Dry Etch of III-V, and Si Materials at UCSB

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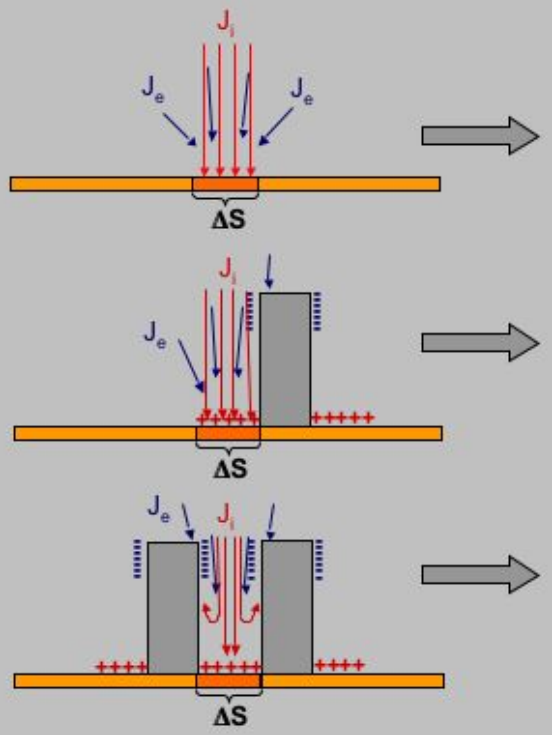
Present at Etch-Workshop
Cornell University
May 21-22, 2013

Charging effects in plasma etching (III)



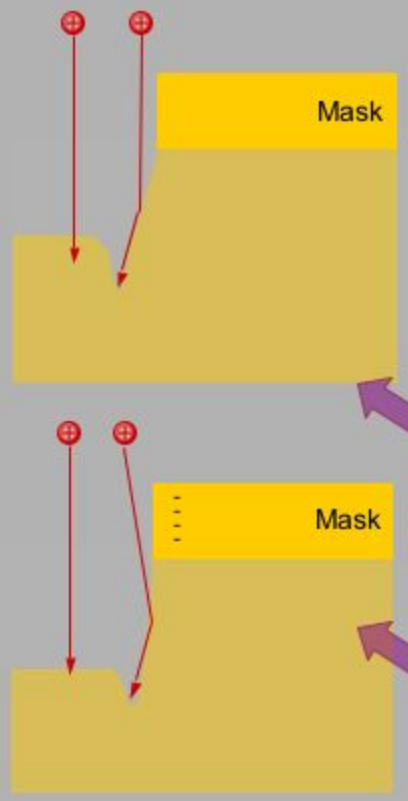
Ion and electron fluxes onto large open areas are equal.

Any vertical surface on the wafer (feature sidewall) screens a part of the electron flux: the net flux of electrons arriving on the surface decreases. In contrast, the ion flux is not impacted. If the surface at the bottom is an insulator, it charges positively, possibly leading to a partial deviation of the ion flux. If the mask is an insulator, it will charge negatively.

For two adjacent sidewalls are present (space between two lines or trenches), the shadowing effect becomes even more pronounced. The insulator between the lines will be charged even more.

Adapted from Hwang and Giapis, JVST B15, 70, (1997)

The Trenching Phenomenon



Profile trenching is caused by ion bombardment.

Ions arriving at grazing angles on the feature sidewalls get reflected and accumlulate leading to a localized higher etch rate.

This effect is well known in sputter etching and in plasma processing.

At least two possbile explanations for trenching can be found in the literature:

1. Ion scattering from sloped sidewall surfaces
(S. Van Nguyen, D. Dobuzinski, S.R. Stiffler, G. Chrisman; J. Electrochem. Soc. 138 (1991) 1112 / T.J. Dalton, J.C. Arnold, H.H. Sawin, D. Corliss; J. Electrochem. Soc. 140 (1993) 2395 / J.C. Arnold, H.H. Sawin; J. Appl. Phys. 70 (1991) 5314 and others)

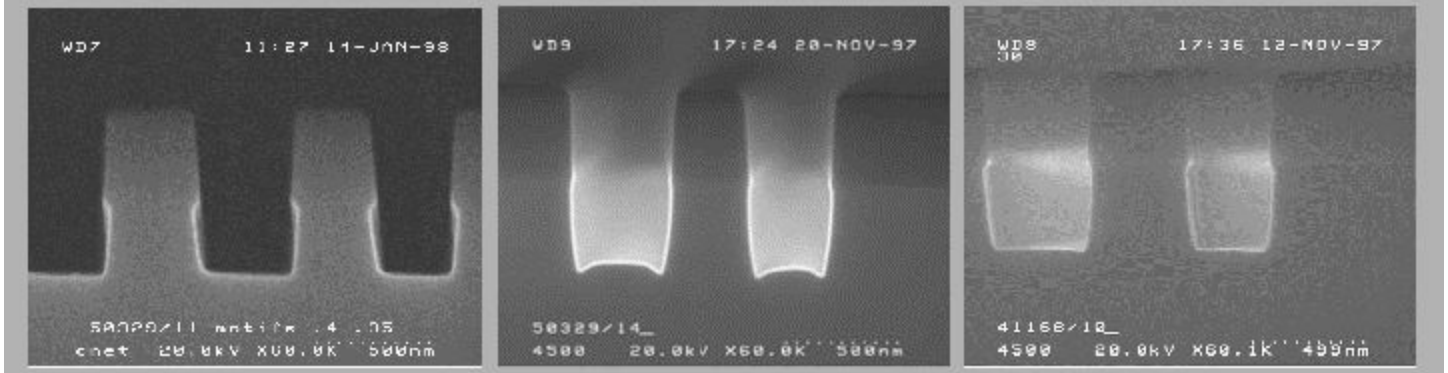
2. Ion deflection due to differential charging of microstructures
(G.S. Hwang, K.P. Giapis; Appl. Phys. Lett. 71 (1997) 458 / M. Schaepkens, G.S. Oehrlein; Appl. Phys. Lett. 72 (1998) 1294 and others)

Mirotrenching: Chemistry Effect

Source power: 500 W
Cathode power: 80 W

500 nm PECVD HM / bulk silicon

P < 10 mTorr



HBr(50)-He(40) Cl_2(50)-He(40) HCl(50)-He(40)

⇨ Severe trenching with pure chlorine chemistry in a bias power range of less than 100 W

⇨Directed by the angular distribution of ions impacting and scattering the evolving feature

⇨Alternative explanation: Presence of fast protons neutralises the negative charging of the mask (HBr and HCl)

InP-Based Etch

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*

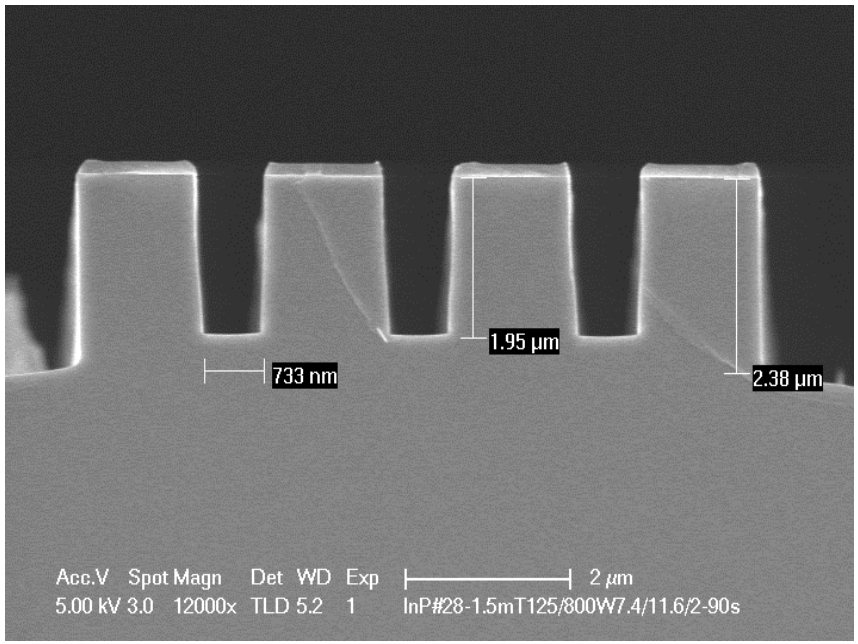
Primarily used for InP and related compounds at 200 C etching temperature, due to $InCl_X$ volatility issues

SF6 added to chamber for selective etching of GaN/ AlGaN

Sapphire and Silicon carrier wafers used.

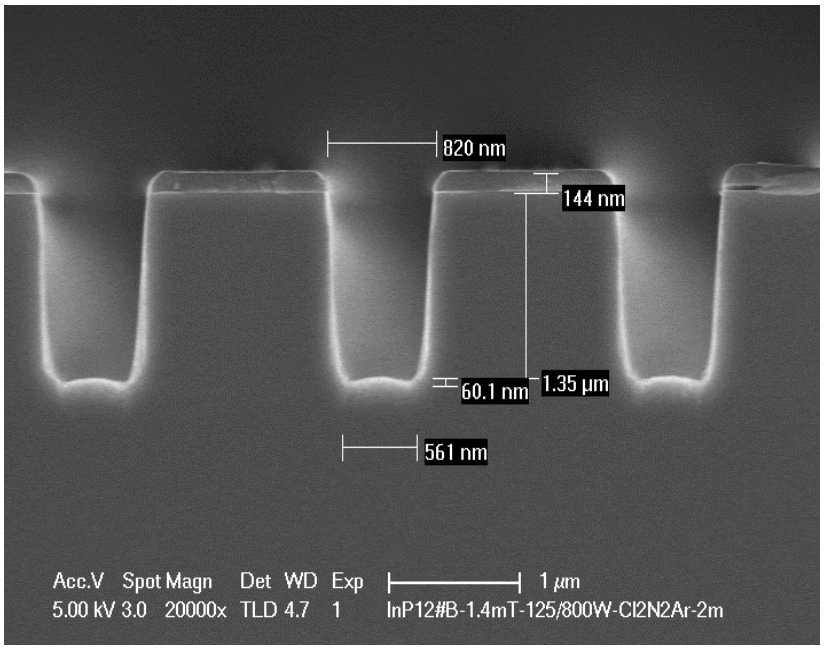
Hydrogen was introduced into the chamber to create H^+ ions in plasma to neutralize the excess electrons on side-wall

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



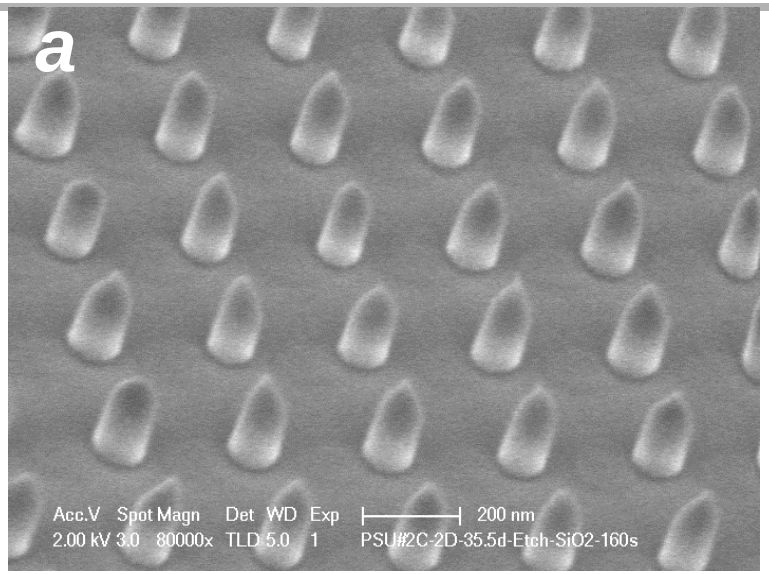
Unaxis VLR: 1.5mT, 125/800W, $Cl_2/H_2/Ar$
Flow-rate=7.4/11.6/2SCCM, and time=90 s
Etch Rate=1.57µm/min (open area),
Etch Selectivity(InP/SiO_2)=15.5
(N. Cao)

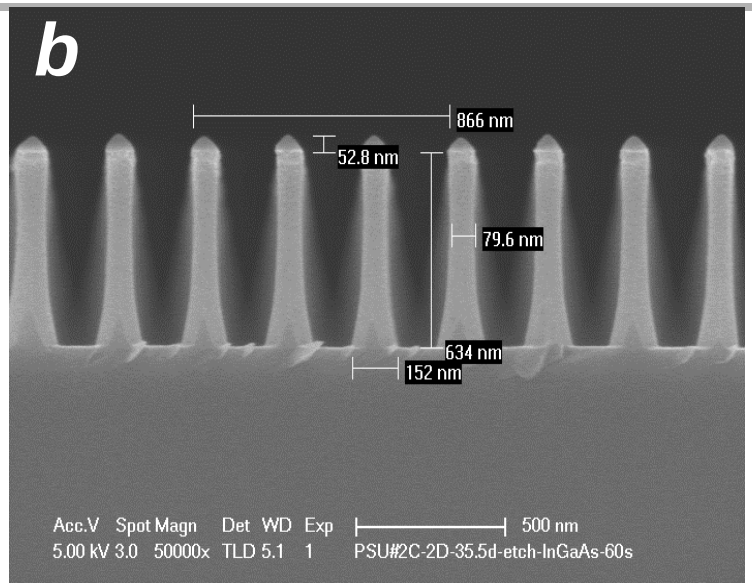
InP Etch with $Cl_2/N_2/Ar$ Chemistry
Micro-trench at Trench Bottom

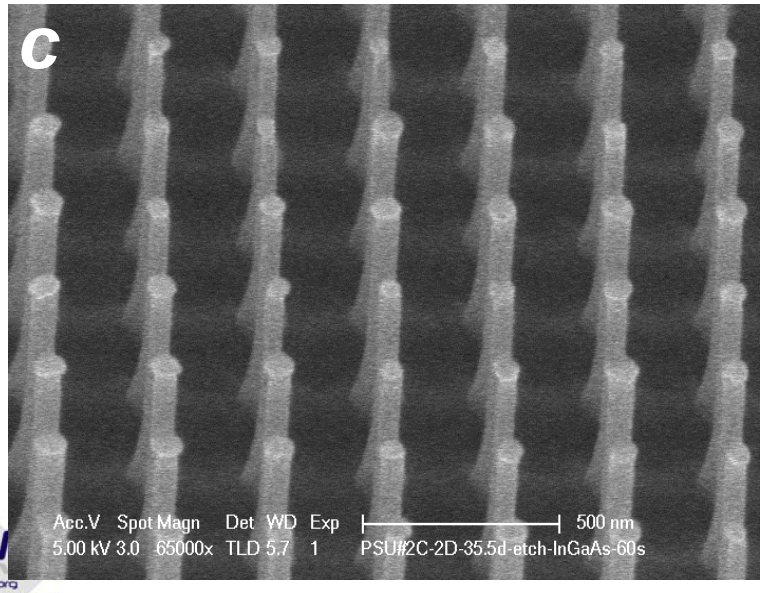


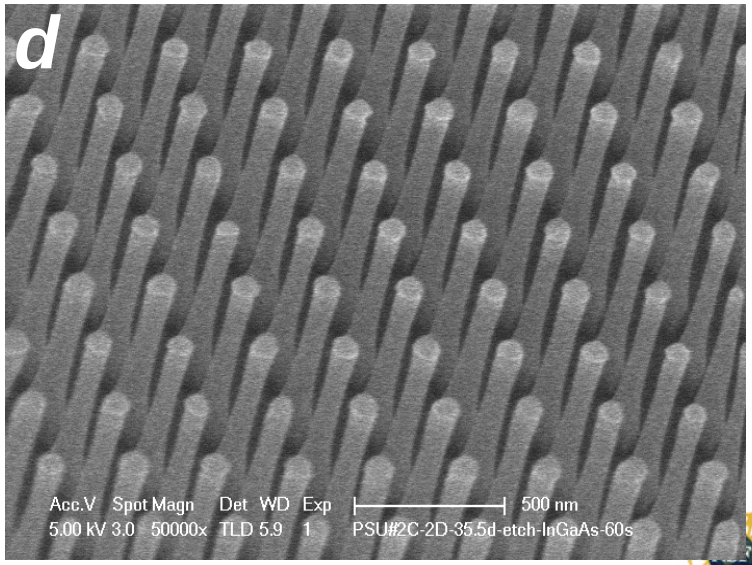
Unaxis VLR: 1.4mT, 125/800W, $Cl_2/N_2/Ar$
Flow-rate=7.4/11.6/2SCCM, and time=120 s
Etch Rate=0.69µm/min,
Etch Selectivity(InP/SiO_2)=9.3
(N. Cao)

InGaAs nano-wires: 1.5mT, 125/800W, $Cl_2/H_2/Ar$=7.4/11.6/2SCCM, and time=60 s (Fig. a: SiO_2 etch mask)









(N. Cao)

GaN- and GaAs-Based Etching

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, SiNx, 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

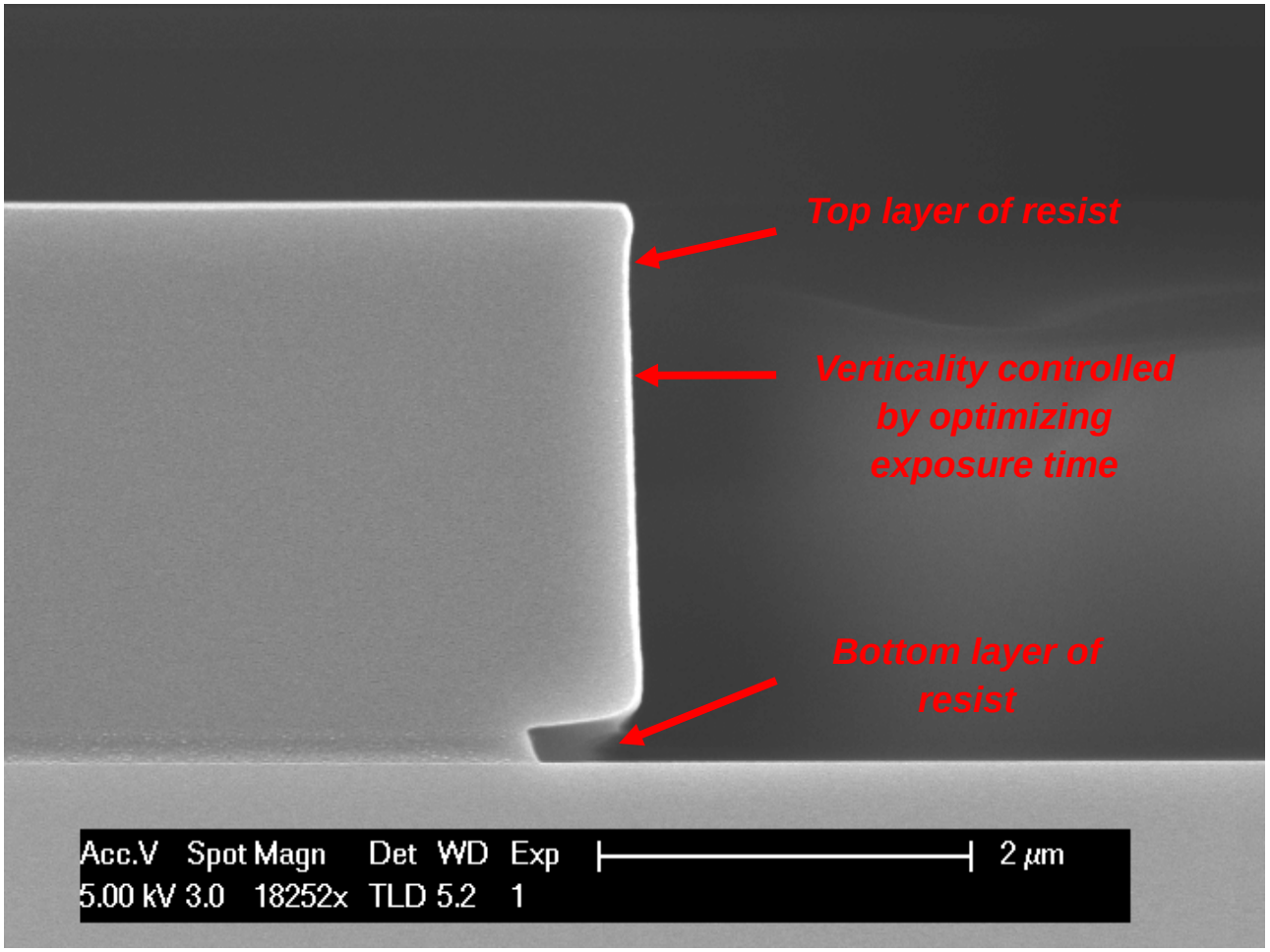
System is down for 3 days minimum after wet clean

GaN-Based Laser Facet Etch

- *Performed a pretreatment etch in BCl_3 to remove surface oxides*
- *Etched facets using two-layer PR as an etch mask → results in a smoother facet etch*
- *Verticality of PR mask controlled by optimizing exposure time*
- *Etch conditions (Plasmatherm RIE #5):*
  - *Pressure: 5 mTorr*
  - *Cl_2 flow rate: 10 sccm*
  - *RF power: 200 W*

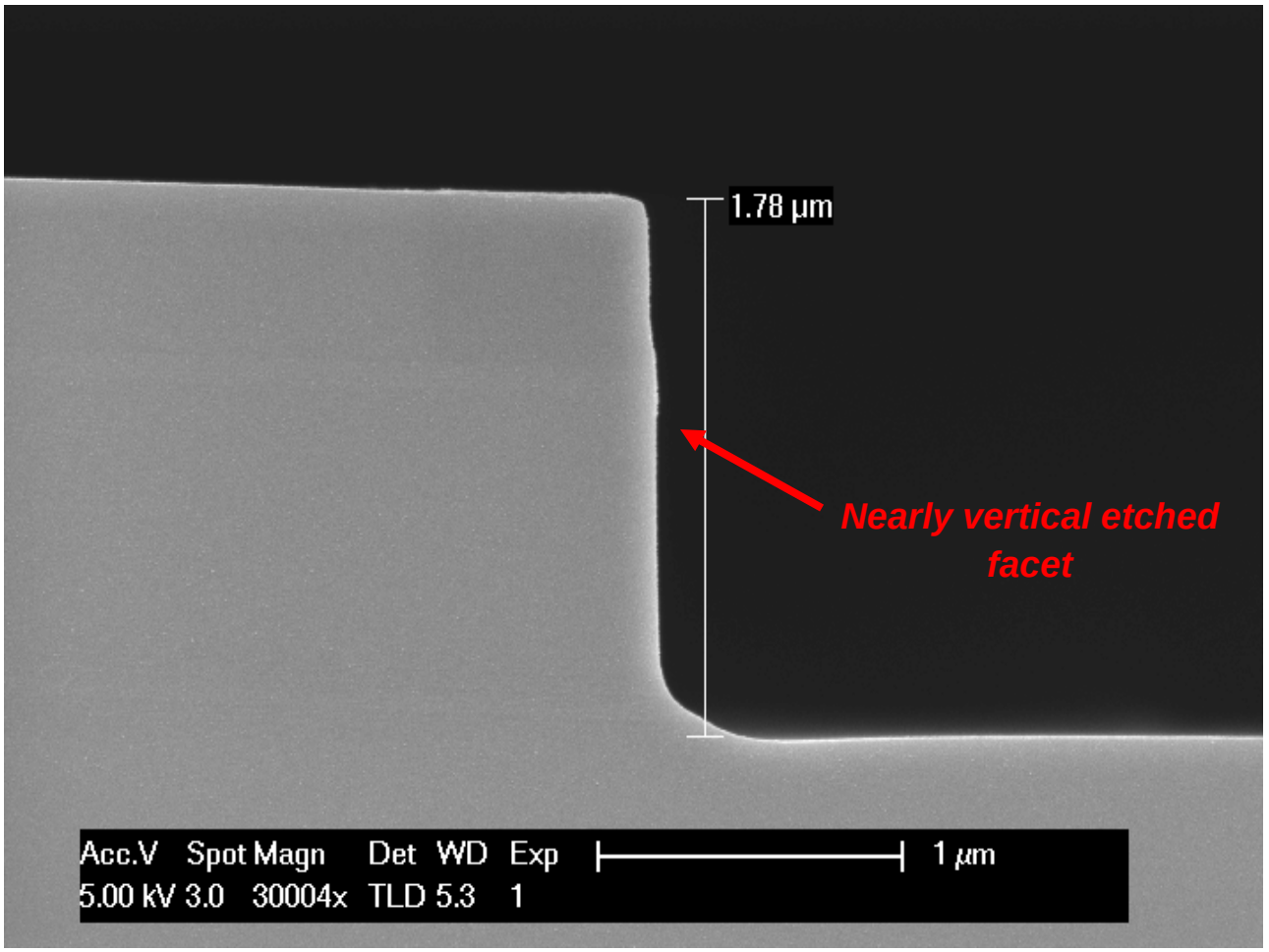
R. M. Farrell, Ph.D. Thesis, University of California, Santa Barbara, 2010.

Bi-Layer Resist Mask



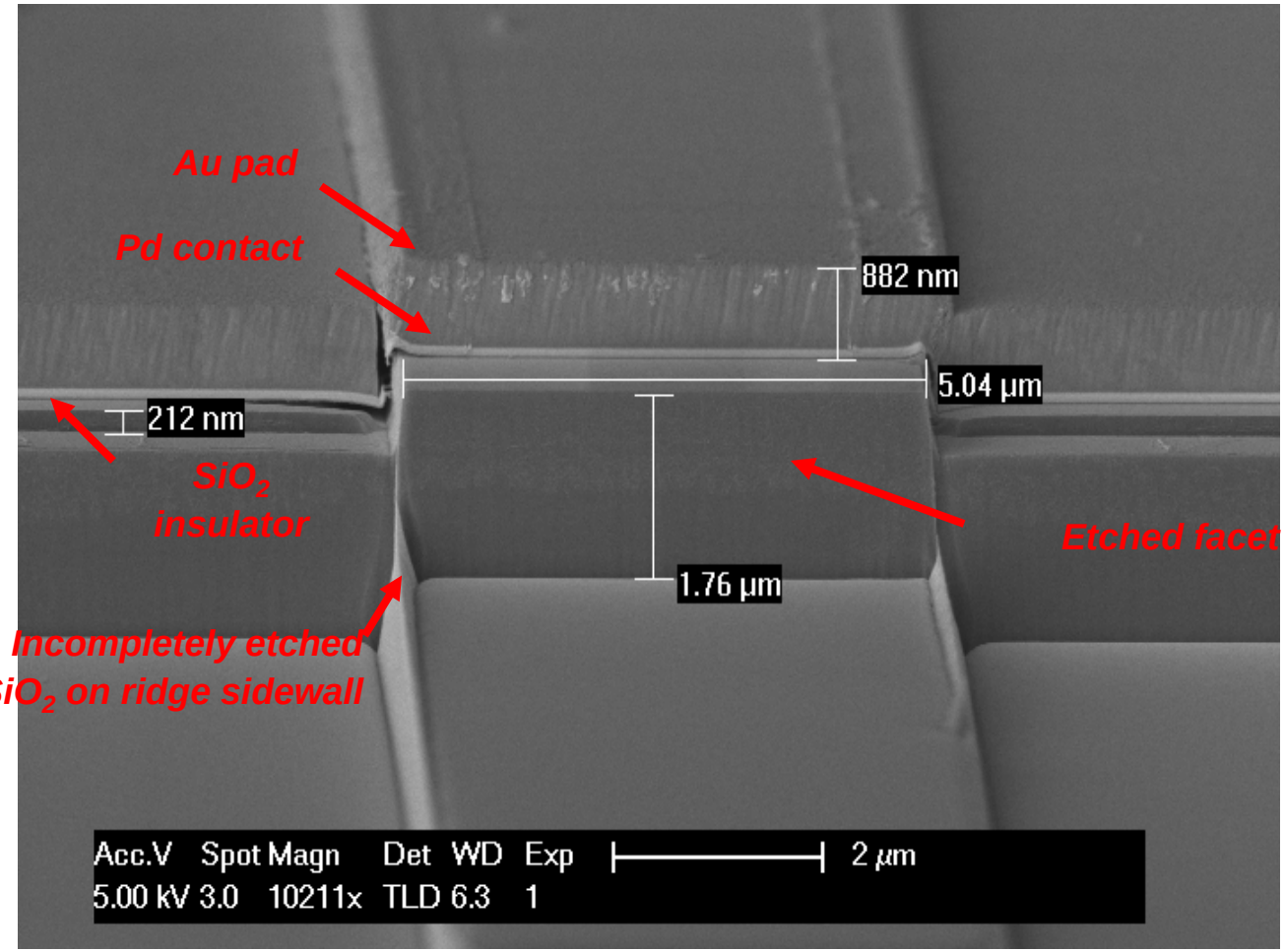
R. M. Farrell, Ph.D. Thesis, University of California, Santa Barbara, 2010.

Etched Facet Cross Section



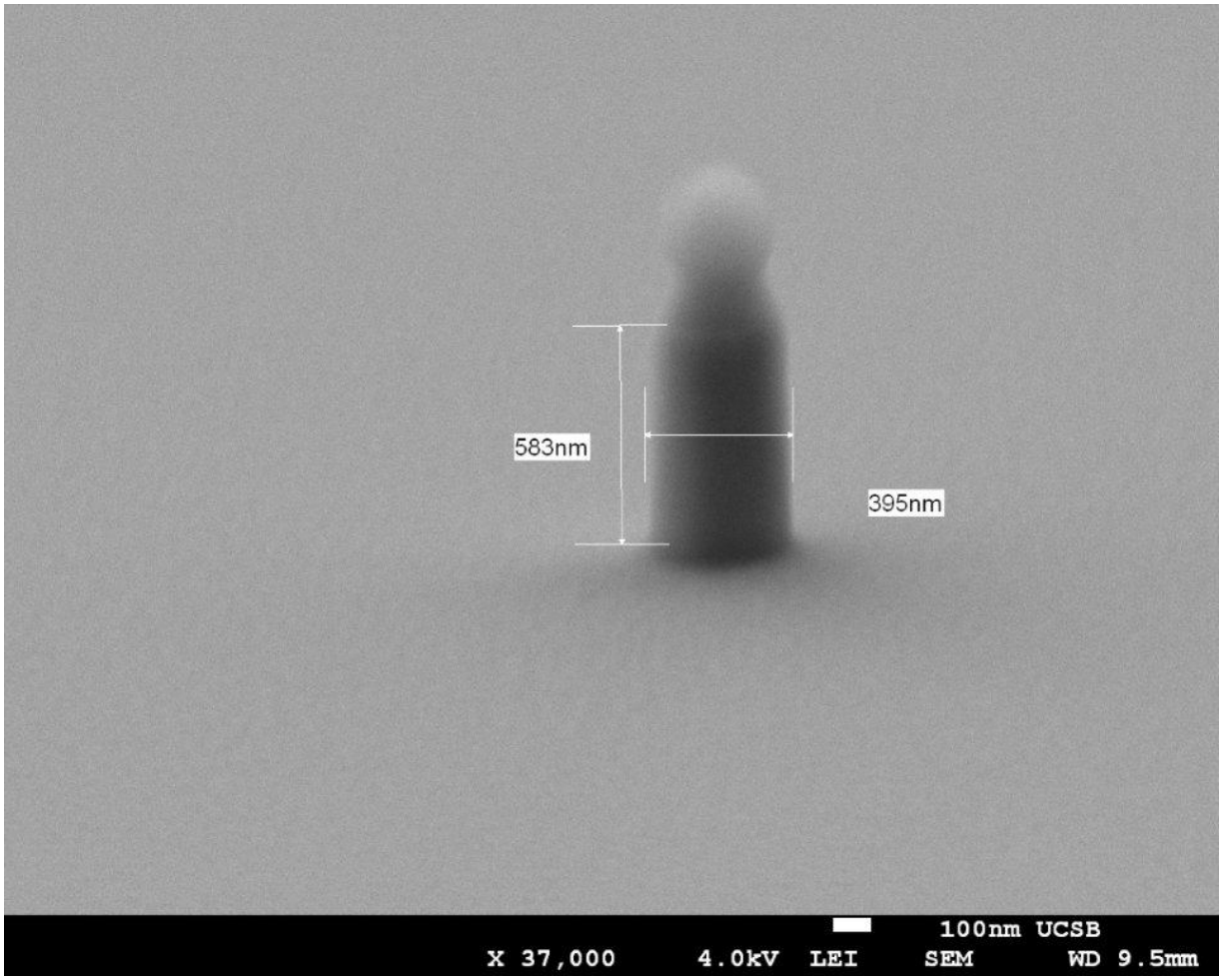
R. M. Farrell, Ph.D. Thesis, University of California, Santa Barbara, 2010.

Etched Facet Surface Morphology



R. M. Farrell, Ph.D. Thesis, University of California, Santa Barbara, 2010.

GaAs/AlGaAs Etch



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

Silicon Deep RIE/ICP – Bosch

UCSB Nanofabrication Facility

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*

20 minute Bosch Season run done before etch if system idle for more than 30 minutes.

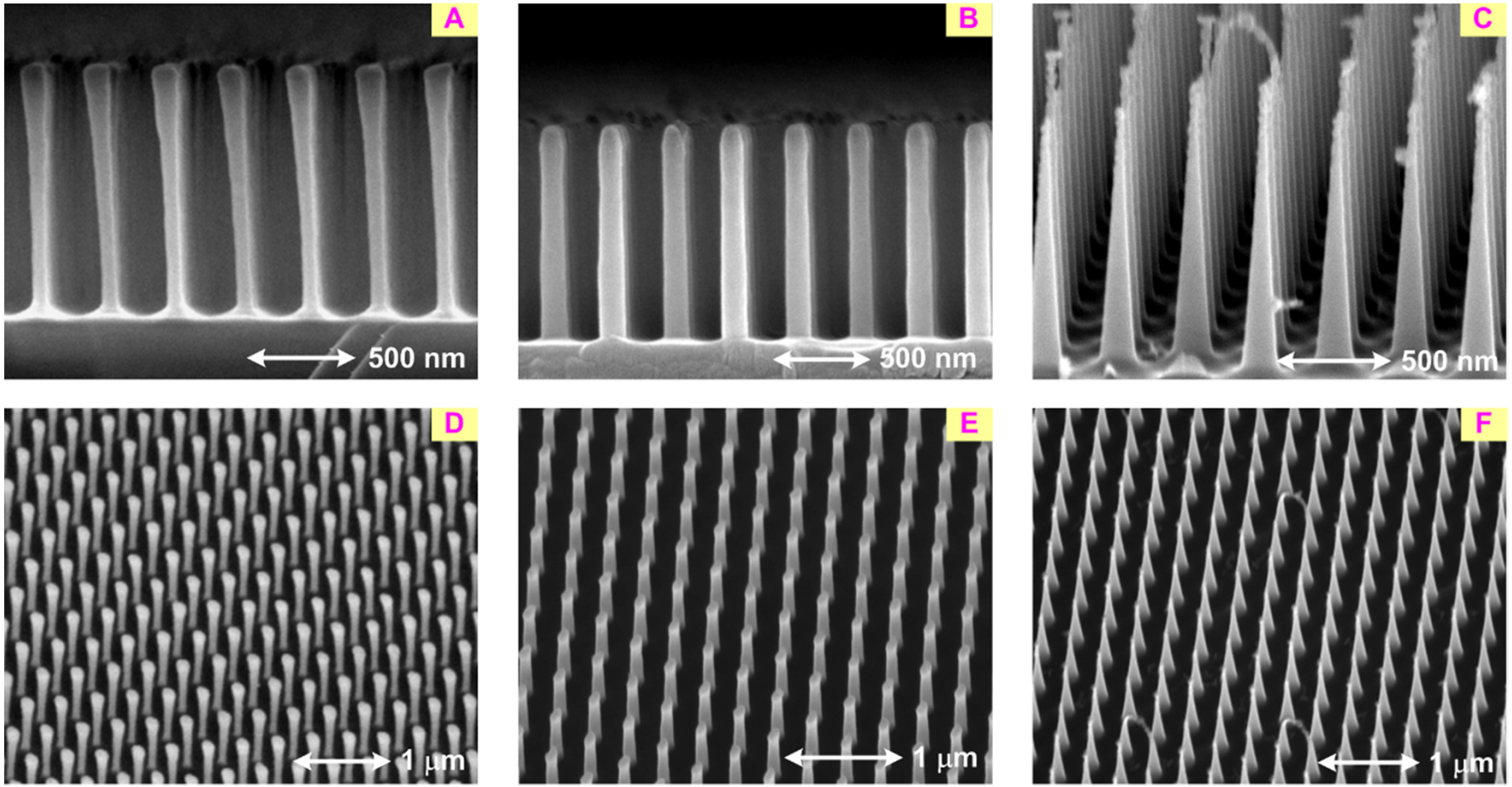
Wet cleans done on as-needed basis.

SF6/Ar release etches also done in the system.

NNIN www.nnin.org Nanoscale Science, Engineering & Technology

National Science Foundation

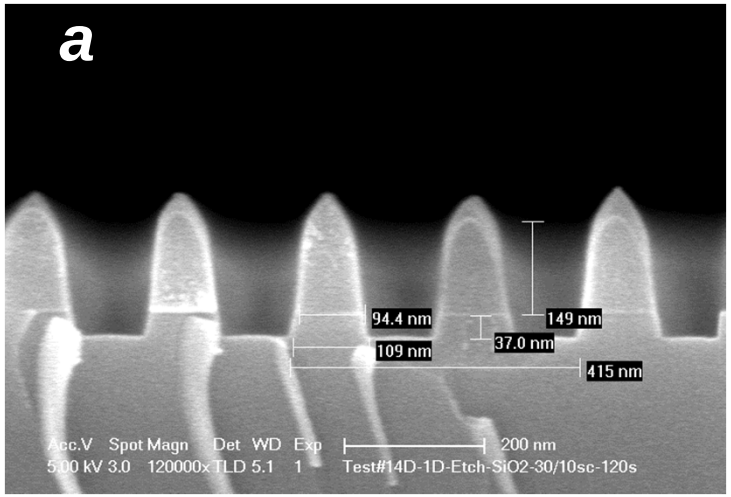
One-step Si etch (remove "scalloped" sidewall profile of Bosch process)

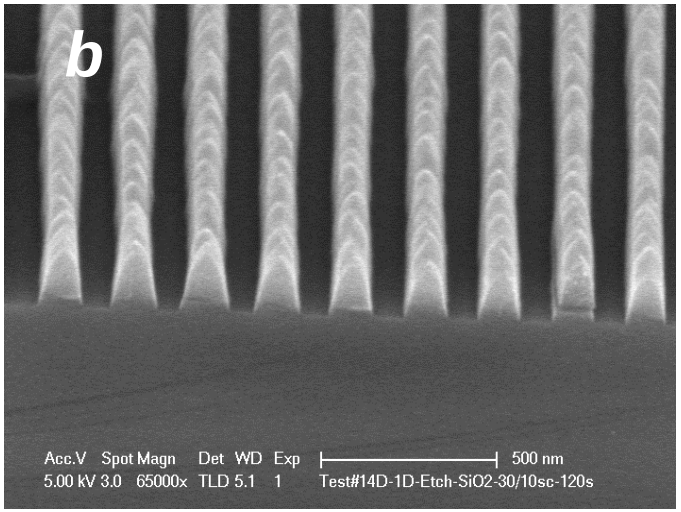


$C_4F_8/SF_6/Ar$: 50/30/20SCCM $C_4F_8/SF_6/Ar$: 52/28/20SCCM $C_4F_8/SF_6/Ar$: 54/26/20SCCM

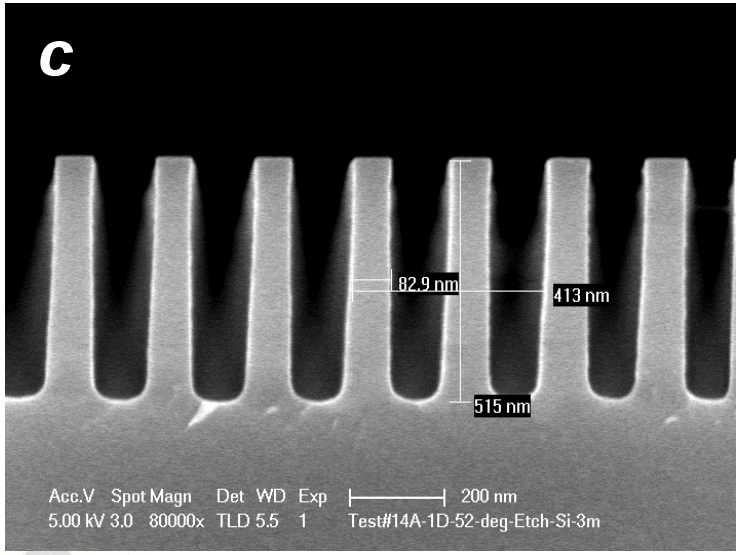
Etch Conditions: total gas flow=100SCCM, 19mT, 9/850W
copied from Yung-Jr Hung, et al.'s paper

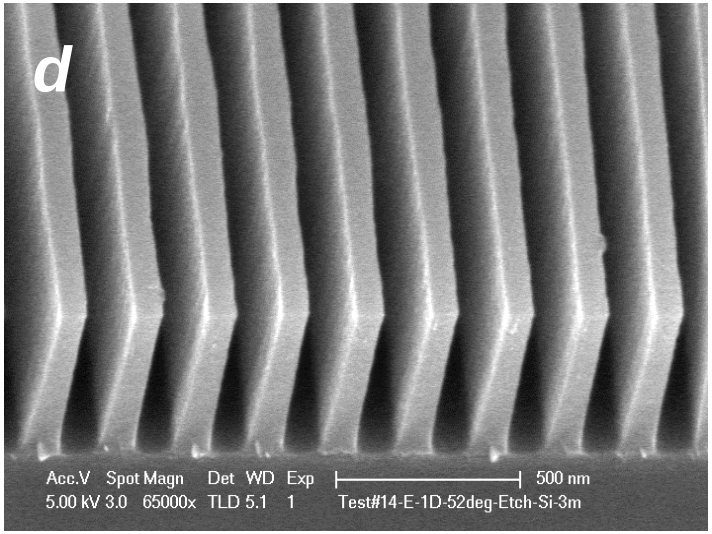
One-step Si etch (narrow trench etching)





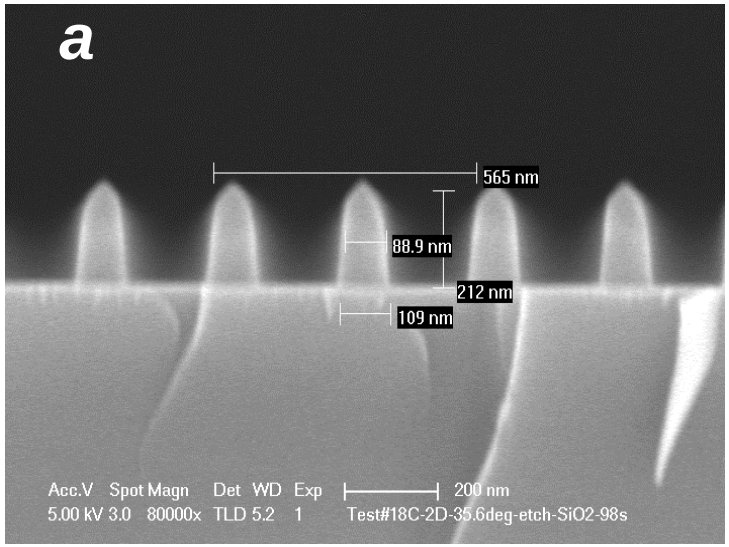
a, b: *SiO_2 etch mask pattern*

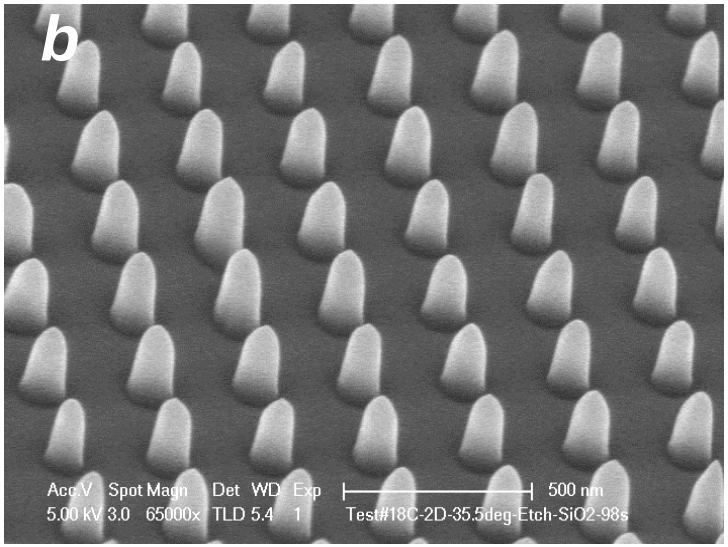




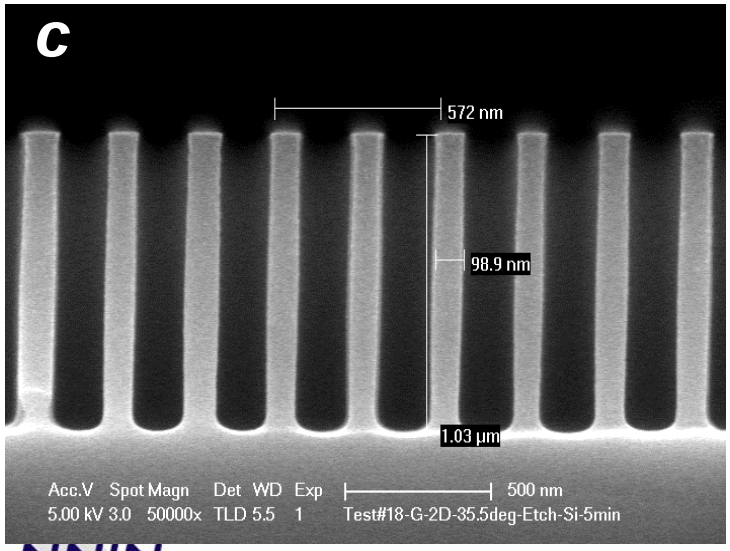
c,d: *After one-step Si etch. Etch condition: 19mT, 15/825W, $C_4F_8/SF_6/Ar$: 54/26/20 SCCM, and time=3min, Etch rate: 171 nm/min (N. Cao)*

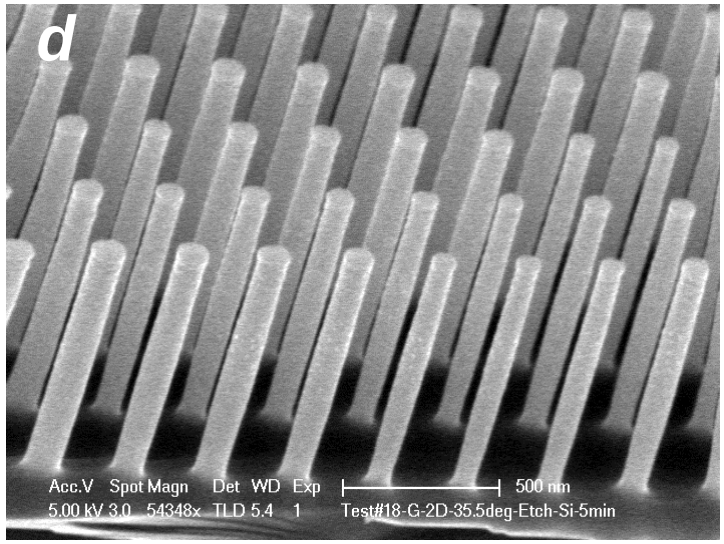
One-step Si etch (nanowire etching)





a, b: *SiO_2 etch mask pattern*

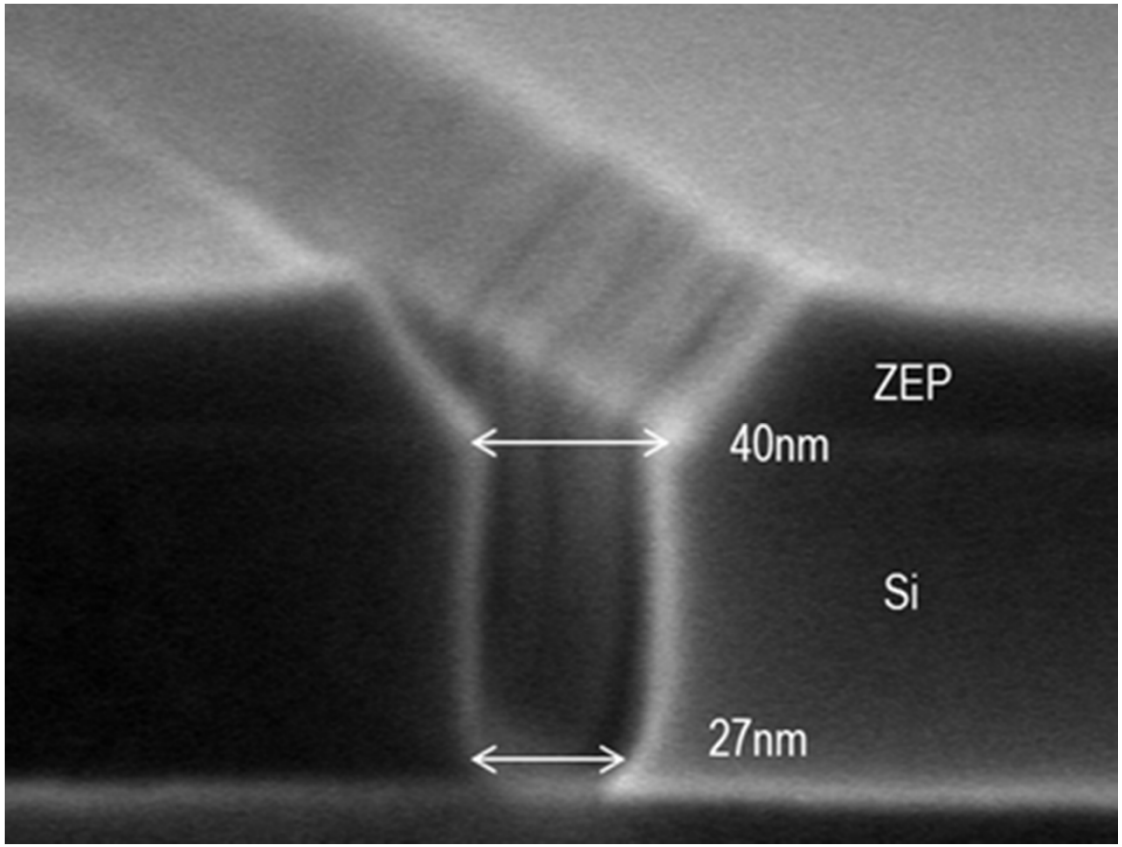




c,d: *After one-step Si etch. Etch condition: 19mT, 15/825W, C_4F_8/SF_6/Ar: 54/26/20 SCCM, and time=5min, Etch rate: 200nm/min (N. Cao)*

One-step Si etch (narrow trench etch)

One-step amorphous Si etch, 19mT, 15/825W, C_4F_8/SF_6/Ar flow-rate=54/26/20 sccm



Application: Thermoelectric Devices with Etched Si Nano-wire Array

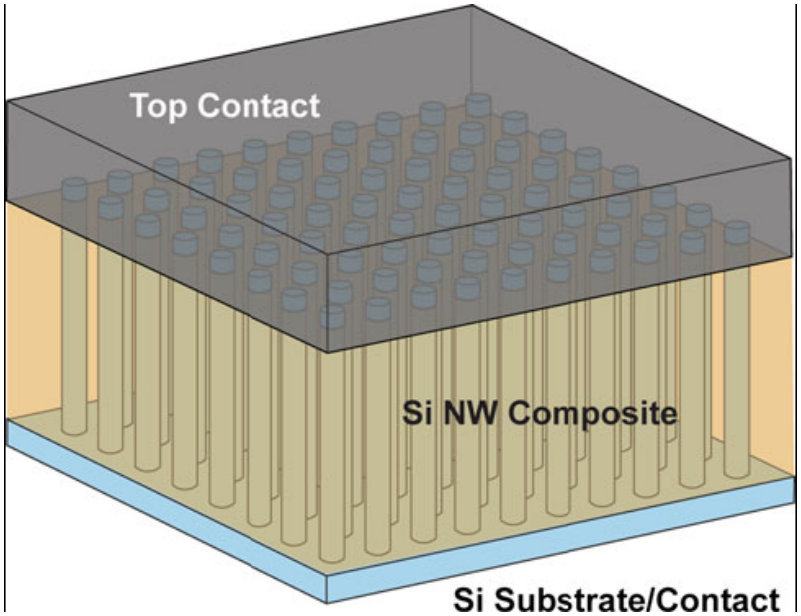


Fig. 1. The vertical Si NW composite thin-film device structure used in this work, illustrating the top contact, Si NWs embedded in a matrix material, and Si substrate bottom contact.

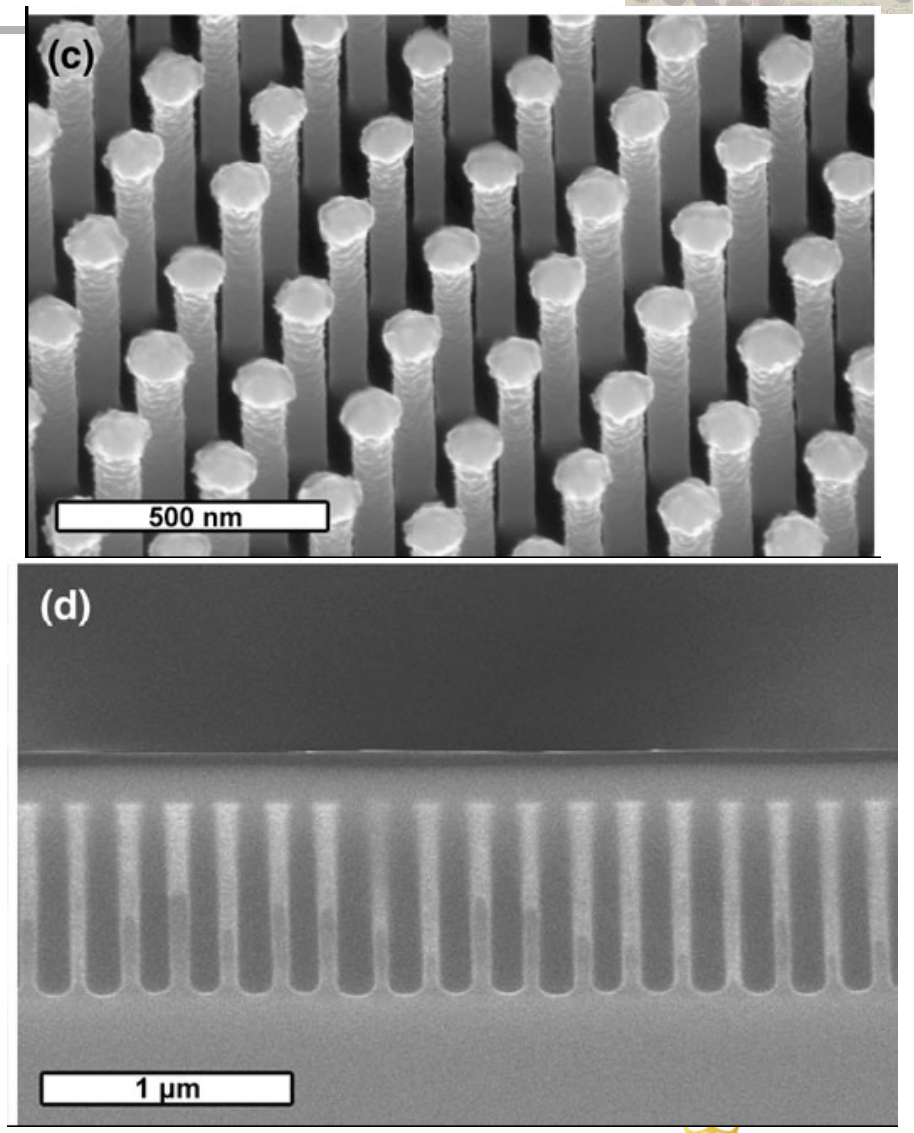
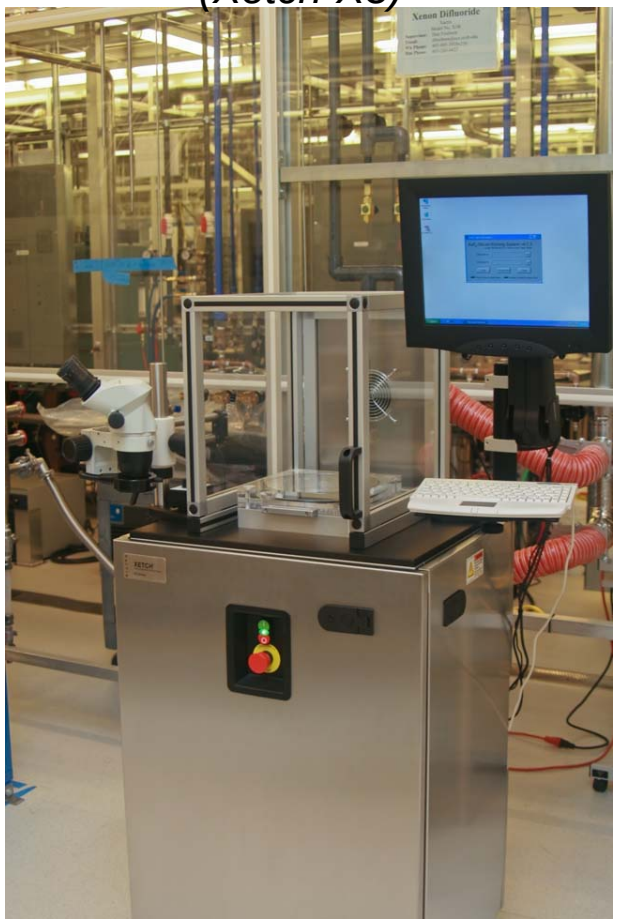


Fig. 2. Scanning electron microscope images of Si NW/SOG substrate fabrication after:(c) etching Si to form Si NWs (SiO2 mask not removed), and (d) embedding the Si NWs with SOG and curing the composite film.

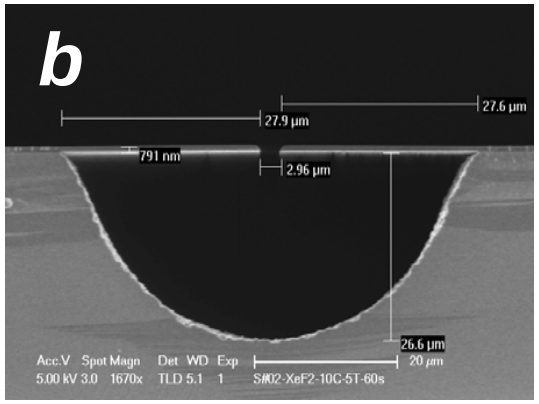
Copied from B.M. Curtin et al.'s paper: J. Elec. Mat., V41, pp887-894, 2012

Si Etch with XeF_2

XeF_2 Gas Etcher
(Xetch-X3)



Manufacturer: *Xactix, Inc.*



Above: Etching Si (3µm opening window line) with a PR (SPR955-0.9) mask. XeF_2 pressure:5Torr.The number of cycles and etch time (each cycle) are 10 and 60s, respectively. (a) Microscopic top view. (b) SEM cross-section etch profile. N. Cao