Dry Etching of InSb Using OX-35 Etcher

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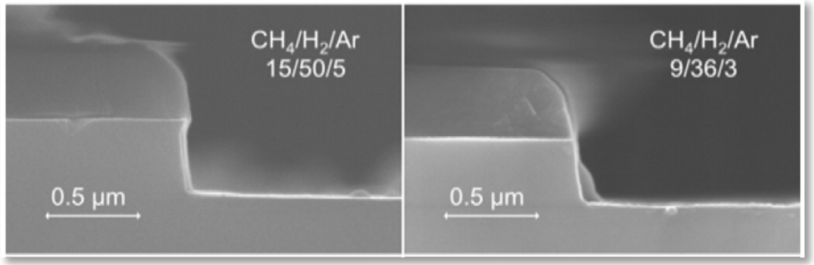
Outline

- Motivation and objectives
- Fabrication process / Characterization
- Design of experiment
- Characterization
- Results
  - Cross-sectional SEM images
  - Etch floor roughness
  - Overall effects
  - Interaction effects
- Issues / Things we wish we had known before
- Summary
- Acknowledgement

Motivation and Objectives

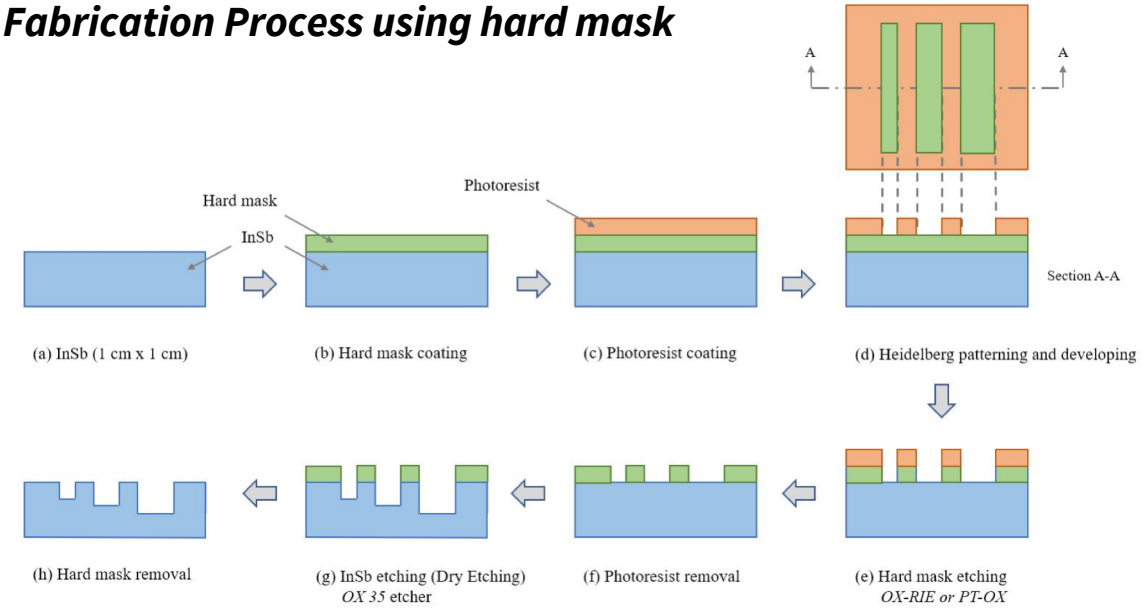
- Obtain smooth anisotropic and vertical walls on InSb substrates with dry etching with appropriate recipe
- Find the corresponding fabrication and etching processes that work to achieve this goal.
- Explore the interaction effect among factors in OX-35 e.g. gas ratio, pressure, RF power
- Add value to the highly capable OX-35



Pusino et al., *Microelectronic Engineering* (2016)

Fabrication Process / Characterization

Fabrication Process using hard mask



Tools used (10 total)

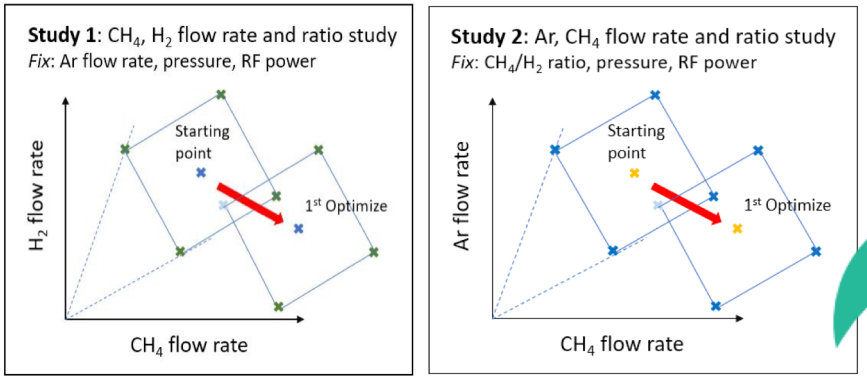
- Lithography: Yes oven, Hot plate, Headway, Heidelberg
- Deposition: CCP-DEP
- Dry Etcher: OX-RIE, Matrix, OX III-V
- Wetbench: Wbflexcorr, Wbmiscres

Characterization

- Quick check
  - Optical Microscope
  - Alphastep
  - S-neox
- Top-down SEM
- Cross-sectional SEM
- AFM

Design of Experiment

Initial DOE



Study 3: Full factorial study of Pressure and RF Power at optimized point

Cons

1. Assumed optimized point from literature (similar but different etchers)
2. Too many cases to study.
3. Better for fine tuning, future study.

Final DOE

- Full Factorial DOE with three two-level factors

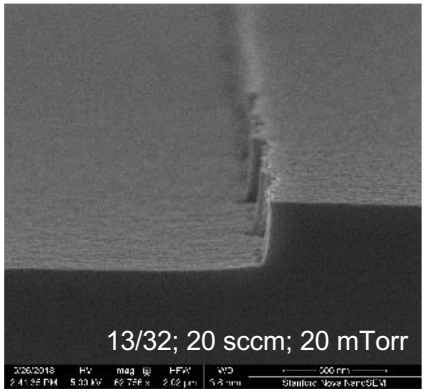
CH4/H2 (sccm)	Ar (sccm)	Pressure (mTorr)	RF Bias Power (W)
13/32	20	20	200 (fixed)
13/32	20	10	200 (fixed)
5/40	20	20	200 (fixed)
5/40	20	10	200 (fixed)
13/32	5	20	200 (fixed)
13/32	5	10	200 (fixed)
5/40	5	20	200 (fixed)
5/40	5	10	200 (fixed)

Results

Results

Cross-Sectional SEM Images

1



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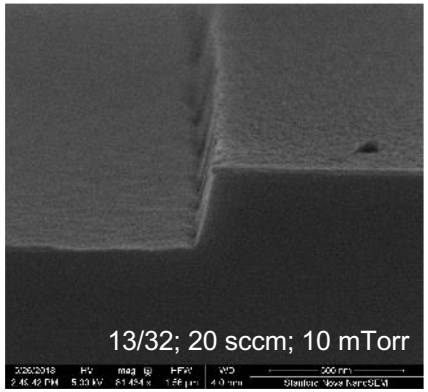

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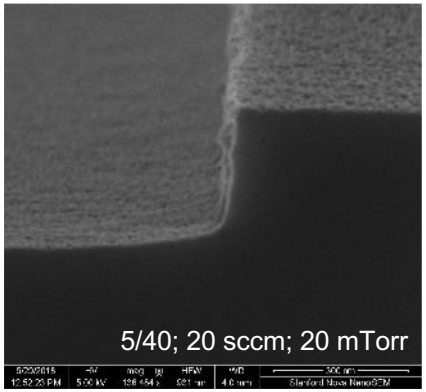

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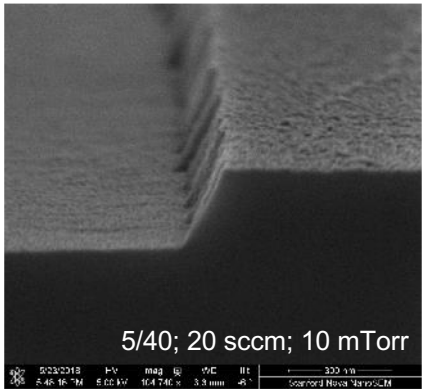

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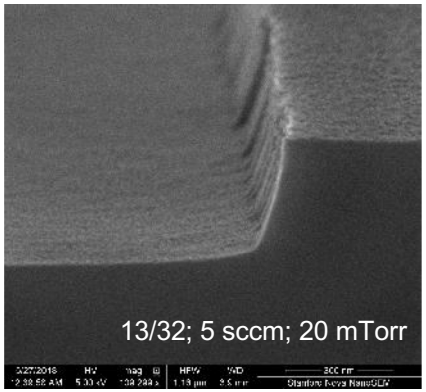

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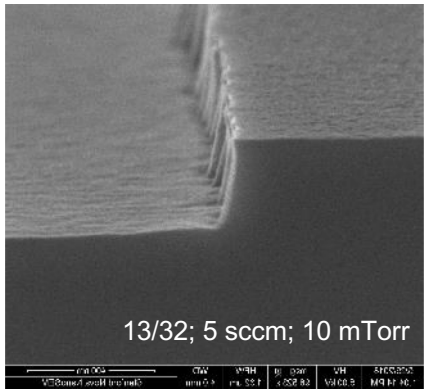

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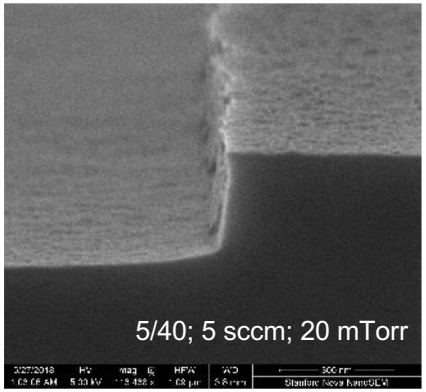

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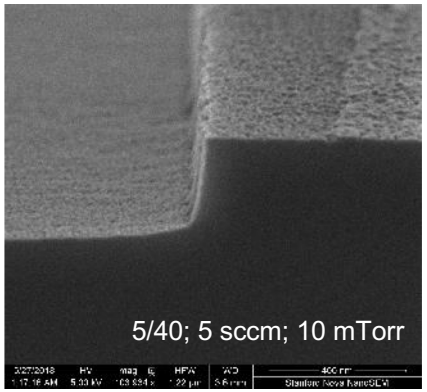
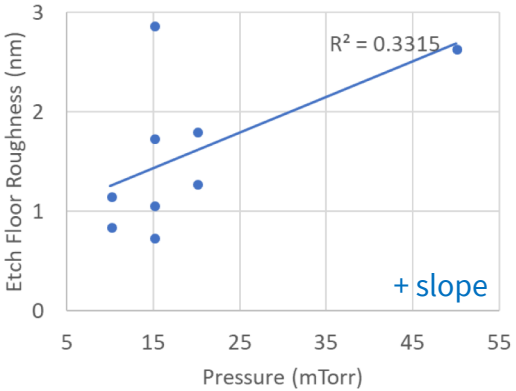


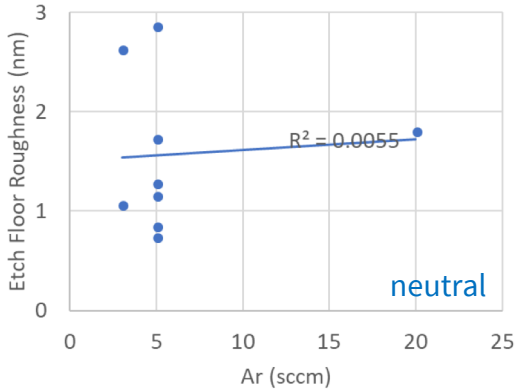
Results

AFM Etch Floor Roughness – Preliminary and DOE Data

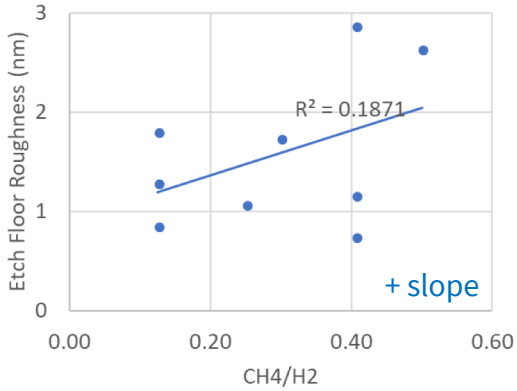
Effect of Pressure



Effect of Ar flow rate



Effect of CH4/H2



Results

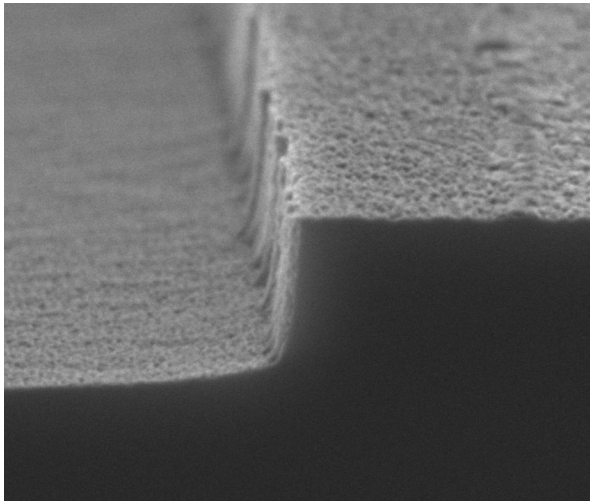
AFM Etch Floor Roughness – Best Roughness Case

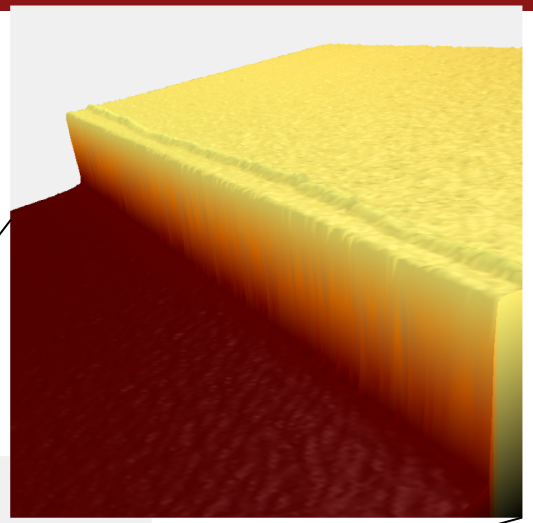
Case

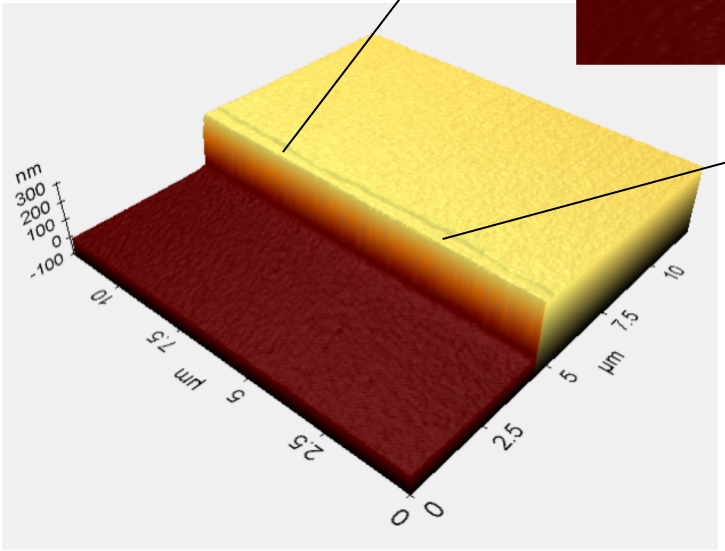
CH4/H2	5/40
Ar (sccm)	5
P (mTorr)	10
RF Power (W)	200 (fixed)

Roughness

Rq trench (nm)	0.85
Rq top surface (nm)	2.70







Results

Overall effects without interaction terms (JMP)

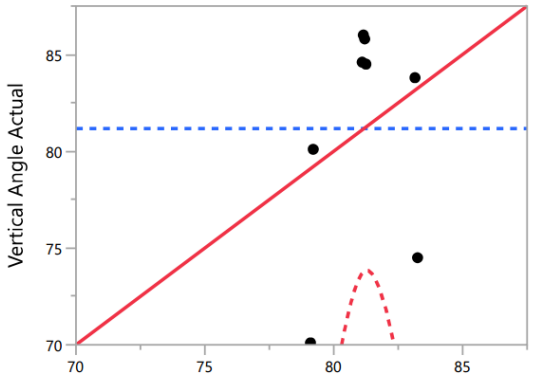
Response = f (intercept, CH4/H2, Ar, P)

Vertical wall angle

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	81.175	2.659241	30.53	<.0001*
CH4/H2(0.13,0.41)	0.05	2.659241	0.02	0.9859
Ar(5,20)	-1	2.659241	-0.38	0.7260
Pressure(10,20)	1.025	2.659241	0.39	0.7195

Actual by Predicted Plot



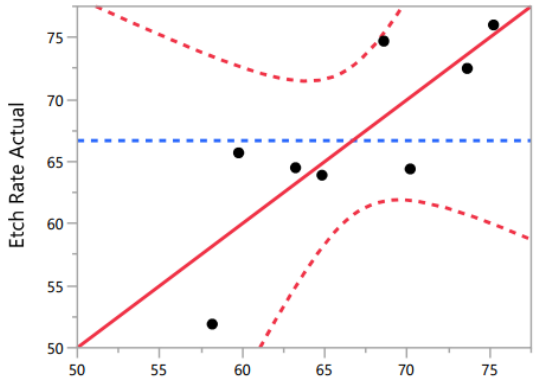
Vertical Angle Predicted P=0.9578 RSq=0.07 RMSE=7.5215

Etch rate

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	66.7	2.162861	30.84	<.0001*
CH4/H2(0.13,0.41)	2.525	2.162861	1.17	0.3079
Ar(5,20)	-0.8	2.162861	-0.37	0.7302
Pressure(10,20)	5.2	2.162861	2.40	0.0740

Actual by Predicted Plot



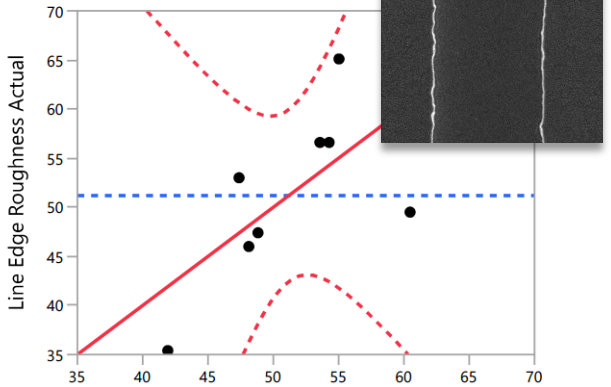
Etch Rate Predicted P=0.2057 RSq=0.65 RMSE=6.1175

Line Edge Roughness

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	51.2	3.148784	16.26	<.0001*
CH4/H2(0.13,0.41)	3.1	3.148784	0.98	0.3806
Ar(5,20)	-2.725	3.148784	-0.87	0.4356
Pressure(10,20)	3.45	3.148784	1.10	0.3348

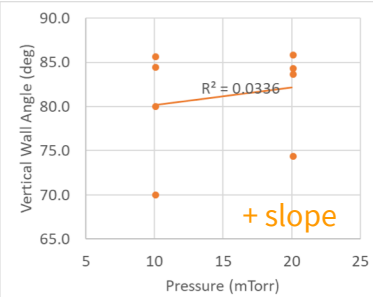
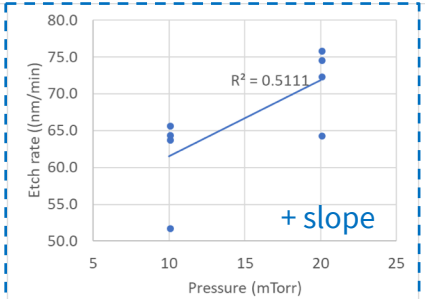
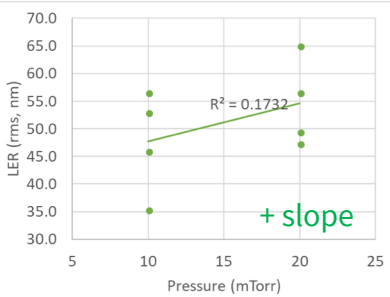
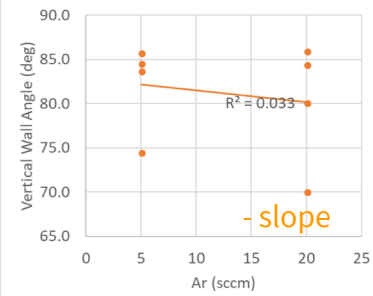
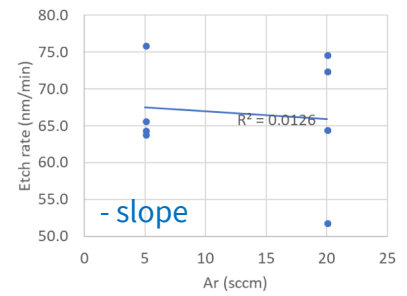
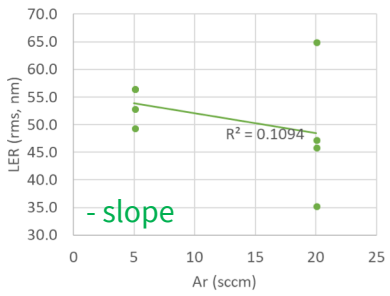
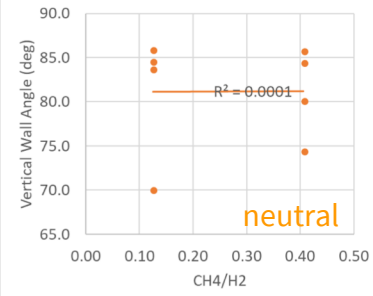
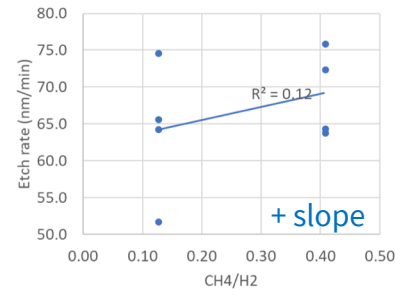
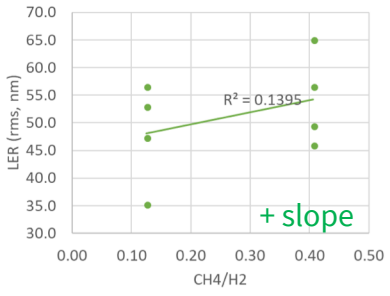
Actual by Predicted Plot



Line Edge Roughness Predicted P=0.4884 RSq=0.42 RMSE=8.9061

Results

Overall effects – Individual factors

	Vertical wall angle	Etch rate	Line Edge Roughness
Effect of Pressure			
Effect of Ar flow rate			
Effect of CH4/H2			

Results

Summary of overall effects

- At current boundaries:
  - Pressure: 10 - 20 mTorr
  - Ar flow rate: 5 – 20 sccm
  - CH4/H2: 0.13 – 0.41

- Maximize Vertical wall angle:

Pressure ↑ , Ar Flow rate ↓ , CH4/H2 -

- Minimize Line Edge Roughness:

Pressure ↓ , Ar Flow rate ↑ , CH4/H2 ↓

Results

Overall effects with interaction terms (JMP)

*Response = f (intercept, CH4/H2, Ar, P, CH4/H2*Ar, CH4/H2*P, Ar*P)*

Vertical wall angle

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	81.175	0.125	649.40	0.0010*
CH4/H2(0.13,0.41)	0.05	0.125	0.40	0.7578
Ar(5,20)	-1	0.125	-8.00	0.0792
Pressure(10,20)	1.025	0.125	8.20	0.0773
CH4/H2*Ar	2.075	0.125	16.60	0.0383*
CH4/H2*Pressure	-2.75	0.125	-22.00	0.0289*
Ar*Pressure	4.05	0.125	32.40	0.0196*

Interaction terms are significant for Vertical wall angle!

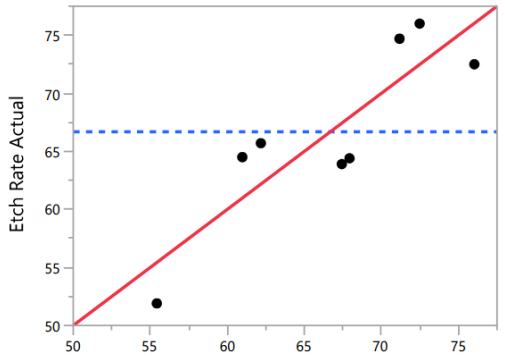
*CH4/H2*Ar* *CH4/H2*P* *Ar*P*

Etch rate

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	66.7	3.525	18.92	0.0336*
CH4/H2(0.13,0.41)	2.525	3.525	0.72	0.6043
Ar(5,20)	-0.8	3.525	-0.23	0.8579
Pressure(10,20)	5.2	3.525	1.48	0.3793
CH4/H2*Ar	0.075	3.525	0.02	0.9865
CH4/H2*Pressure	-0.175	3.525	-0.05	0.9684
Ar*Pressure	2.5	3.525	0.71	0.6073

Actual by Predicted Plot



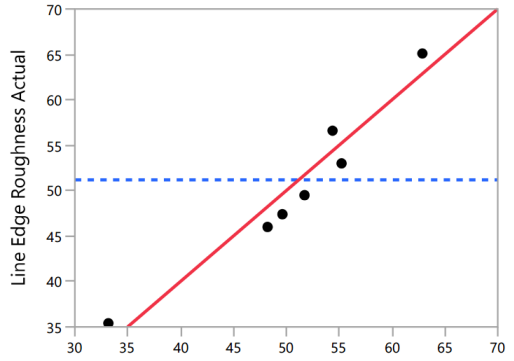
Etch Rate Predicted P=0.7771 RSq=0.76 RMSE=9.9702

Line Edge Roughness

Parameter Estimates

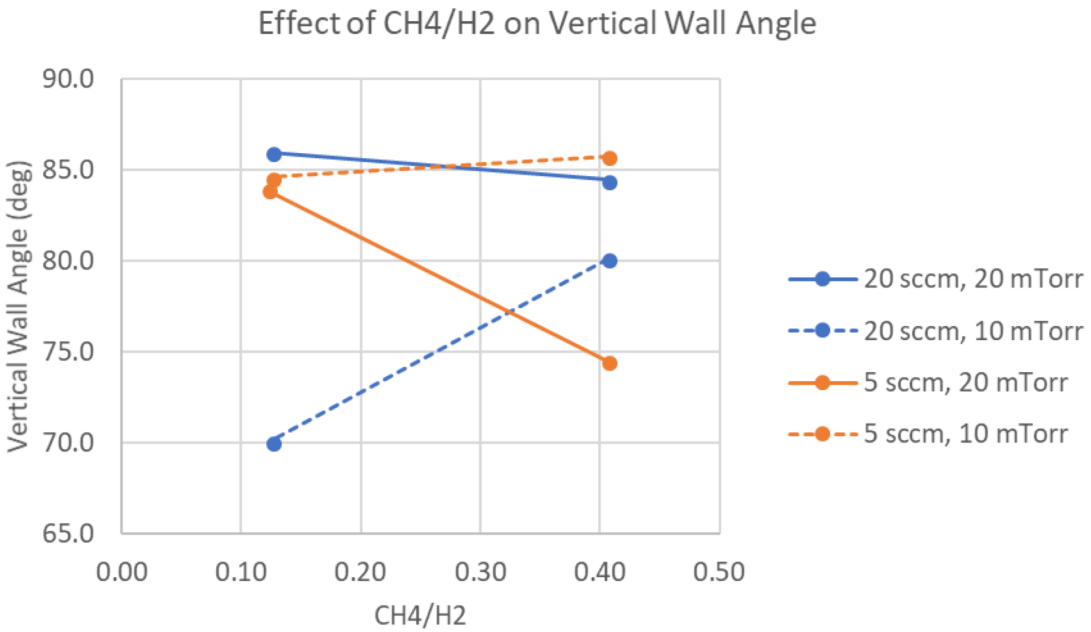
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	51.2	2.225	23.01	0.0276*
CH4/H2(0.13,0.41)	3.1	2.225	1.39	0.3963
Ar(5,20)	-2.725	2.225	-1.22	0.4359
Pressure(10,20)	3.45	2.225	1.55	0.3647
CH4/H2*Ar	3.975	2.225	1.79	0.3249
CH4/H2*Pressure	-0.45	2.225	-0.20	0.8730
Ar*Pressure	4.325	2.225	1.94	0.3025

Actual by Predicted Plot



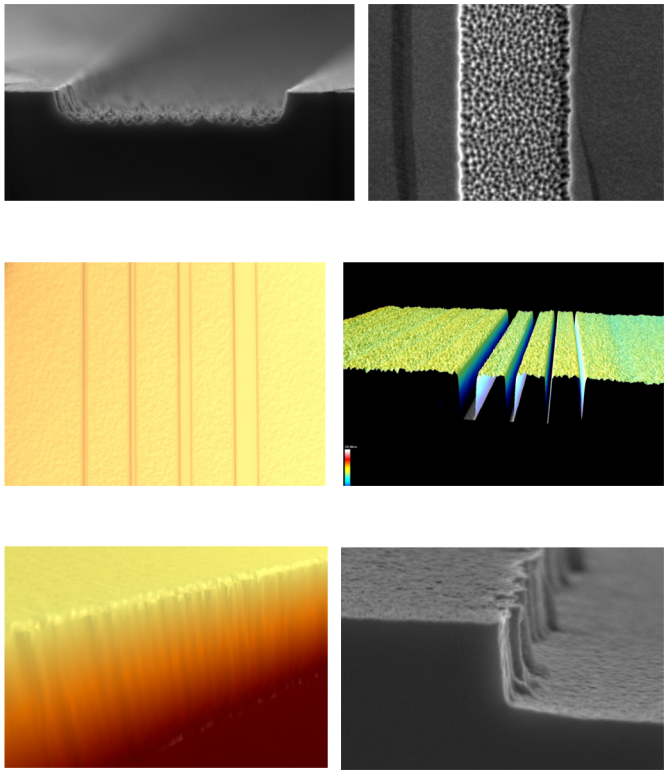
Line Edge Roughness Predicted P=0.48 RSq=0.93 RMSE=6.2933

Results
Interaction effects



- Look at the large change in response only.
- At 20 sccm Ar (blue), only at low pressure (10 mTorr) that
  - Angle ↑ as CH4/H2 ↑
- At 5 sccm Ar (orange), only at high pressure (20 mTorr) that
  - Angle ↓ as CH4/H2 ↑

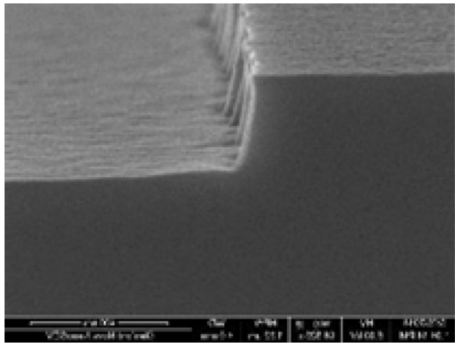
Issues / Things we wish we had known before



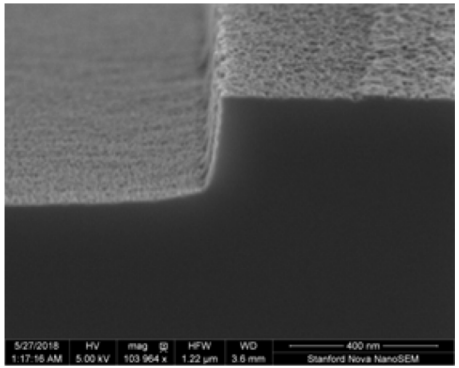
- "Grass" roughness Issue
  - Pieces of the hardmask remaining due to lack of hardmask overetch
- Top surface roughness
  - Caused by thin hardmask being etched through during InSb etching
- Use of oil in hardmask etching (OX-RIE)
  - More oil results in better etch of hardmask, more uniform temperature distribution at the back contact
- Line Edge Roughness (LER)
  - Could be caused by our etching conditions (RF power)
  - Could also be from polymer being deposited onto sidewalls
  - (Ongoing)

Summary

- Most vertical wall angle: 86.5 degrees
  - 13/32 sccm CH4/H2 Ratio, 5 sccm Ar flow rate, 10 mTorr chamber pressure
- Best surface roughness: 0.85nm
  - 5/40 sccm CH4/H2 Ratio, 5 sccm Ar flow rate, 10 mTorr chamber pressure
- To maximize vertical wall angle:
  - Increase pressure, decrease Ar flow
- To minimize line edge roughness:
  - Decrease pressure and CH4/H2 ratio, increase Ar flow



Most vertical wall angle
13/32/5sccm (CH4/H2/Ar) flow rate, 10 mTorr



Best Surface Roughness
5/40/5sccm (CH4/H2/Ar) flow rate, 10 mTorr

Acknowledgement

We would like to acknowledge our SNF mentors, Usha and Jim, and our external mentors, Vijay and Seoung-Jai, and the E241 teaching team. We would also like to acknowledge the hardworking SNF staff. Thank you for all your help this quarter!

Q & A