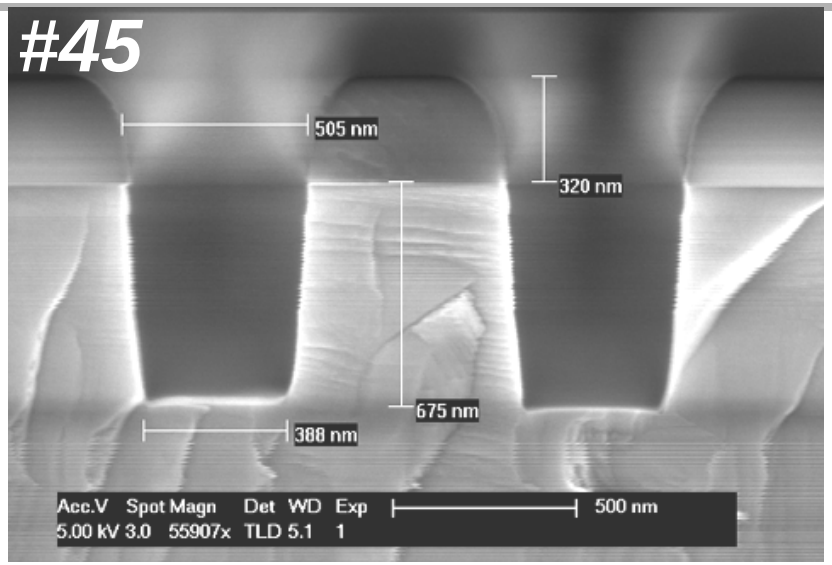
ICP#2-GaN Etching

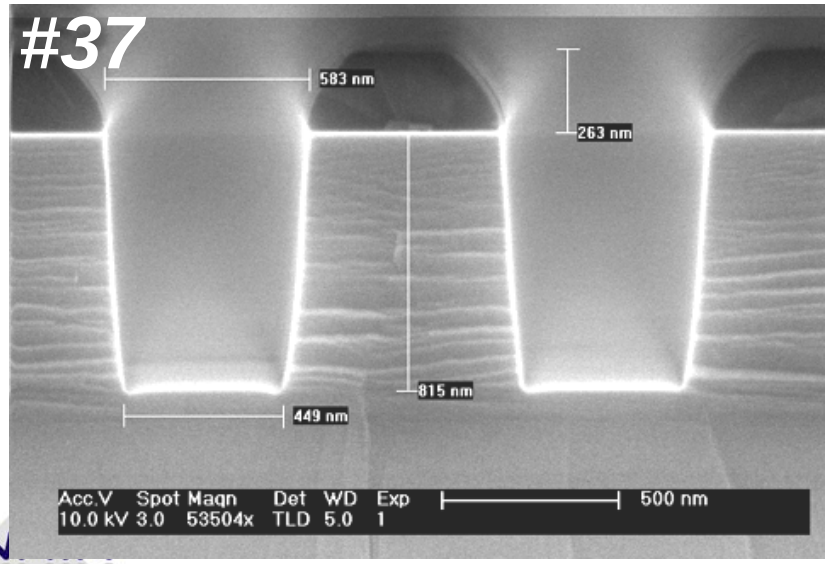
GaN Etch using Panasonic ICP Etcher @Room Temperature

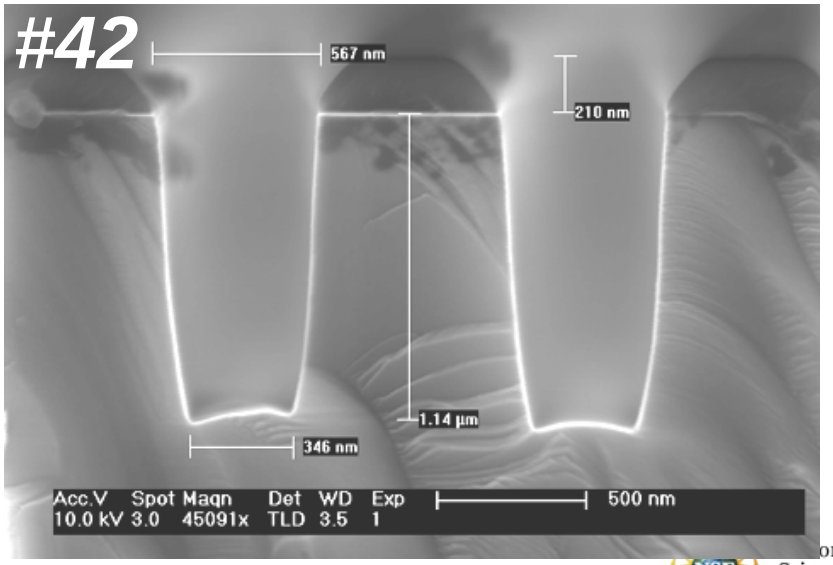
Sample #	Gas Flow Rate (sccm)		Pressure (Pa)	Bias Power (W)	ICP Power (W)	Etch Rate (µm/min.)	Etch Selectivity (GaN/SiO_2)	Side-wall Angle (^{o})
	Cl_2	N_2						
GaN#38	37.5	12.5	1.2	200	500	0.645	13.3	85.2
GaN#46	7	43	0.7	100	500	0.116	5.8	83.1
GaN#30	12.5	37.5	0.7	100	500	0.16	7.1	82.5
GaN#32	12.5	37.5	0.7	200	500	0.26	6.2	79.9
GaN#27	25	25	0.7	100	500	0.202	7.6	83.2
GaN#31	25	25	0.7	200	500	0.35	6.7	85.1
GaN#33	37.5	12.5	0.7	200	500	0.503	7.6	85.4
GaN#34	37.5	12.5	0.35	200	500	0.45	7.1	84.3
GaN#36	37.5	(BCl_3=12.5)	0.35	200	500	0.48	7.9	86.9
GaN#35	50	0	0.35	200	500	0.432	5	82.8
GaN#43	22.5	(Ar=7.5)	0.3	200	500	0.504	4.6	80.3
GaN#40	22.5	7.5	0.2	100	500	0.268	14.3	84.7
GaN#37	22.5	7.5	0.2	200	500	0.336	5.5	86.2
GaN#41	22.5	7.5	0.2	200	900	0.345	6.7	85.8
GaN#42	22.5	7.5	0.2	300	500	0.605	6.2	86
GaN#39	30	0	0.2	200	500	0.44	5.8	83.8
GaN#47	11	33	0.2	50	900	0.0826	5.7	83.3
GaN#44	22.5	7.5	0.15	200	500	0.367	5.4	85.4
GaN#45	22.5	7.5	0.1	200	500	0.356	6.1	86.7
GaN#48	$Cl_2/BCl_3/Ar$:20/8/5		0.67	100	500	0.213	3.8	71.9

ICP#2-GaN Etching

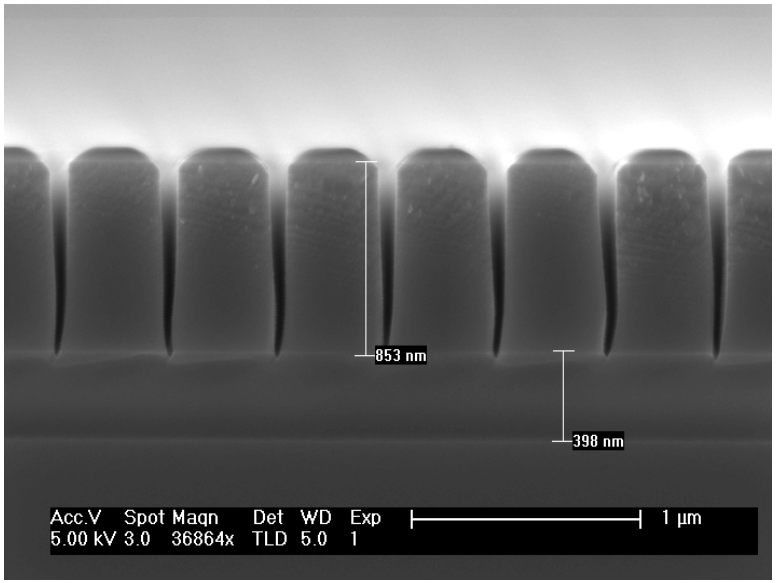




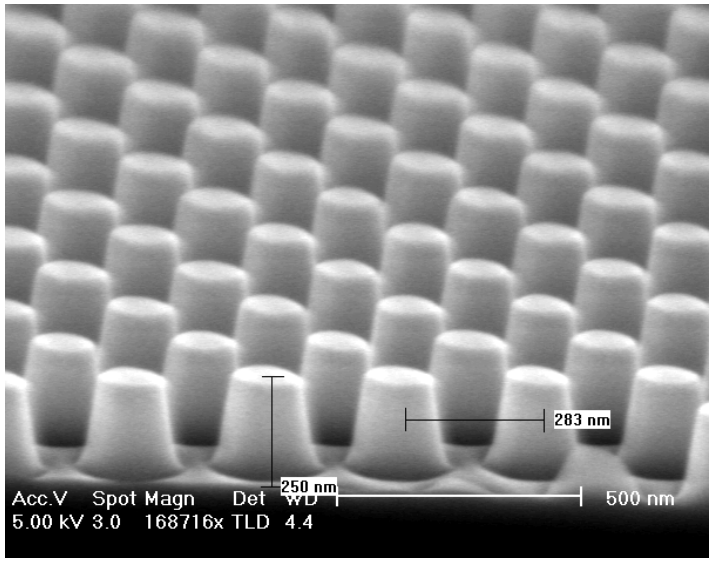




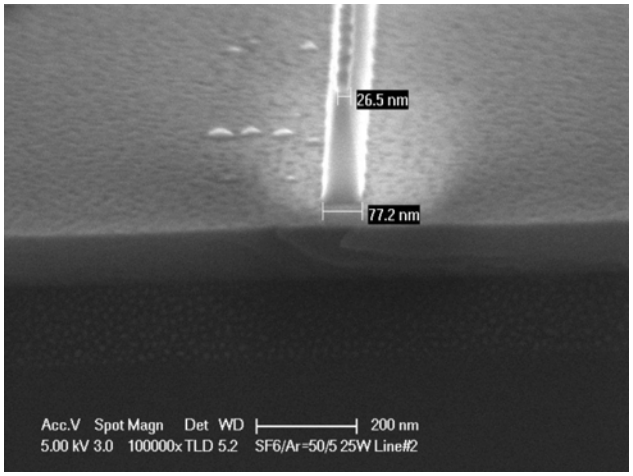
ICP#2 –Silicon Etch (Chlorine Based)



Silicon Etching – BCl_3/Cl_2, 1Pa, 700W ICP, 80W RF, 130nm/min. 60nm lines 15:1 Aspect Ratio Panasonic ICP, A. Parynjpe

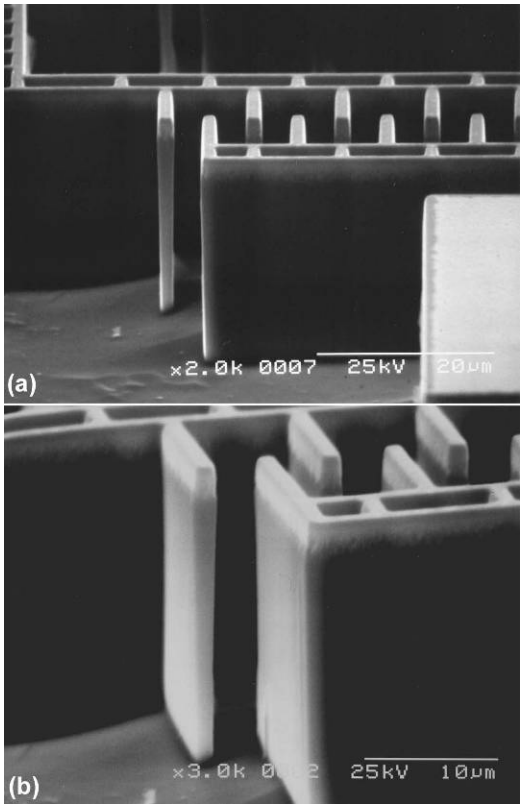


Silicon Etching – Cl_2, 1.2Pa, 400W ICP, 60W RF, 110nm/min. For imprint stamps, Panasonic ICP F. Diana



Left: SiO2 Etching
SF6/Ar:50/5 sccm, 25W RF, Cr mask

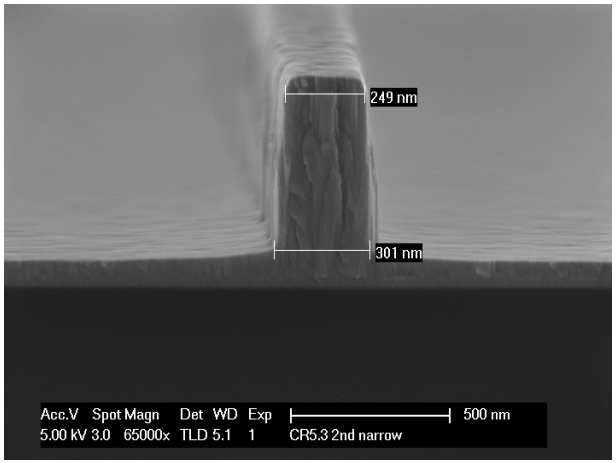
ICP#2 - Metals



High Aspect Ratio Bulk Ti Etching – Cl_2/Ar, 400W ICP, 100W RF. 2um/min Rates
E. Parker, B. Thibeault

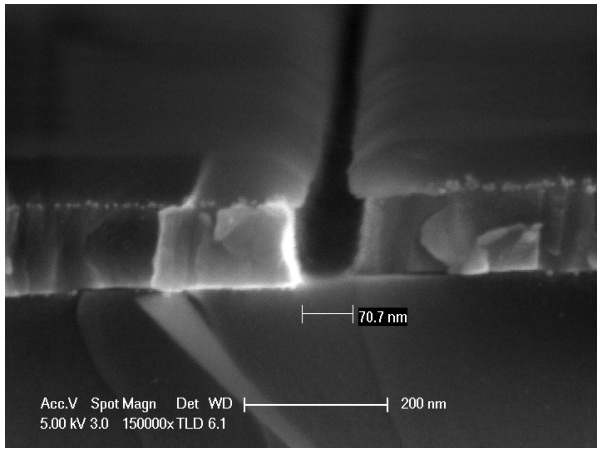
TiW etch:
Gases: SF6/Ar 50/5 sccm
Power: ICP/RF 600/150 W
Pressure: 1 Pa
Etch Rate: ~ 250 nm min
>20:1 selectivity over Cr
For Narrow Emitter HBTs

E. Lind

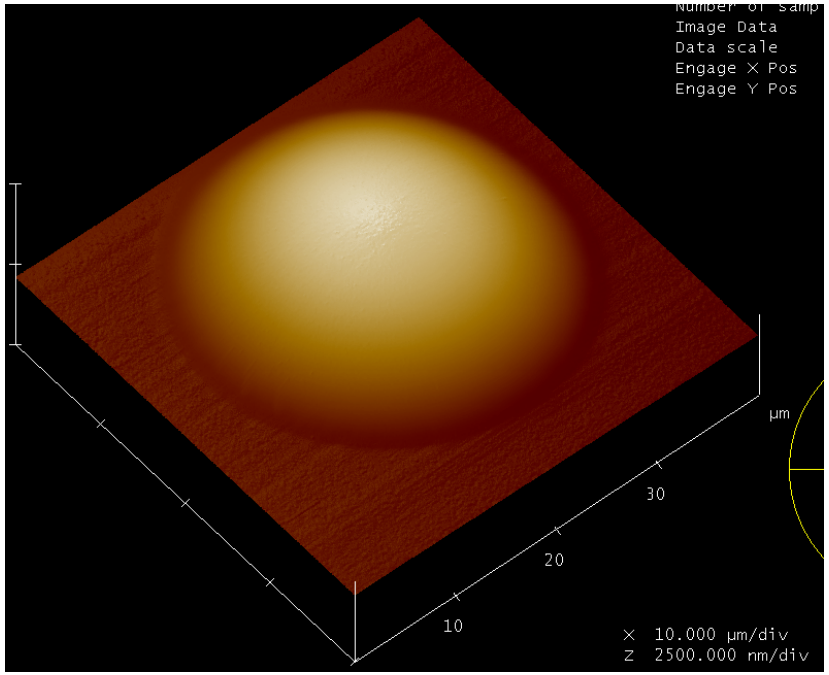


Cr etch – SiO2 mask
Mask not removed
130nm Cr
24sccm Cl2, 6sccm
O2/600W ICP, 50W RF
10 mTorr
Etch Rate = 36nm/min
Slight undercut-reduce
with more RF power

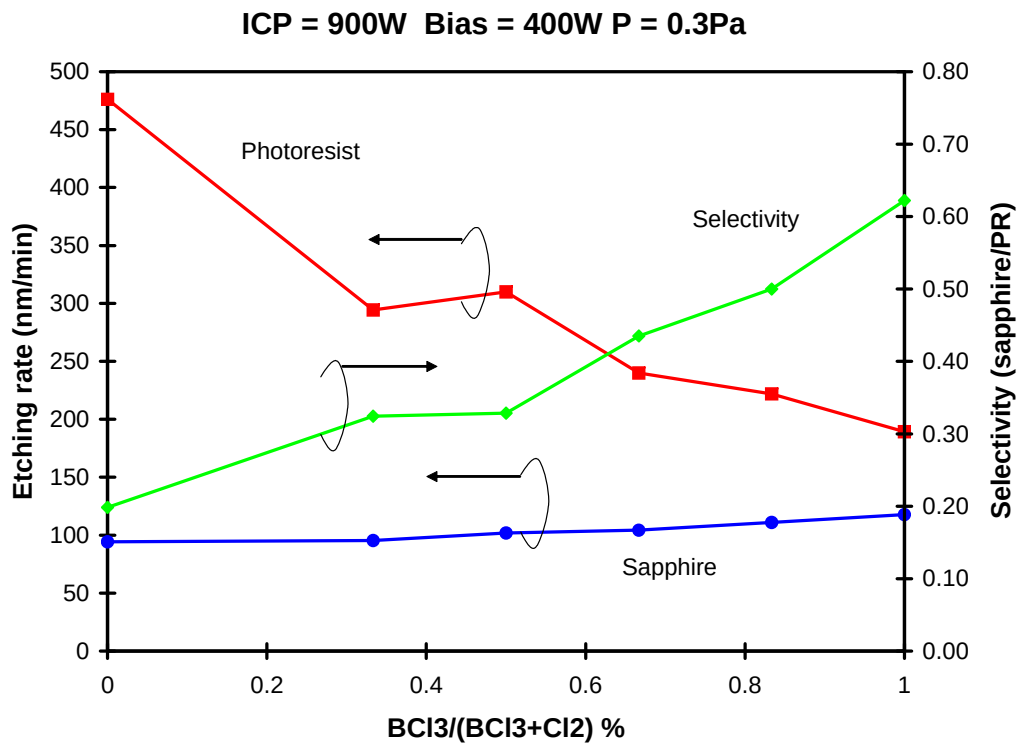
B. Mitchell



ICP#2 - Sapphire Etching



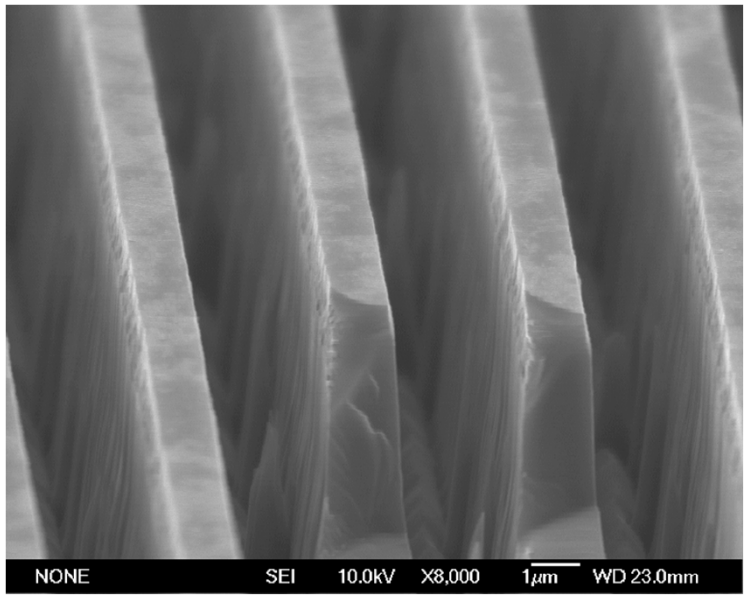
Sapphire Microlenses
Pr reflowed, pattern transferred.
RMS roughness < 1nm



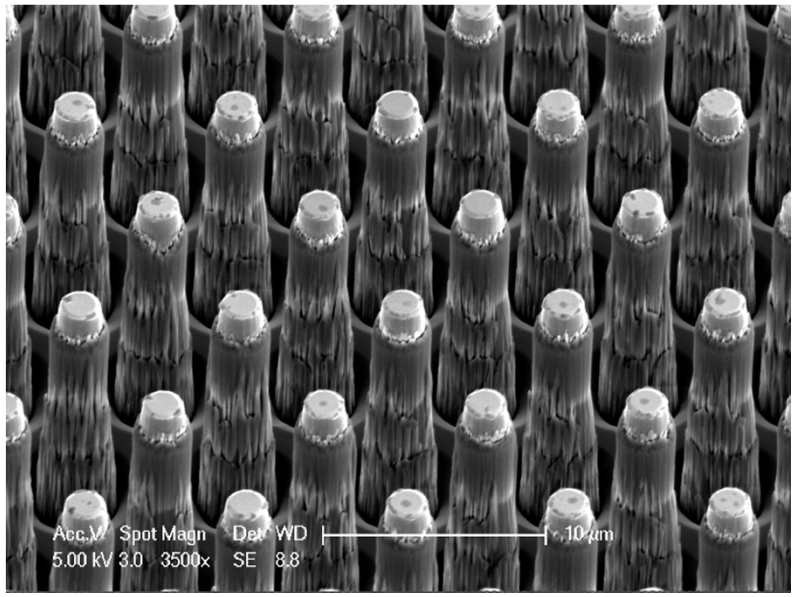
Rates up to 100nm/min. Selectivity controllable to get desired lens shape

R. Farrell

ICP#2 - SiC



Ni mask removed

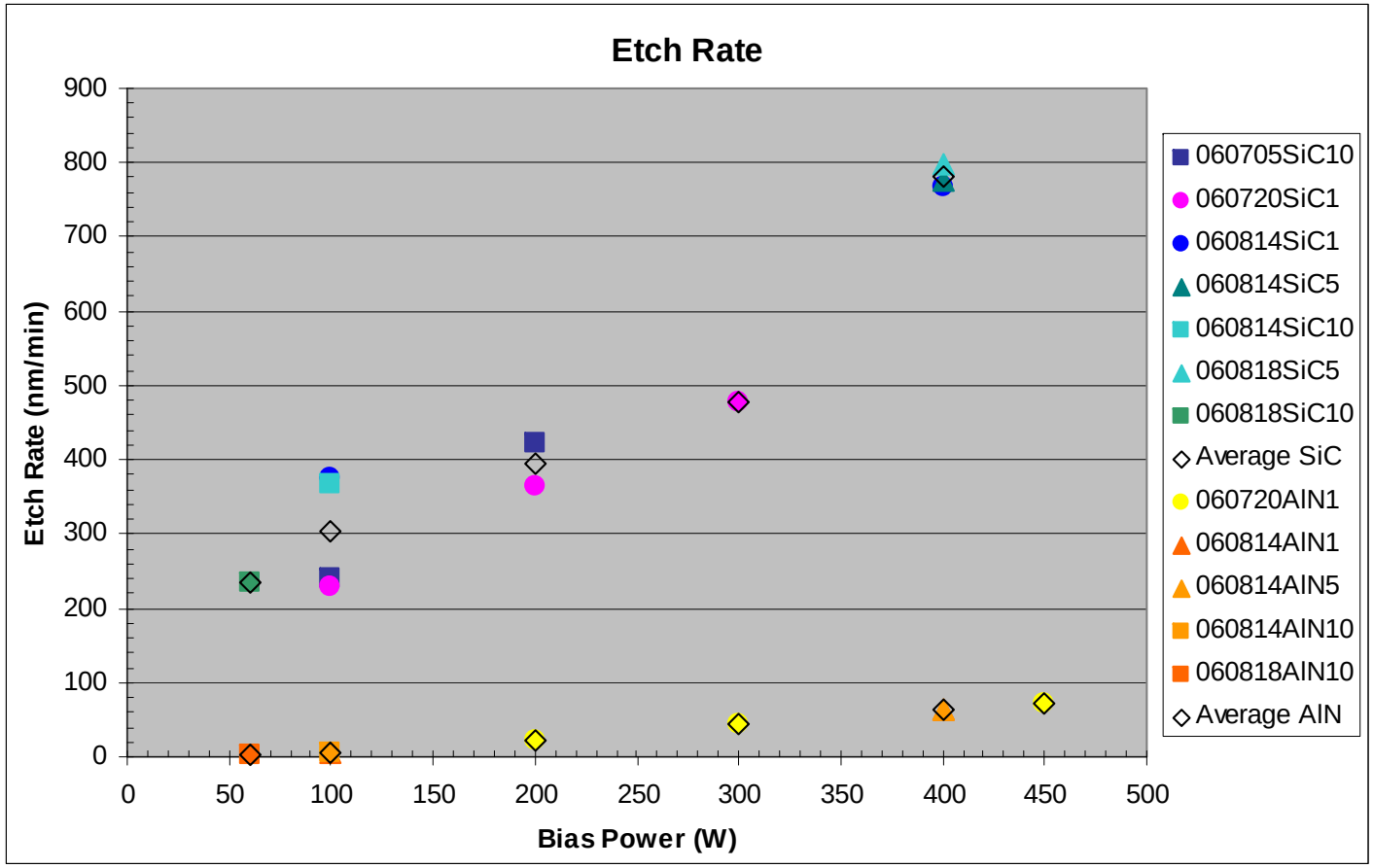


Ni mask remaining
Pillars ~ 10um tall

Deep SiC ridge or pillar/mesa etch
40 sccm SF6
0.8 Pa (6 mT)
900 W ICP, 200 W Bias
Etch Rate: 540 nm/min
Ni hard Mask

S. Newman, K. Vampola, C. Neufeld

ICP#2 - SiC



For Substrate Removal – Stop on AlN

ICP Power = 900 W
SF6 Gas 40 sccm
Pressure 0.8 Pa
Aluminum Carrier Wafer

Highest ER for SiC ~ 800nm/min.
High selectivity > 100:1 with AlN at low power

K. Vampola

Etcher 7 (ICP#3)-Chlorine Based

Unaxis VLR tool

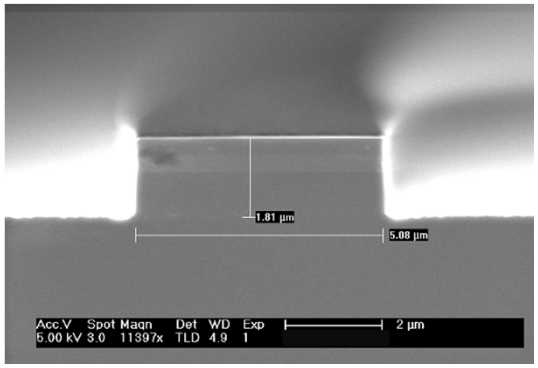
- *Chlorine-based Load-locked System, turbo-pumped*
- *RT – 200 C, 4" Electrode, Heated walls and liner, ceramic clamp*
- *He cooling. Pieces mounted with DOW silicone thermal grease*
- *1 kW, 2 MHz ICP source, 500 W RF Bias source*
- *Laser monitoring – Vis.*
- *Cl_2, BCl_3, H_2, O_2, Ar, SF_6, N_2*
- *InP and related compounds, all other III-V As,N,P,Sb materials*

Primarily used for InP and related compounds at 200 C etching temperature, due to $InCl_X$ volatility issues

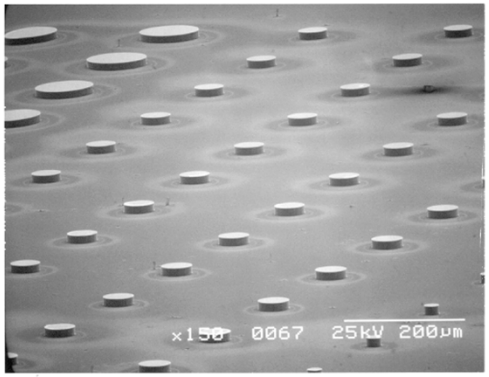
SF6 added to chamber for selective etching of GaN/ AlGaN

Sapphire and Silicon carrier wafers used.

ICP#3-InP Based Etching (Cl_2/N_2 @200 C)

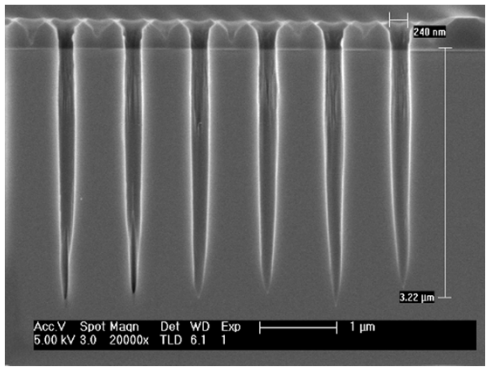


Recipe1 – InP/InGaAsP Mesa

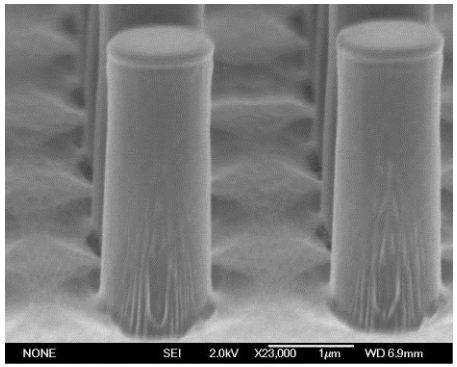


Recipe2 – InGaAlAs/InAlAs DBRs – 10um deep posts

		Recipe 1 (High Aspect-Ratio)	Recipe 2 (Deep Mesa Etch)	Recipe 3 (PC Hole Etch#1, 0.24 µm)	Recipe 4 (PC Hole Etch#2, 0.35 µm)	Recipe 5 (PC Hole Etch#3, 0.5 µm)	Recipe 6 (Post Etch#1)	Recipe 7 (Post Etch#2)
Pressure (mT)		7	7	1	5	2.5	5	1
Bias Power (W)		100	75	250	200	125	125	125
ICP Power (W)		500	900	900	900	500	900	500
Gas Flowing Rate (sccm)	Cl_2	10	15	2.5	20	12.5	20	4
	N_2	70	45	12.5 (Ar)	60	27.5	60	6
Substrate Temperature (^{0}C)		200	200	200	200	200	200	200
Etch Rate (µm/minute)		0.27 (InP)	0.42 (AlInGaAs/AlInAs)	N/A	0.68 (InP)	0.53 (InP)	0.52 (InP)	N/A
Etch Mask		SiO_2	SrF2	SiO_2	SiO_2	SiO_2	SiO_2	SiO_2
Etch Selectivity		7	120	N/A	10	12	13	N/A



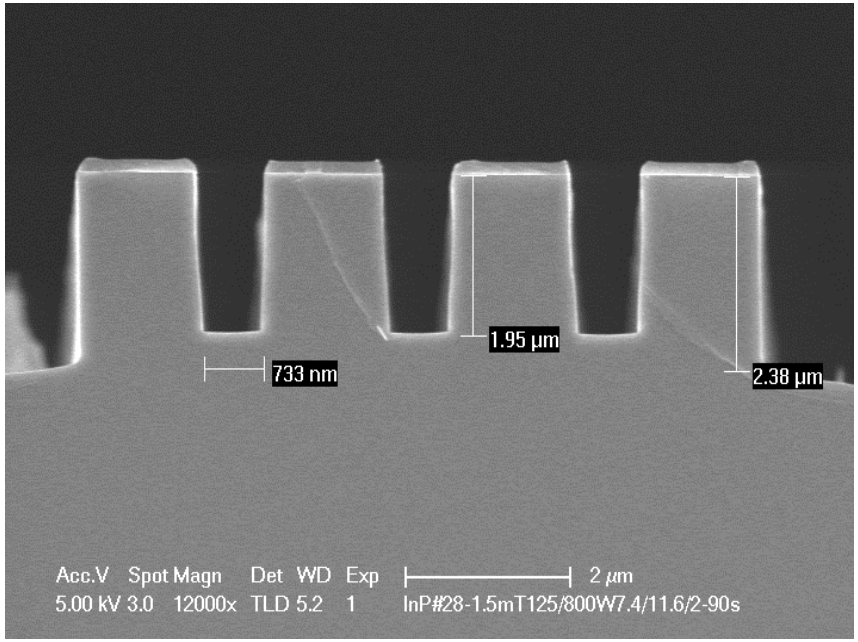
Recipe3 High Aspect Ratio Etch – Photonic crystal - InP



Recipe6 Smooth Vertical Posts - InP

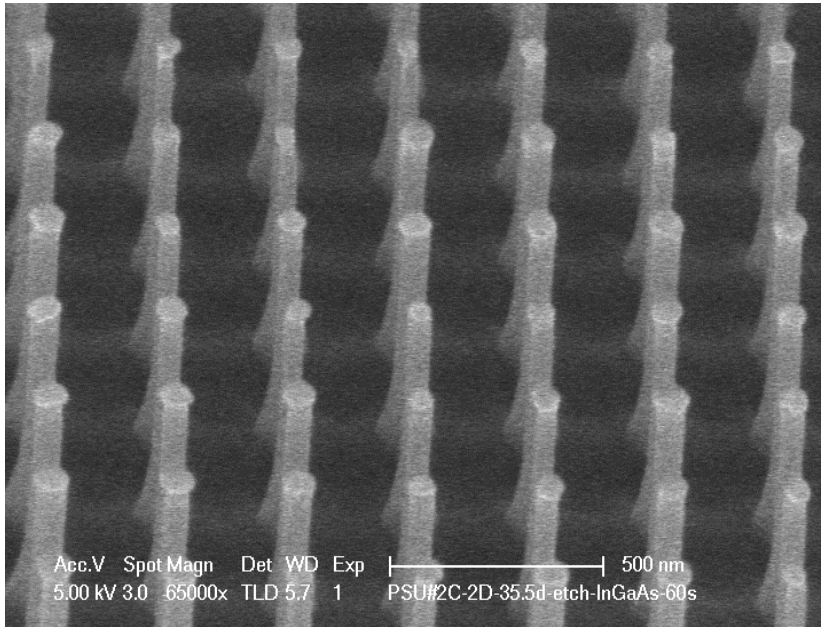
ICP#3-InP Based Etching ($Cl_2/H_2/Ar$@200 C)

InP Etch with $Cl_2/H_2/Ar$ Chemistry
Flat Trench Bottom (no Micro-trench)



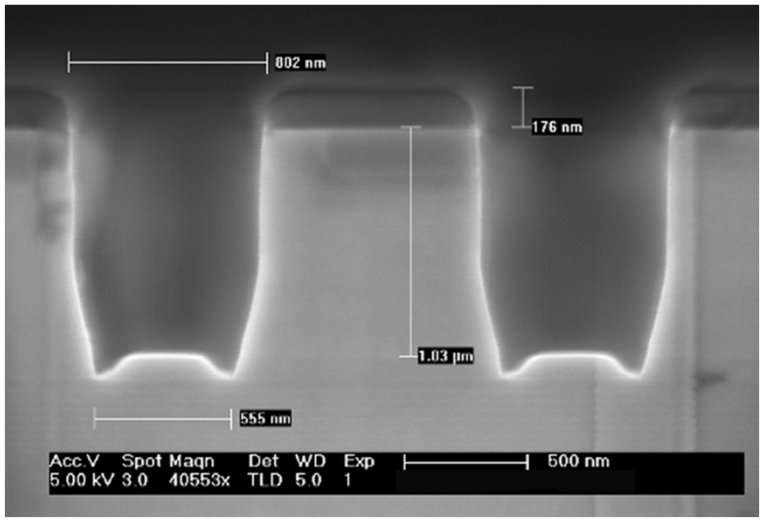
1.5mT, 125/800W, $Cl_2/H_2/Ar$
Flow-rate=7.4/11.6/2SCCM, and time=90 s
Etch Rate=1.57μm/min (open area),
Etch Selectivity(InP/SiO_2)=15.5

InGaAs nano-wires: 1.5mT, 125/800W,
$Cl_2/H_2/Ar$=7.4/11.6/2SCCM, and time=60 s



ICP#3-Other III-V Material Etch

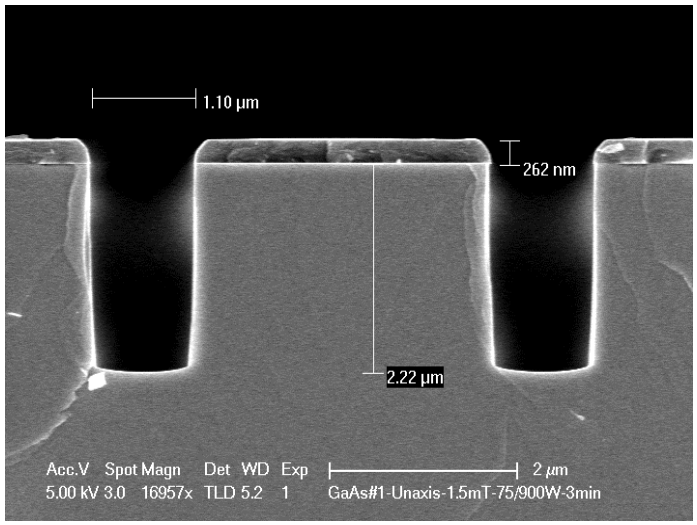
GaN Mesa Etch@85 C



Cl_2/N_2:25/25sccm,5mT,
100(142v)/500W,
Etch Rate: 0.34µm/min
Selectivity(GaN/SiO_2):4.4

(Ning Cao)

GaAs Trench Etch @30 C



Cl_2/N_2:20/10sccm,1.5mT,
75 (120v)/900W,
Etch Rate: 0.74µm/min
Selectivity($GaAs/SiO_2$):9.9

(Ning Cao)

Etcher 8 (ICP#4)-Fluorine/Chlorine Based

UCSB Nanofabrication Facility

ICP#4

Panasonic E620 ICP Etcher

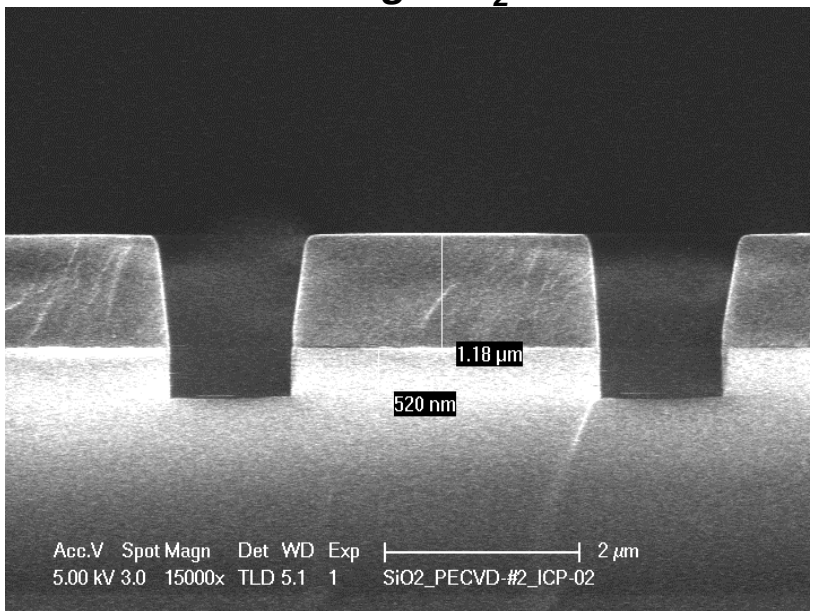
- *Multi-Purpose ICP etcher*
- *1.25kW ICP, Pancake style, 13.56 MHz. 600 W Sample bias source power.*
- *RT – 80 C, 6" Electrode, Electrostatic Chuck, 6" silicon carrier wafers, Back-side He Cooling*
- *Pieces mounted with Diff Pump Oil (Santovac 5)*
- *Cl_2, BCl_3, CF_4, SF_6, CHF_3, N_2, Ar, O_2, He*
- *Load-Locked*
- *Up to 20 steps per recipe*
- *III-V As/N. Ceramics, Dielectrics, Metals, Silicon.*
- *Various Masks used depending on chemistry*
- *Etch pressure from 0.1Pa (0.75mT) to 5Pa (37.5mT)*

Dry cleans done after every run to "reset" system. System pre-coats are often recommended

System wet-cleaned on a two-week cycle due to heavy use (up to 18 hours a day)

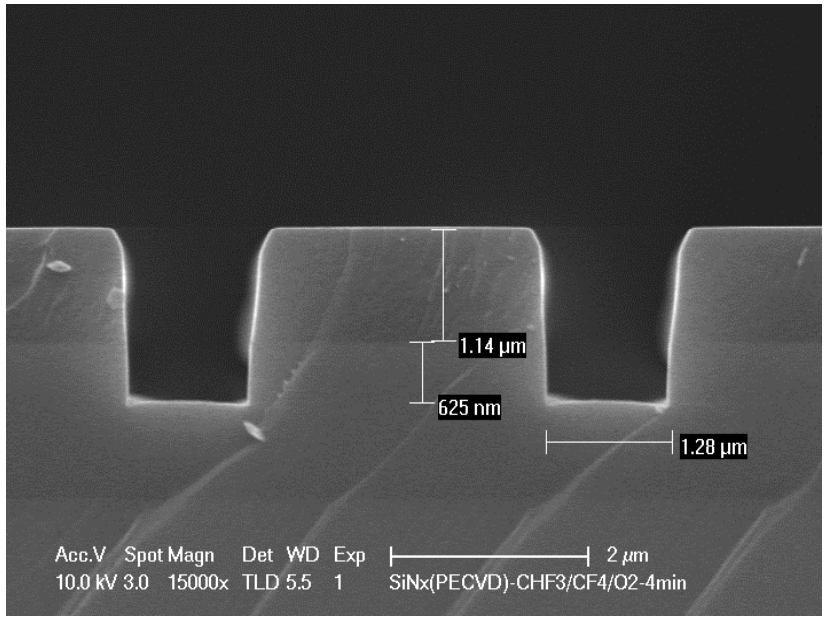
ICP#4-Etching Dielectrics

Etching SiO_2



0.5Pa (3.75mT), CF4/CHF3: 20/20 sccm, 50/900W. Etch Rate: 107nm/min.
Selectivity (SiO2/PR): 1.5
N. Cao

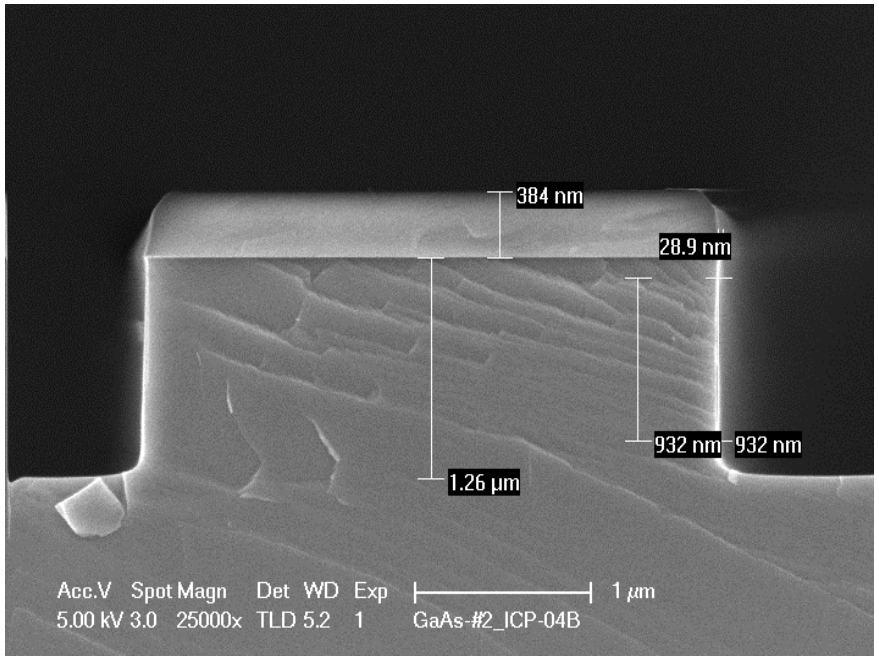
Etching SiN_x



0.5Pa (3.75mT), CHF3/CF4/O2: 35/5/10 sccm, 50/500W. Etch Rate: 155 nm/min.
Selectivity (SiN_x/PR): 1.7
B. Mitchell

ICP#4-Etching GaAs

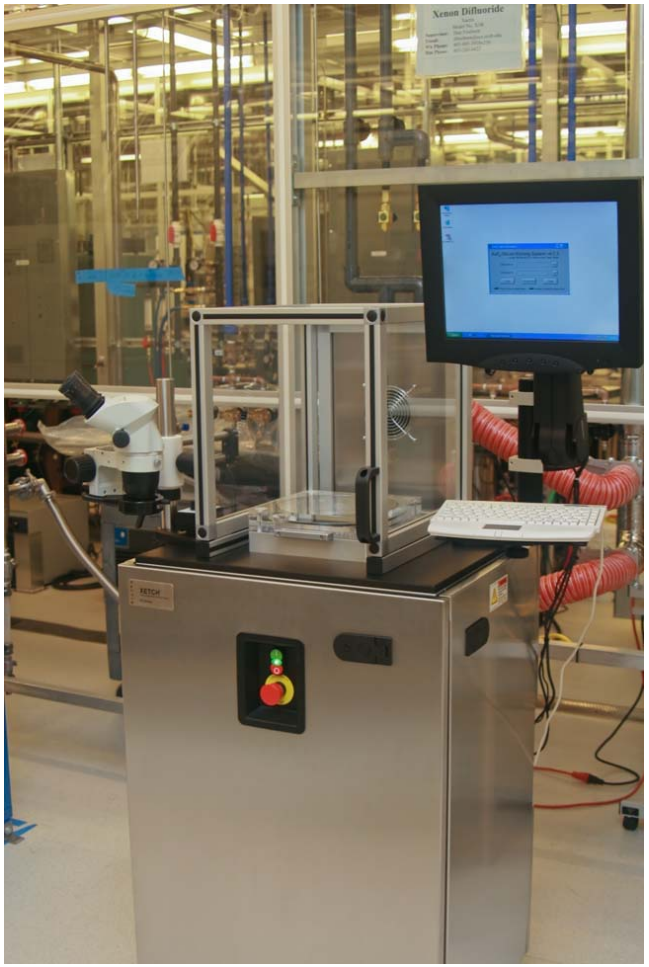
Etching GaAs



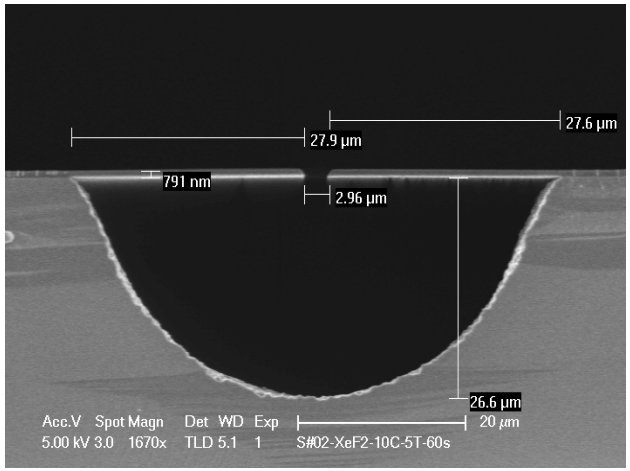
0.2Pa (1.5mT), 75/900W
Cl2/N2: 15/10 sccm
Etch rate: 403nm/min
Selectivity (GaAs/SiO2): 13.2

XeF_2 Gas Etcher

Xetch-X3



- *Using Gaseous XeF_2 (no plasma, no heating)*
- *Isotropically dry etch of Si, Ga, Mo.*
- *SiO_2, PR, Al Masks*
- *Running in a Pulsed Mode: Etch chamber repeatedly filled with XeF_2, then, pumped out (to 0.3 Torr)*
- *Flexible operation software*
- *Monitoring Microscope attached*



Etching Si

PR Mask

3-µm window line

Pressure: 5 Torr

10 Cycles

Cycle Time: 60 s

Vapor HF Etcher

SPTS μEtch VHF Etcher

- *DRY vapor phase process*
- *Stiction-free*
- *Process up to 1 x200mm wafer per run*
- *Operating pressure range 50-150 torr*
- *Wafer temperature by resistive element heaters*
- *Etch rate range: 100 Å/min-1000 Å/min*
- *Etched materials: thermal oxide, TEOS, SOI bonded oxide, quartz, PECVD oxide (SiH_4+N_2O, bake after etch)*
- *Mask materials: Si, Al_2O_3, SiC, Al, Au, Ni, Cr*

Oxygen Radical Downstream Asher

Gasonics Aura 2000-LL Downstream Asher

- *Aura 2000 system: a microwave downstream asher to remove resist and other organic materials.*
- *Reactive oxygen flowing through a showerhead to expose sample, no ion bombardment*
- *8" carrier wafer*
- *Sample heating by lamps: 100 ~350 C*
- *Resist etch rates : up to several microns per minute*
- *Effective removal of fluorine and chlorine plasma exposed resist*

Technics PE-IIA Plasma Etching Systems

- These two parallel plate plasma systems: clean organic residue, etch organic films, or etch Si_3N_4 film
- Oxygen plasma wafer-surface treatment for facilitating wetting of water-based etchants
- Right one has CF_4/O_2 88%/12% for etching Si_3N_4
- CF_4/O_2 and O_2 gases
- ~10mT ultimate chamber pressure
- 100kHz directly coupled excitation source
- Sample size: piece to 6" wafer
- Gas flow and power control
- Typical process conditions:
  - Ashing: O_2 300mT, 100W, 30 sec.
  - Si_3N_4 Etching: CF_4/O_2, 300mT, 100W, etch rate~150 nm/min.