PECVD SiNx Conformal Stressor Films

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Outline

- Motivation
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- Design of Experiments
- Results & Discussion
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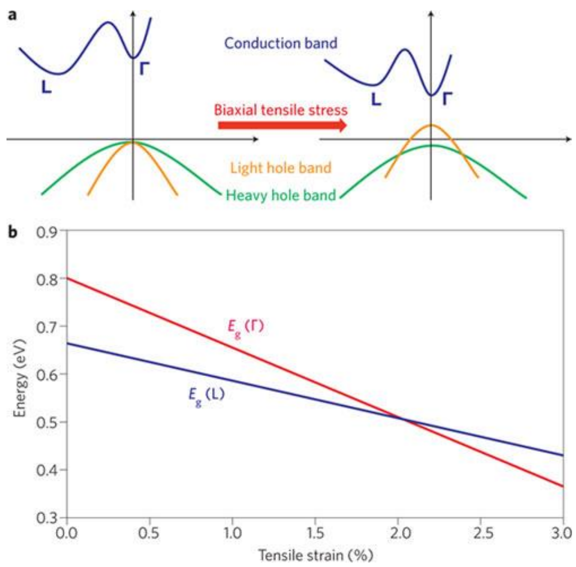
  - Stress
  - Strain
  - Conformity
- Conclusion

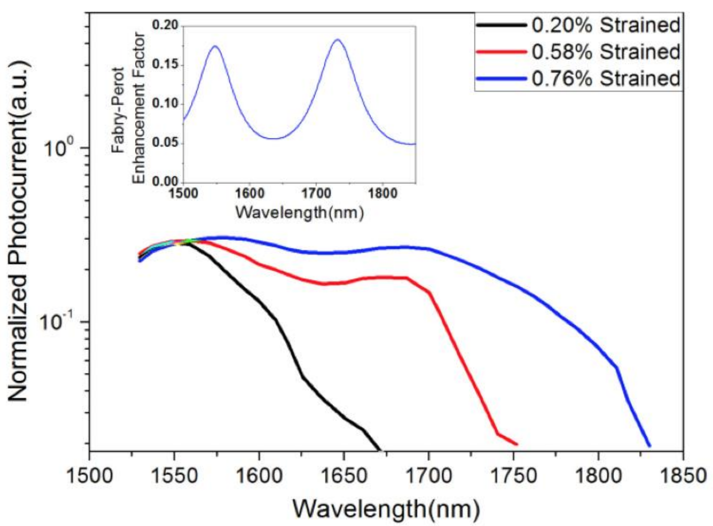
Motivation

Why is strain interesting?

- Band engineering by tensile strain can make Ge closer to being a direct-gap material. Ge is predicted to become direct-gap at 2% tensile strain.
- Applications: light-emitting devices, expanding the operating wavelength for modulators and detectors.



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



D. Nam et al., Optics Express 19.27 (2011): 25866.

SiN Induced Tensile Strain

Why compressive SiN?

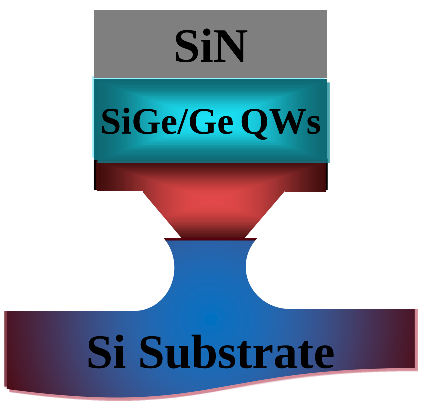
- Due to balance of force, compressively stressed SiN on Ge induces tensile strain in the underlying Ge.

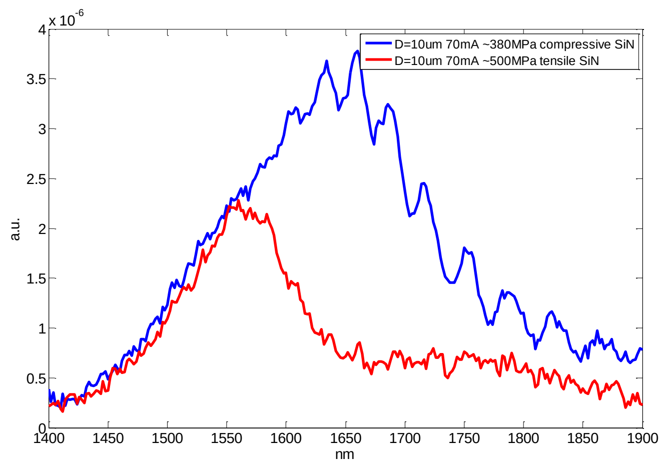
Current progress

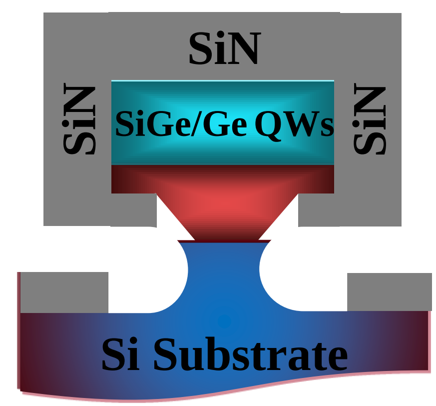
- Our group has demonstrated a shift and enhancement in photoluminescence peak with SiN deposited on top of the SiGe/Ge QWs.

How to further improve strain?

- How about conformal SiN?





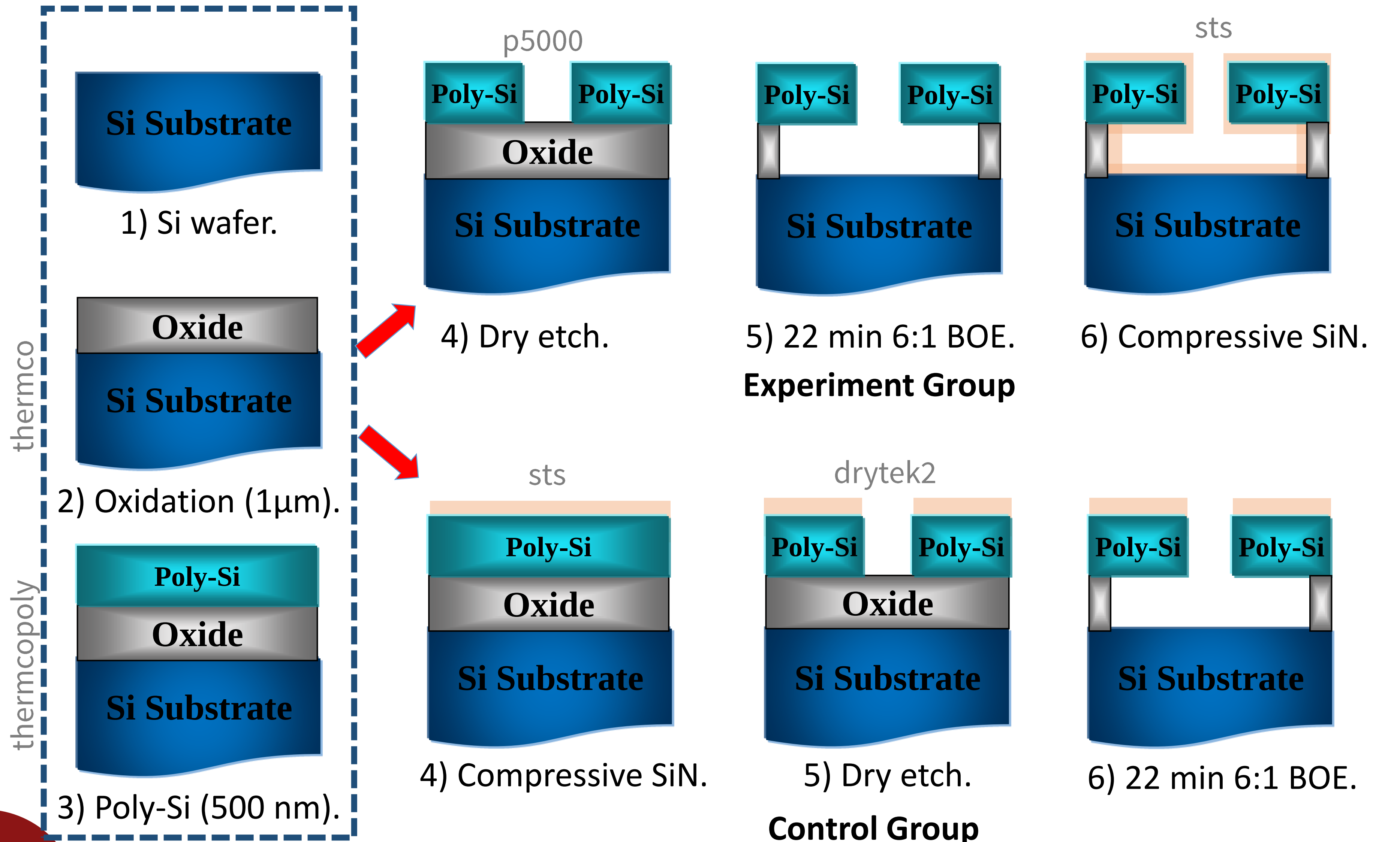


Harris Group

Main Goals

- Investigate how much thickness we can get at the back side and the side wall of a suspended structure with different SiN deposition recipes.
- Develop a SiN deposition recipe that maximizes the tensile strain in the suspended structure.
- Demonstrate that conformal SiN deposition gives a larger strain compared to top SiN deposition.

Test Structure & Process



Design of Experiments - Background Info

Strain is affected by SiN stress and thickness

- Increasing stress increases strain
- Increasing thickness increases strain but can slowly saturate

General trends

- Thinner film ↔ higher stress
- Lower process power ↔ higher stress
- Lower chamber pressure ↔ higher stress
- Lower NH_3/SiH_4 ratio ↔ higher stress (but changes little for thick SiN deposition)

K.D. Mackenzie et al., 207th Electrochemical Society Meeting, PV2005-01 (2005): 148-159.

DOE – 2^3 Full Factorial + 1

- Fixed: temperature at 300 ˚C, NH_3/SiH_4 ratio = 0.82.
- Variables: pressure, power, and deposition time
- What to measure: thickness, stress, and strain
- Center condition:

Power (mW)	Pressure (mTorr)	Deposition time
25	500	30 min

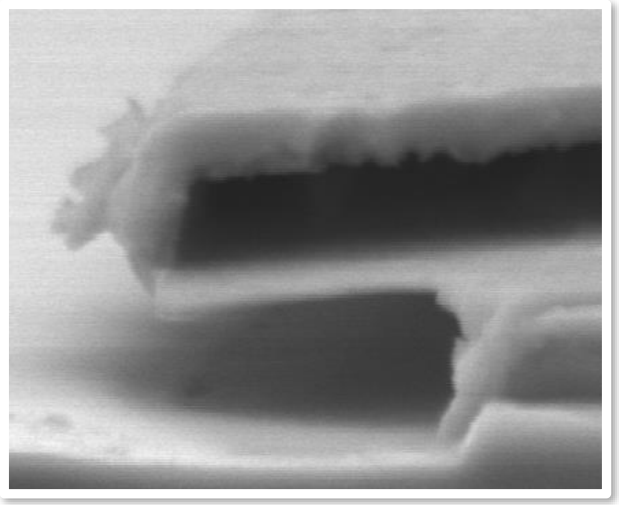
- Conditions to try (9 in total for each group):

	Power (W)	Pressure (mTorr)	Time
-	15	350	20 min
center	25	500	30 min
+	35	650	40 min

- 27 wafers in total:
  - Experimental group
  - Control group
  - Dummy group – only SiN on Si

Results & Discussion

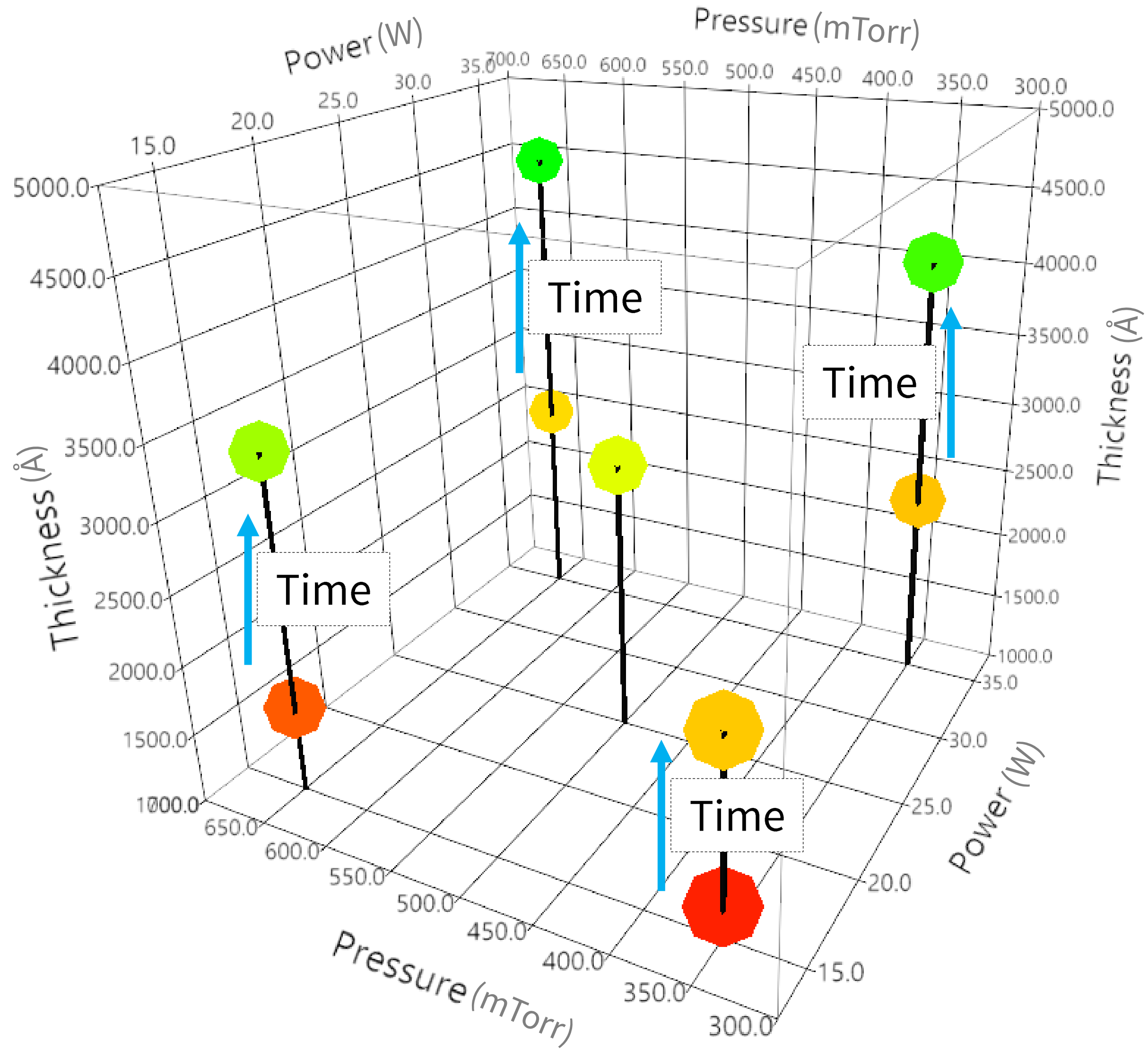
THICKNESS & CONFORMITY,
STRESS & STRAIN



Characterization Tools

- Thickness
  - Woollam M2000 Spectroscopic Ellipsometer
    - "Dummy" group
  - Nanometrics Nanospec
  - Hitachi S4160 SEM (sem4160)
- Stress/strain
  - Flexus 2320 Stress Gage (stresstest)
    - "Dummy" group
  - Horiba Labram Raman spectroscopy in SNC
    - Experimental group
    - Control group

Results – Thickness



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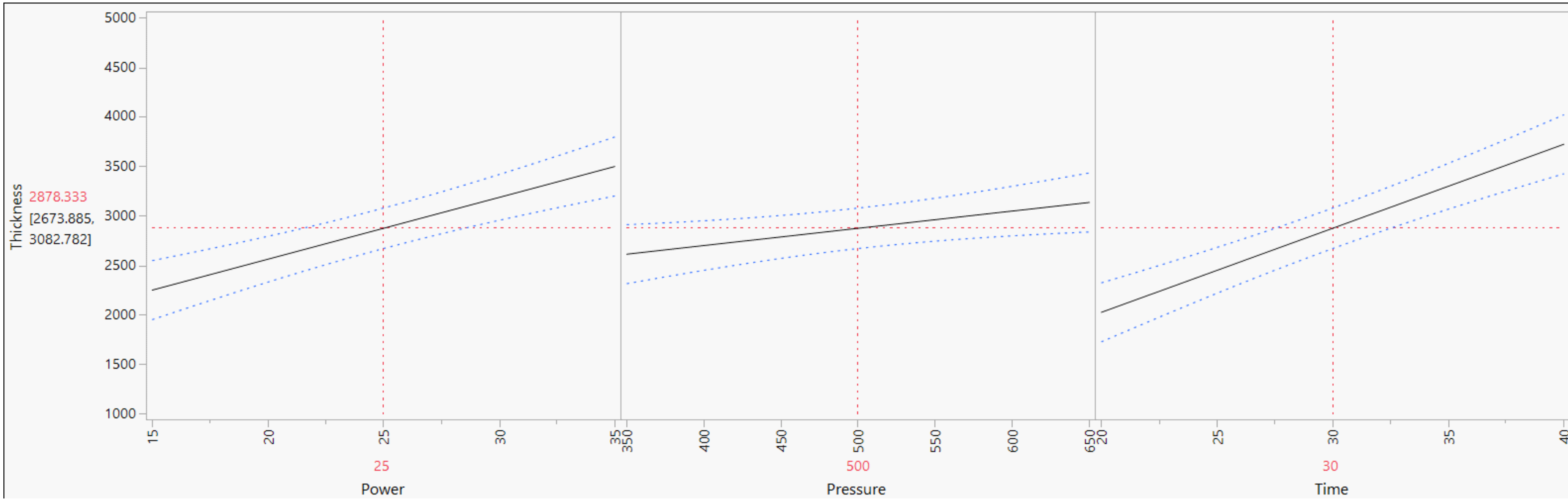
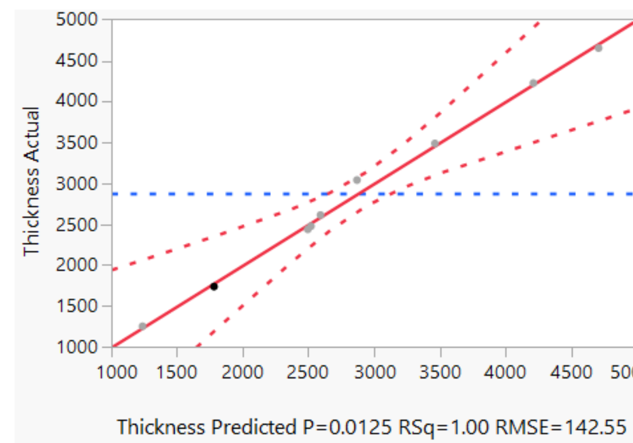
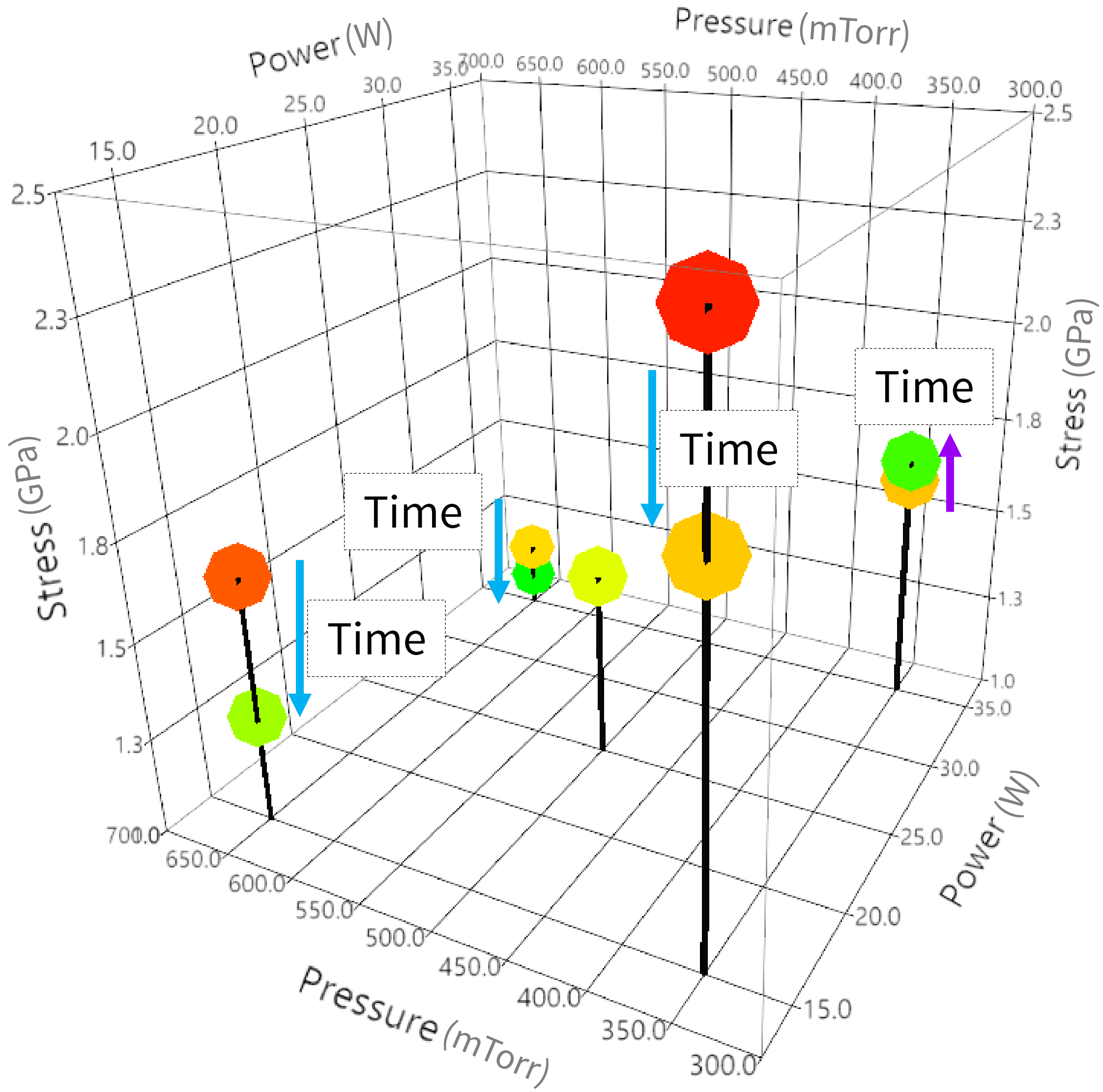
Thickness – Fitting by JMP



Key observation: Power and time have a stronger effect on thickness than pressure

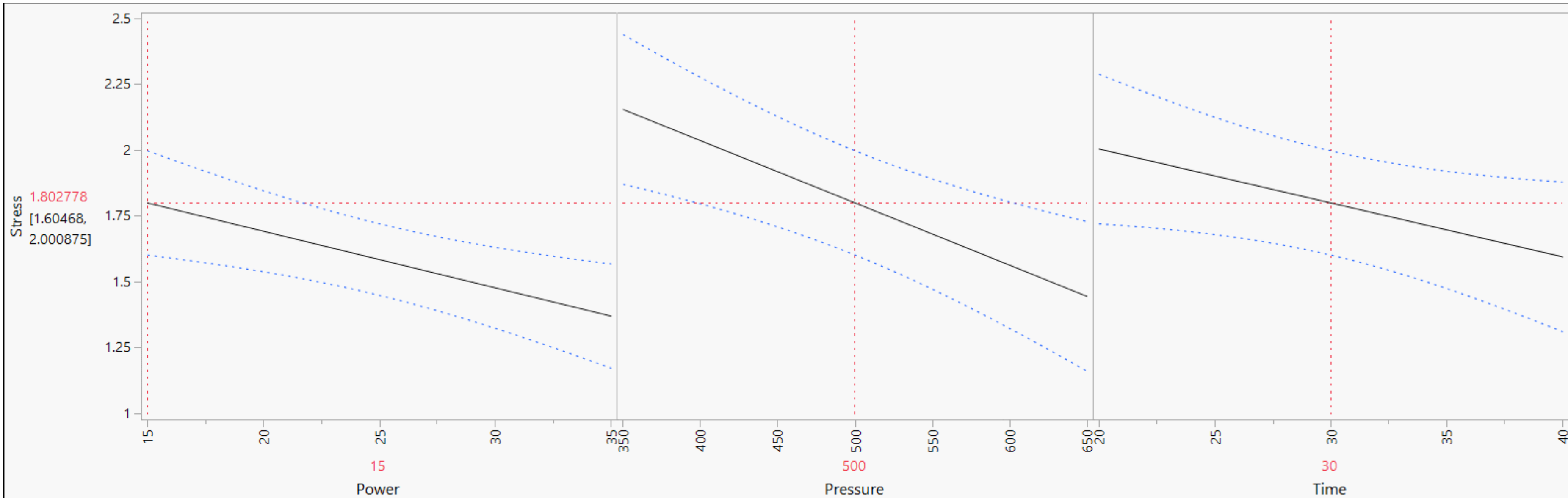


Results – Compressive Stress



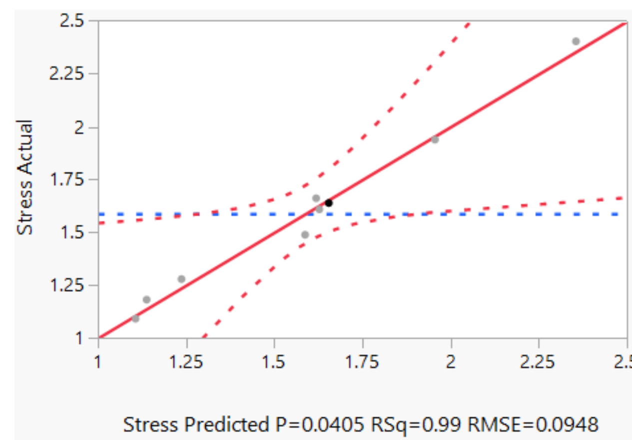
Stanford University

Stress – Fitting by JMP



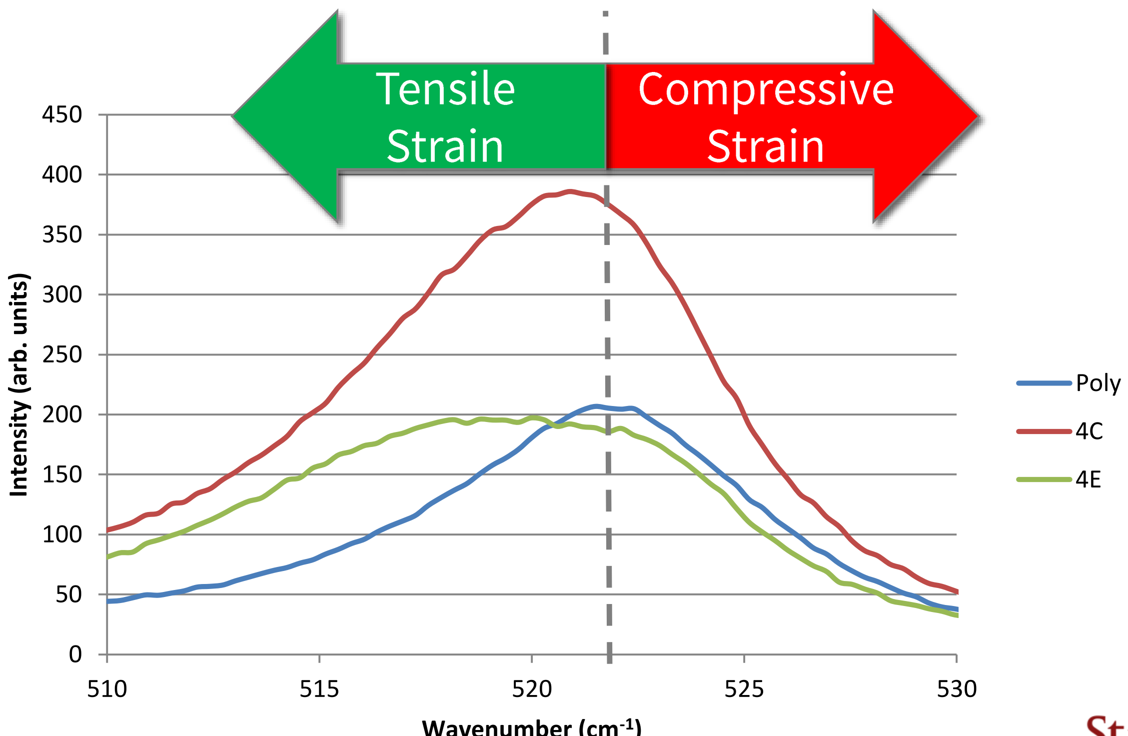
Key observations:

- Stress decreases with power, pressure, and time
- Stress changes little with time at high power
- Importance by order: pressure, power, time



Raman Strain Measurements

- Raman spectroscopy used to observe molecular vibrational modes of material
- Measures inelastic (Raman) scattering of monochromatic light: a 532 nm laser in our case
- Peak shift can represent strain: $e_{\parallel} = \Delta w / b$, b = -773.9 for Si.
- Fitting required to find peak shift



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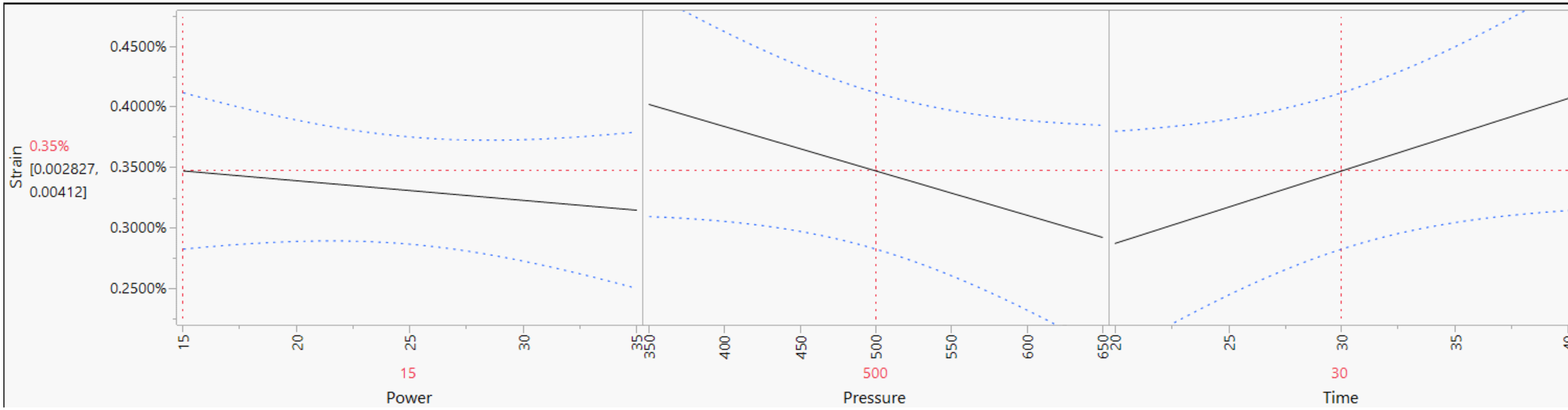
Strain Comparison

Label		Power (W)	Pressure (mTorr)	Time (min)	Thickness (Å)	Compressive Stress (GPa)	Control Group Strain	Experimental Group Strain
0	0	25	500	30	3048	1.4948	0.18%	0.35%
1	---	15	350	20	1249	**2.4005**	-	0.34%
2	+-+	35	350	20	2446	1.6121	-	0.42%
3	--+	15	350	40	2468	1.9437	-	**0.46%**
4	+-+	35	350	40	4220	1.6462	0.17%	0.34%
5	-+-	15	650	20	1731	1.6434	-	**0.23%**
6	++-	35	650	20	2606	1.1810	0.09%	**0.23%**
7	-++	15	650	40	3482	1.2849	0.09%	0.35%
8	+++	35	650	40	4655	**1.0911**	0.07%	0.26%

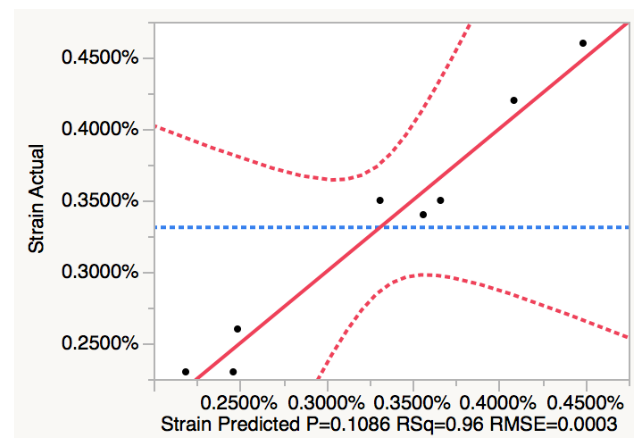
- Strain is higher for samples in experimental group
- Strain in the poly-Si is a function of the stress and thickness of the SiN film

Strain – Fitting by JMP

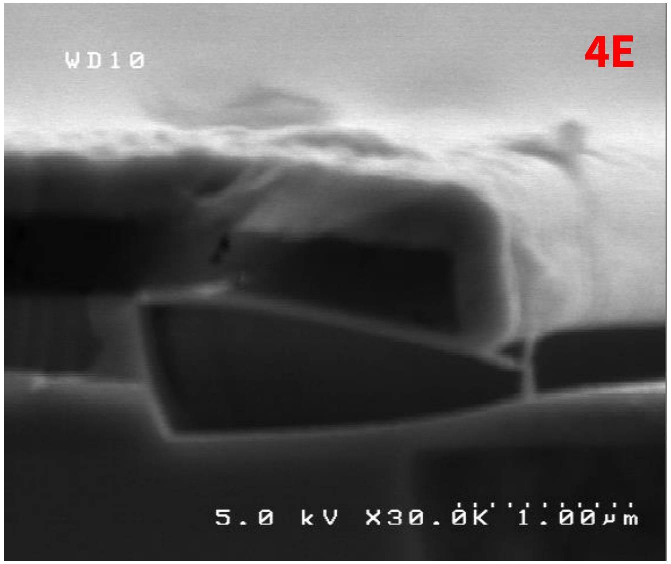


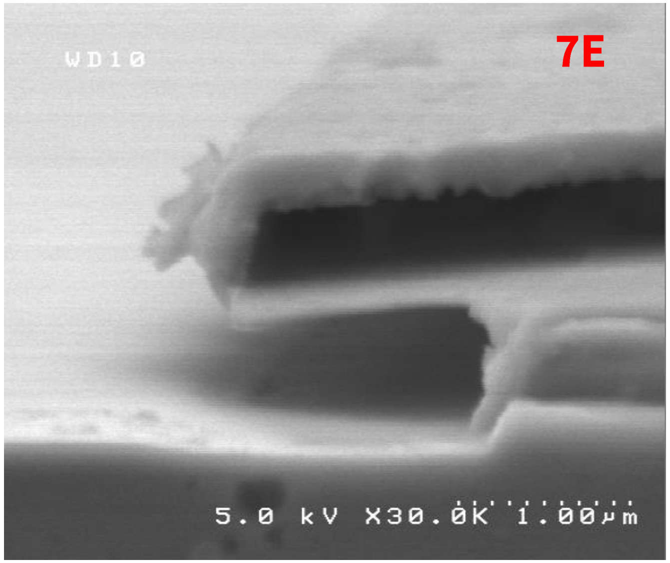
Key observations:

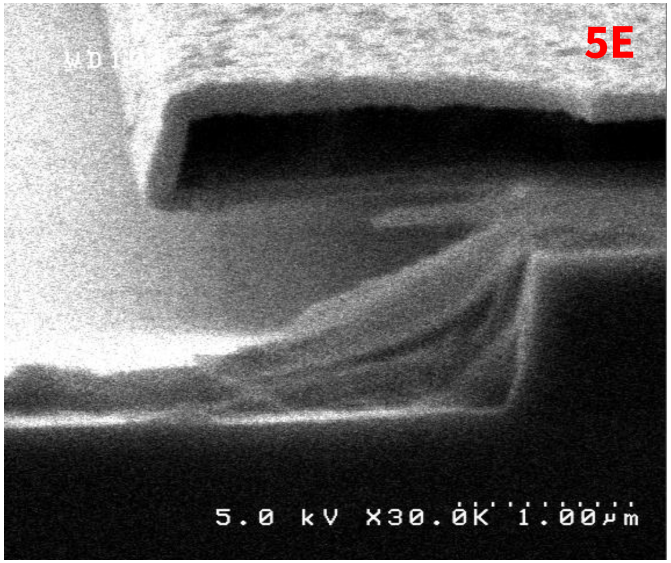
- Lower pressure generally gives a larger strain
- Strain increases more significantly with time when power is low.
- Strain is a more complicated function such that 2nd order interactions are also important.
- Importance by order: pressure, power * time

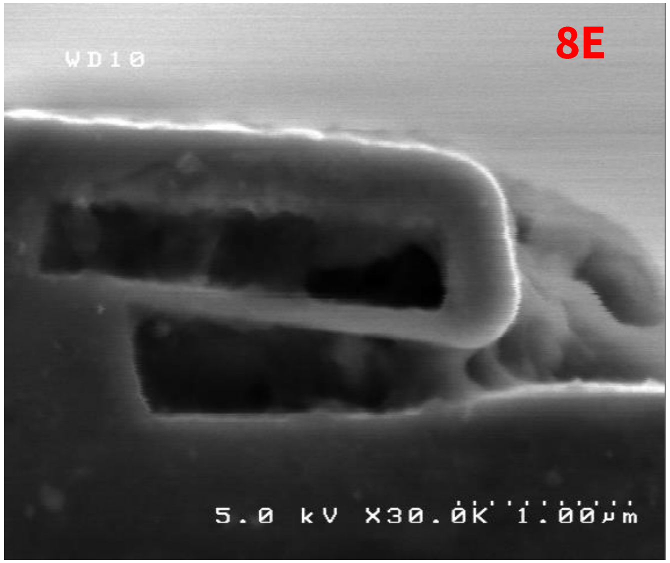


Conformity – SEM Images



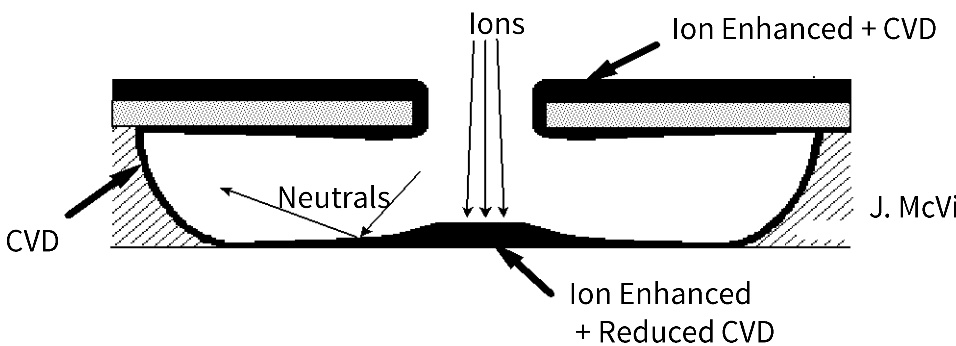






Conformity

Sample	Top Thickness (Å)	Bottom Thickness (Å)	Bottom/Top Ratio	Side Thickness (Å)	Side/Top Ratio
0	3048	956	0.31	2801	0.92
1	1249	1158	0.93	1388	1.11
2	2446	943	0.39	1538	0.63
3	2031	984	0.48	1584	0.78
4	4220	1118	0.27	3073	0.73
5	1731	1253	0.72	1644	0.95
6	2606	1209	0.46	2246	0.86
7	3482	1864	0.54	3199	0.92
8	4655	1480	0.32	4159	0.89



J. McVittie, Talk TC1-WeM6, AVS Mtg (1993).

Conclusion

- Developed a SiN deposition recipe with > 2 GPa compressive stress
- Created an optimized recipe for high tensile strain
- Demonstrated that conformal SiN deposition gives a larger strain compared to top SiN deposition
- Found that the sidewall deposition is roughly equal to the top thickness and that the deposition on the bottom is not strongly affected by our experimental variables
- Future work:
  - Run strain simulations through COMSOL and verify the experimental results
  - Apply our optimized SiN recipes to Ge lasers and other photonic devices

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- Dr. Nancy Latta

Harris group members:

- Yusi Chen
- Muyu Xue
- Kai Zang

Appendix

Tabulated Results

Label		Power (W)	Pressure (mTorr)	Time (min)	Thickness (Å)	Compressive Stress (GPa)	Uniformity	Refractive Index
0	0	25	500	30	3048	1.4948	6.81%	1.9393
1	---	15	350	20	1249	2.4005	4.65%	1.9415
2	+-+	35	350	20	2446	1.6121	9.67%	1.9291
3	--+	15	350	40	2468	1.9437	5.94%	1.9314
4	+-+	35	350	40	4220	1.6462	6.68%	1.9318
5	-+-	15	650	20	1731	1.6434	9.53%	1.9457
6	++-	35	650	20	2606	1.1810	4.73%	1.9402
7	-++	15	650	40	3482	1.2849	5.67%	1.9442
8	+++	35	650	40	4655	1.0911	3.36%	1.9375

- Growth rate decreases with time.

$$s = \frac{Eh^2}{(1-\nu)6Rt}$$

$E/(1-\nu)$ = biaxial elastic modulus of substrate (Pa)
h = substrate thickness (m)
R = radius of curvature of substrate (m)
t = thickness of film
σ = average film stress (Pa)

F Ratio

F-ratio is MSB (mean square between) /MSW (mean square within).

The F-ratio can be thought of a measure of how different the means are relative to the variability within each sample. The larger this value, the greater the likelihood that the differences between the means are due to something other than chance alone, namely real effects.

The F-ratio is the statistic used to test the hypothesis that the effects are real; in other words, that the means are significantly different from one another.

Tools Used

- Wet benches
  - Wbclean
  - Wbnonmetal
  - Wbflexcorr
- Oxidation Furance: Thermco
- Deposition
  - Thermco LPCVD Poly
  - STS PECVD
- Photolithography
  - YES oven
  - Svgcoat
  - ASML
  - Svgdev
- Dry Etching
  - P5000
  - Drytek2
  - Gasonics
  - Xactix Xenon Difluoride
- Sputtering and SEM
  - Hummer
  - SEM4160 (Hitachi)
- Characterization
  - Woollam
  - Stresstest
  - Nanospec
  - Horiba Raman (SNC)