Wafer Nanotopography Effects on CMP: Experimental Validation of Modeling Methods

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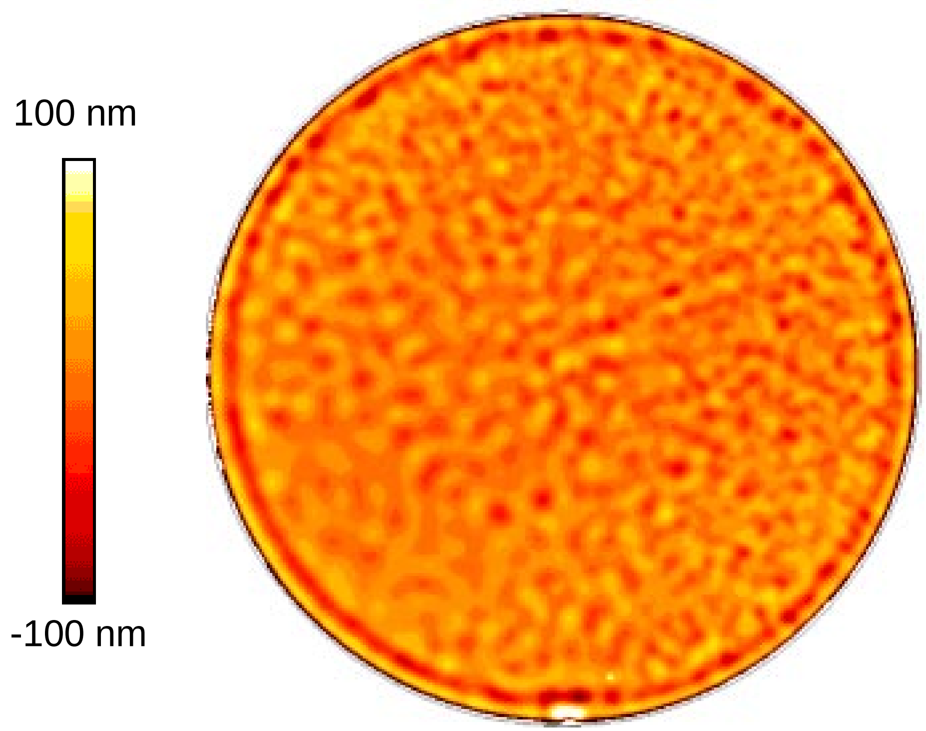
What is Nanotopography?

"Nanotopography" refers to wafer surface variations with:

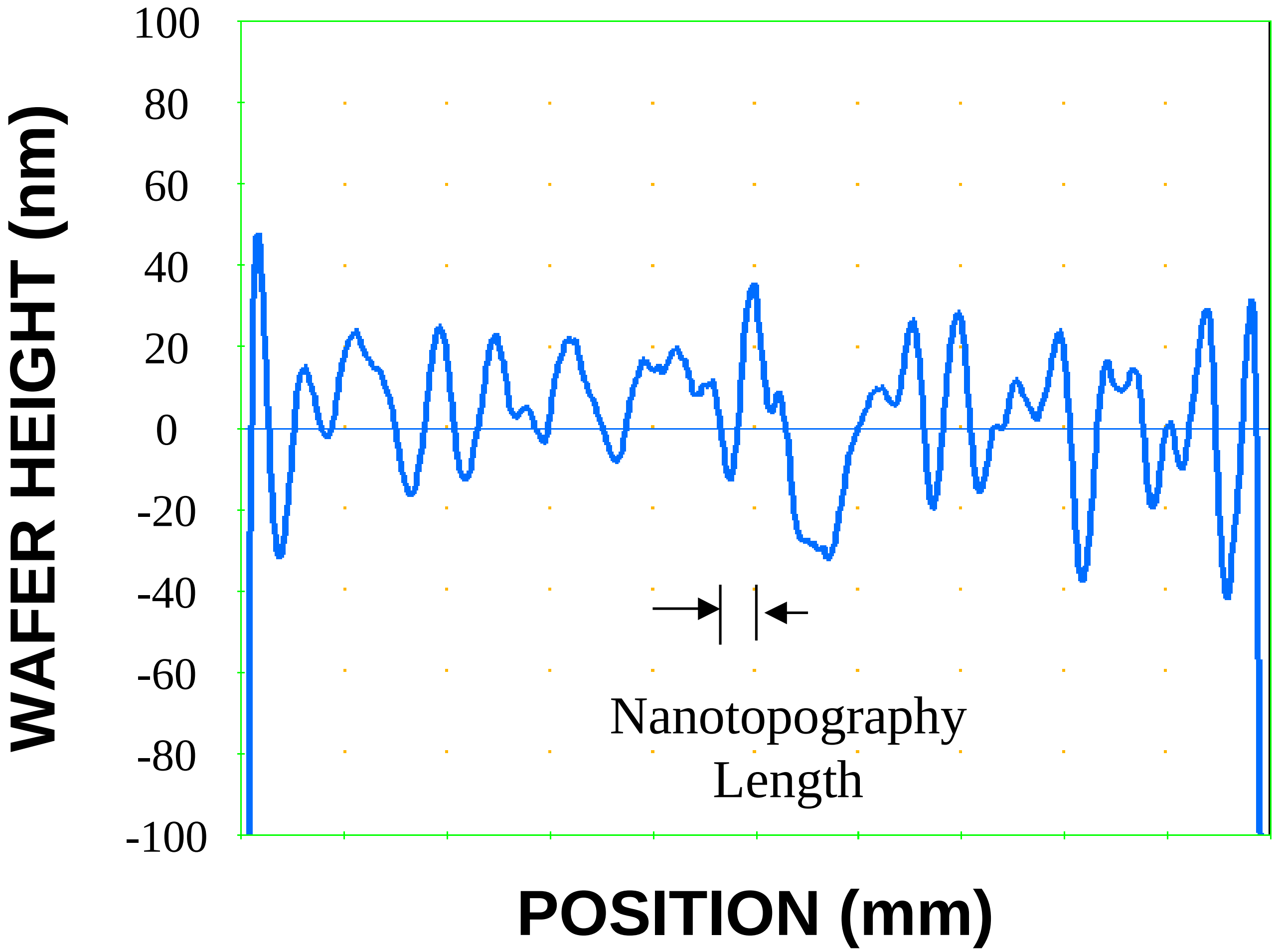
1. Lateral length scales from 0.2 mm to 20 mm
2. Height variations ~ 10 to 100 nm



Nanotopography Map: 8" SSP Silicon Epi Wafer

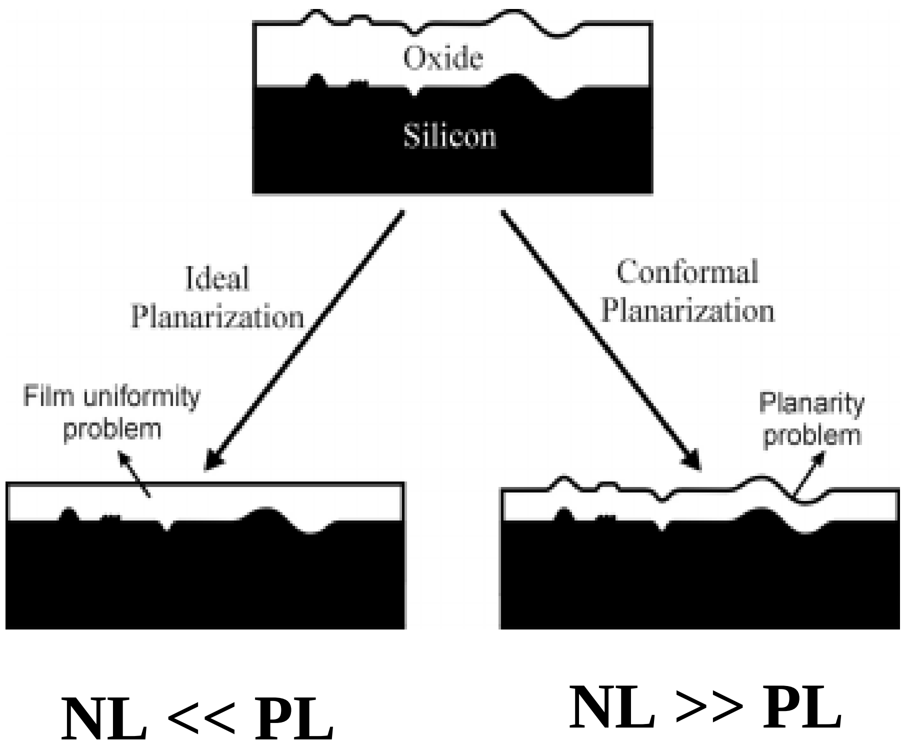
Filtered data measured using a NanoMapper™ production nanotopography tool at ADE Phase Shift in Tucson, AZ

SSP wafer, Diameter Scan (Filtered Data) using NanoMapper™



*Measured using a NanoMapper™ production nanotopography tool at ADE Phase Shift in Tucson, AZ

Motivation – Film Thinning Effect



Xu *et al*, Electrochemical and Solid-State Letters, **1**, 181, 1998.

- **Conformal Polishing**
  - Observed with "soft" pads (short planarization length)
  - Oxide thins uniformly
  - Nanotopography propagates as variation in ***surface height***

  ⇒ ***Lithography concern***
- **Ideal Planarization**
  - Observed with "stiff" pads (long planarization length)
  - Nanotopography propagates as variation in ***final oxide thickness***
  - Flat surface

  ⇒ ***STI yield concern***

Outline

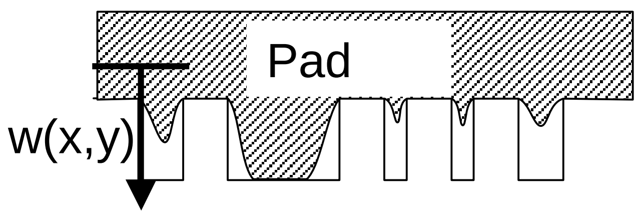
- Introduction
  - Background – review of nanotopography
  - Motivation - nanotopography impact on CMP of films
- **<u>Experiment Overview</u>**
- Nanotopography Modeling
  - Contact mechanics model
- Experiment Details and Results
  - Comparison of nanotopography to film thinning
  - Comparison of model prediction to measured data
- Conclusions and Future Work

Experiment Overview

- Key idea:
  - Use wafers with various nanotopography signatures (length scales)
  - Use CMP processes with various planarization lengths
  - Extract planarization length AND measure oxide thickness results
- Previous experimental work:
  - Xu, et al. (ESSL 1998): showed CMP oxide thinning related to both original wafer height variation and pad properties
  - JEIDA experiments: splits on wafers and CMP pads
- Goals of this work:
  - Examine nanotopography length vs. planarization length
  - Provide a predictive model for the thinning due to nanotopography for any characterized CMP process

CMP Film Thickness Evolution Model

Contact Wear CMP Model[1,2]



$$w(x,y)=\left[\frac{(1-\upsilon^2)}{(\pi E)}\right]\int_A \frac{p(\xi,\eta)}{\left[(x-\xi)^2+(y-\eta)^2\right]^{\frac{1}{2}}}d\xi d\eta$$

w(x,y) = displacement of pad

p(x,y) = pressure of pad on wafer

ν: Poisson's ratio

E: Young's modulus

$$RR(x,y) = K_p * p(x,y) * v(x,y)$$

RR: film removal rate

K_p: Preston's coefficient

p(x,y): pressure

v(x,y): velocity

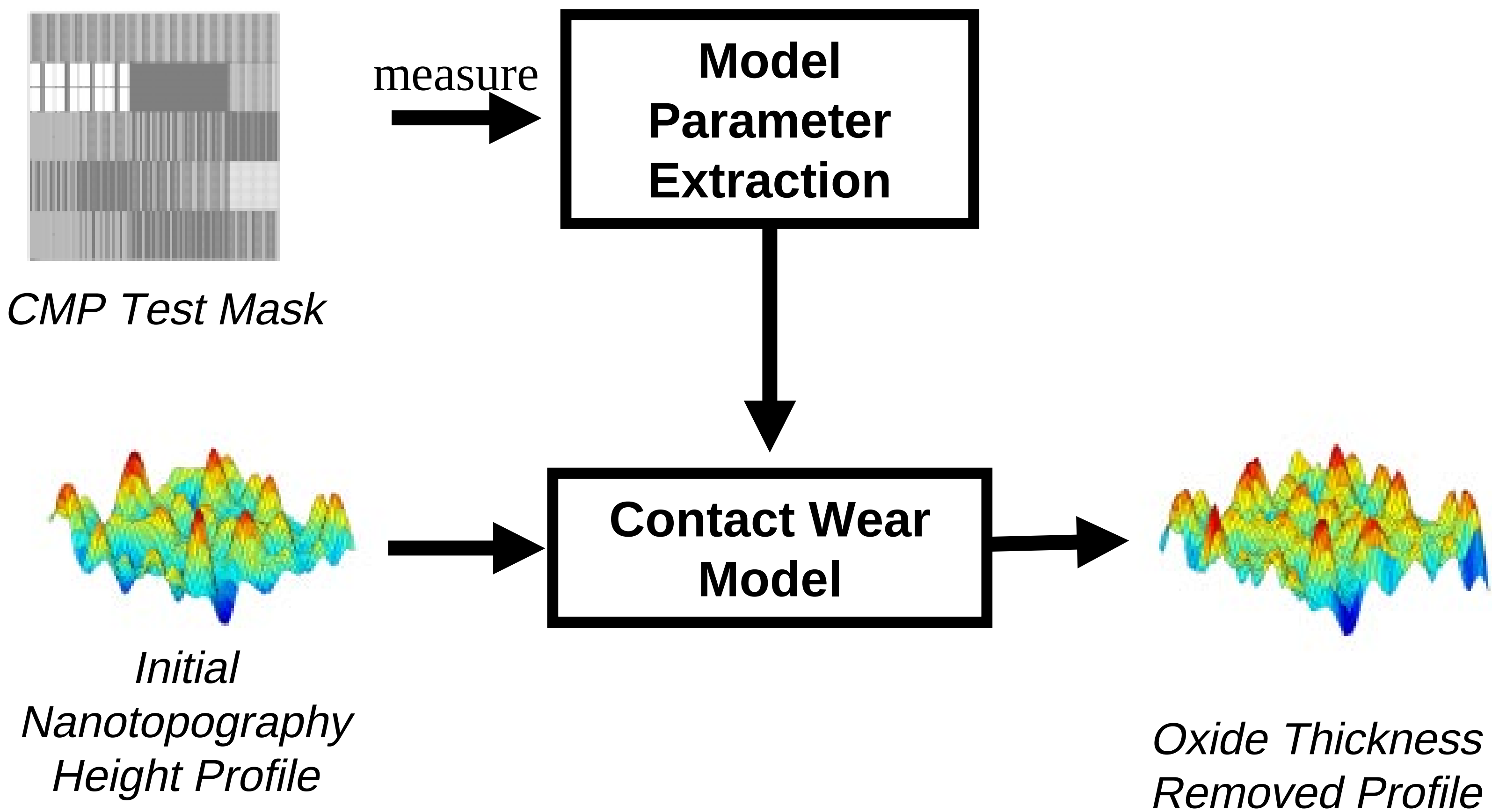
Key ideas:

- Use pressure-displacement equation to solve for pressures everywhere
- Use Preston's equation to calculate removal rates
- Advance boundary elements, and iterate to reach desired polish time

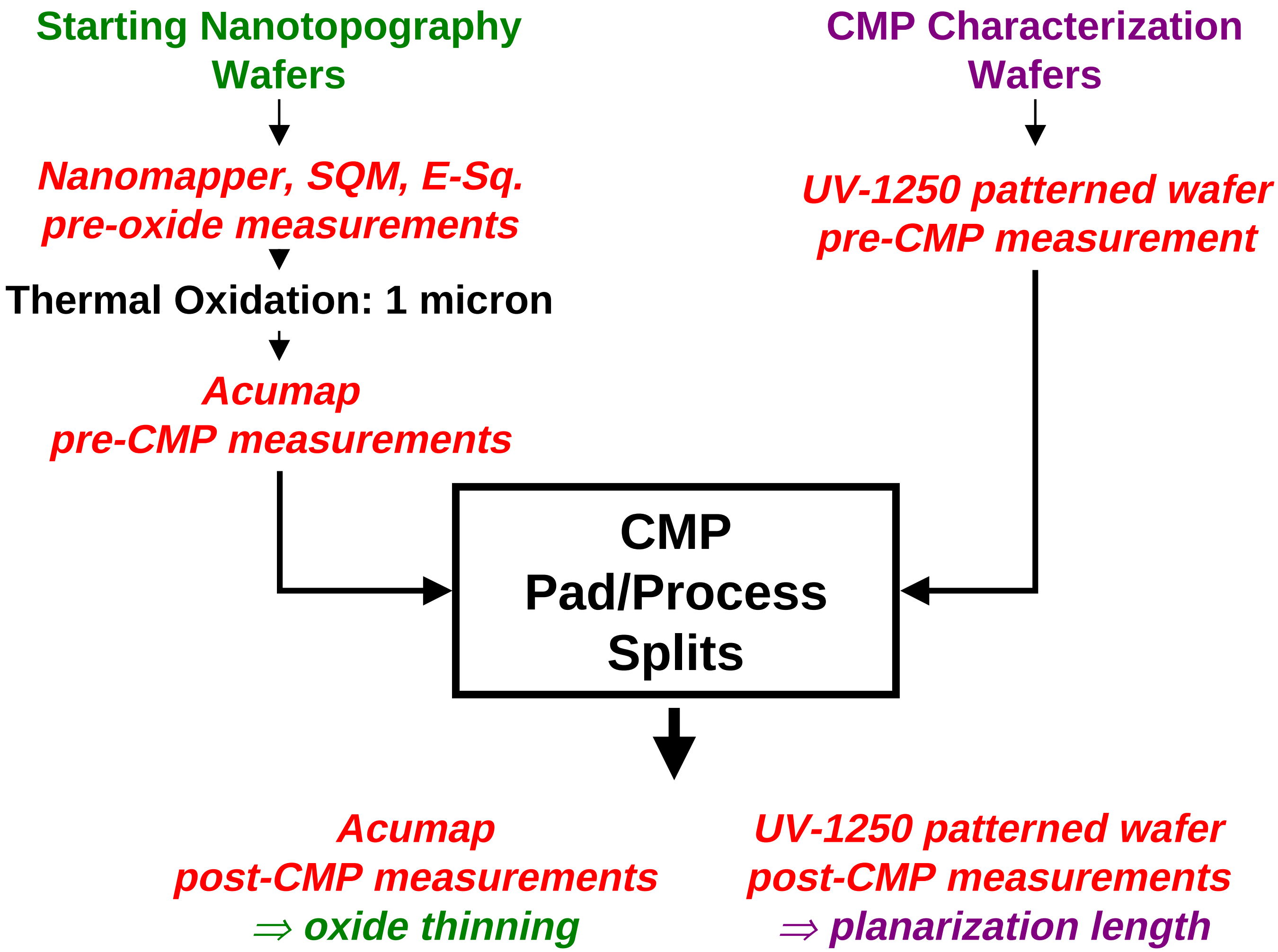
[1] O. G. Chekina, et al., "Wear-contact problems and modeling of chemical mechanical polishing," *JECS*, Vol 145, June. 1998.

[2] T. Yoshida, "Three-dimensional chemical mechanical polishing process model by BEM," *ECS Conf.*, Oct. 1999.

Contact Wear Modeling



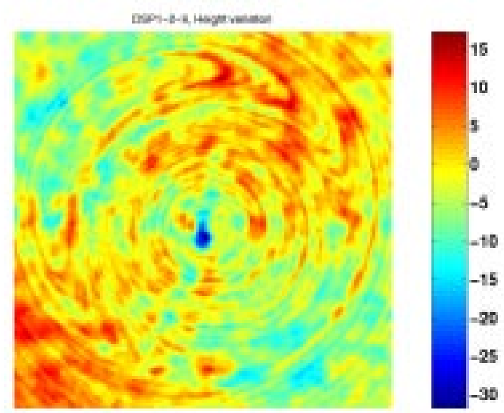
Experiment Details



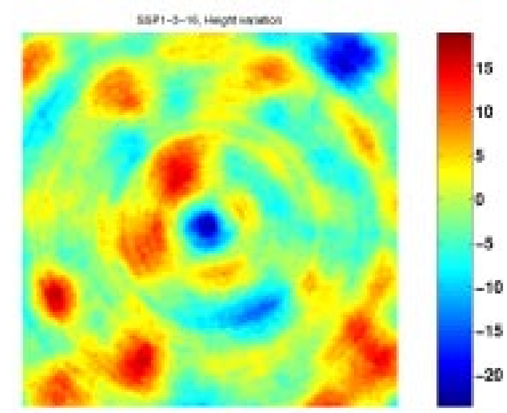
Experiment Details

- Eight different CMP pads/processes
  - three tools
- Four different nanotopography signatures
  - DSP1: small amplitude, long wavelength
  - SSP1: ring-like variation, long wavelength
  - SSP2: clusters at short wavelength
  - SSP3: clusters at medium wavelength

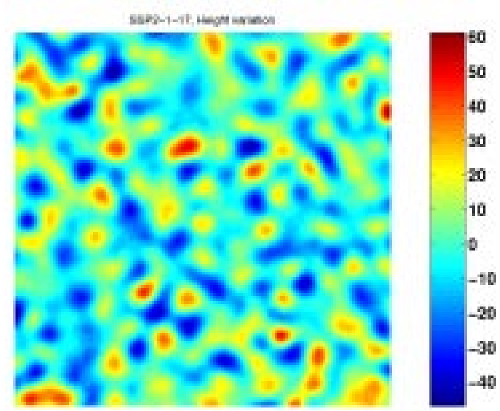
Wafer Nanotopography Types



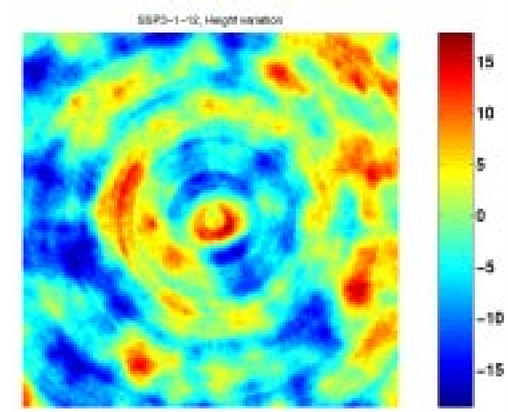
DSP1



SSP1



SSP2

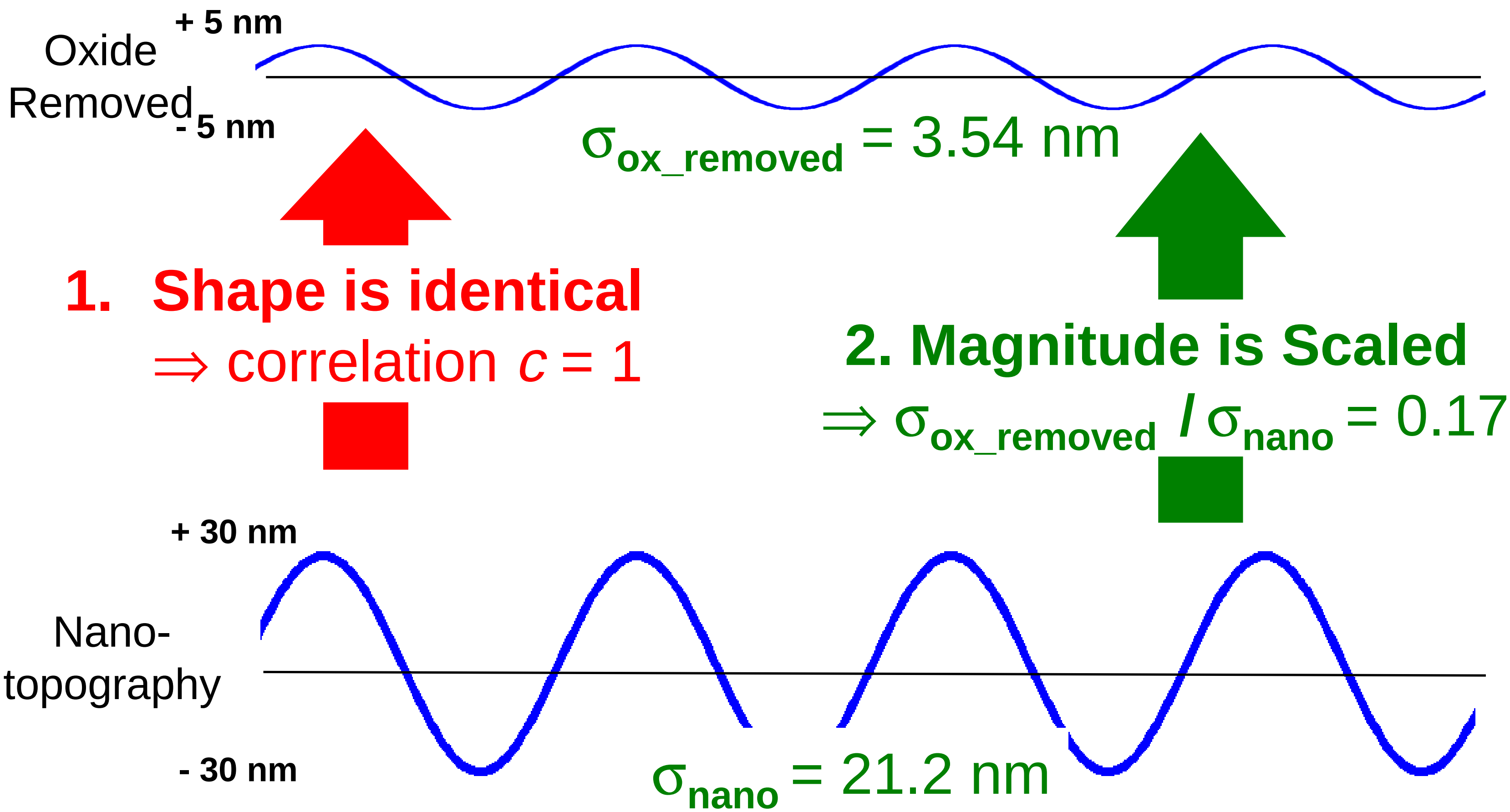


SSP3

Planarization Lengths

	Tool 1			Tool 2			Tool 3	
Pad/Process	A	B	C	D	E	H	F	G
Planarization Length (mm)	8.4	3.4	1.9	3.1	4.6	13.7	9.7	6.4

Metrics for Nanotopography Propagation to Film Thinning



Metrics for Nanotopography Propagation to Film Thinning

- Calculate a correlation coefficient *c* over 2D map *(i,j)* to capture "similarity" in the ***shape of the variation*** (% deviations around each mean) between:
  - *x:* nanotopography height
  - *y*: oxide removed:

$$c = \frac{\sum_i \sum_j \left(x_{ij} - \mu_x\right)\left(y_{ij} - \mu_y\right)}{\sigma_x \sigma_y}$$

- $c \to 0$: no correlation

  $c \to 1$: complete (positive) correlation

  $c \to -1$: complete correlation (inversion)

- Calculate the standard deviation σ_x and σ_y to summarize the ***magnitude of the variation*** in the nanotopography and the polished oxide thickness, respectively

Nanotopography – Oxide: Correlations

Wafer Type	transmitted shape: corr. coef. ***C***							
SSP1	0.17	0.25	0.14	0.12	0.64	0.56	0.94	0.65
SSP3	0.13	0.17	0.34	0.14	0.70	0.59	0.88	0.60
DSP1	0.12	0.14	0.24	0.06	0.66	0.35	0.81	0.54
SSP2 short NL	0.52	0.51	**0.75**	0.40	0.81	**0.84**	0.89	0.88
	1.9 mm	3.1 mm	3.4 mm	4.6 mm	6.4 mm	8.4 mm	9.7 mm	13.7 mm
	C	D	B	E	G	A	F	H
	Planarization Length / Process							

NL > PL

NL < PL

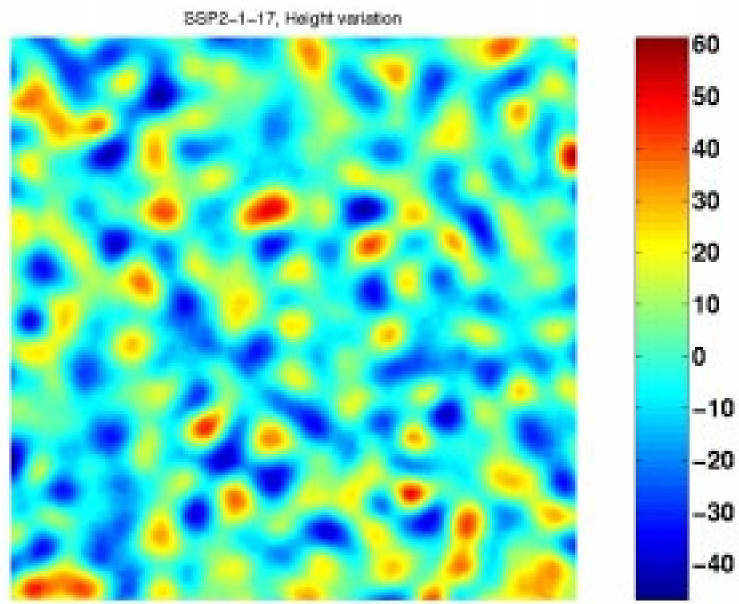
Filtered with 30mm double gaussian to remove wafer level trend

Nanotopography – Oxide: Std Devs.

Nanotopography Wafer Type		transmitted height: $\sigma_{ox\_removed}$ / σ_{nano}							
	SSP1 long λ	0.30 **1.1/3.7**	0.69 **2.6/3.8**	0.33 **1.2/3.5**	1.05 **4.3/4.0**	0.32 **1.1/3.5**	1.26 **4.2/3.3**	0.98 **3.3/3.3**	1.14 **3.9/3.4**
	SSP3	0.30 **1.0/3.5**	0.77 **2.7/3.5**	0.38 **1.3/3.4**	1.01 **3.8/3.7**	0.37 **1.4/3.9**	1.27 **4.7/3.7**	0.83 **3.0/3.6**	1.23 **4.2/3.4**
	DSP1	0.33 **1.1/3.4**	0.82 **2.7/3.3**	0.47 **1.7/3.6**	1.33 **4.6/3.4**	0.57 **1.7/3.1**	1.22 **4.3/3.5**	0.88 **3.1/3.5**	0.98 **3.7/3.8**
	SSP2 short λ	0.07 **1.2/16**	0.18 **2.9/16**	**0.14** **1.9/14**	0.29 **4.3/15**	0.31 **4.4/14**	**0.67** **9.5/14**	0.75 **11/15**	0.76 **12/16**
		1.9 mm	3.1 mm	3.4 mm	4.6 mm	6.4 mm	8.4 mm	9.7 mm	13.7 mm
		C	D	B	E	G	A	F	H
		Planarization Length / Process							

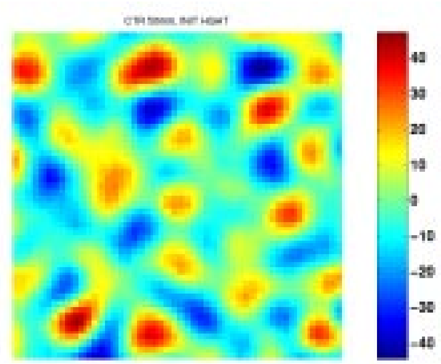
Filtered with 30mm double gaussian to remove wafer level trend

Contact Wear Modeling



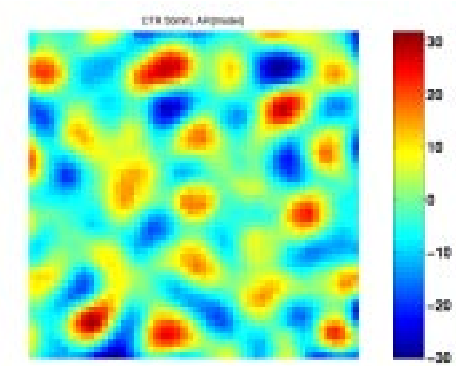
- Consider wafers with short nanotopography length, large height variation (SSP2 wafer)
- Simulate long PL process (Proc. A, 8.4 mm) and short PL process (Proc. B, 3.4 mm)

Contact Wear Modeling – SSP2, Process A (PL = 8.4 mm)

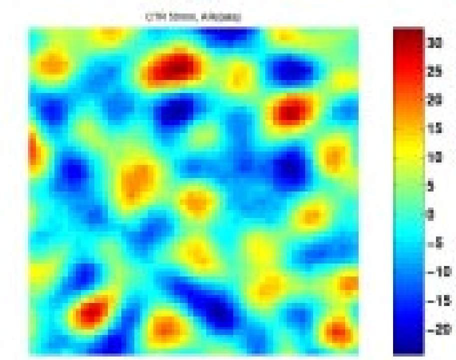


Initial Nanotopography Height (Data)

- c = 0.92
- σ_{model} = 9.7 nm
- σ_{data} = 9.6 nm

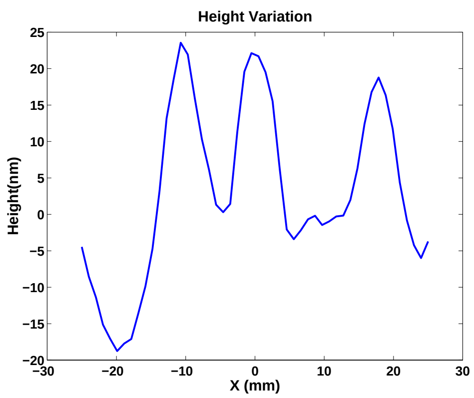


Oxide Thickness Removed (Model)

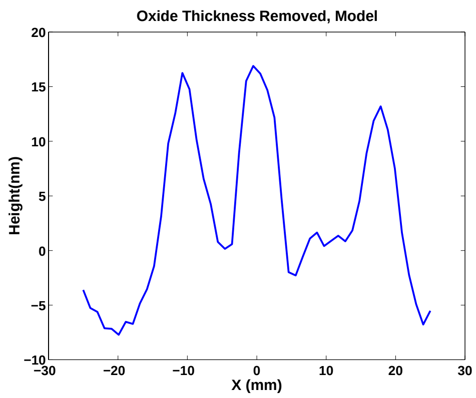


Oxide Thickness Removed (Data)

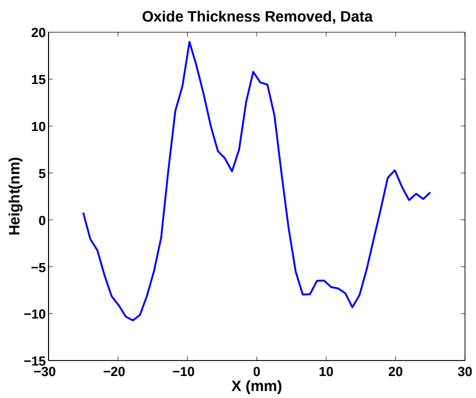
Contact Wear Modeling – SSP2, Process A (PL = 8.4 mm)



Initial Nanotopography Height (Data)

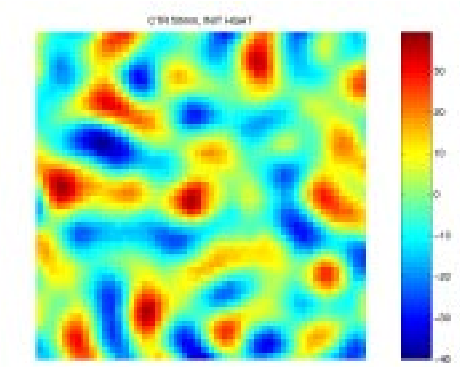


Oxide Thickness Removed (Model)

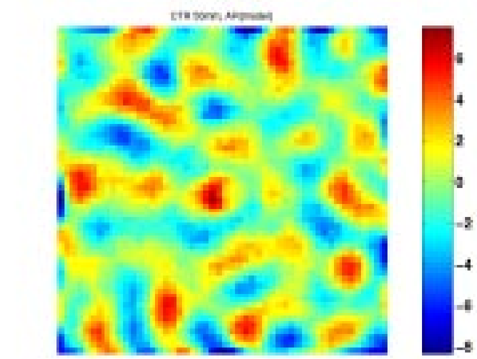


Oxide Thickness Removed (Data)

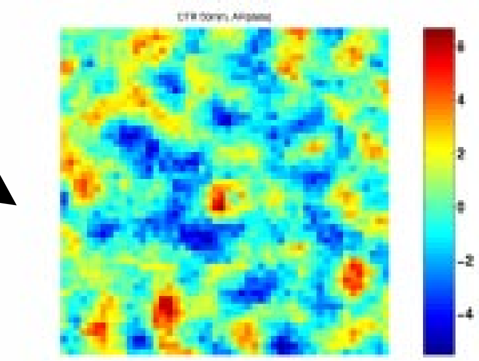
Contact Wear Modeling – SSP2, Process B (PL = 3.4 mm)



Initial Nanotopography Height (Data)



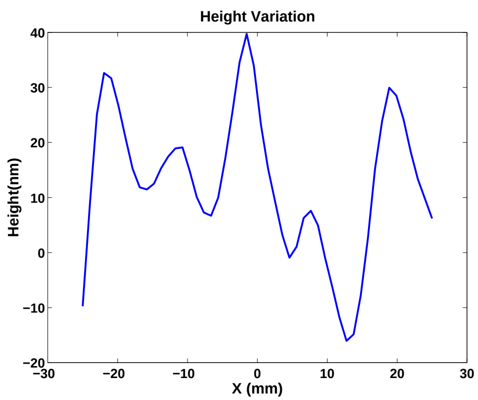
Oxide Thickness Removed (Model)



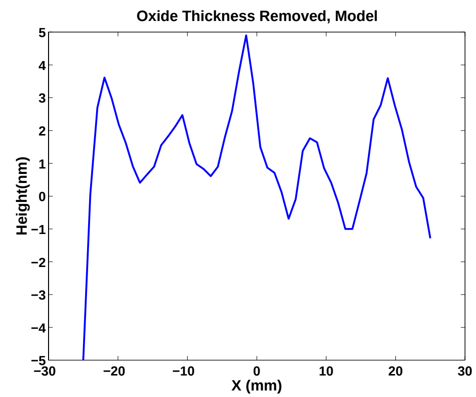
Oxide Thickness Removed (Data)

- $C = 0.82$
- $\sigma_{model} = 1.62$ nm
- $\sigma_{data} = 1.88$ nm

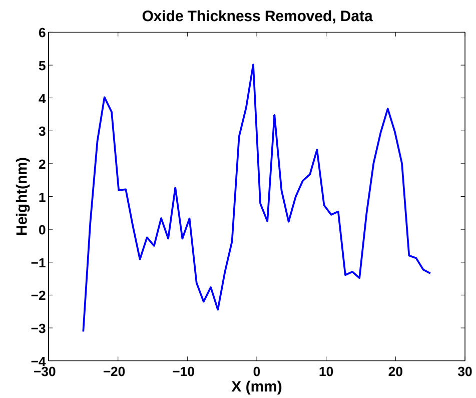
Contact Wear Modeling – SSP2, Process B (PL = 3.4 mm)



Initial Nanotopography Height (Data)



Oxide Thickness Removed (Model)



Oxide Thickness Removed (Data)

Conclusions

- Experimental results verify NL vs. PL hypothesis
- Can use contact wear model to simulate CMP process on nanotopography

Future work

- Investigate nanotopography impact regarding yield concerns in STI
- Incorporate nanotopography model into STI CMP pattern model to create a full model to use to predict nanotopography impact yield of STI structures