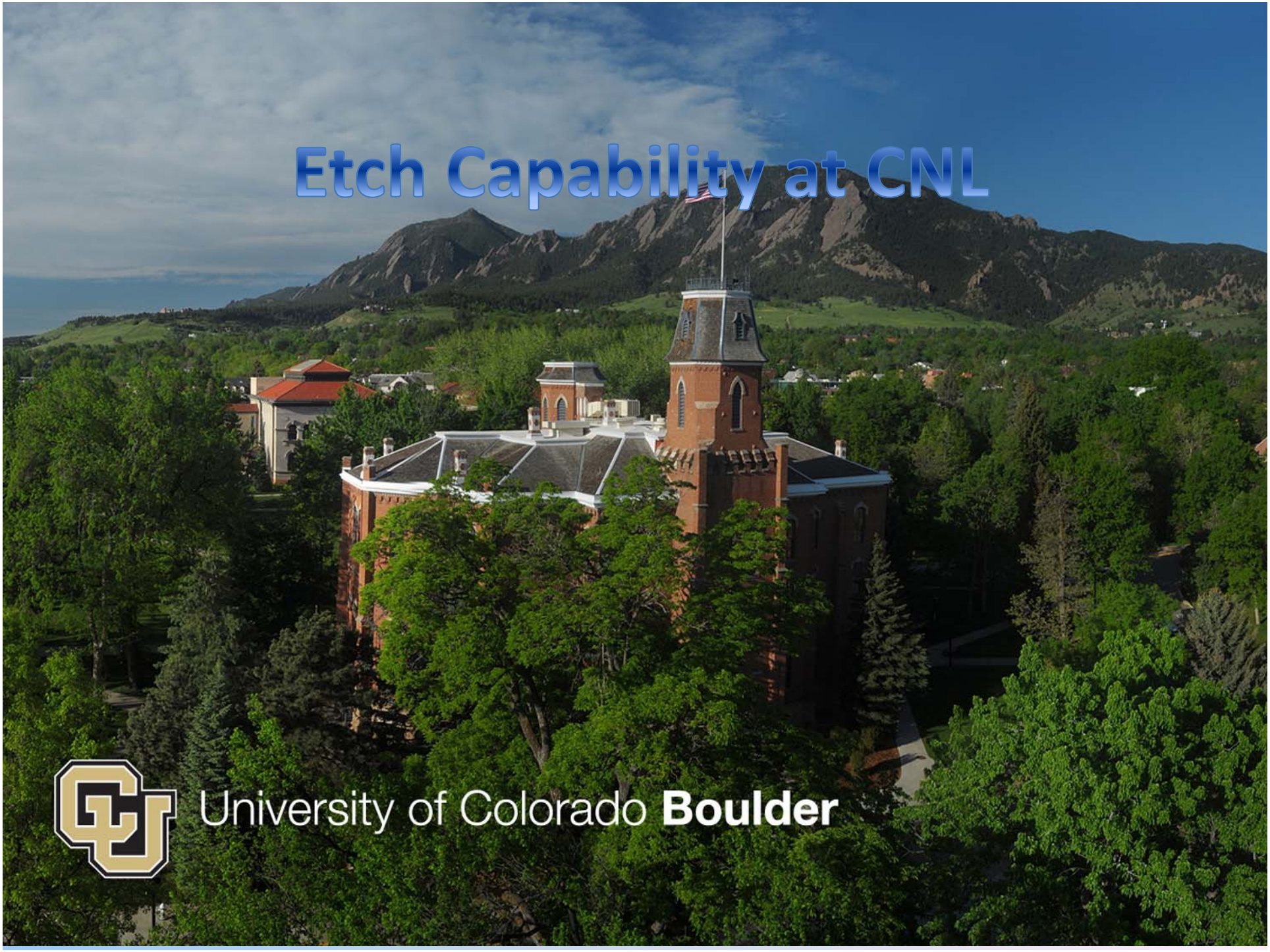
Etch Capability at CNL

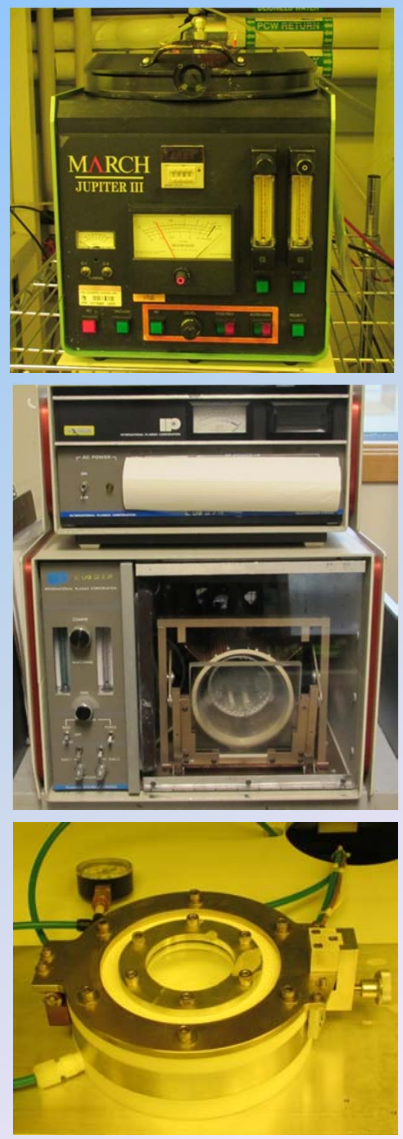


University of Colorado **Boulder**

Colorado Nanofabrication Lab

Outline

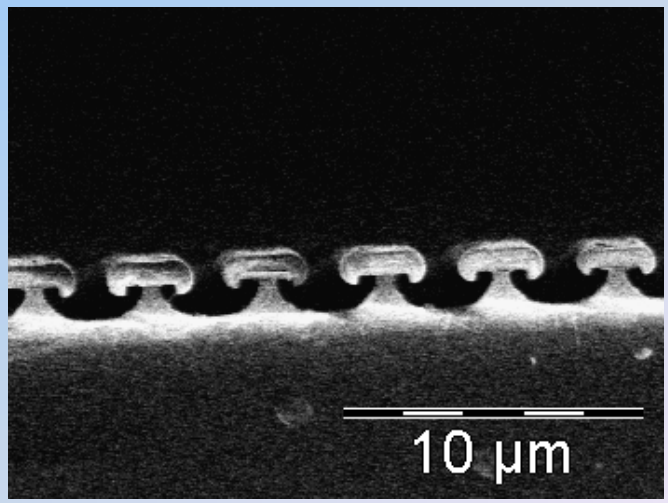
- Overview of CNL's etchers
- RIE I
  - Silicon carbide etch process
- RIE II
  - Anisotropic Si etch process
  - Silicon dioxide etch process
- STS ICP etcher
  - Anisotropic Si etch process
  - HSQ process
- Conclusions



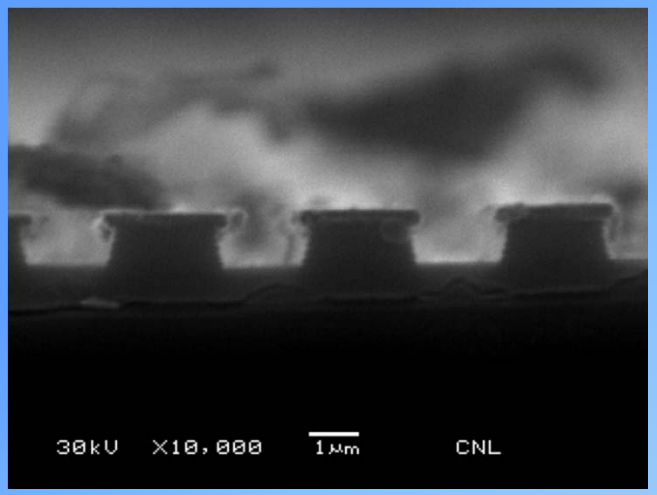
RIE I: Plasmatherm 540/540 Dual Chamber RIE system

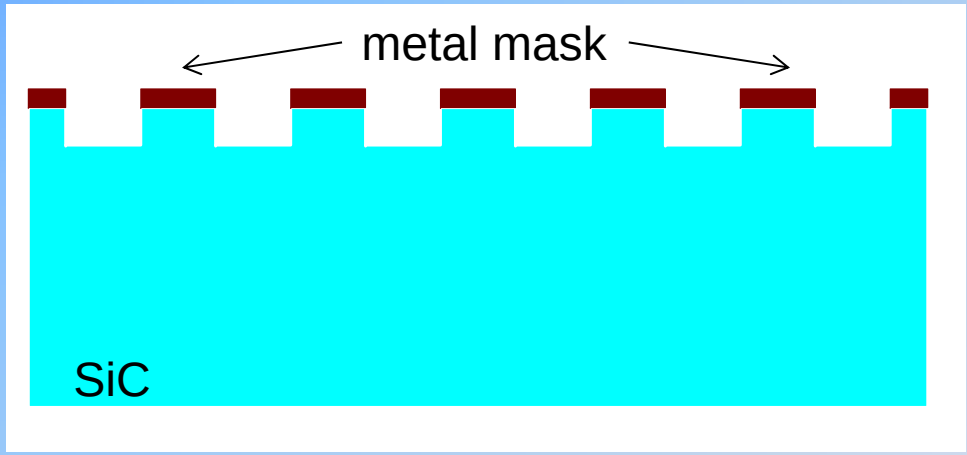
- ***Right chamber***: F-based etch
  - Almost isotropic Si etch (gas/pressure)
- ***Left chamber***: currently not in use

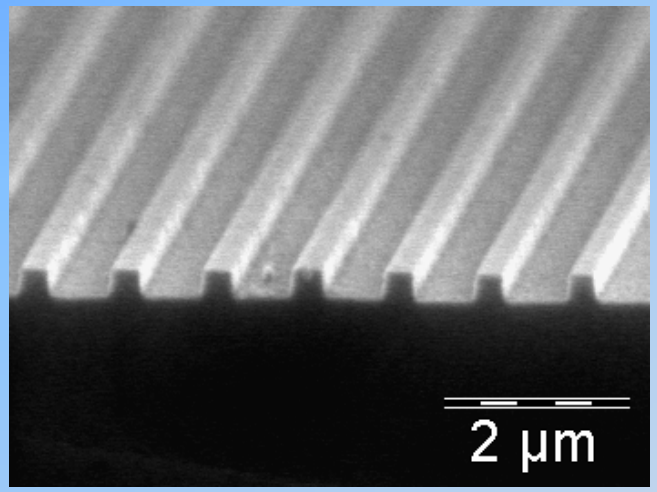
- ***Materials not allowed***: CaS, Cd, Pb, Se, S, Sb etc. (materials poisoning the vacuum system) and radioactive materials. Toxic materials need prior permission.



Emitter ridge etching







Test structure
Line width: 300 nm
Spacing: 700 nm
RIE etch: SF_6 100 mTorr, 150 W, 5 min
SiC etch depth: 200 nm

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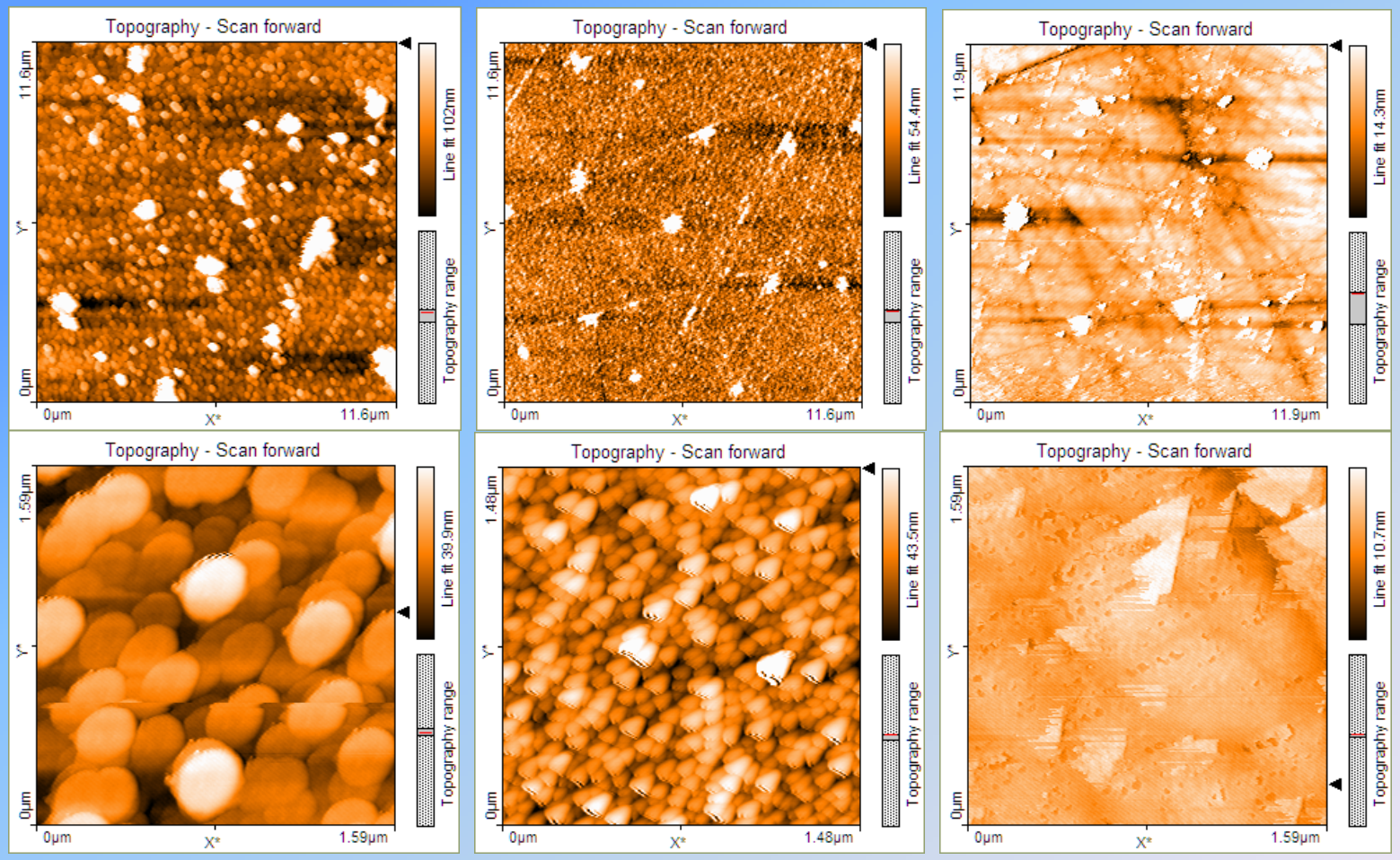
SiC surface cleaning after RIE



(a) After SF6 RIE **(b) After dry oxidation** **(c) After BOE cleaning**

Micromasking effect?

SiC field emitter fabrication

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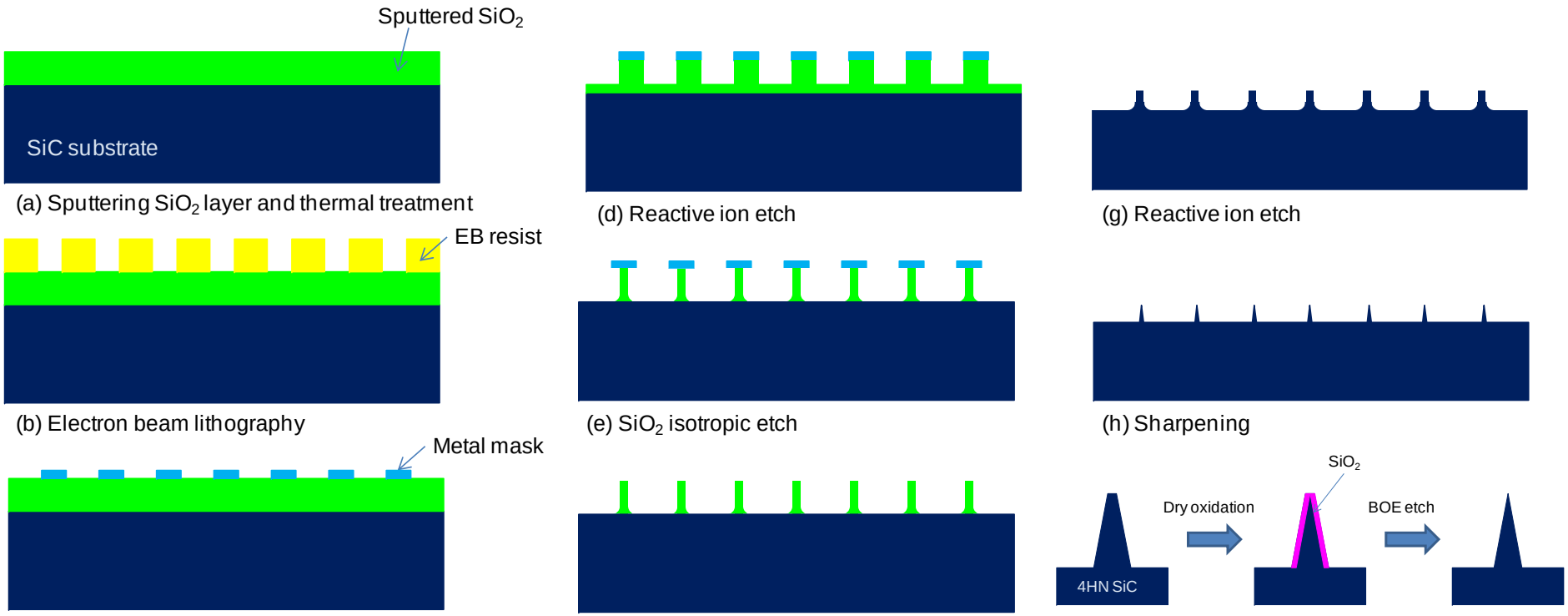

(a) Sputtering SiO_2 layer and thermal treatment

(b) Electron beam lithography

(c) Lift off to create metal mask

(d) Reactive ion etch

(e) SiO_2 isotropic etch

(f) Metal mask removal

(g) Reactive ion etch

(h) Sharpening

(h) Sharpening (in detail)

SiO_2 pillars and SiC emitters

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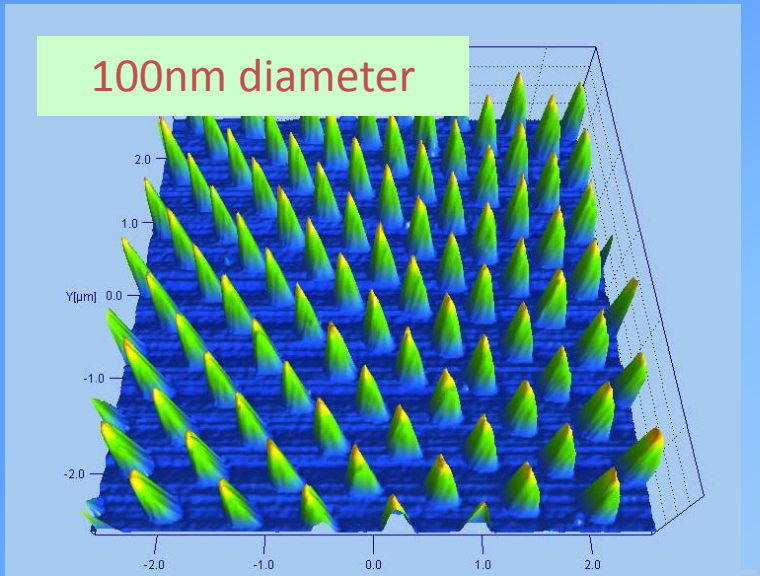

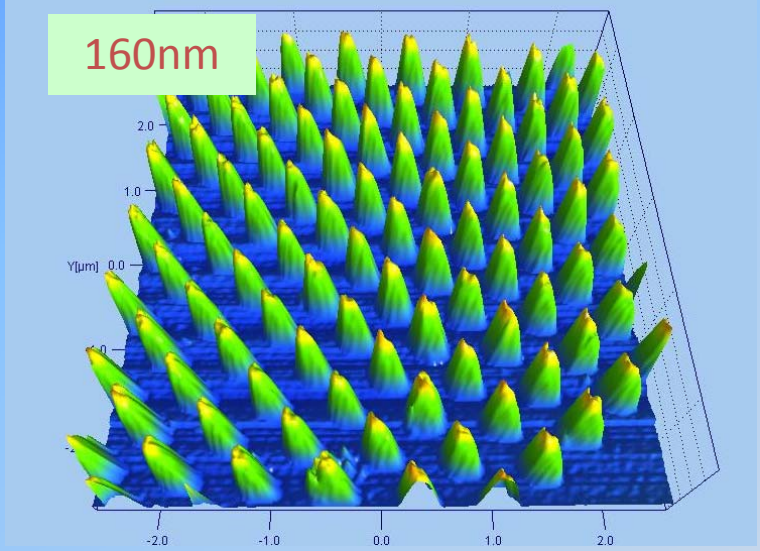

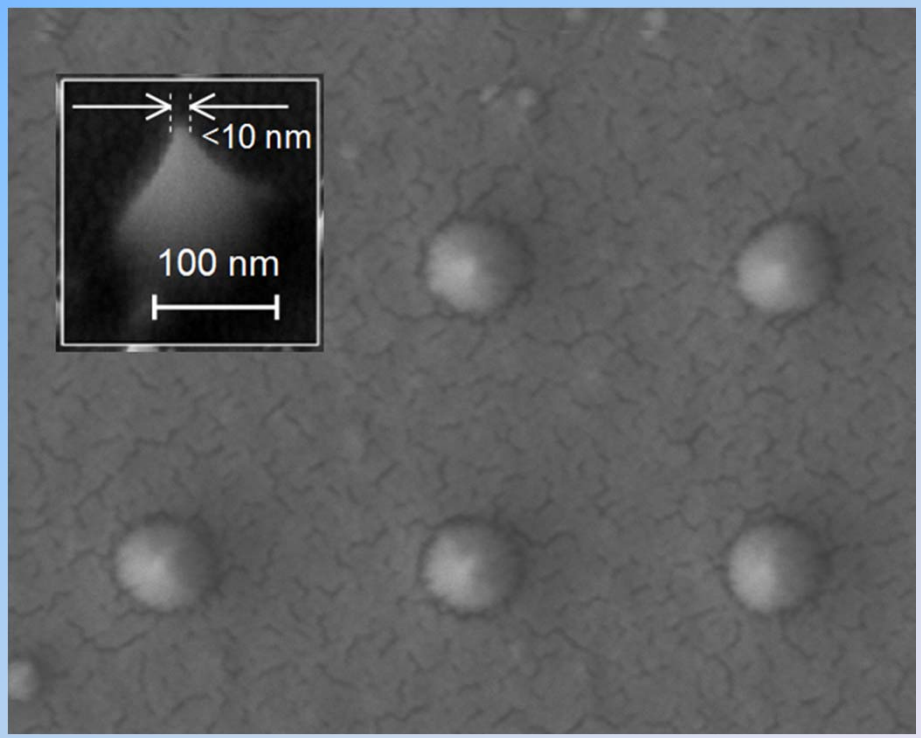

RIE II: Plasmatherm Dual Chamber RIE system

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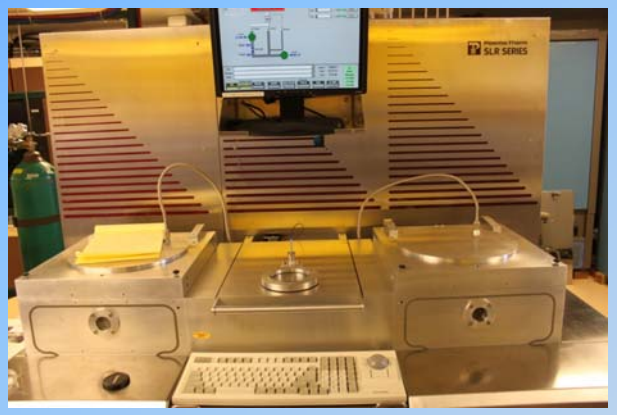
Left chamber

- Chlorine-based etch
- III-V compounds
- Gases: BCl_3, Ar
- Slow



Right chamber

- Fluorine-based etch
- Si, SiC, SiO_2, Si_3N_4 , refractory metals (such as W and Ta)
- Mask material: Si oxide, Si nitride, photoresist, EB resist, Cr and Ni
- Gases: CF_4, O_2, SF_6, CHF_3
- Current processes
  - Anisotropic Si etch with SF_6/CHF_3
  - Silicon dioxide etch with CF_4/CHF_3
  - Silicon dioxide etch with CF_4/O_2
  - Graphene etch with O_2

This conventional dual chamber reactive ion etcher operates at pressures between 10 to 500 mTorr with an 13.56 MHz RF etch power up to 500 Watts. The vacuum system is setup with a roughing pump and turbopump.

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Anisotropic Si RIE

- SF_6-CHF_3 gas mixture
- Effect of pressure
- Oxide mask (PR mask)
- Etch rate/Selectivity/Etch profile

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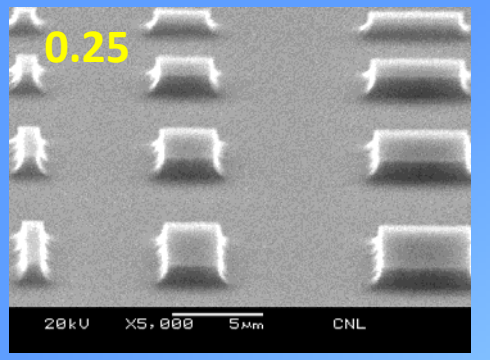
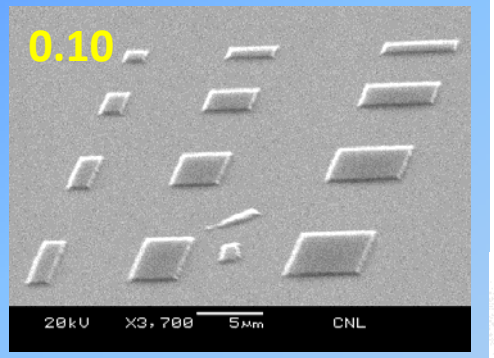
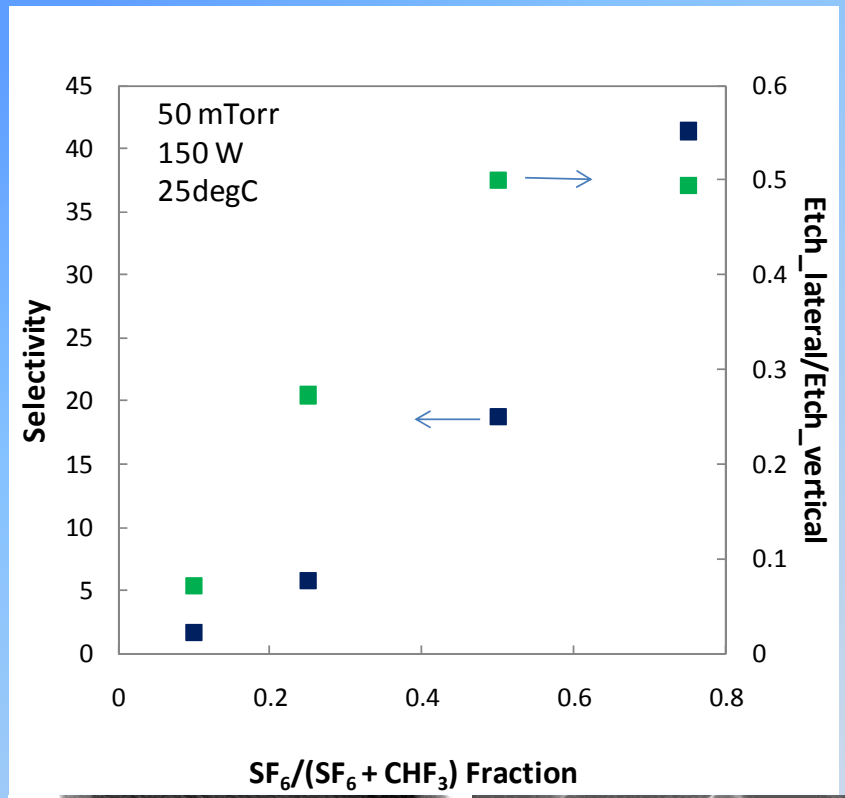
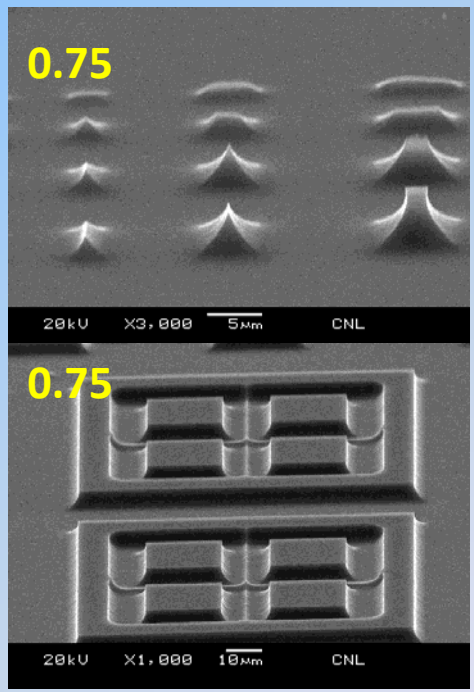
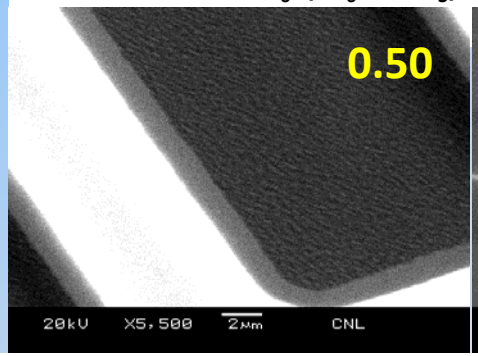
Results: Effect of Gas Composition @ 50 mTorr

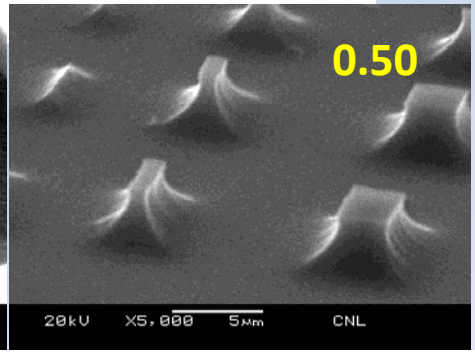












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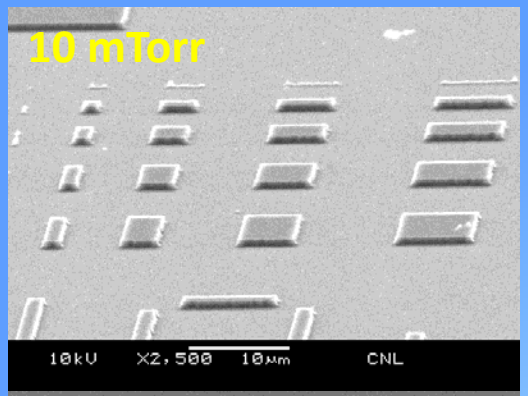
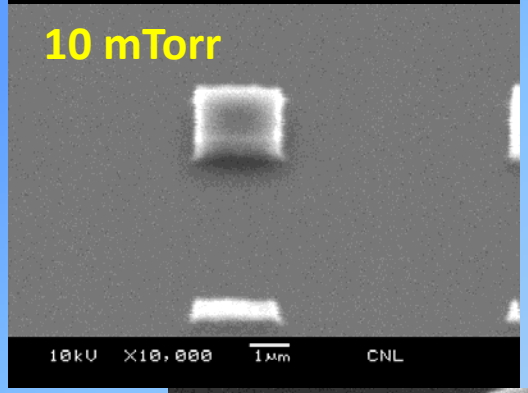
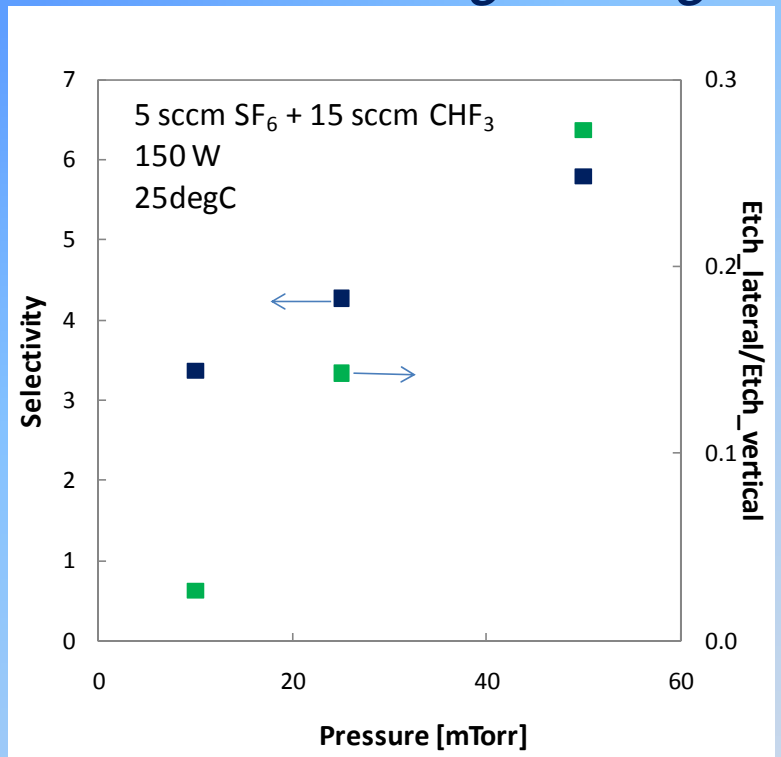
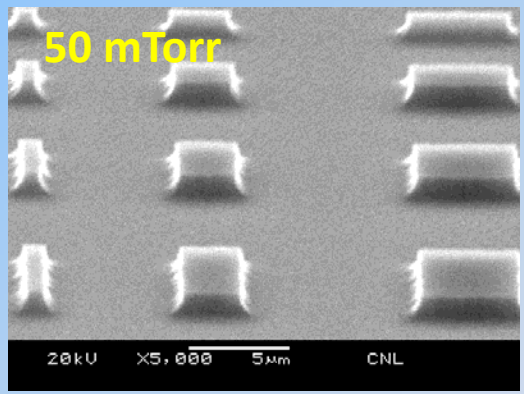
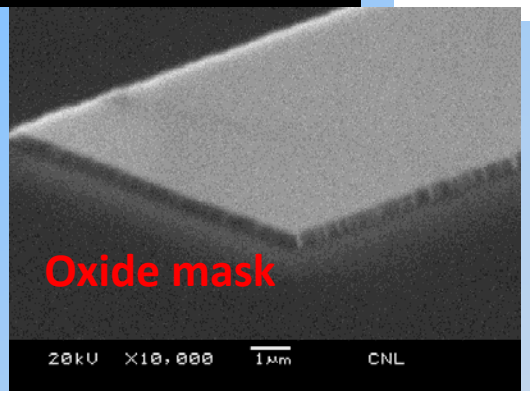
Results: Effect of Pressure @ 0.25 $SF_6/(SF_6 + CHF_3)$

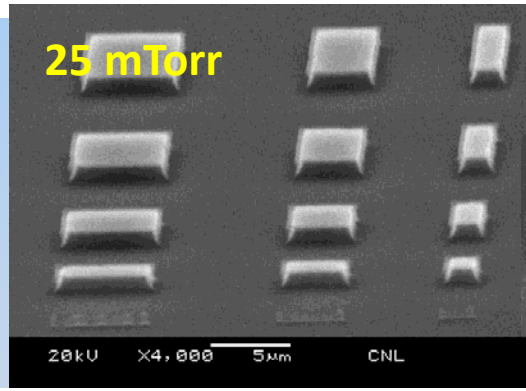


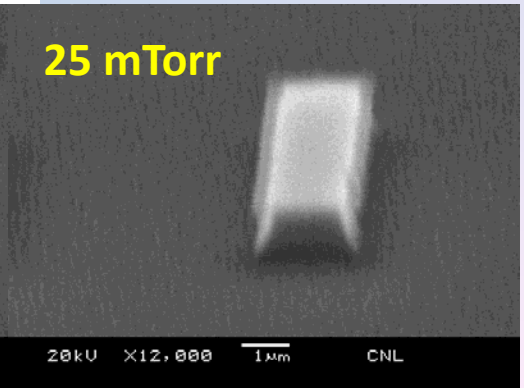












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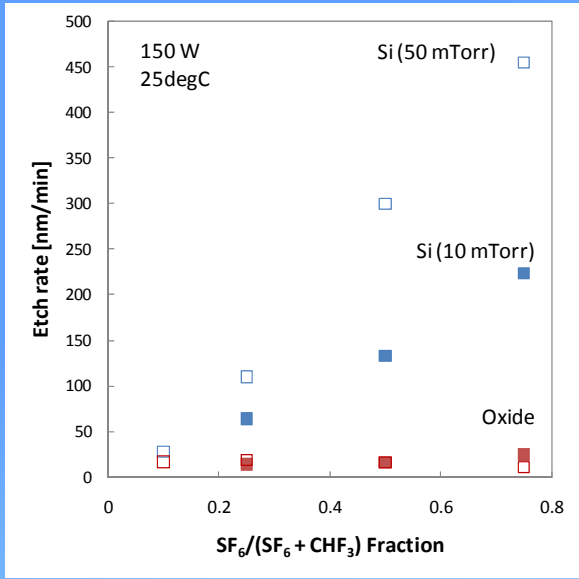
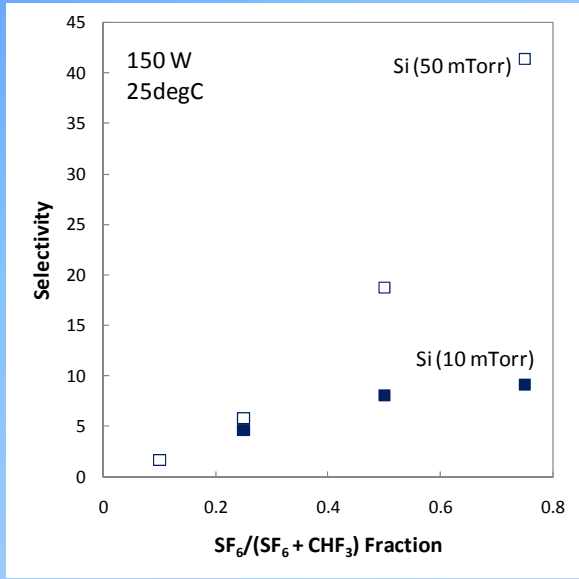
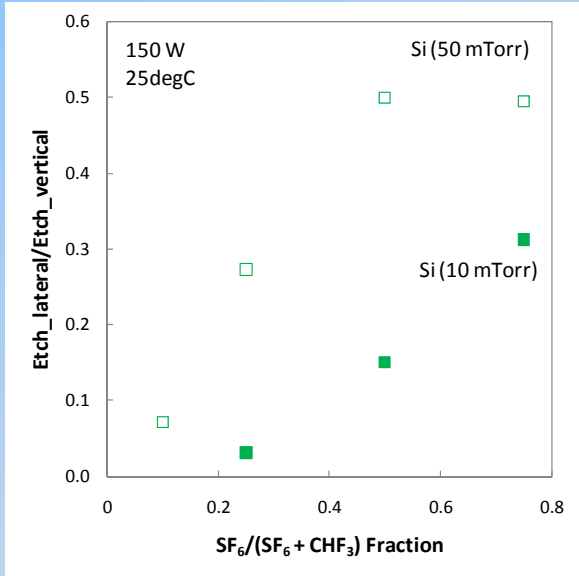
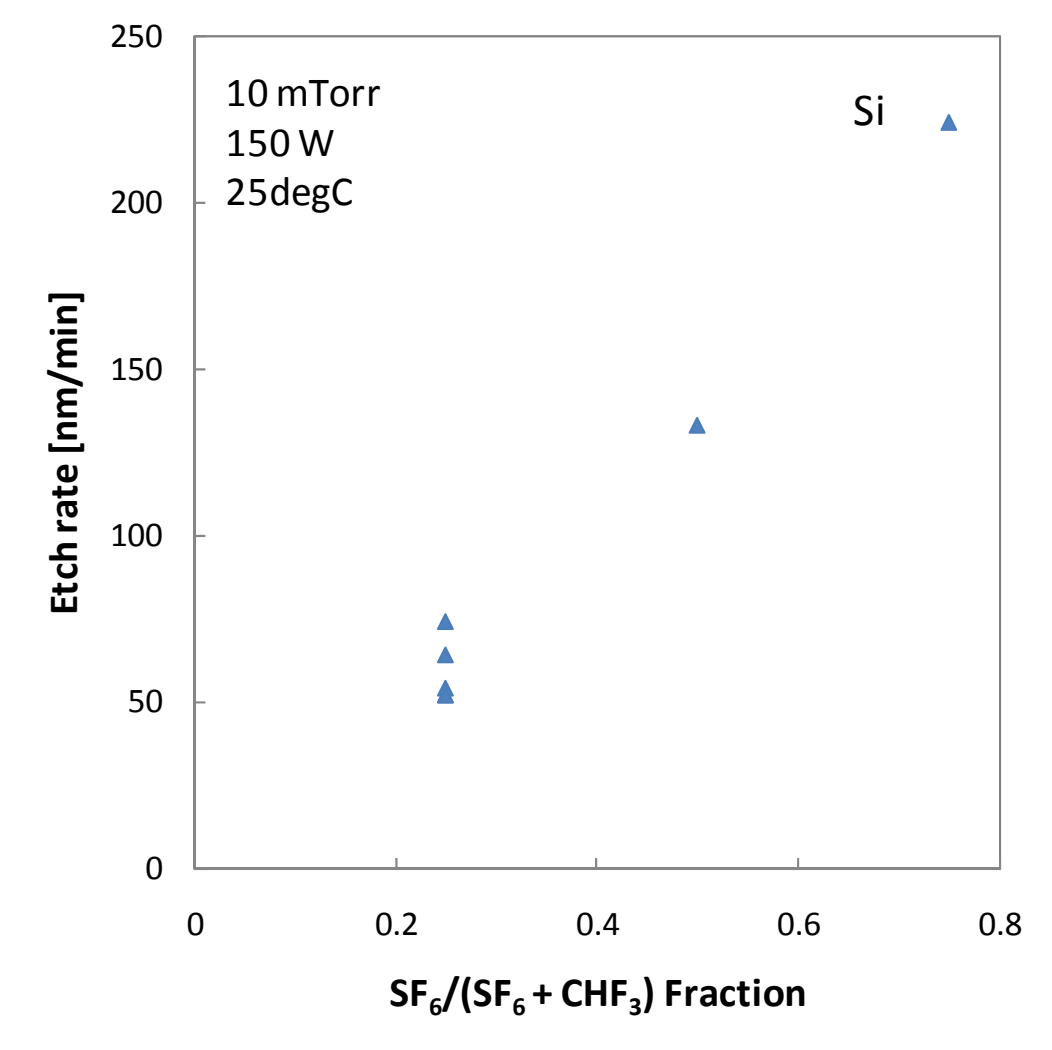
Results: Effect of Gas Composition







Results: Etch Rate Variation



Results: Positive PR as Mask

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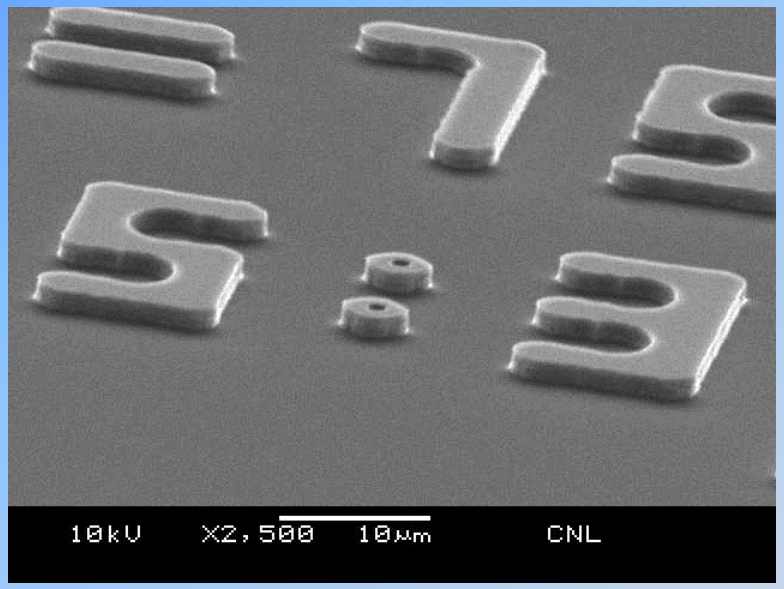
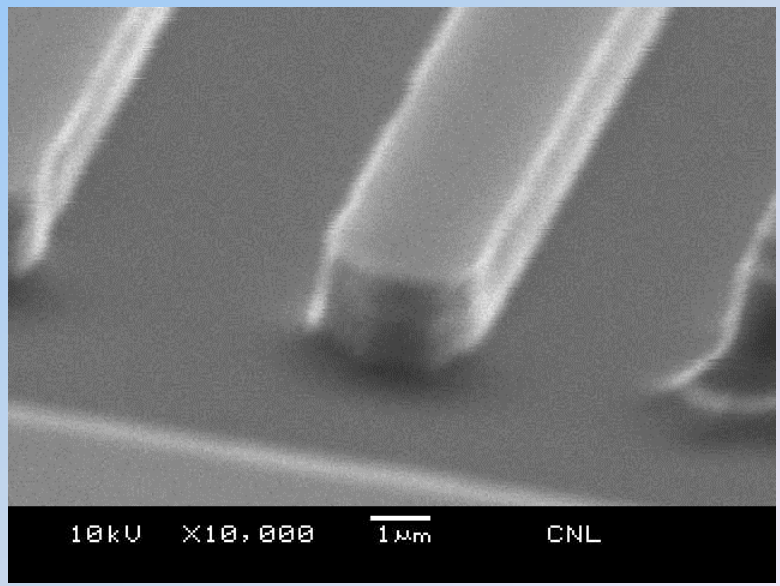
RIE parameters

- 0.25 $SF_6/(SF_6 + CHF_3)$
- 10 mTorr
- 35 minutes
- 25^oC
- 150 W

RIE results

- 1.8 μm deep
- Nice vertical profile
- Smooth surface
- PR etch rate: ~30 nm/min
- Si etch rate: ~50 nm/min





CNL logo (EB resist as mask)

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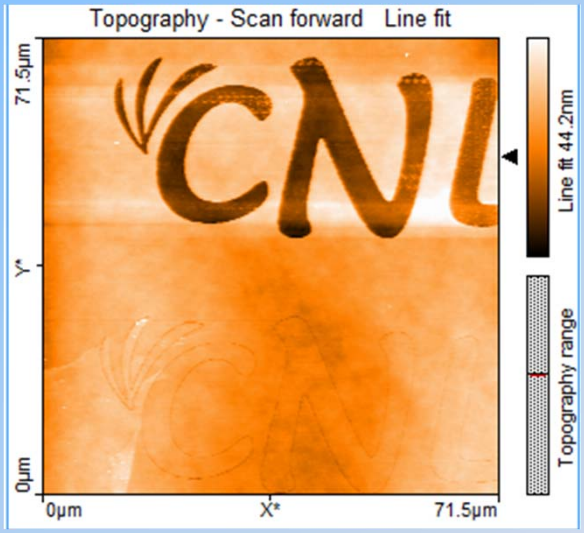
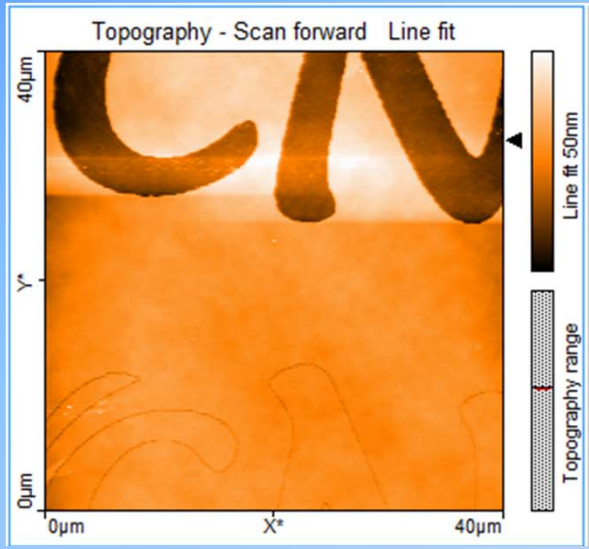
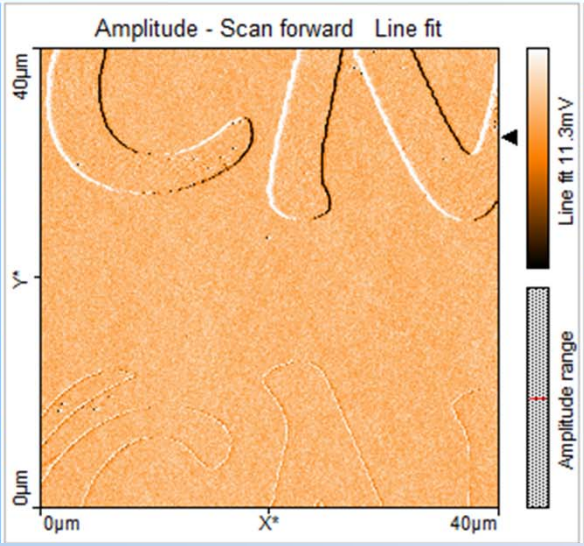
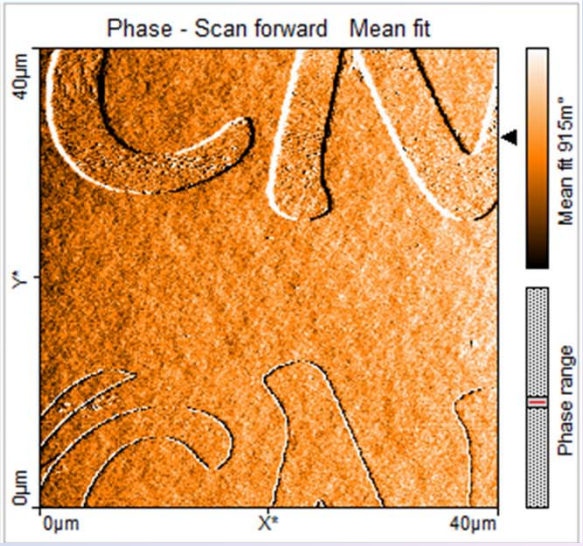
- Mask: approximately 50 nm thick PMMA (950k)
- Standard anisotropic Si RIE process for 45 seconds
- Etch depth in Si is about 30 nm
- ZEP520A is supposed to have a better etch resistance

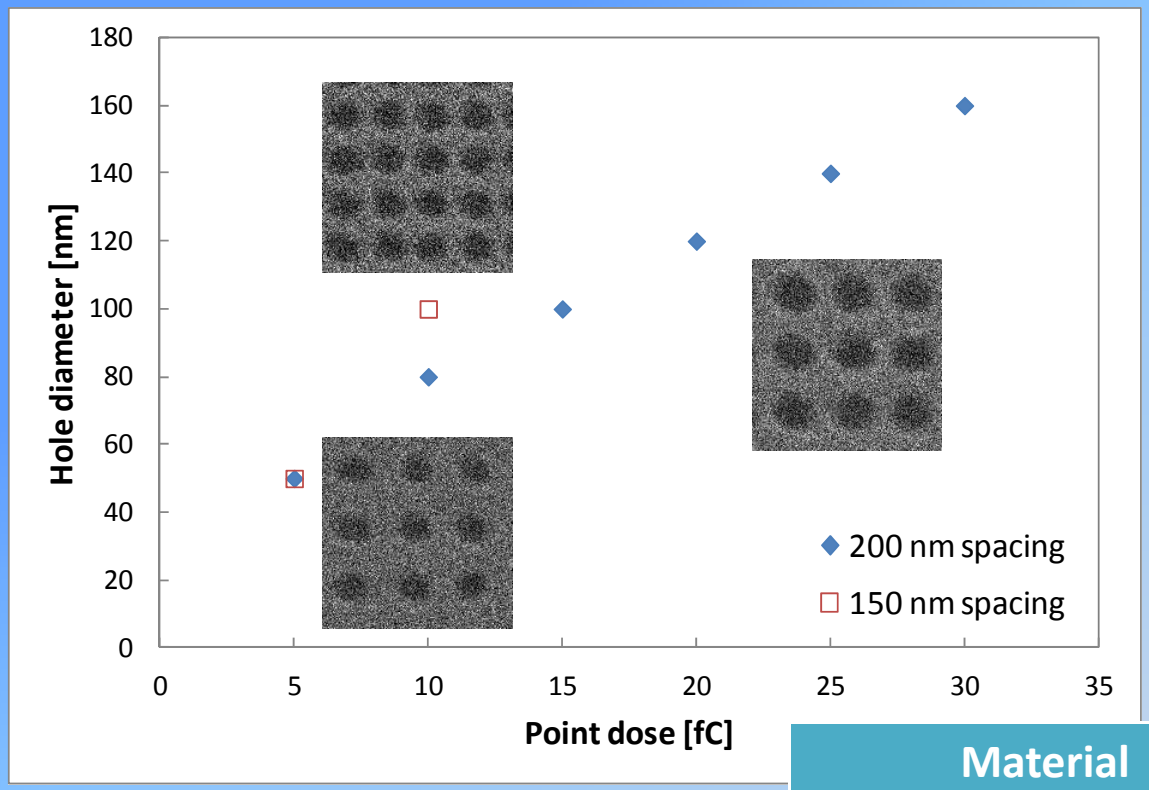








Result: ZEP RIE Process



RIE conditions: 150 W, 10 mTorr, SF_6 5 sccm + CHF_3 15 sccm

Material	Etch rate
PMMA (950K)	85 nm/min
ZEP520A	50 nm/min
Si	50-80 nm/min

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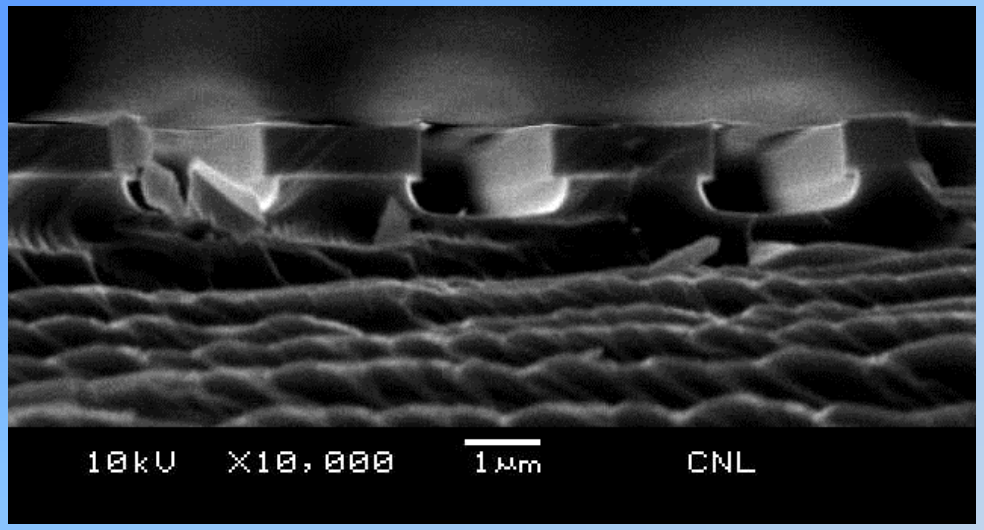
How good is it?



RIE II issues in nanofabrication

- ***Side wall profile → maybe not so good…***
- ***Passivation layer property → hard to remove***
- ***Selectivity → not so good…***

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It is not easy to etch oxide!

- Scenario I: I want to etch my oxide, and I don't need to worry about the silicon layer underneath.
- Scenario II: I want to etch my oxide, and I need to worry about the silicon layer underneath.
- Scenario III: I want to transfer my grayscale pattern into oxide layer.

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What kind of oxide to etch?

Type	RIE Etch rate [nm/min]	6:1 BOE etch rate @ RT [nm/min]	Note
Thermal oxide	15	97	
Sputtered oxide	17	276	As deposited, BOE etch rate 108 nm/min after annealing
PECVD oxide	15	216	As deposited
Fused silica	17	~100	
AZ P4210	23		
Si	13		

RIE conditions

- *50 mTorr, 150 W, 5 CHF_3 + 15 CF_4, 10 minutes, 25 ℃*

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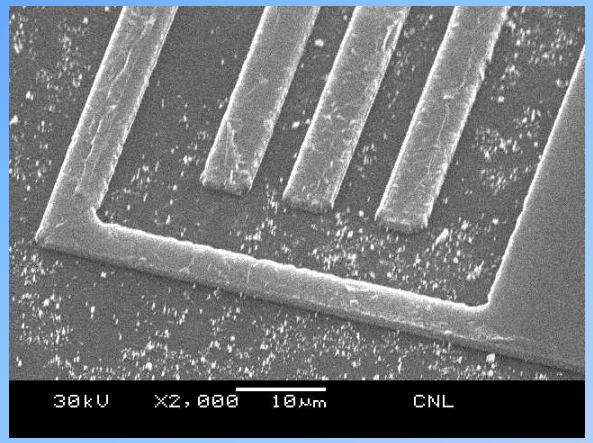
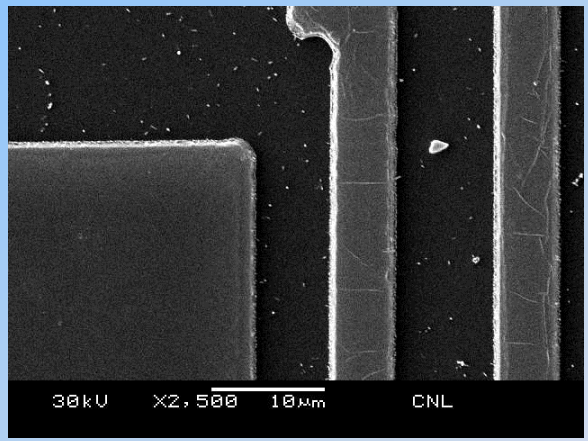
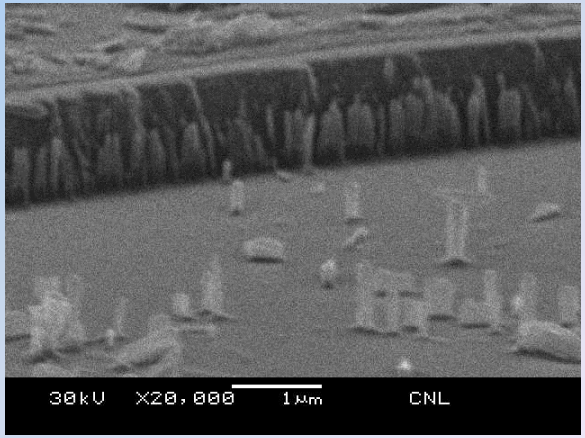
Fused silica etch

- Very hard
- Not clean

- Improvement required!







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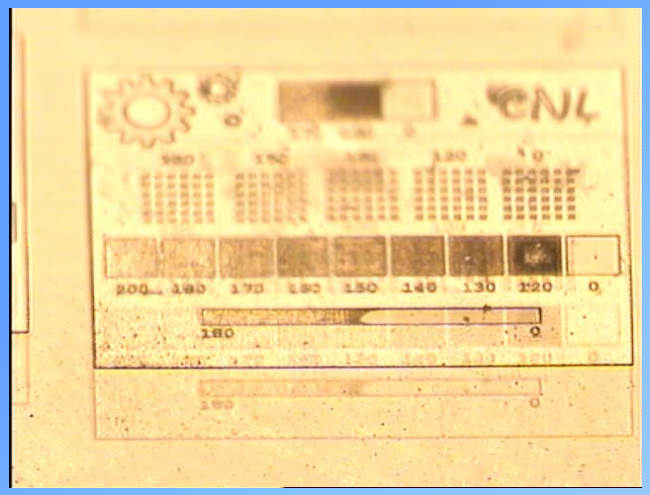
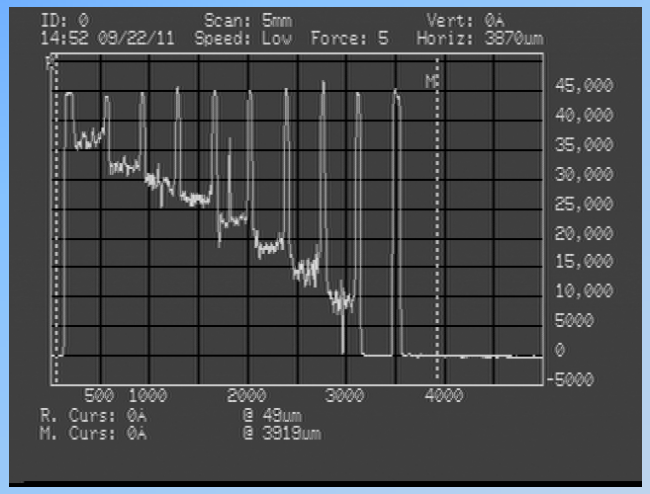
SU8 grayscale etch

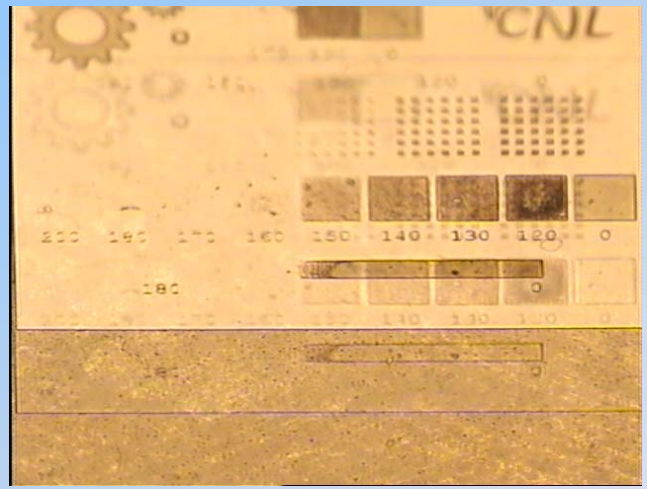




RIE
300 W
60 min

→

Mask
removal in
Nanostrip



Etch depth ~1.4 μm

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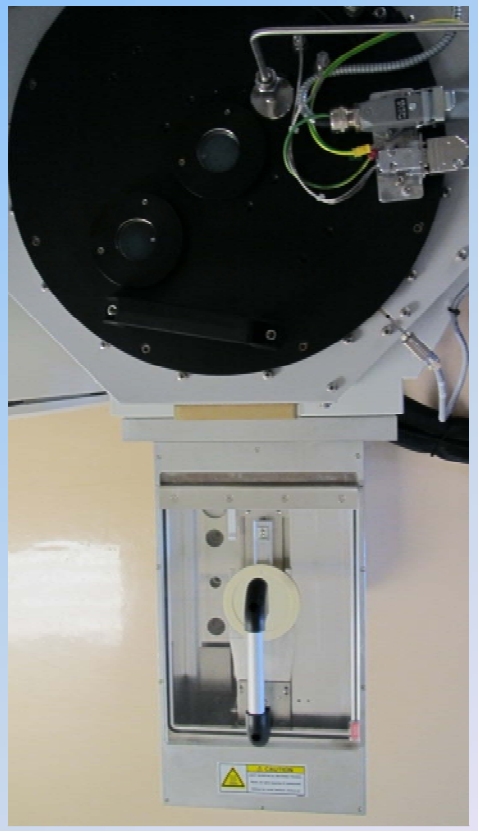
New Tool: STS LPX-ICP Etcher

- Process module: ICP
- Platform: LPX (single process chamber with single wafer loadlock)
- Windows XP based GUI (graphical user interface) software



STS ICP Etcher

- Fluorine-based etch
- Gases: CF_4, O_2, SF_6, CHF_3, C_4F_8, Ar
- Materials allowed: Si, SiO_2, Si_3N_4
- Mask material: oxide, nitride, photoresist, EB resist
- Current process
  - Anisotropic Si etch with SF_6/ C_4F_8
- Maximum etch time: 30 minutes
- Users can change only gas flow rates and time
- Rule violation may results in losing access to this tool

Anisotropic Si etch process
(non Bosch process)
SF_6/C_4F_8 gas mixture

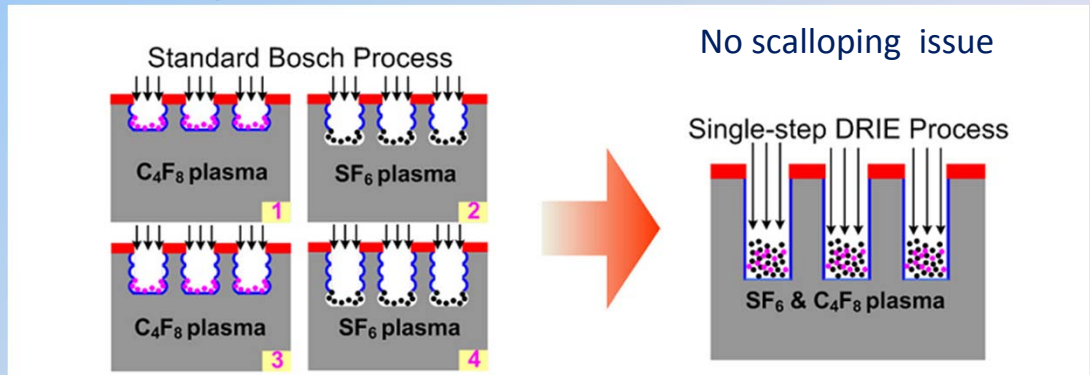


Figure 2 Comparison of process flow between conventional Bosch process and SDRIE process

Hung 2010, Mater. Res. Soc. Symp. Proc. Vol. 1258, 1258-Q14-02

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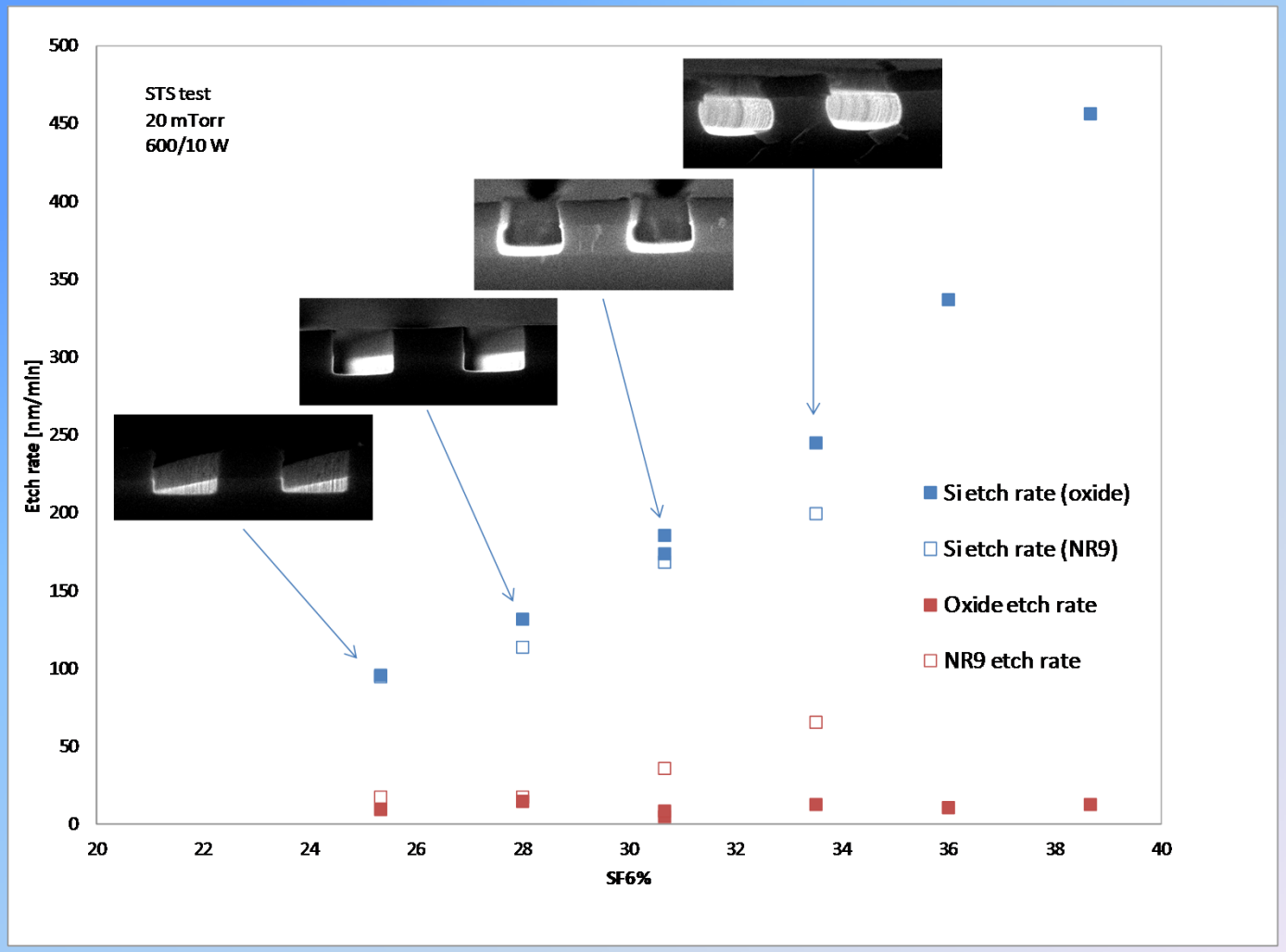
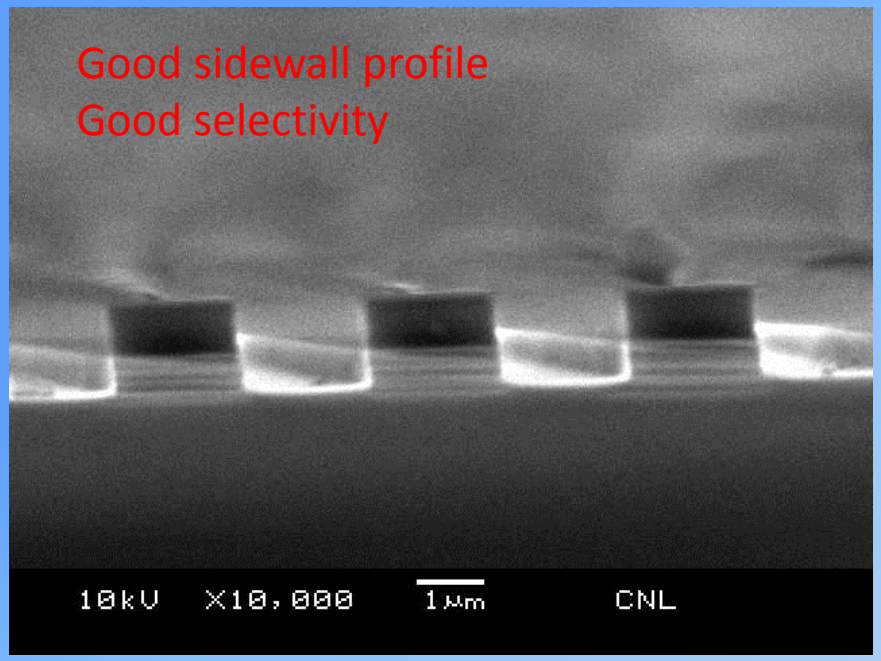
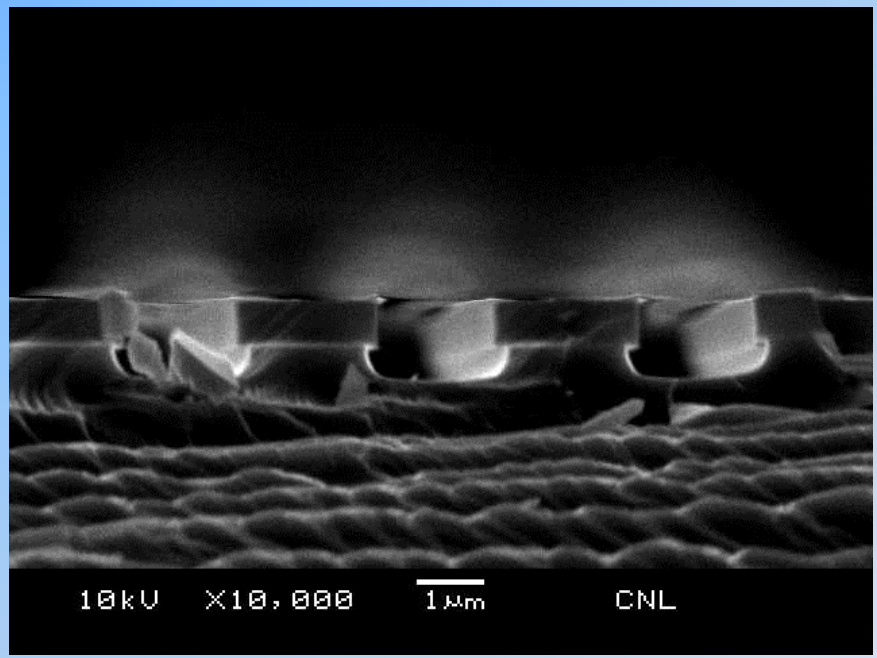
Anisotropic Etch of Silicon



Colorado Nanofabrication Lab

Anisotropic Etch of Silicon

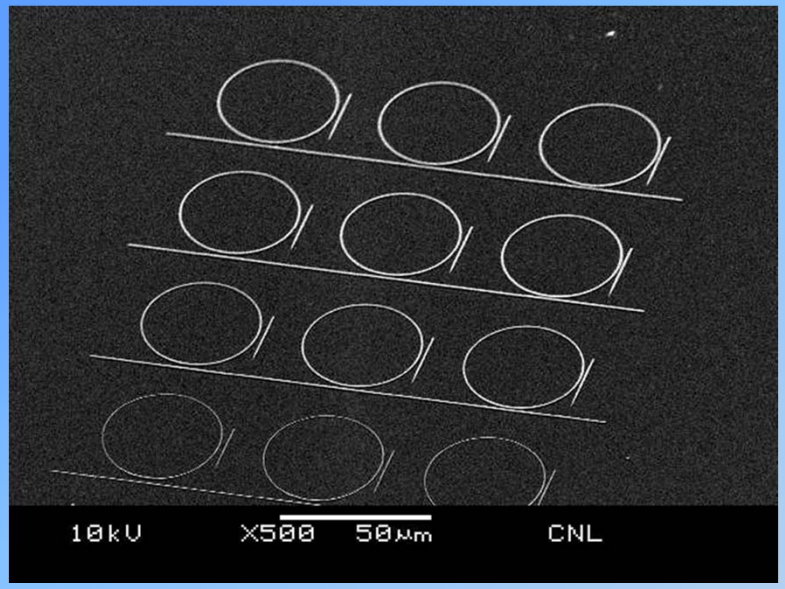


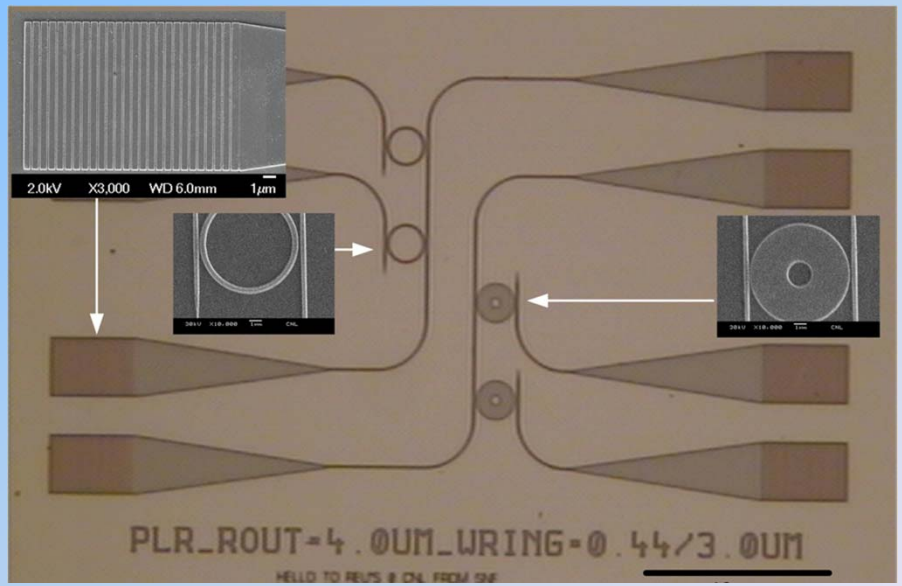


	STS ICP	RIE II
Si etch rate [nm/min]	~95	50~70
Selectivity to oxide	9	4
Selectivity to PR	5	> 2
Sidewall profile	Good	OK for microfabication Not good for nanofabrication

HSQ EB Process

- HSQ: negative, high resolution E-beam resist
- HSQ: can act as hard oxide mask after heat treatment



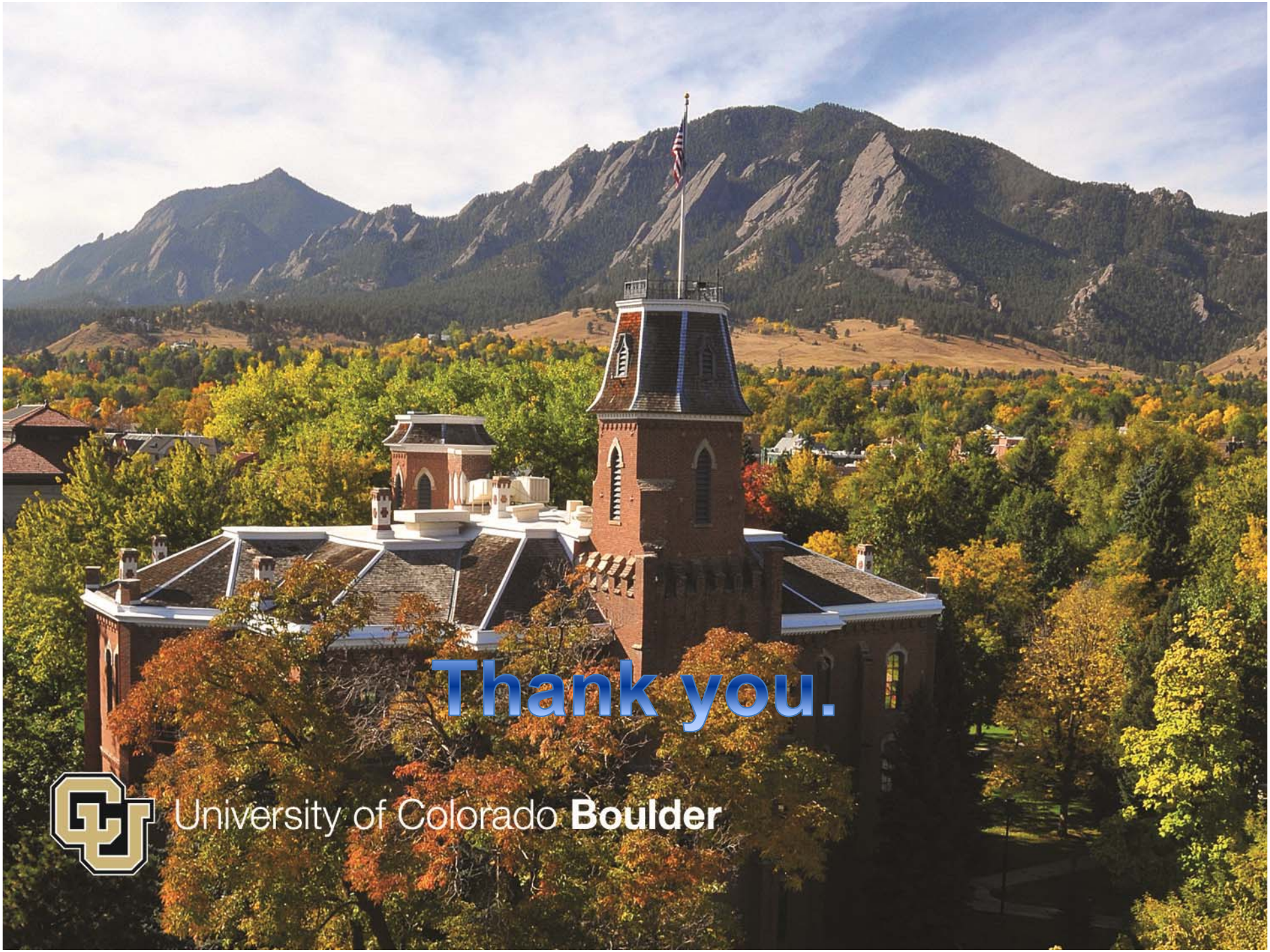


Scale bar = 40 μm

Colorado Nanofabrication Lab

Which instrument to choose?

	RIE I	RIE II	STS ICP
Materials allowed to etch	Except "not allowed materials"	Si, SiC, SiO_2, Si_3N_4 , refractory metals (such as W and Ta)	Si, SiO_2, Si_3N_4
Mask material		oxide, nitride, photoresist, EB resist, Cr and Ni	oxide, nitride, photoresist, EB resist
Gases	CF_4, O_2, SF_6	CF_4, O_2, SF_6, CHF_3	CF_4, O_2, SF_6, CHF_3, C_4F_8, Ar
Typical power	150 W	150 W	600/10 W
Pressure	100 mTorr	10-100 mTorr	10-100 mTorr
Max etch time	***Up to your process but ask if long***	120 minutes	30 minutes
Recipes	***Make you own but ask before***	Anisotropic Si etch with SF_6/CHF_3 Silicon dioxide etch with CF_4/CHF_3 Silicon dioxide etch with CF_4/O_2 Graphene etch with O_2 ***Other recipes: contact CNL***	Anisotropic Si etch with SF_6/ C_4F_8 ***Other recipes: contact CNL***


Thank you.
University of Colorado Boulder