EE412 Spring 2014
SiN_x Deposition and Etching recipe Development

Yusi Chen & Muyu Xue

SNF Mentor: Jim McVittie

Faculty Mentor: James Harris

Outline

0. Motivation

1. High stress SiN deposition using CCP and STS

2. SiN nanostructure etching using PT-OX

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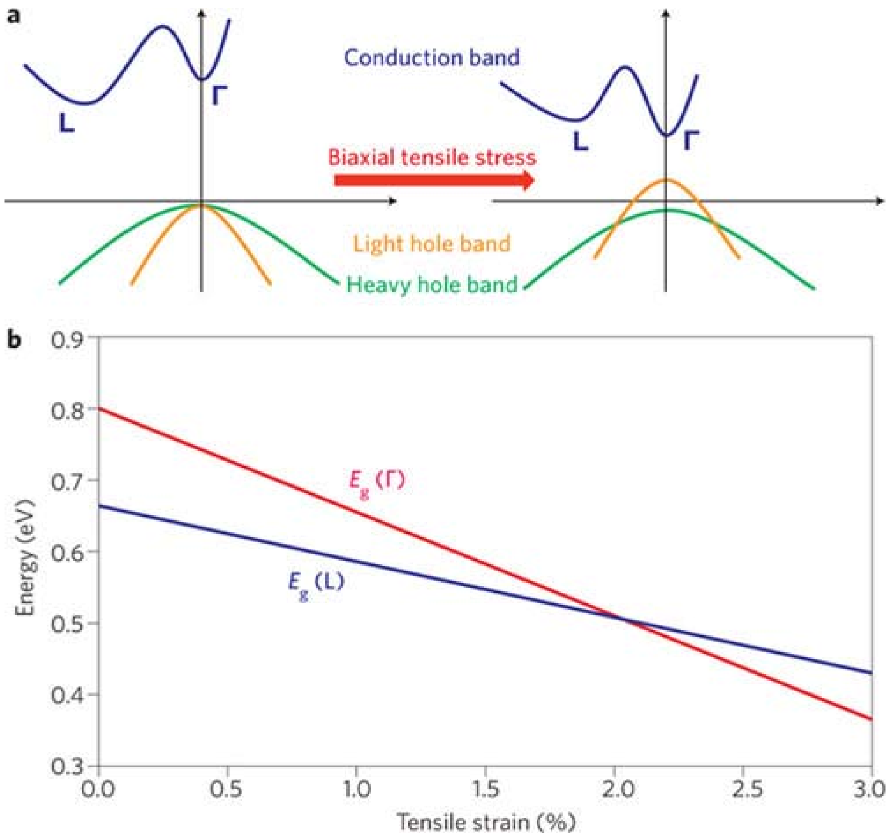
Motivation

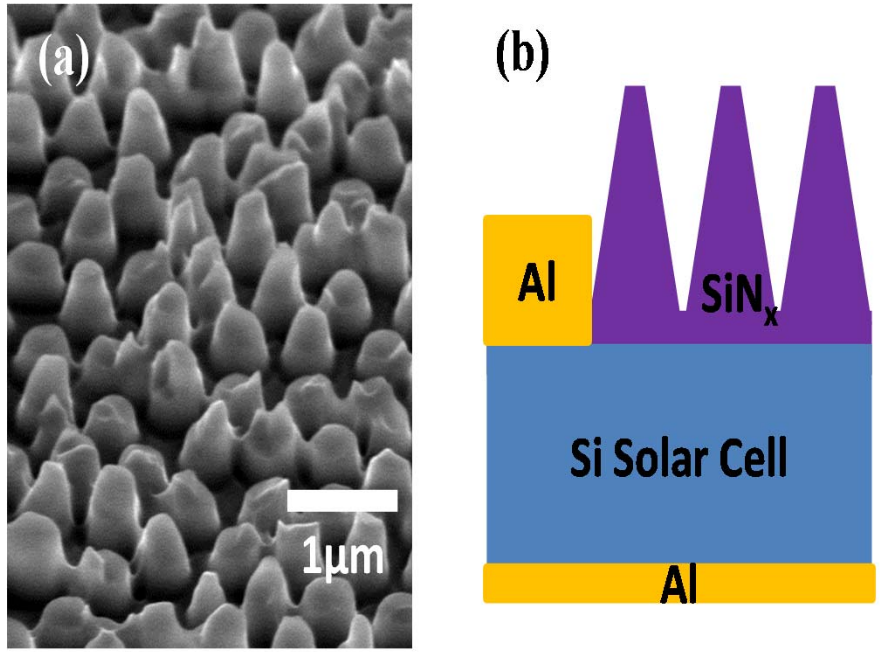
- SiN_x has been widely using in micro/nanoelectronics
- More applications in optoelectronics/photonics

Add stress to Ge



J. Michel, et. al., *Nature Photonics* 4.8 (2010): 527-534.

Light trapping using nanostrucutres



Y. Chen, et. al., *PVSC 2014, Denver*

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Stress Control Physics

Target:

Highly compressive stress SiN_x layer.

Method:

1. Increase Si content. (Si atom volume larger than N atom)
   - NH_3/SiH_4 ratio ↓.
2. Increase SiN_x film density
   - Low frequency % ↑. (ion bombardment ↑)
   - Chamber pressure ↓. (mean free path ↑, ion bombardment ↑)
   - Power ↓. (growth rate ↓, more time for atoms to move)
3. Change ion species.
   - Inert gas dilution, add He. (↑ the creation of N^+ ions, hydrogen bond density)

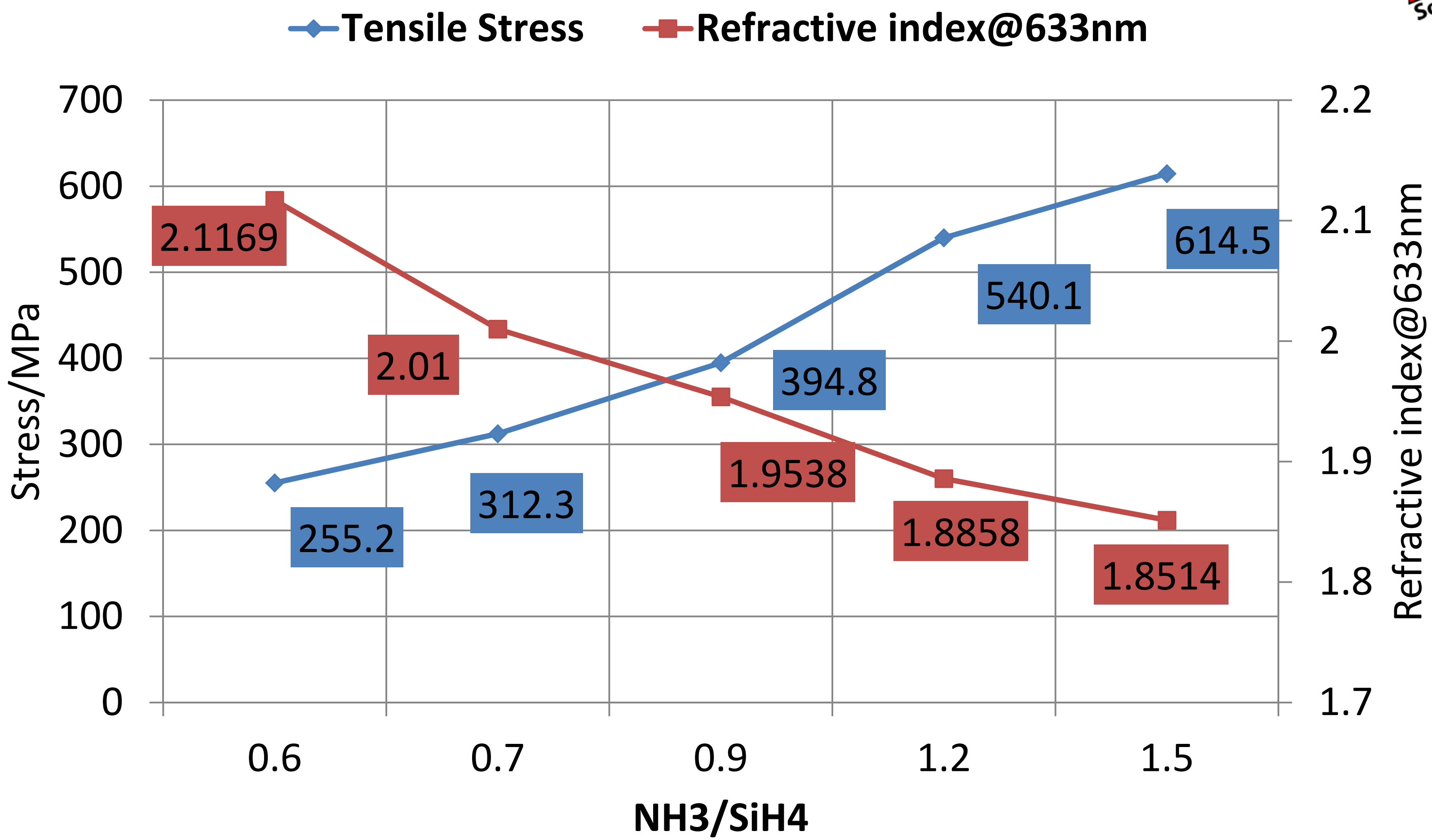
CCP Deposition Method

- Temperature 350˚C, Pressure 950mTorr, Deposition time 10min

- N_2/ (N_2+He)=0.8 (tensile limit),
  =0.6 (intermediate case),
  = 0 (compressive limit)

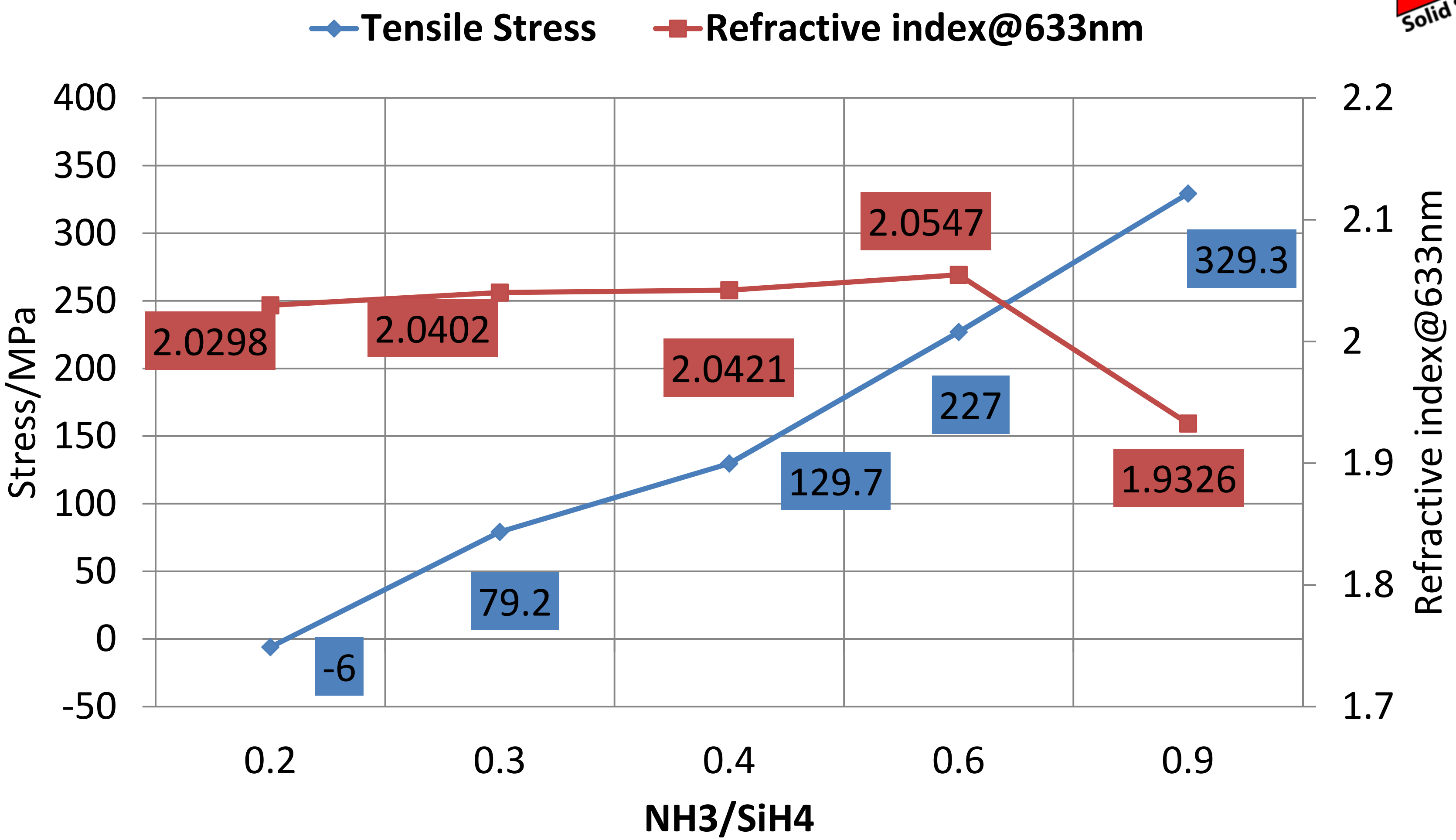
- Change ratio of NH_3/SiH_4

CCP Tensile Limit



- $N_2/(N_2+He)$=80% (N_2=800 sccm, He=200 sccm)
- Change ratio of NH_3/SiH_4: 0.6, 0.7, 0.9, 1.2, 1.5

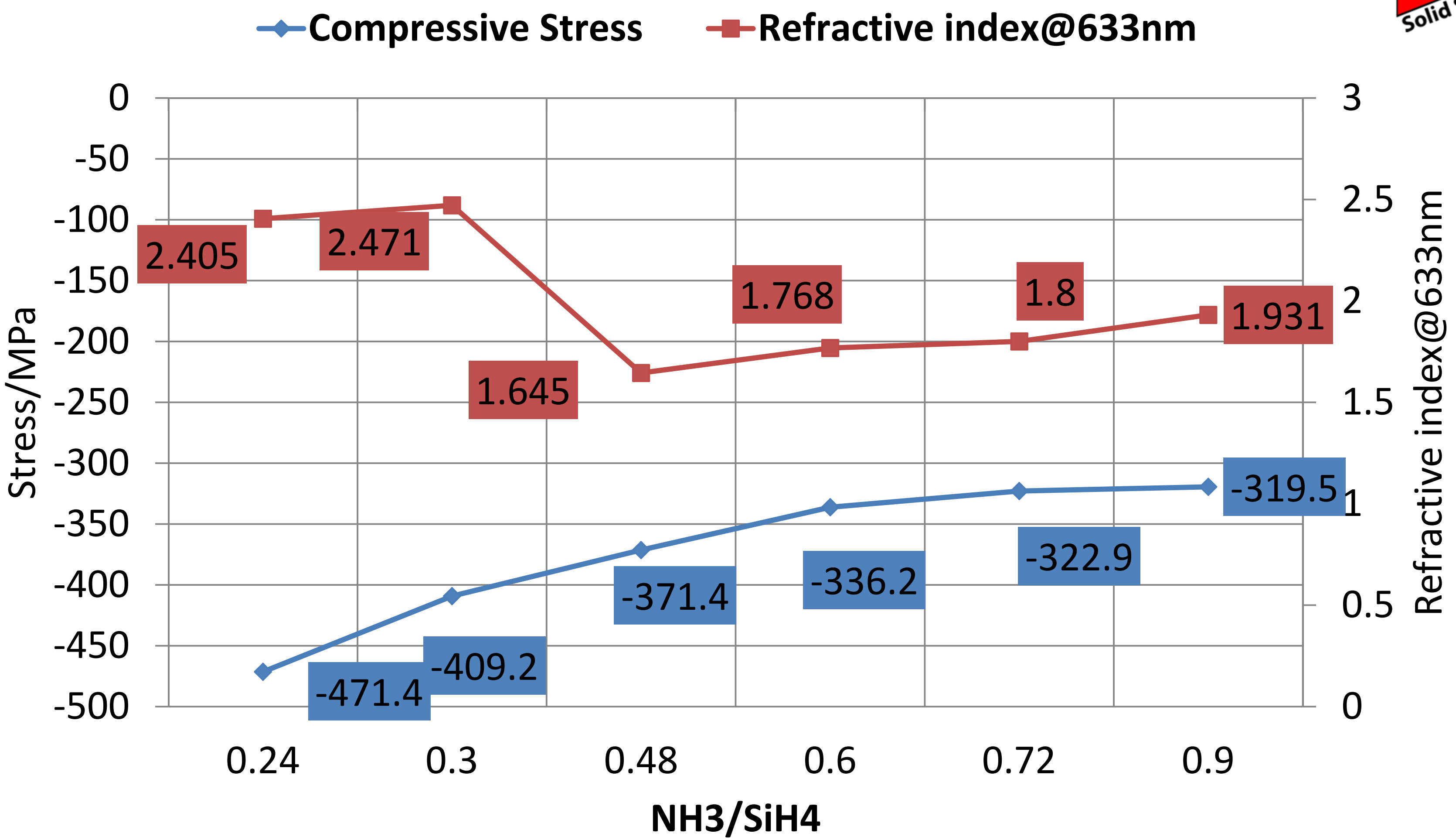
CCP Intermediate Case



- $N_2/(N_2+He)$=60% (N_2=600 sccm, He=400 sccm)

- Change ratio of NH_3/SiH_4: 0, 0.2, 0.3, 0.4, 0.6, 0.9

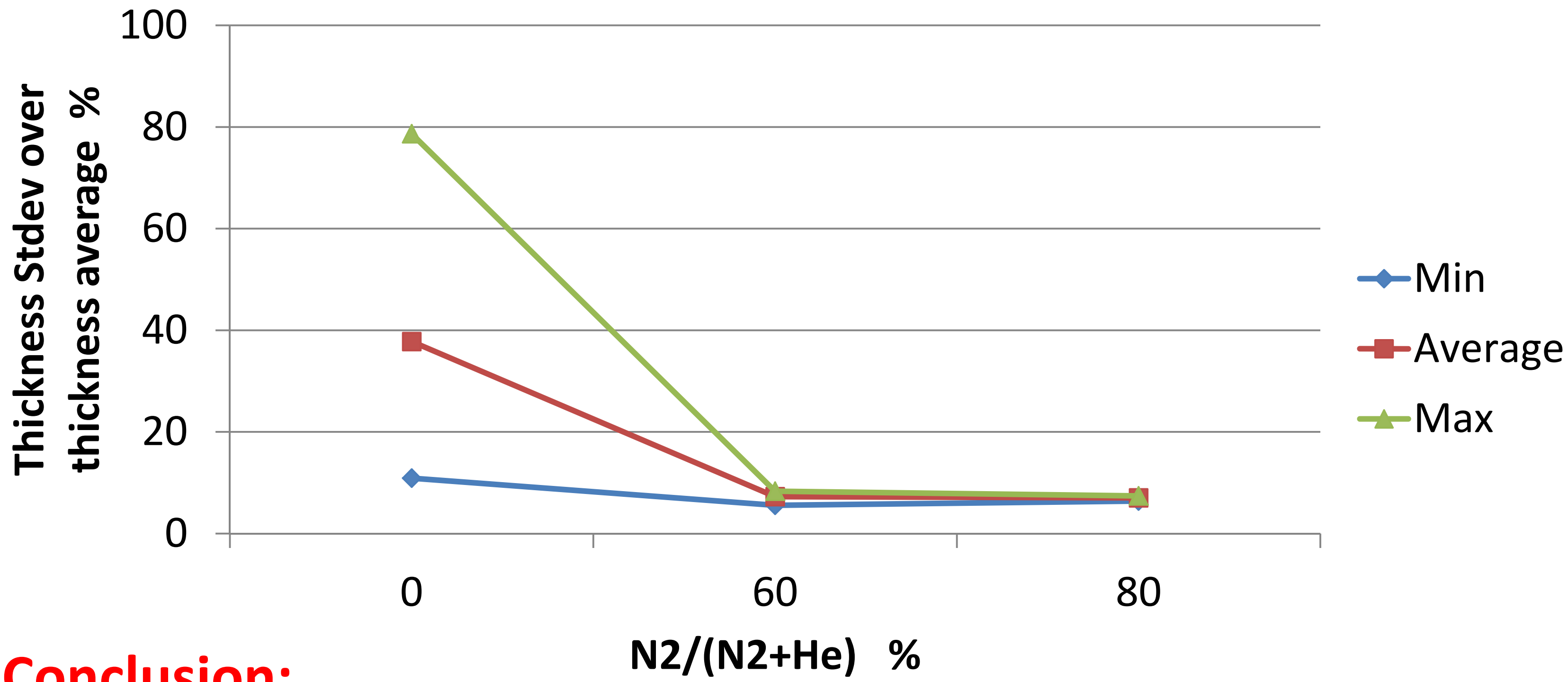
CCP Compressive Limit



- $N_2/(N_2+He)=0$ (He=1300 sccm)
- Change ratio of NH3/SiH4: 0.24, 0.30, 0.48, 0.60, 0.72, 0.9

Effect of N_2 on Uniformity

- Using Woollam 9 point mapping
- Characterize thickness standard deviation over thickness average



Conclusion:
N_2 is critical for SiNx uniformity!

STS Deposition Method

Target:

Highly compressive stress SiN_x layer.

Steps:

Fixed: Percentage of low frequency power (100%)

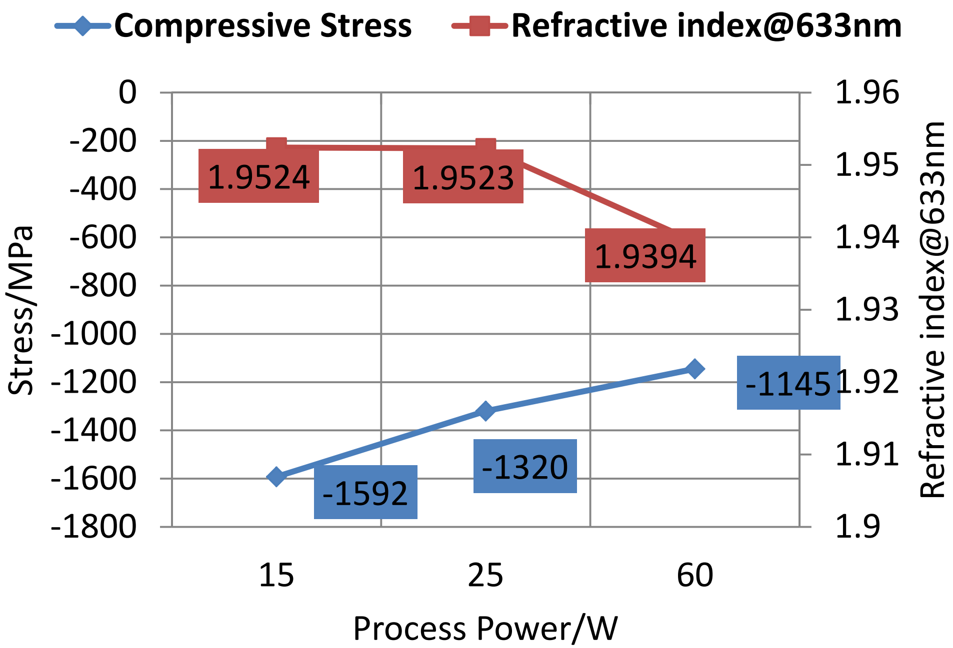
1. Process power ↓: 60w, 25w, 10w
2. Chamber pressure ↓: 650mTorr, 500mTorr
3. NH_3/SiH_4 ↓: 0.8, 0.38

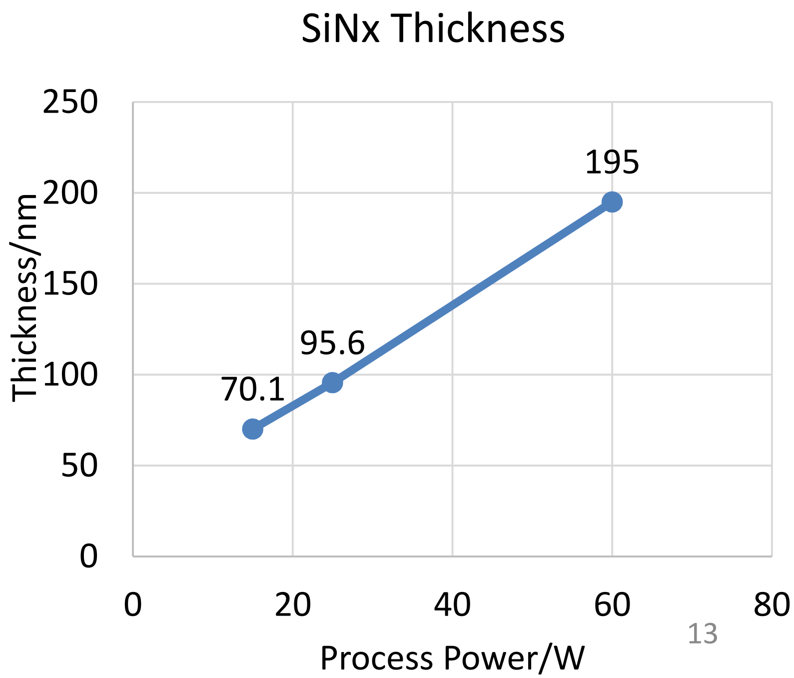
Try thicker SiNx (600nm)

STS Deposition Result

Fixed: Percentage of low frequency power (100%)

Step 1	Process power/w	Pressure/ mTorr	NH_3/SiH_4	Deposition time/min	Thickness/nm	Stress/MPa
S1	60	650	0.84	10	195	-1145
S2	25	650	0.84	10	95.6	-1320
S3	15	650	0.84	10	70.1	-1592





STS Deposition

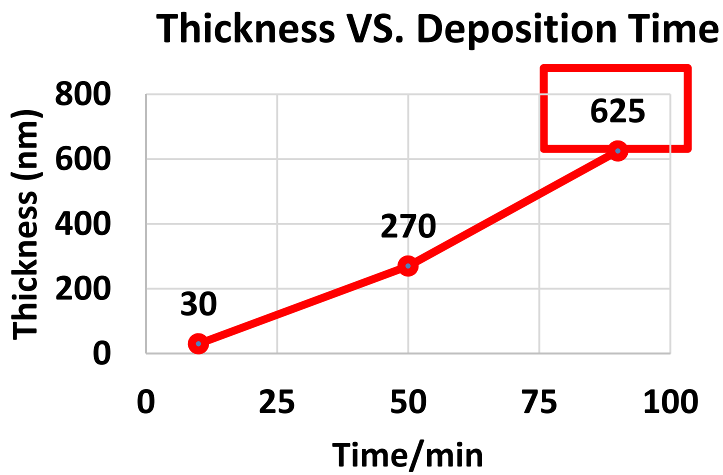
Step 2	Process power/w	Pressure/ mTorr	NH_3/SiH_4	Deposition time/min	Stress/MPa	n @ 633nm
S21	25	650	0.84	10	-1320	1.9523
S22	25	500	0.84	10	-1770	1.9488

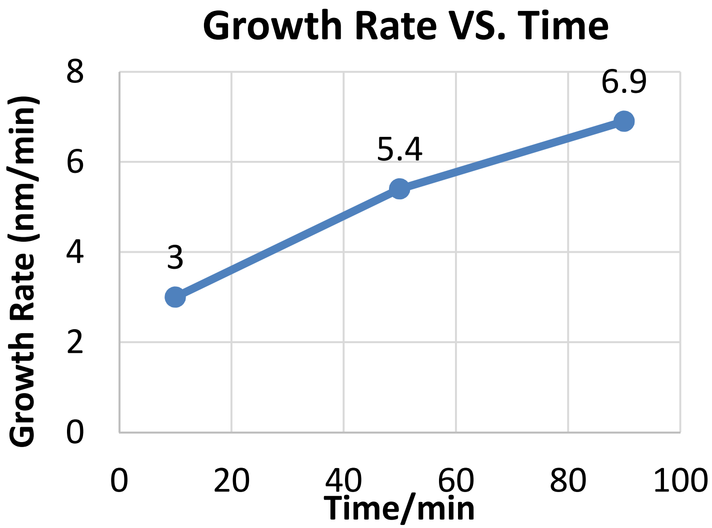
Step 3	Process power/w	Pressure/ mTorr	NH_3/SiH_4	Deposition time/min	Stress/MPa	n @ 633nm
S31	10	500	0.84	10	-1711	1.9404
S32	10	500	0.38	10	**-2095**	N/A

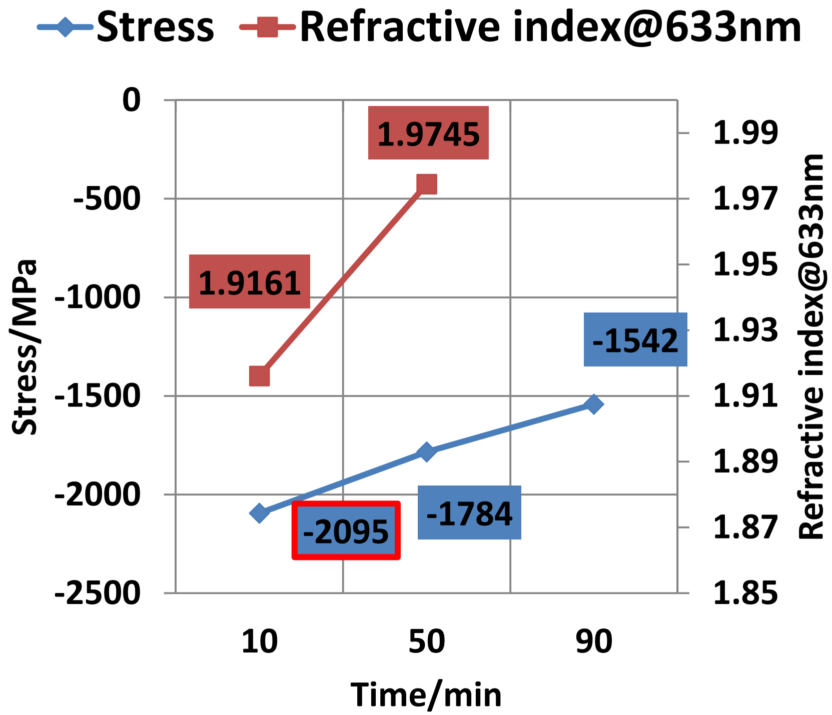
-2 Gpa!

Thicker SiNx (600nm)

PF power=10w, NH_3/SiH_4=0.37, t=10/50/90min



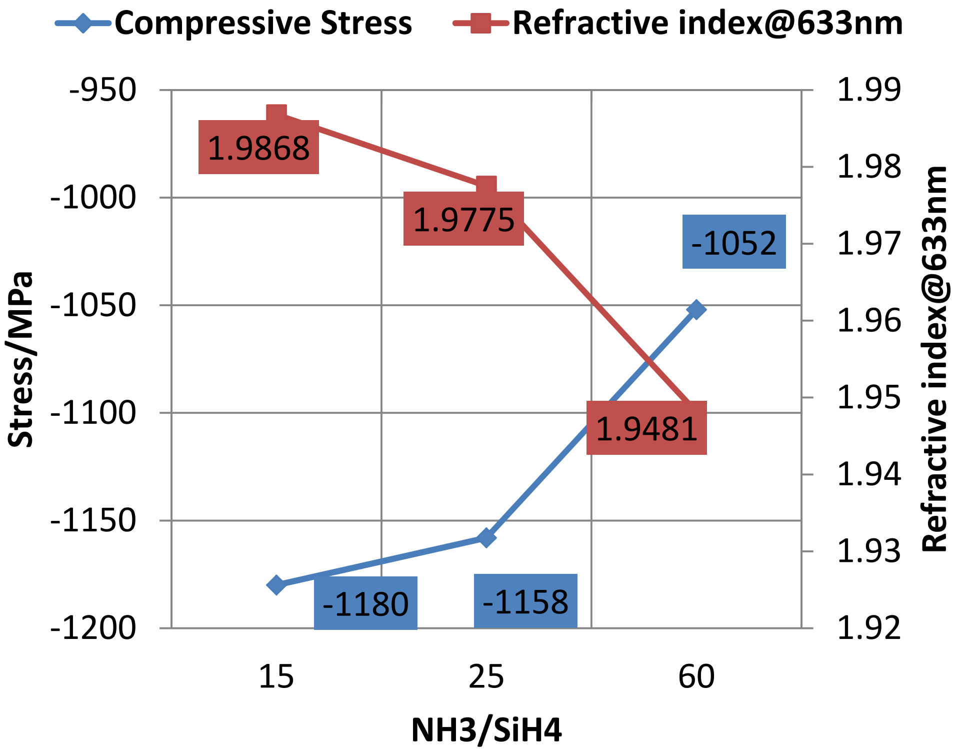


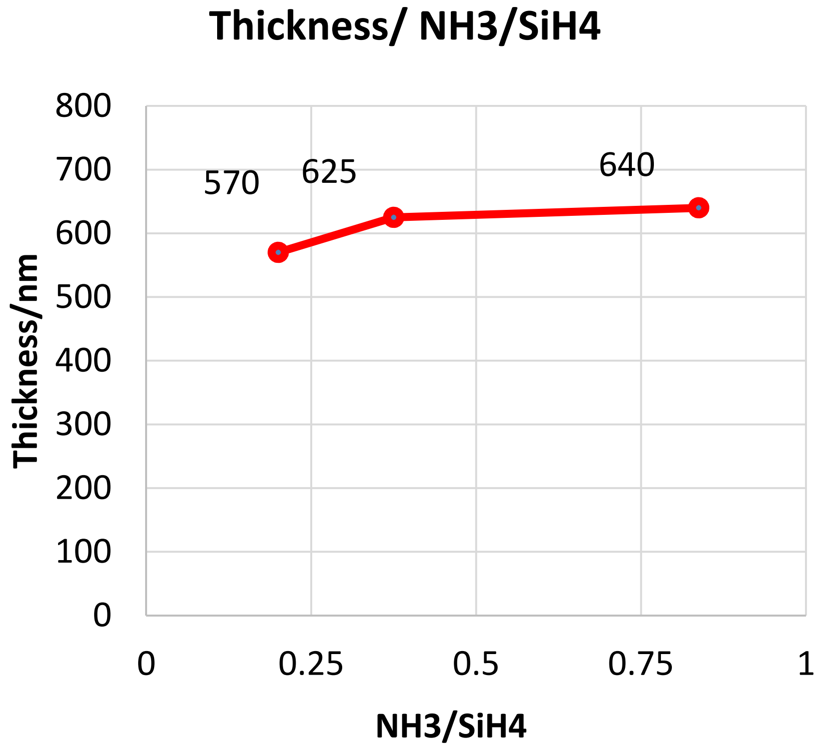


1. Get 600nm thick SiNx in STS
2. Get -1.5Gpa compressive stress

Thicker SiNx (600nm)

RF power=60w, t=30min, NH_3/SiH_4=0.2/0.37/0.84





Conclusions:

NH_3/SiH_4 ratio is secondary for SiNx stress & thickness

Conclusions

1. Stress range on CCP:
   -470MPa ----- 614MPa

2. Achieved largest compressive stress using STS:

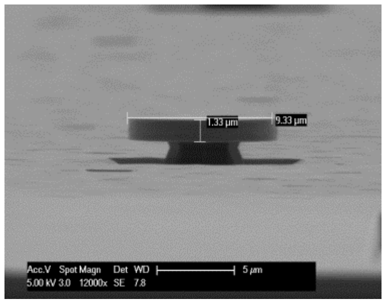
Process power/w	Pressure/ mTorr	NH_3/SiH_4	Deposition time/min	Stress/MPa
10	500	0.38	10	**-2095**

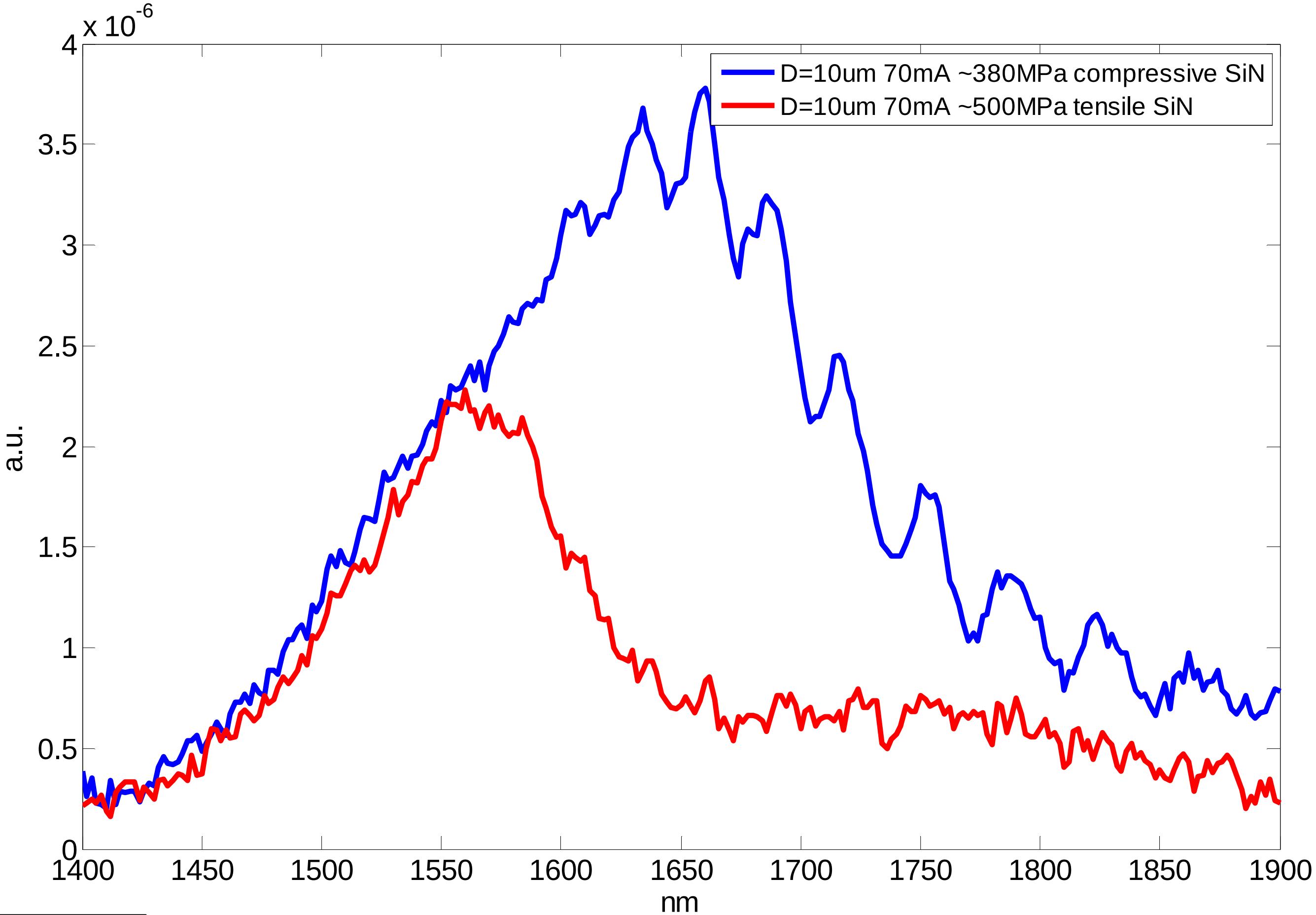
3. Thick SiN_x may reduce stress due to anneal effect

4. Add N_2 is important for SiN_x uniformity!

Application

High stress SiN_x on SiGe multi-quantum-well ring resonator





- Peak shift ~90nm.
- Intensity ~x2

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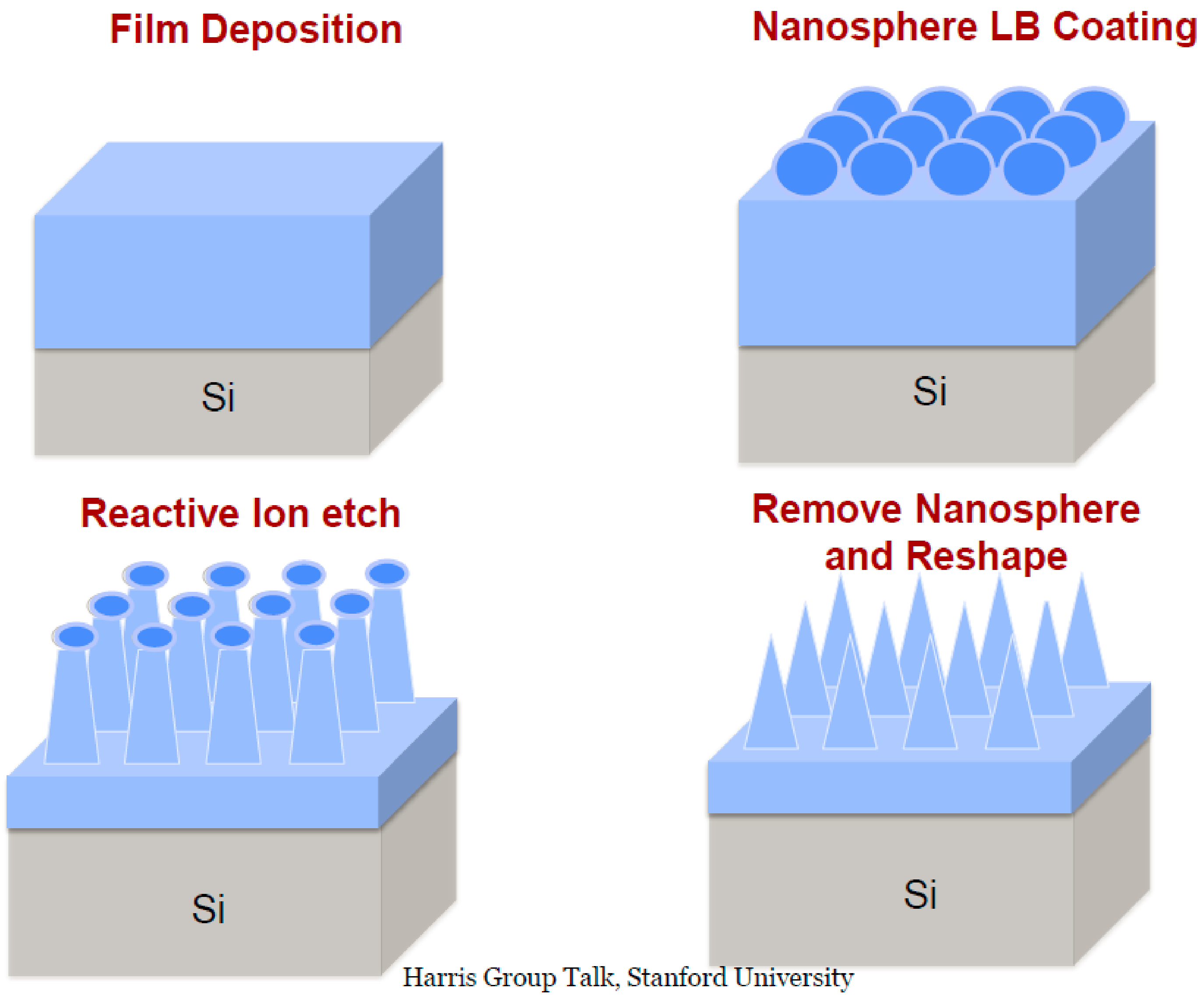
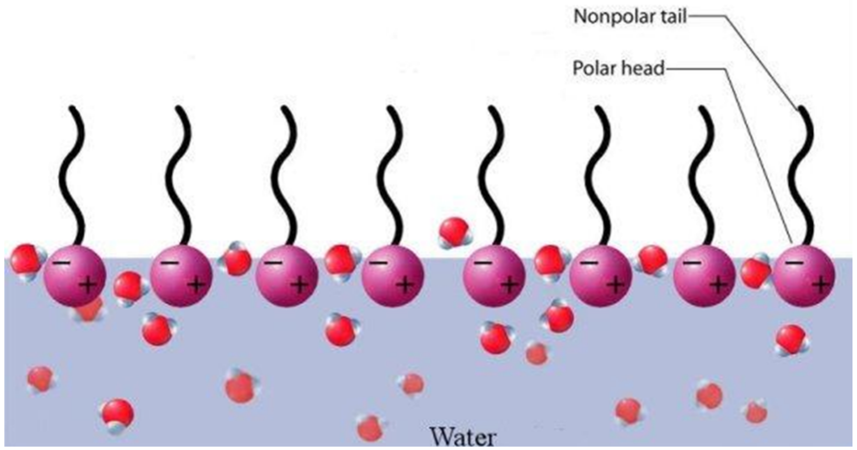
Nanosphere lithography



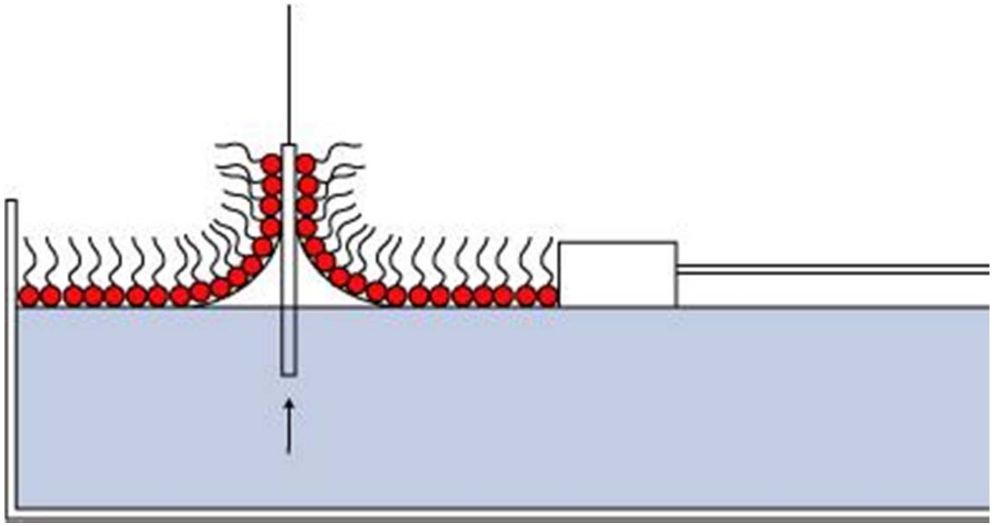
Langmuir–Blodgett Method

- Molecules with hydrophobic 'tails' and hydrophilic 'heads'.



- In water, amphiphilic molecules interact with air at an air–water interface.
  - o Tails exposed to air
  - o Heads stay inside water

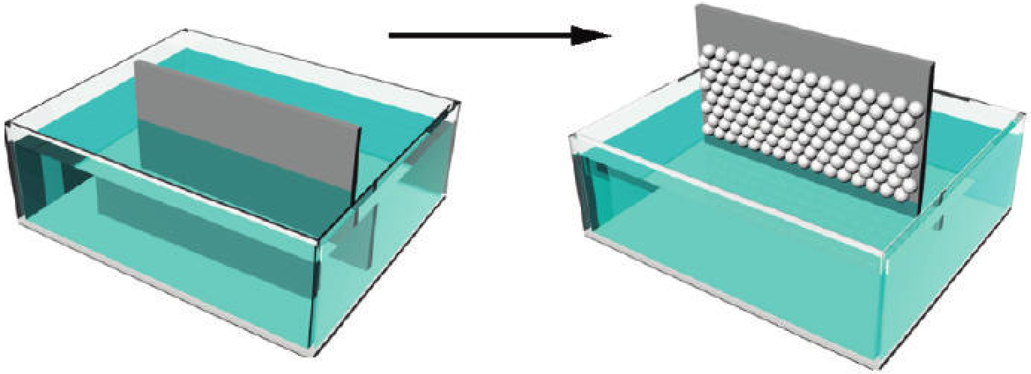
- When compressed, one compact film will be formed



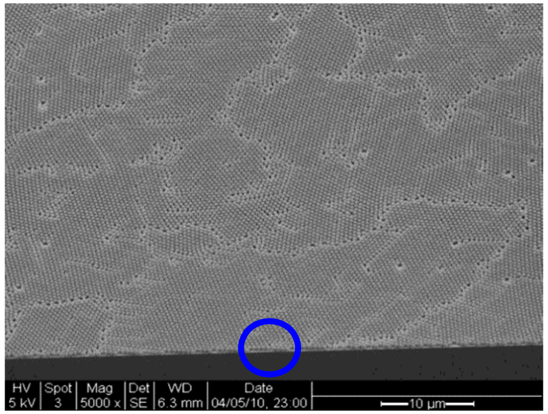
- Then transfer monolayer onto a substrate after film compression.

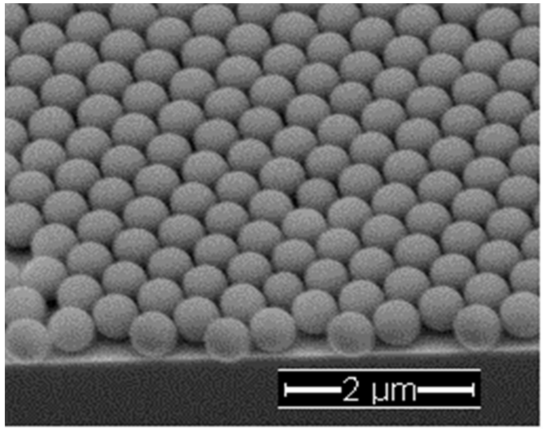
Coating in LB Trough

LB coating in silica
nano-sphere solution



Erik Garnett, et al. Nano Lett. 2010



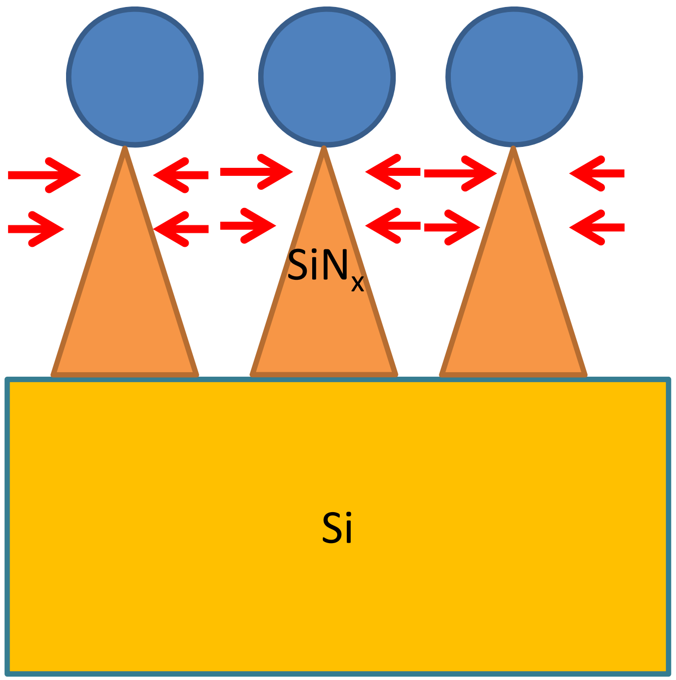


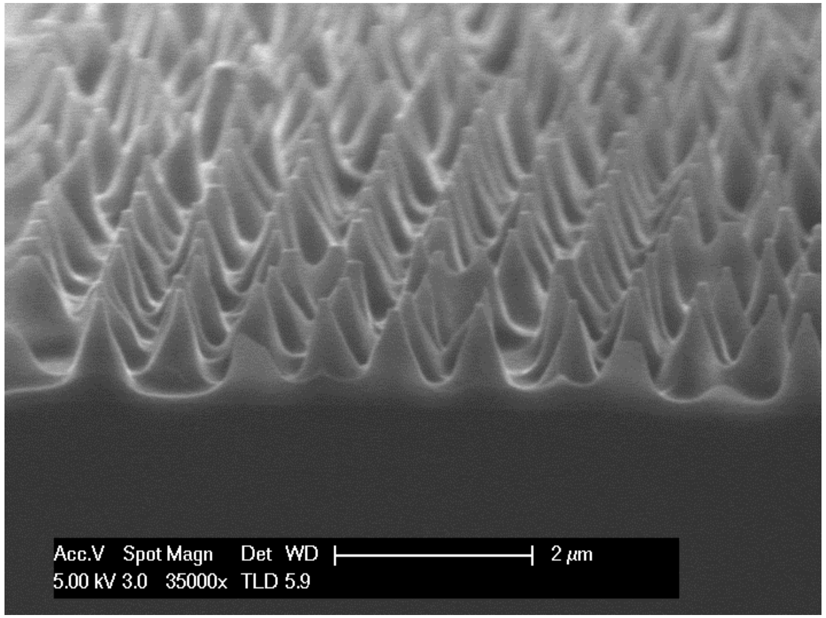
- Feedback control system
  - Use surface tension pressure of compact film as parameter

- Pull up substrate from water

Nano-cone Structures

- Using PT-OX: ICP RIE etcher
- High gas pressure: 40-50 mtorr, high scattering, more isotropic





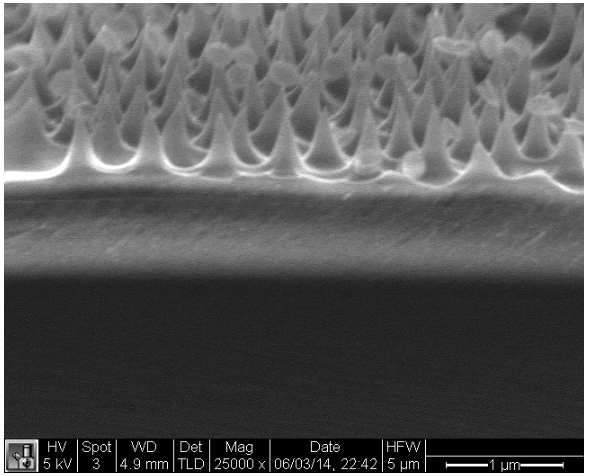
Etching recipe development

- Fixed parameters:
  - 600nm nanospheres
  - 900nm thick SiN_x using CCP SiN300 recipe
  - 10 degree C temperature
  - 1000W ICP power
  - 50V RF DC bias

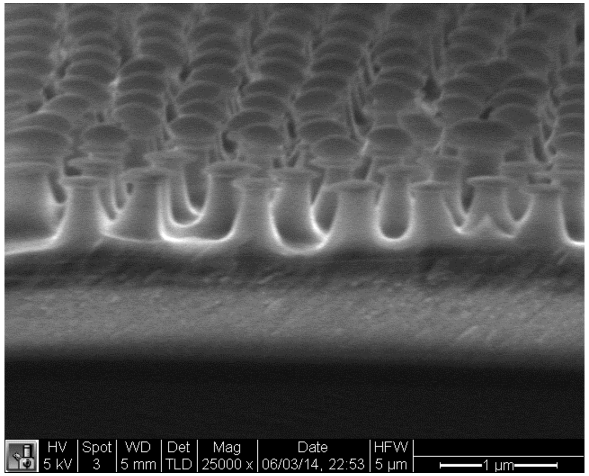
- 3 main parameter tuning:
  - Etching chemistry
  - Etching pressure
  - Etching time

Etching chemistry

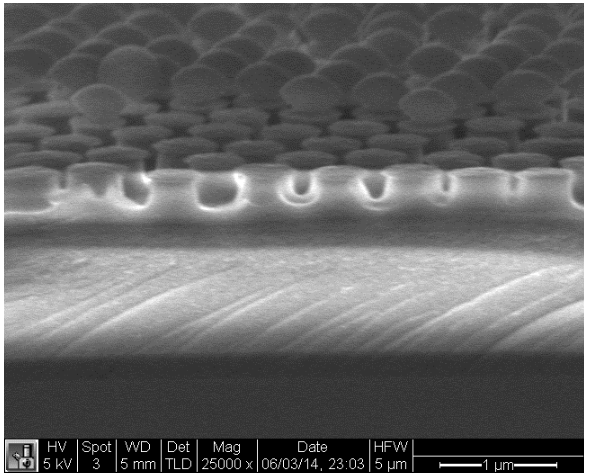
- Tried CF4, CHF3 and O2
- 240s etching, 30 mtorr pressure
- 5sccm O2, CF4+CHF3=50sccm



5% CHF3



50% CHF3

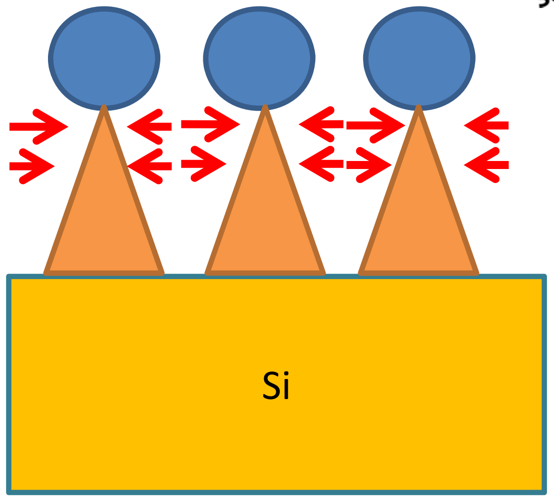


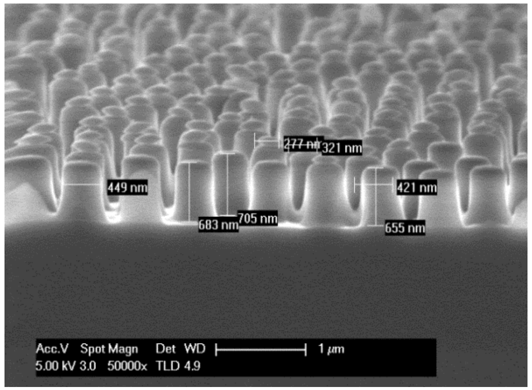
95% CHF3

- **More CF4, more isotropic**

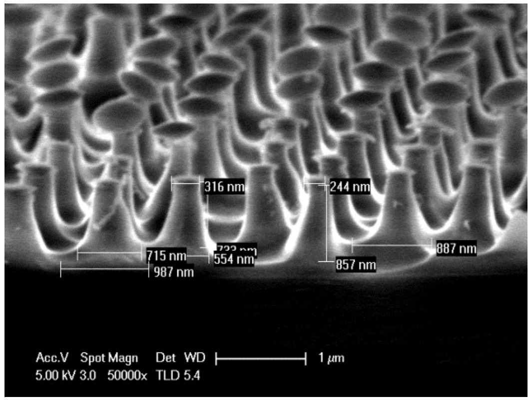
Etching pressure

- Larger pressure, more isotropic etching
- Pressure cannot be too high: plasma not working

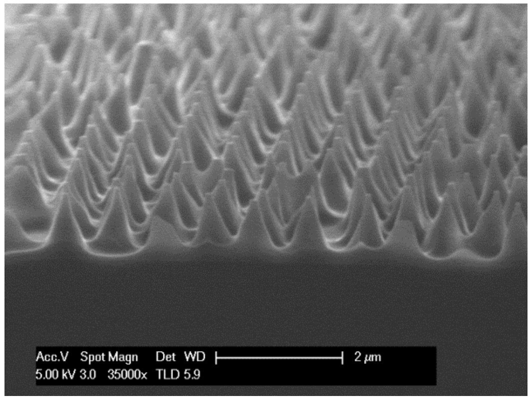




10mtorr, 120s



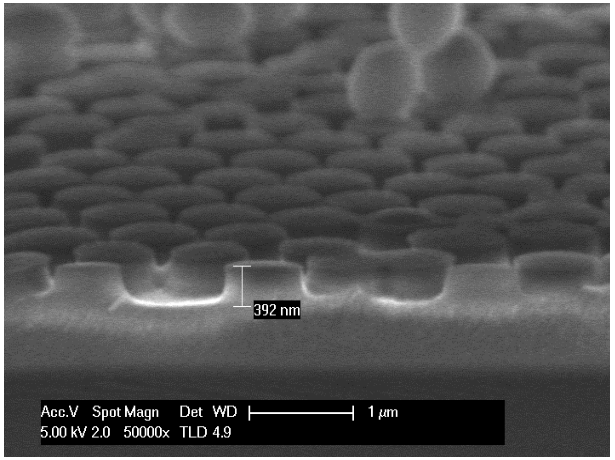
30mtorr, 240s



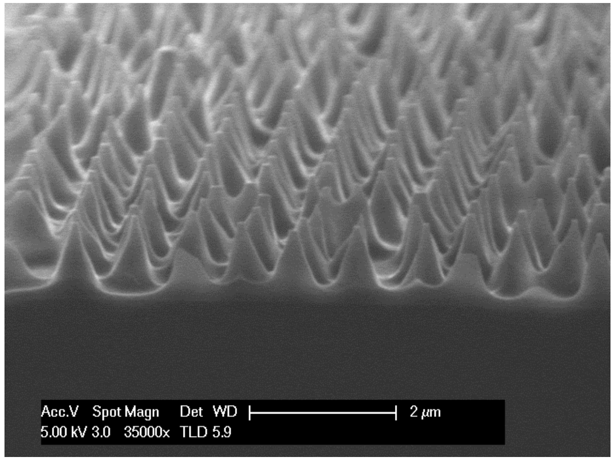
50mtorr, 240s

Etching time

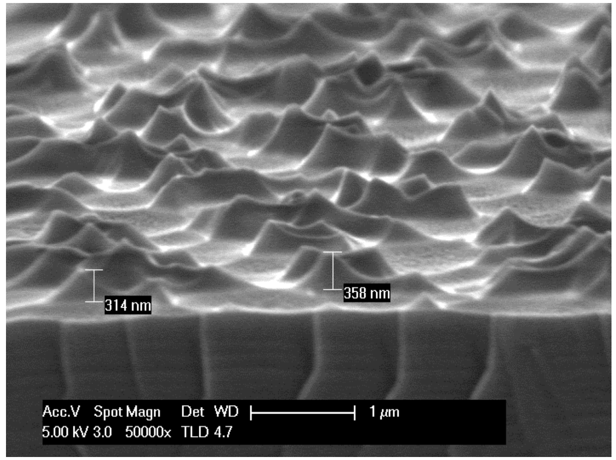
- Need to be carefully tuned
- 50sccm CF4 + 5sccm O2, 50 mtorr pressure



120s, not enough



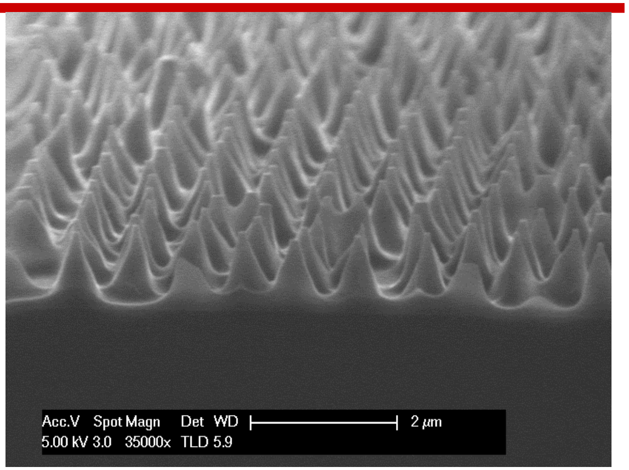
240s, good

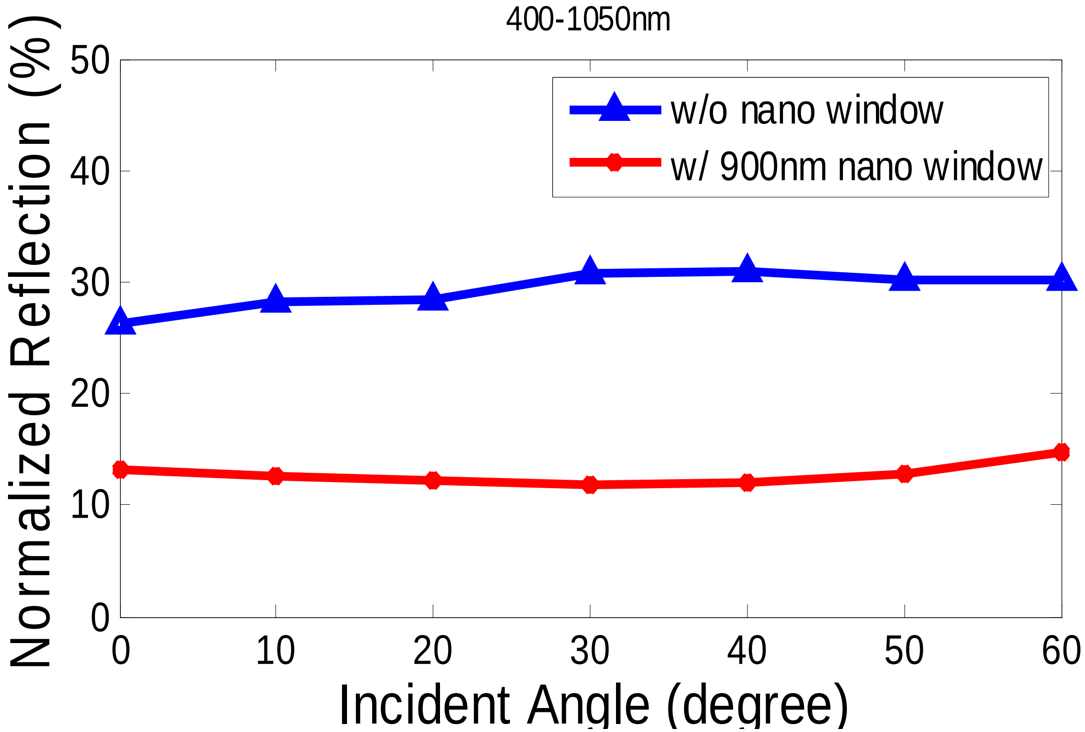


360s, over-etch

BKM Recipe and Result

- 50sccm CF4 + 5sccm O2
- 50 mtorr pressure
- 240s





- Reflection measurement
- Integrated range of wavelength 400 -1050nm

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- EE412 Teaching Team
  - Prof. Roger Howe, Dr. Mary Tang and Dr. Michelle Rincon
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