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Chemical Mechanical Polishing to Create Pure Ge-filled trenches within Silicon Dioxide

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Research outline

Problem

- Need to achieve on-chip optical interconnect consisting of pure germanium (Ge) material confined within an oxide (SiO_2) dielectric.
- New process flow is required which must result in filled trenches with a planar top surface.
- There is a need to develop 300mm Chemical Mechanical Planarization (CMP) process to remove overburden and smooth epitaxial grown pure Ge patterned in blanket oxide on silicon substrates.

Approach

I. Slurry feasibility testing utilizing Blanket epitaxial grown pure Ge
   - Utilization of Atomic Force Microscopy, elipsometry, optical microscopy.

II. Test Mask Patterned wafer process time split evaluation
   - Understanding of progression of process including over polish behavior

III. Product Mask Patterned wafer process evaluation

Resources

Albany NanoTech 300mm cleanroom facility

CMP:	Applied Materials 300mm LK Reflexion Platform 3 platens, 4 heads, onboard elipsometer, ultrasonic and brush cleaning modules along with IPA wafer dryer.
Metrology:	FIB SEM KLA profilometer KLA FX Elipsometer Leica optical scope AFM

Blanket Study

Initial evaluation of Slurry utilizing blanket Ge wafers

- High Metal:Oxide selective removal silica abrasive slurry with low pH
- Packaged vendor slurry, Mix with H_2O_2 < 1% by volume to mitigate risk of pitting/roughness

Lot Info		Initial Rs		CMP		Final Metrology									
Slot	Wafer ID	Rs Mean	Rs StDev	Pressure (psi)	Time (sec)	Final Thickness	Center			Mid Radius			Edge		
							Rq	Ra	Rmax	Rq	Ra	Rmax	Rq	Ra	Rmax
1	461A3D2XSED0	N/A	N/A	N/A	N/A	2923	1.02	0.68	52.28	0.91	0.64	47.06	26.90	14.50	307.20
2	461A3D2USEF0	201.38	2.16	2	30	1827	2.861	0.387	195.55	2.374	0.345	187.68	34.345	15.708	398.29
3	461A3D2TSEA6	201.80	1.84	2	60	312	1.835	0.753	127.53	0.575	0.435	18.585	0.645	0.499	14.374
4	461A3D2ASEB1	203.67	1.87	3	30	1332	0.611	0.43	16.662	0.664	0.425	28.93	0.845	0.507	44.036
5	461A3D2FSEA2	203.57	2.13	3	60	0	0.247	0.177	8.056	0.279	0.193	10.391	0.394	0.302	12.085

*Roughness within acceptable range considering Ge easily chemically attacked.

- Extended 4 min polish completed with blanket oxide wafers without a measureable difference in thickness. Rate observed to be zero.

Test Mask

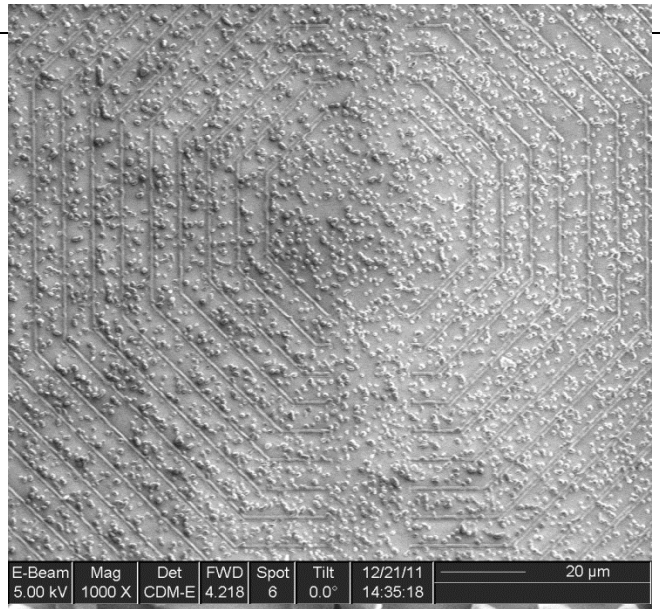
Initial evaluation of Slurry utilizing test mask patterned Ge wafers

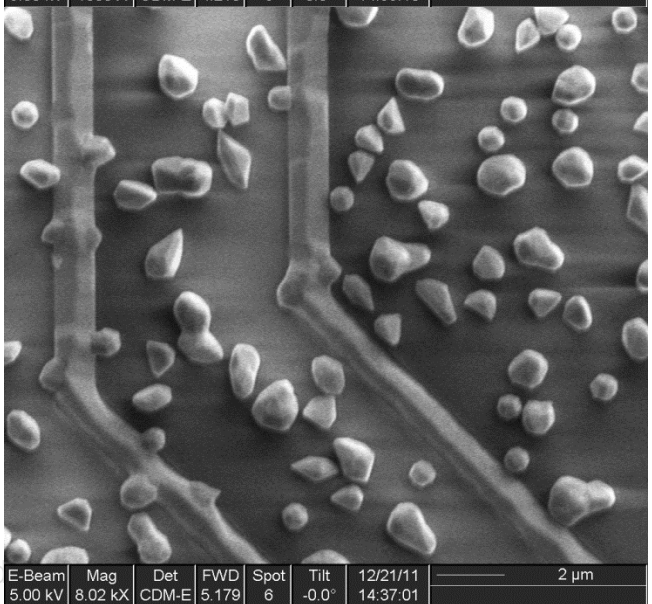
- 2 psi time splits (30s, 60s, 120s, 240s)

Slurry: Metal:Oxide selective with <1% H_2O_2
Pad: Dow IC1010
Disc: 3M A160

Pad Break-in : 6min, 6lb force on disc, 200ml/min slurry flow rate
Pad Warm-up: 3 x SiO_2 Blanket , 2psi 60s

Pre-CMP Top down optical view of patterned and epitaxial grown Ge





Observations:

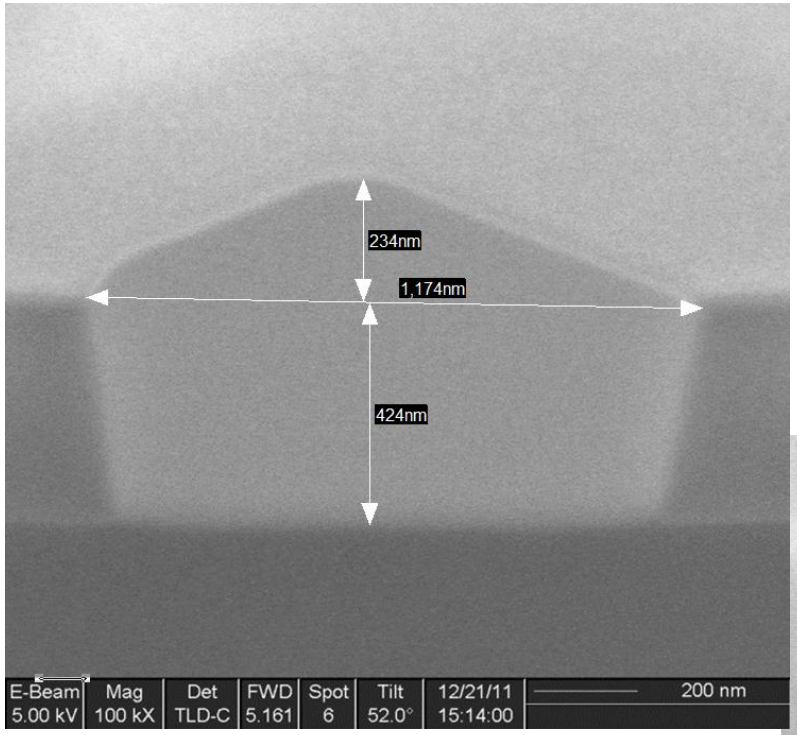
-Trenches appear to be filled with pyramidal peak at center of the lines.

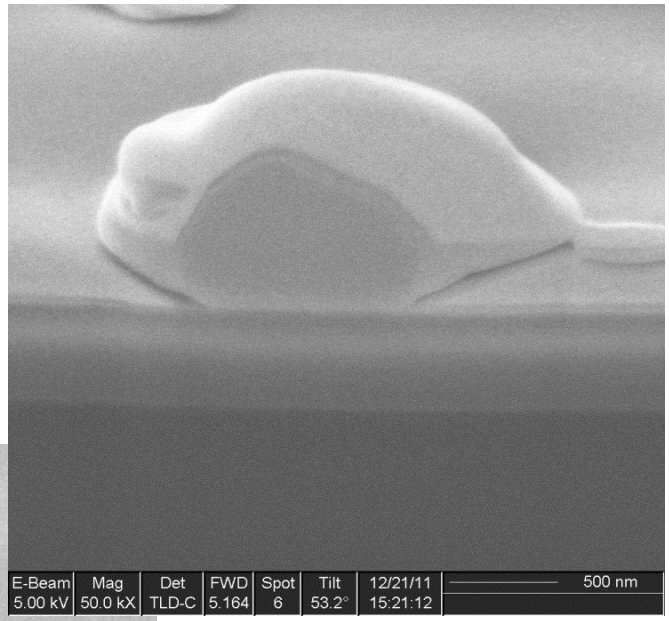
-Random nodules apparent on the surface of the silicon dioxide. Size on average estimated at 1 um.

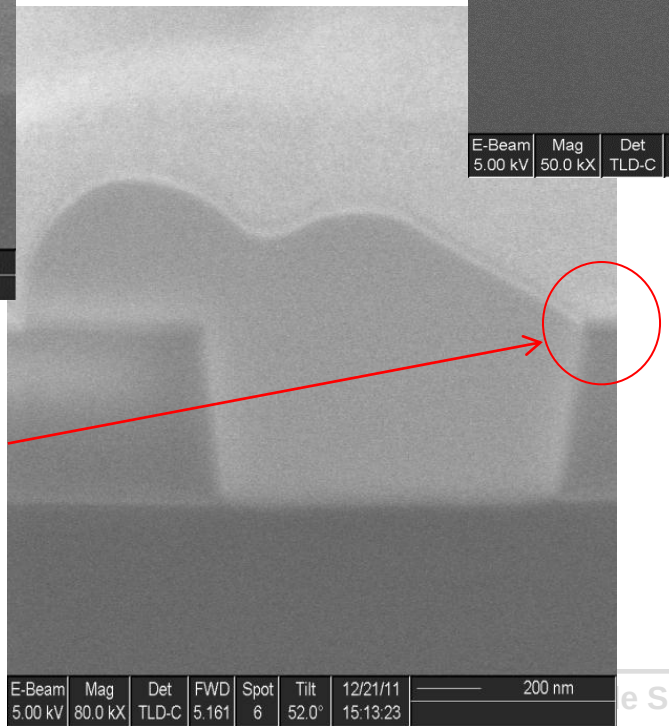
Concerns:

- *Nodules strength a concern as potential for scratching defects if dislodging occurs during process.*

SEM cross sectional view of Ge filled trenches

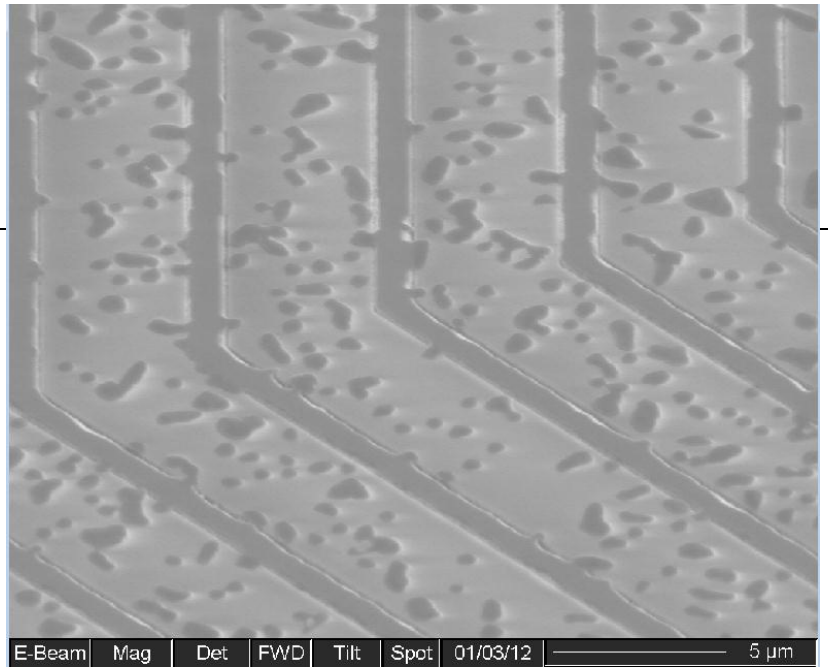






Concern with insufficient fill and exposure of line edge to CMP environment for the duration of the process

SEM top down view post 60s 2psi CMP



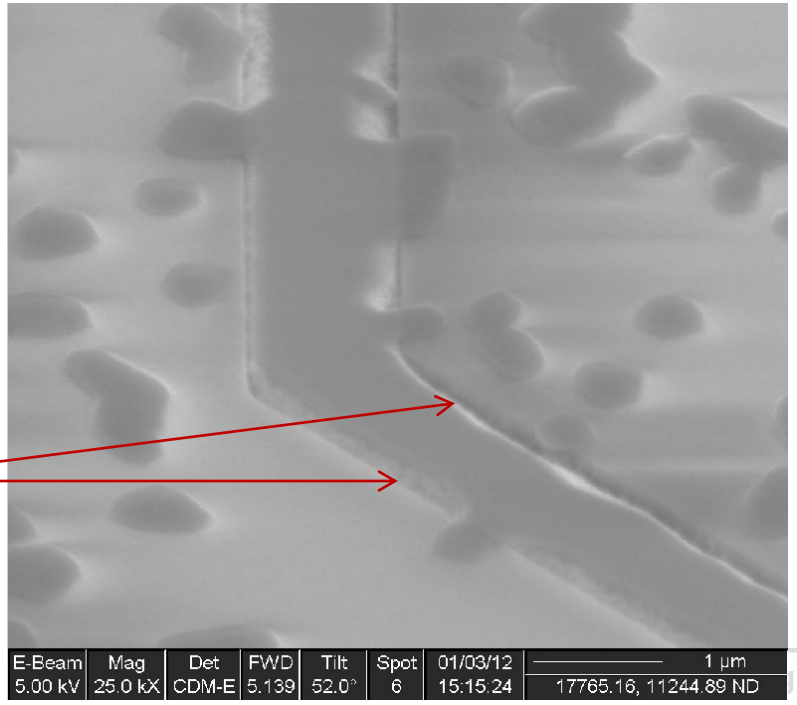
Observations:

-Trenches appear to have a line edge degradation.

-Random nodules appear to be intact and not breaking free.

- Scratching not observed

Line edge degradation



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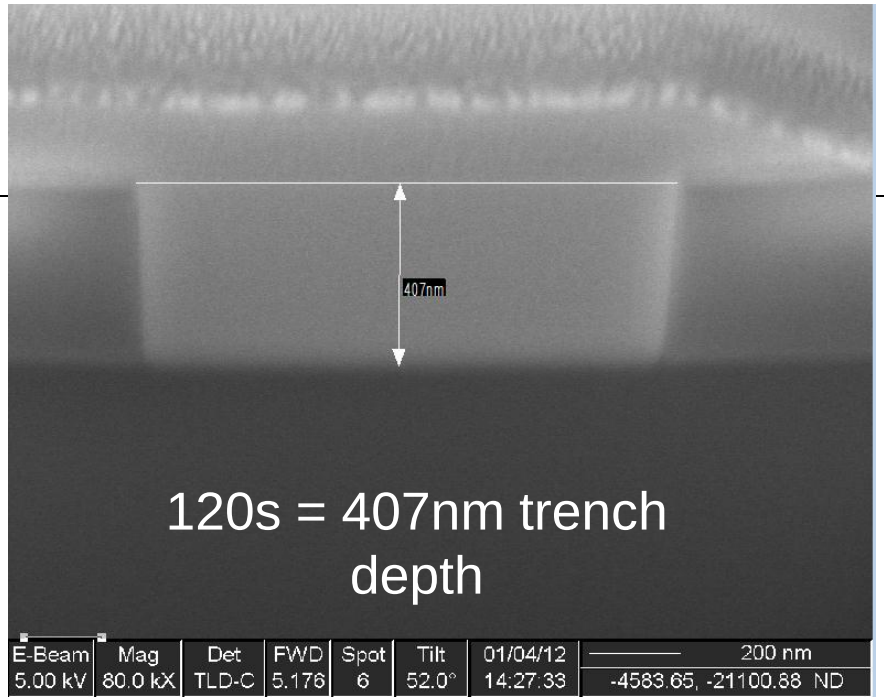
SEM cross section view post 120s, 240s CMP

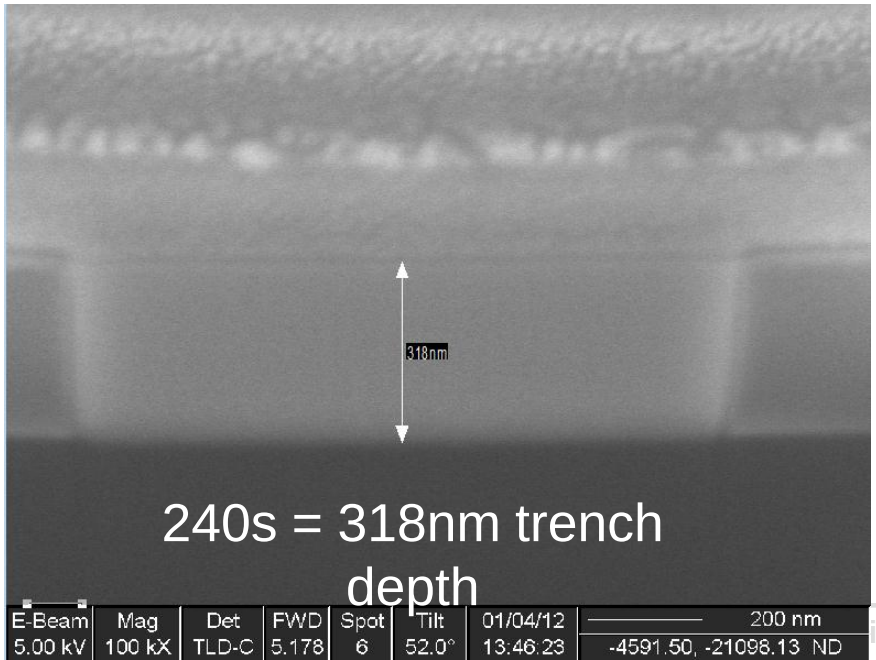
Observations:

-Wafer clear of Ge overburden at 120s with trench depth not diminished significantly

-Wafer over polished to 240s showing ~90nm additional trench depth reduction (~45nm/min)

-Dishing observed to extend beyond the width of the trench. Erosion of SiO_2





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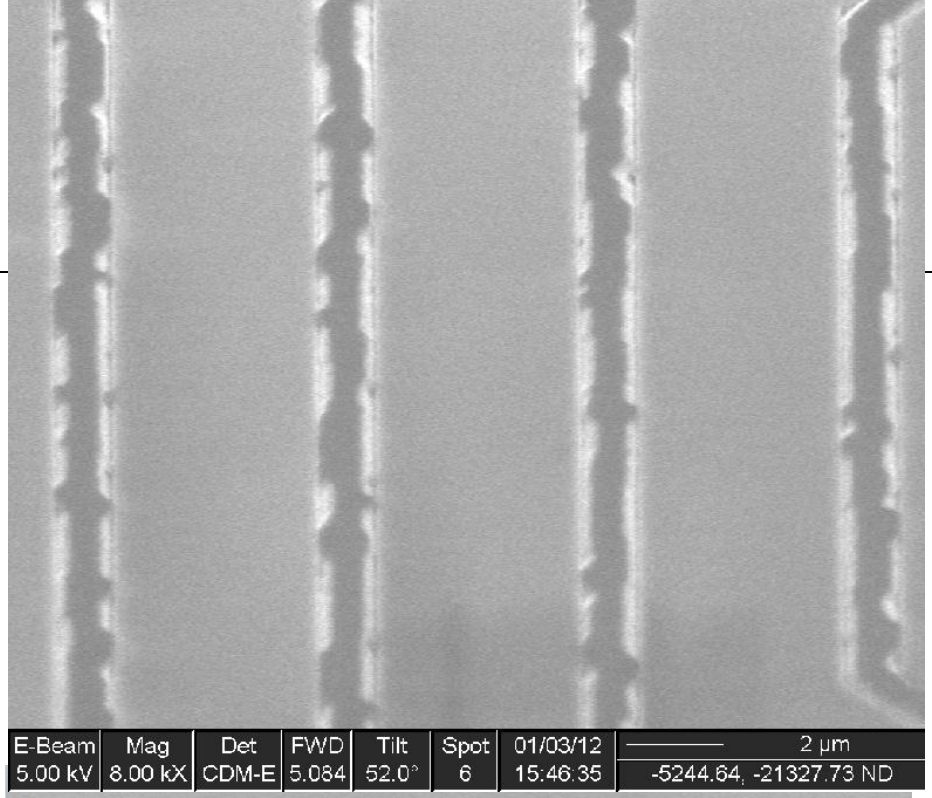
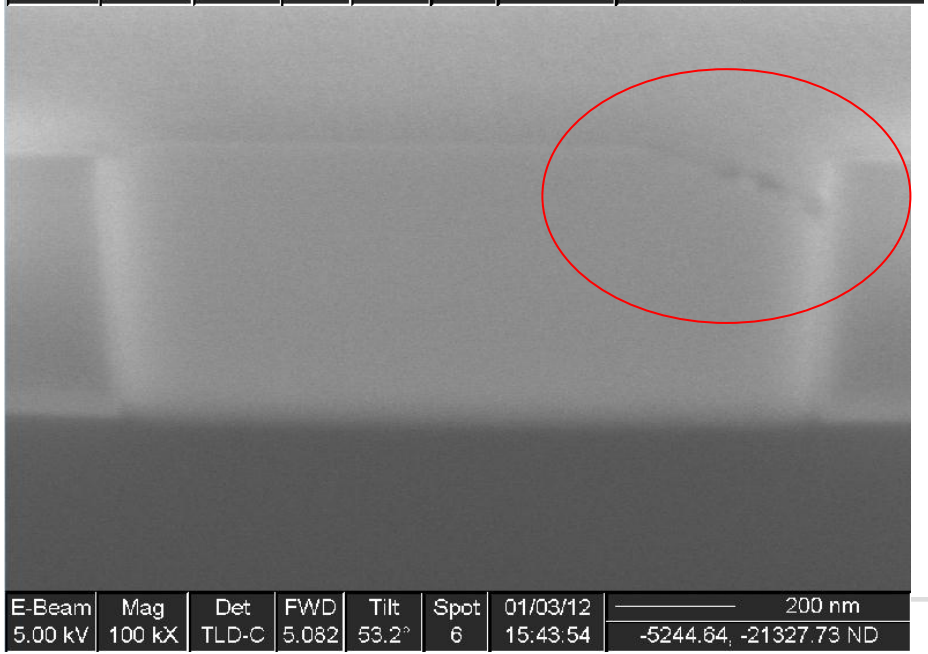
SEM view post CMP

Observations:

-Line edge degradation observed due to "weak" point. Potentially caused by mechanical stress or chemical attack at point exposed for the duration of the polish process. Determined that additional overfill is necessary.





Product Mask

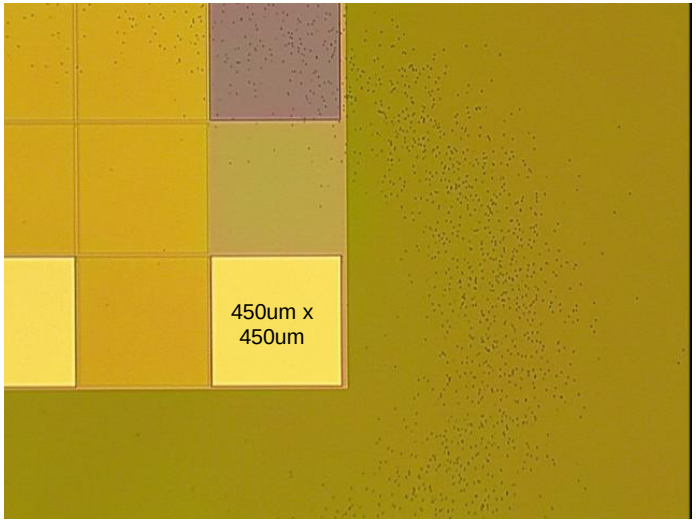
Evaluation of test mask process utilizing product mask patterned Ge wafers

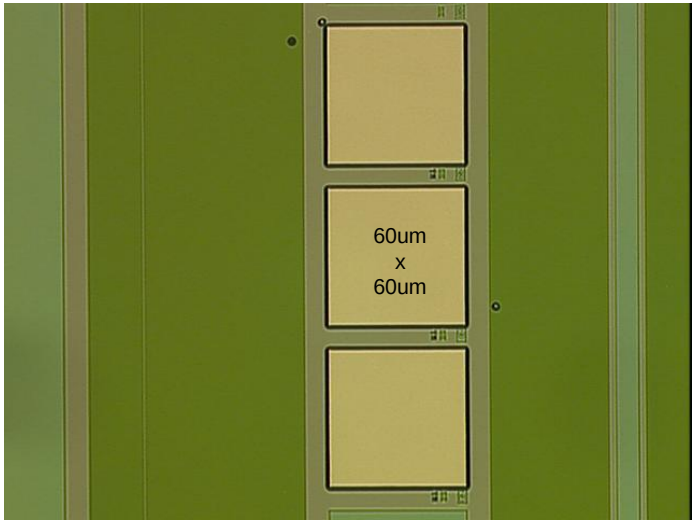
- 2 psi time splits (60s, 120s, 240s)
- Ge 1.5um Overfill height, 0.8 um lateral overflow
- Ge epitaxy process optimized to reduce random nodule growth

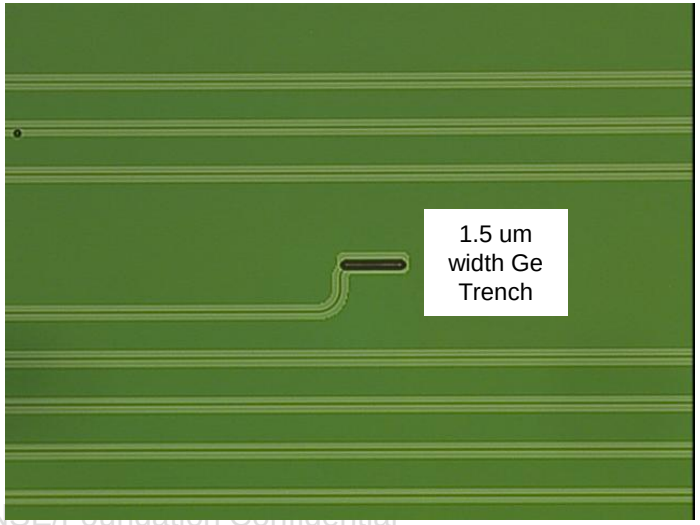
Slurry: Metal:Oxide selective with <1% H_2O_2
Pad: Dow IC1010
Disc: 3M A160

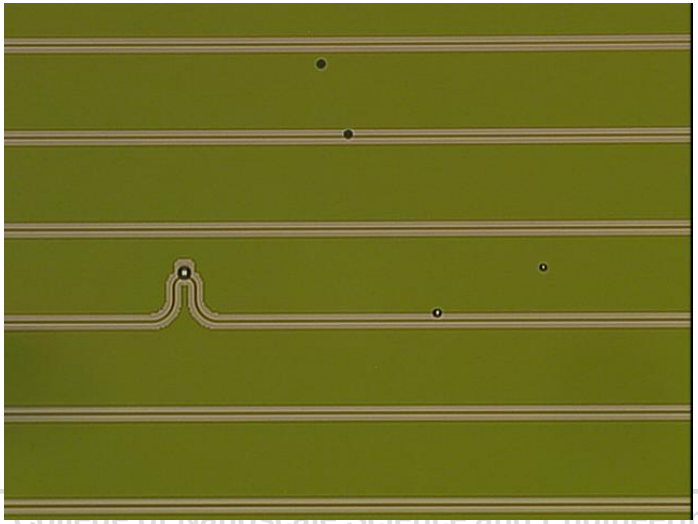
Pad Break-in : 6min, 6lb force on disc, 200ml/min slurry flow rate
Pad Warm-up: 3 x SiO_2 Blanket , 2psi 60s

Pre – CMP top down optical microscopy

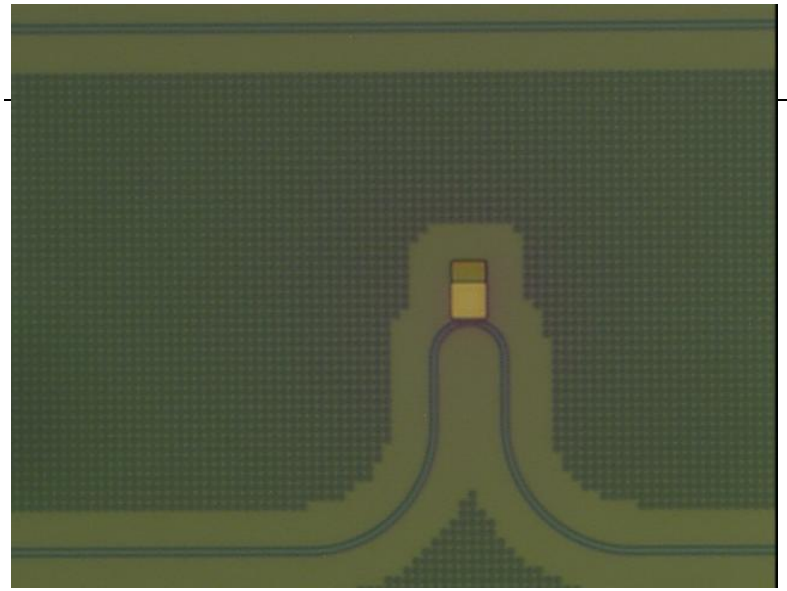






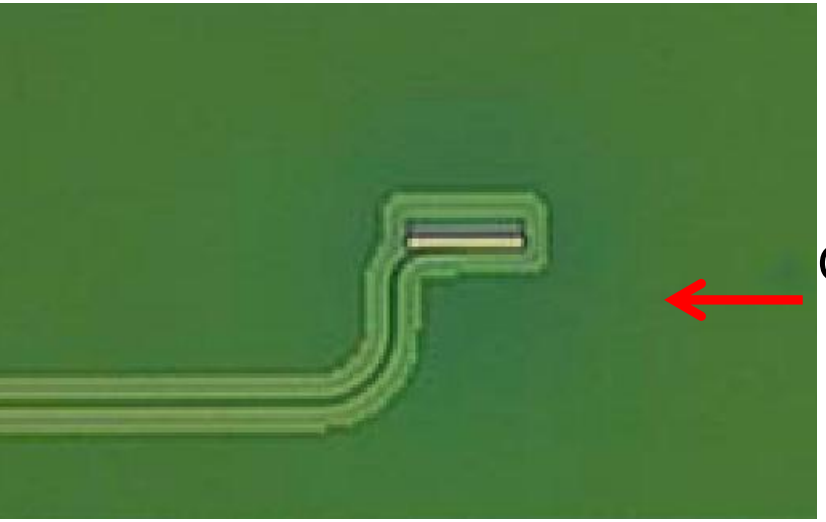


Post 60s CMP Optical Microscopy

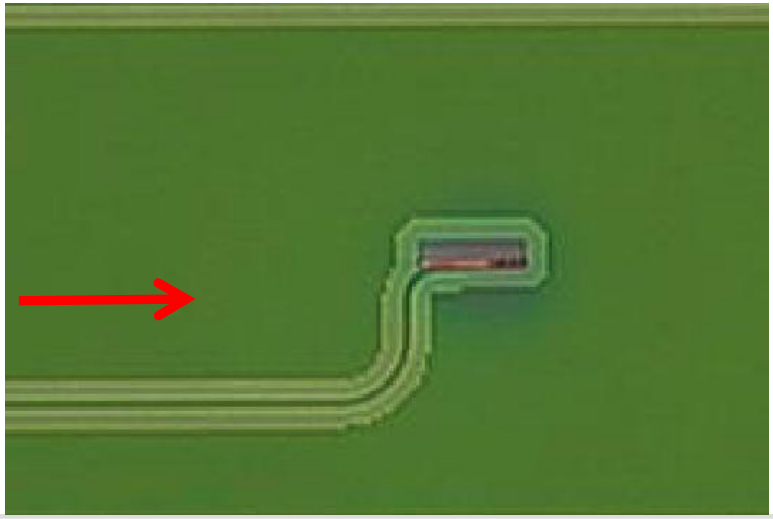


Observations:

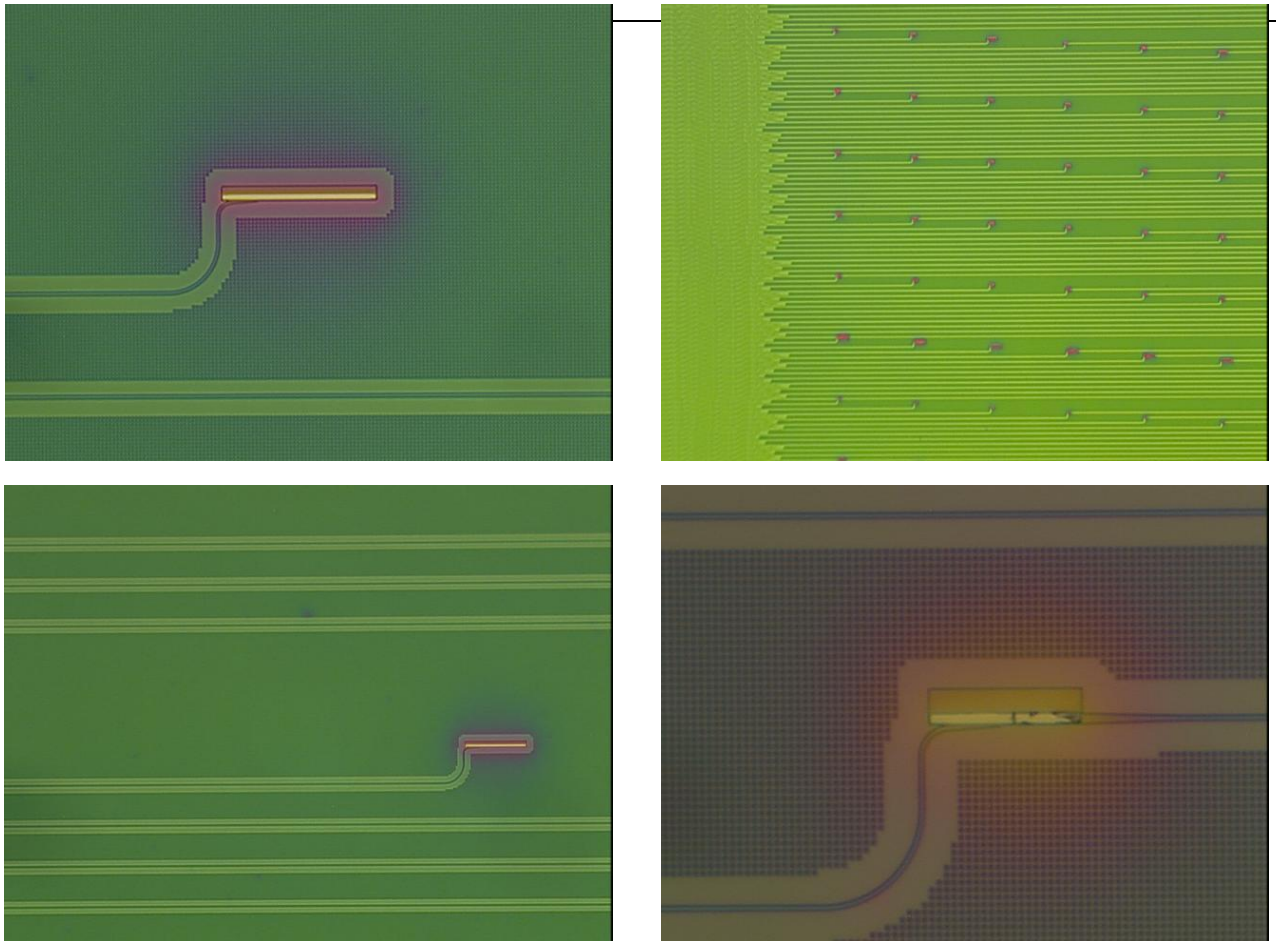
- *Very slight discolorations observed around critical structures*
- *Occasional line "pull out" causing severe discoloration where Ge previously existed. Thought to be caused mechanically due to height of Ge and lack of nodules to support the pad.*



Good Bad



Post 120s CMP Optical Microscopy

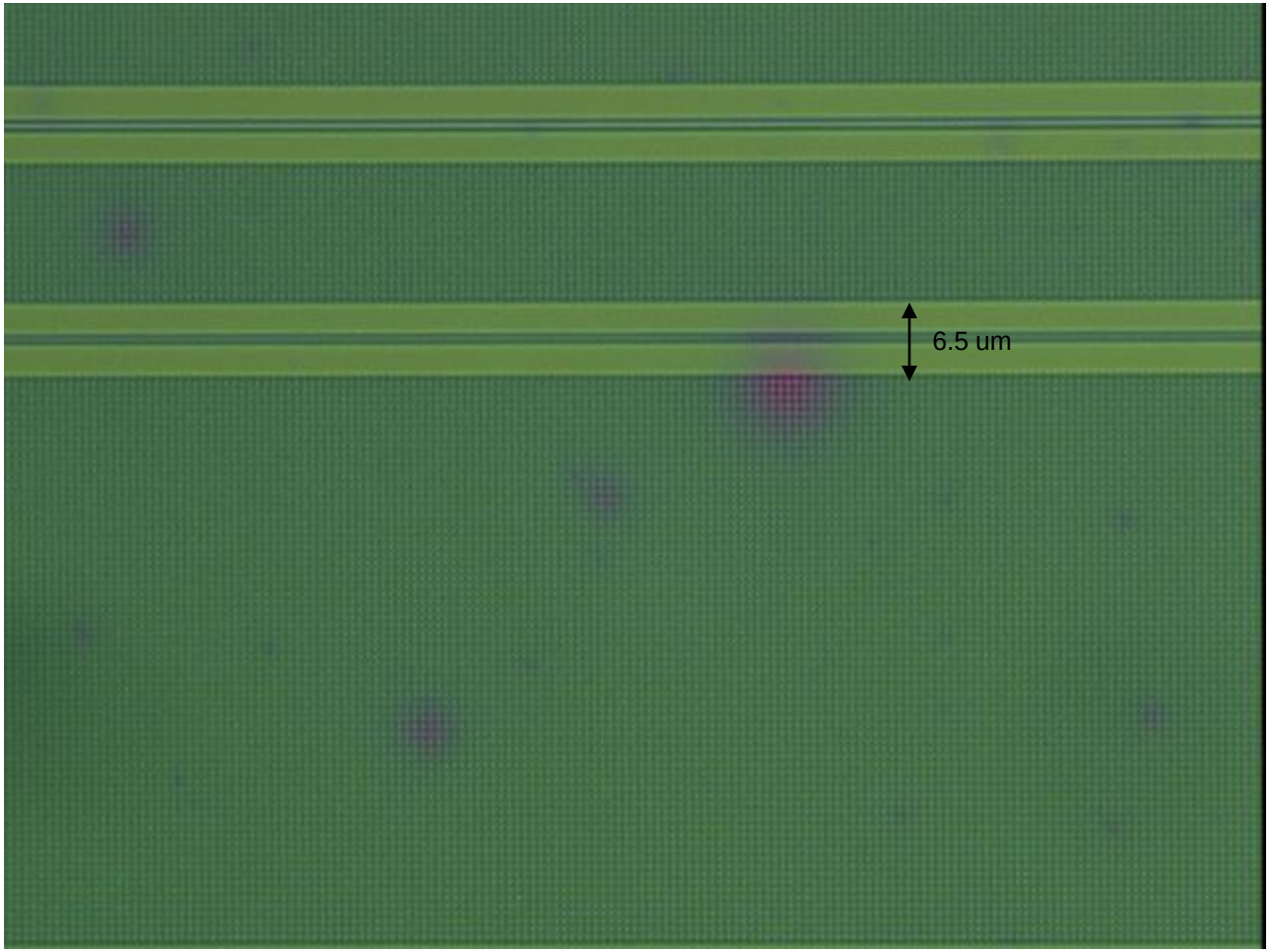


Observations:

- *Heavy discolorations observed around critical structures*
- *Line "pull out" as with 60s wafer observed on narrow structures.*

Pre CMP Oxide Thickness = 5586A
Pst CMP Oxide Thickness = 5561A

Post 240s CMP Optical Microscopy



Note that SiO_2 CMP rate is increased in areas suspected where Ge nodules previously existed.

Product Mask – Soft pad evaluation

Ge 1.5um Overfill height, 0.8 um lateral overflow

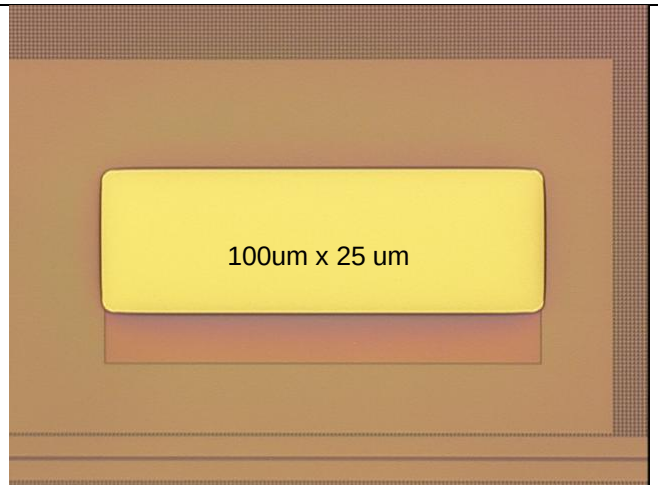
Soft pad (Fujibo) evaluation

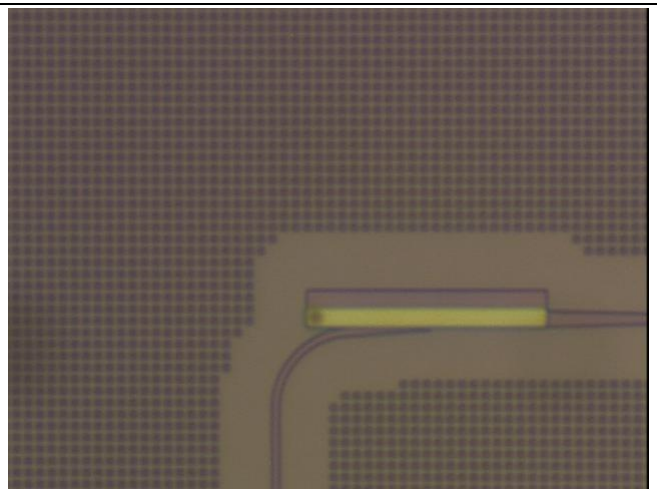
Slot	Pad	Process description	Purpose
1	IC1010	2psi 30s + Leica + 30s TU	Control
4	Fujibo	2psi 60s + Leica	Soft pad effect
5	Fujibo	2psi 45s + Leica	Soft pad
6	Fujibo	2psi 30s + Leica	Optimized process

Note:

- Slot 1 run as control, pull out still observed with 30s 2psi recipe and portions of lines still not clear. Touch up 30s polish run to clear Ge.
- Slot 4 run with Fujibo pad for 60s. Significant dishing present while lines appear to be clear and pull out not visible.
- Slots 5 & 6 run for shorter time splits. Dishing still present while large structures appear to not be clear. Pull out not observed.
- Slot 6 inspected again 4 days after polish and small “growths” observed on predominantly narrow lines.

Slot 6 – Fujibo pad (soft) at 2psi + 30s

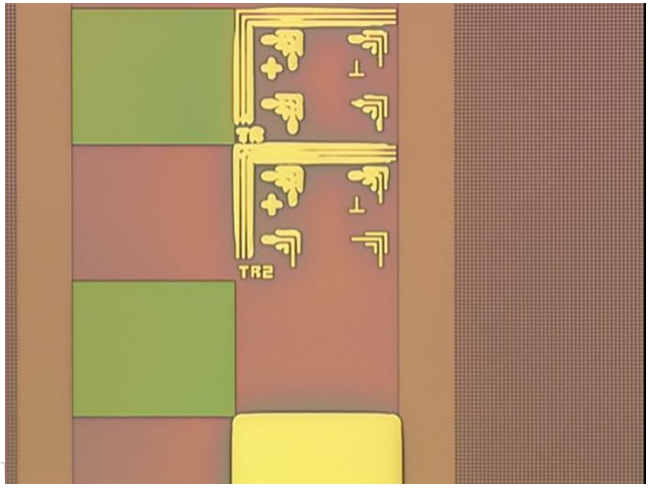


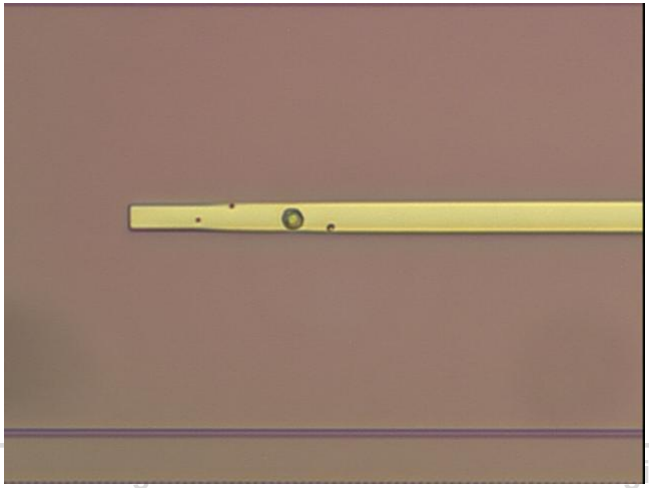


Under Polish

4 Day Growth

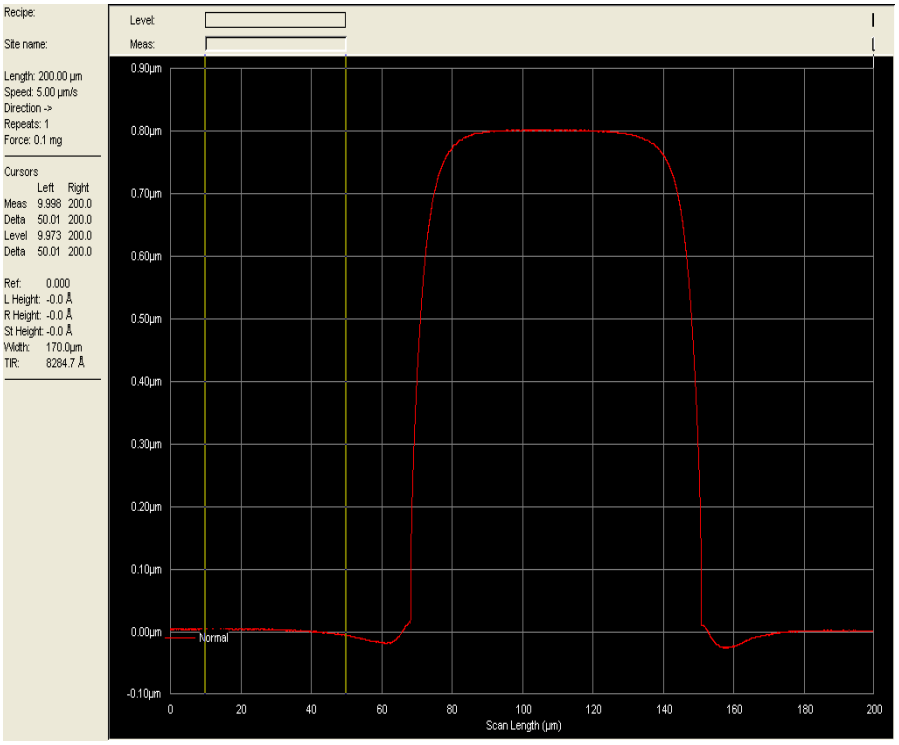
Queue time required





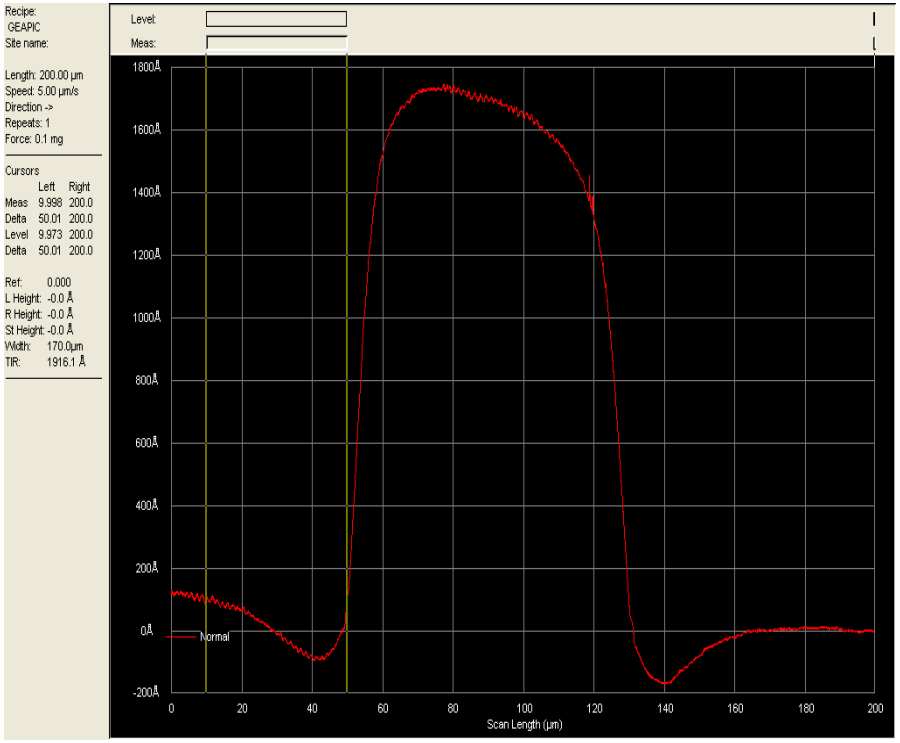
Post CMP Profilometry

Fujibo pad 30s, 100 x 25 um Ge structure



0.8 um Ge remaining above Oxide

IC1010 pad 60s, 100 x 25 um Ge structure



0.16 um Ge remaining above Oxide

Product Mask – Process improvement DOE

- 1.5um Overfill height, 0.8 um lateral overflow
- DOE to modulate Pull out, Dishing, Large structure lag
- Variables: Soft pad buff time, Rotational velocity/down force, Slurry dilution

Slot	Soft Buff (s)	Hard Polish Rot. Vel./DF	Slurry Con.
11	20	110/2	As-is
12	20	60/1	4:1
13	10	60/1	As-is
14	10	110/2	4:1
15	10	110/2	As-is
16	20	110/2	4:1
17	20	60/1	As-is
18	10	60/1	4:1
19	n/a	110/2	As-is

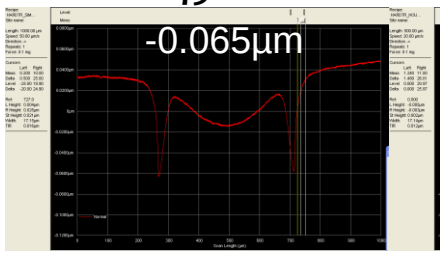
Step Height by Structure size

	Structure size (um)					Step height Calculation				
Slot	**450**	**60**	**25 x 100**	**1.5**	**0.5**	Max	Min	Range	Avg	Stdev
11	800	2000	400	-400	-300	2000	-400	2400	500	974.6794
12	300	1700	550	-410	-270	1700	-410	2110	374	840.2559
13	2200	4700	900	-260	-200	4700	-260	4960	1468	2065.943
14	300	2000	1000	-450	-300	2000	-450	2450	510	1010.198
15	1100	2900	400	-350	-300	2900	-350	3250	750	1339.776
16	-650	1150	0	-460	-350	1150	-650	1800	-62	717.6141
17	1600	4200	1400	-280	-200	4200	-280	4480	1344	1819.802
18	180	2500	400	-400	-280	2500	-400	2900	480	1175.67
19	1200	3100	550	-380	-300	3100	-380	3480	834	1423.826

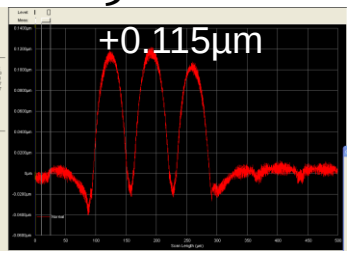
*All step height values in Angstroms

Slot 16 profilometry

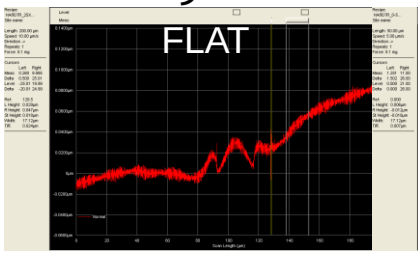
450 um



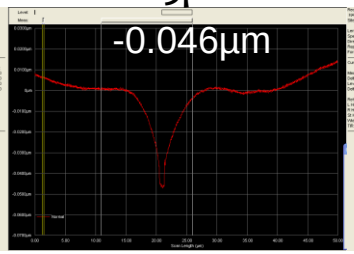
3X 60 um



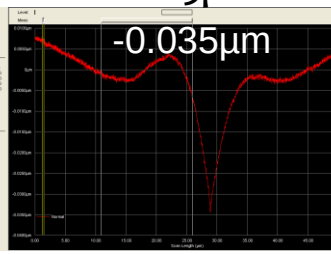
25x100



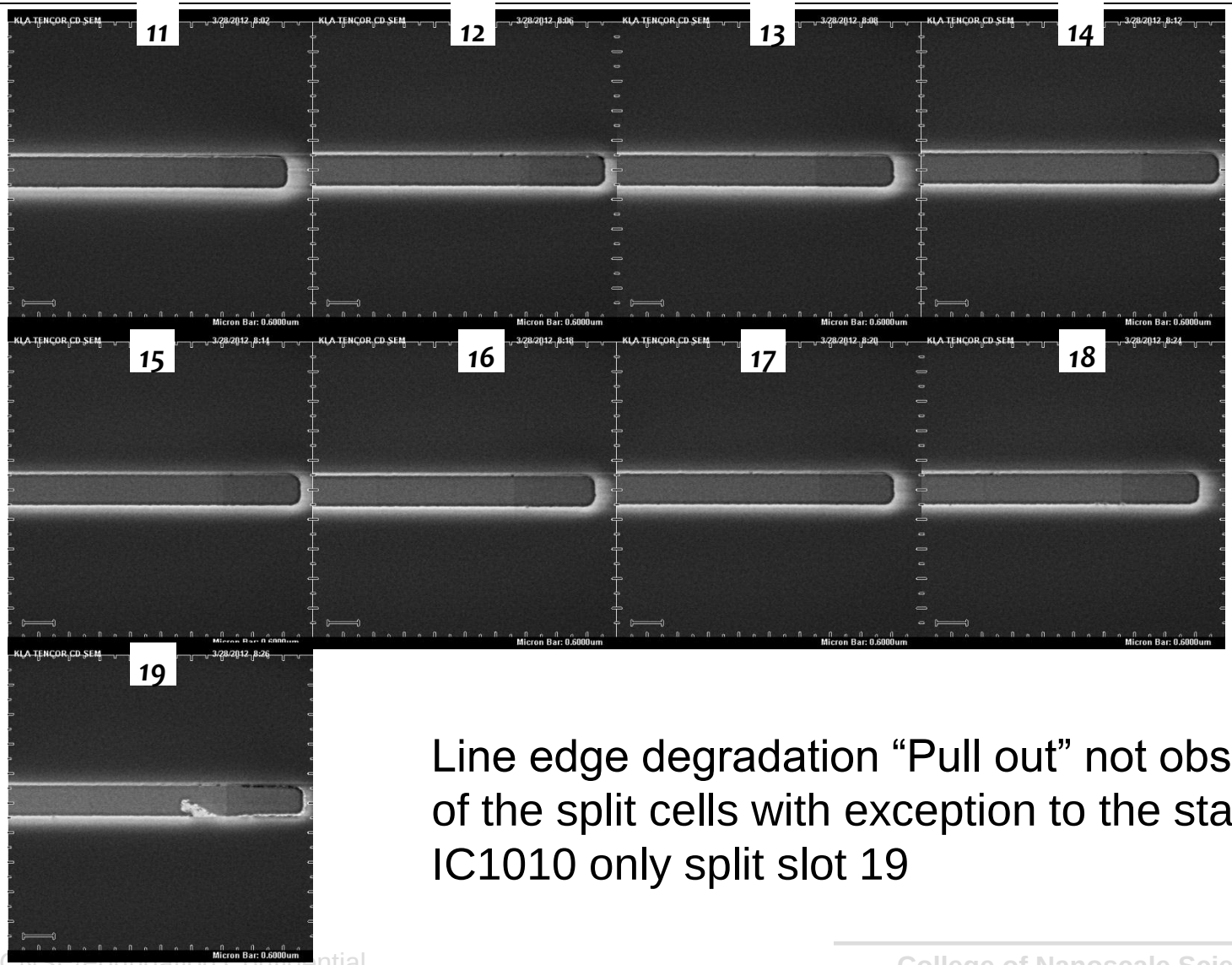
1.5µm



0.5µm

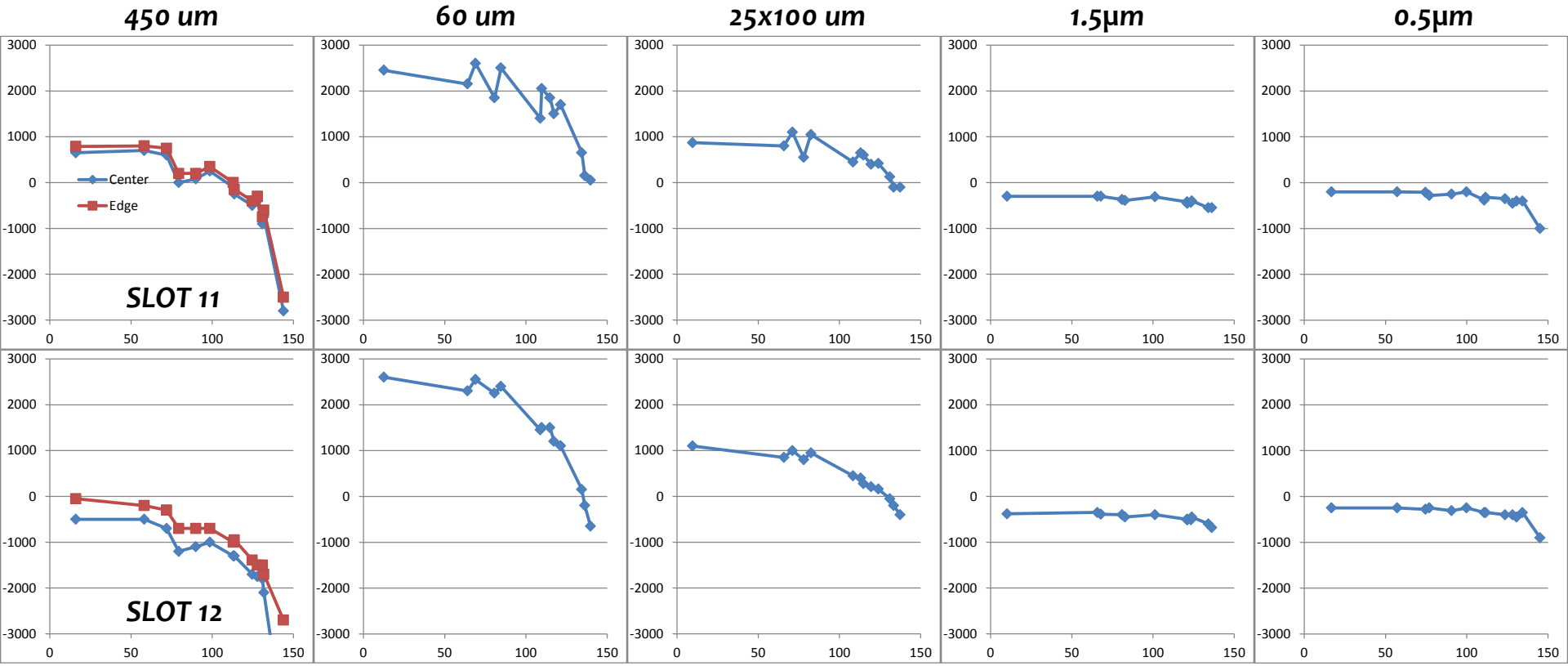


20s buff, 2psi, 110rpm, 4:1 dilution



Line edge degradation “Pull out” not observed on any of the split cells with exception to the standard IC1010 only split slot 19

Step height radial uniformity



Data suggests that smaller isolated structures are “protected” by surrounding oxide. Also suggests that future improvement can be achieved through Epi growth and CMP removal uniformity optimization.

Summary:

- Preliminary Blanket tests
  - show promising smoothing, sufficient removal rate, and suggest stop on oxide capability.
- Test mask experiments
  - Epitaxial grown Ge within patterned trenches will planarize well but reveal importance of sufficient overfill.
- Product mask experiments
  - Show mechanical weakness (pull out) of properly overfilled isolated Ge trenches.
  - Suggest necessity of post CMP processing Queue time
  - Suggest production worthy process is achievable through across wafer uniformity optimization.
  - Show initial buff with soft pad necessary for “pull out” prevention
- Ge nodule usage as artificial pattern fill? Help with structure size dependency? Eliminate need for buff step for pull out?