COLLEGES OF NANOSCALE
SCIENCE + ENGINEERING
SUNY POLYTECHNIC INSTITUTE

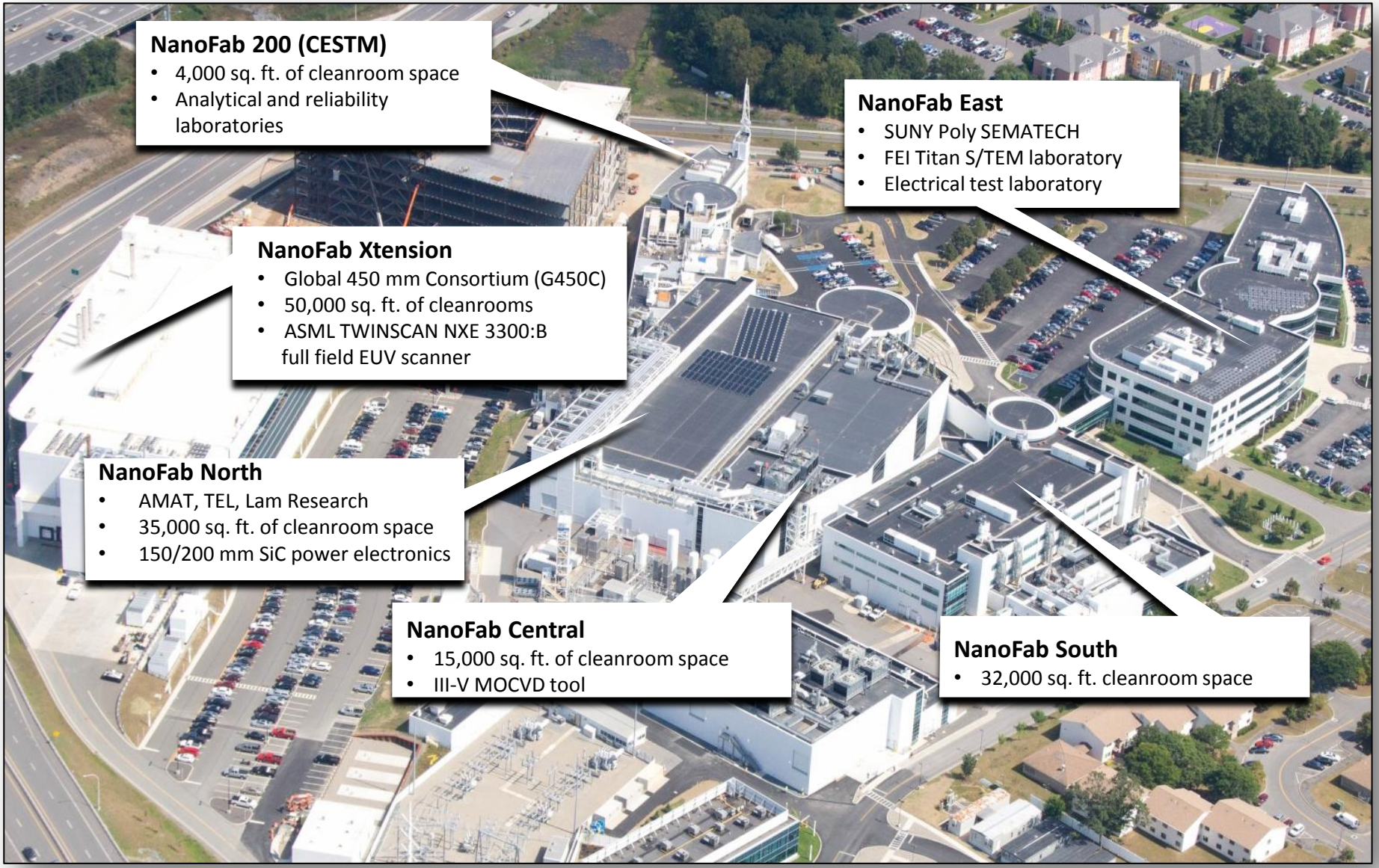
ADK14 – The Test Vehicle for Standardized Characterization of CMP Consumables and Processes in the FinFET Era

J. Nalaskowski, T. Burroughs, D. Penigalapati, M. Smalley, P.Y. Hung, C. Johnson, W. Advocate, B. Bunday, A. Cordes, S. Bennett, B. Martinick, D. DiPaola, J. St. Louis, D. Ashworth, P. Khare, M. Zhu, H. Stamper, A. Vert, K. Petrarca, F. Goodwin, M. Rodgers, B. Baker-O'Neal, F. Tolic, J.R. Lloyd, C. Borst, B. Sapp, S. Papa Rao

April 07, 2016

CMPUG Spring Meeting, Austin, TX

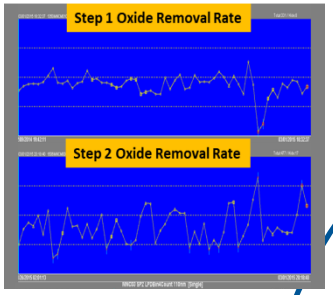
World-Class R&D Facilities



SUNY Poly CMP Capability

Right Balance of Research Flexibility and Operational Discipline

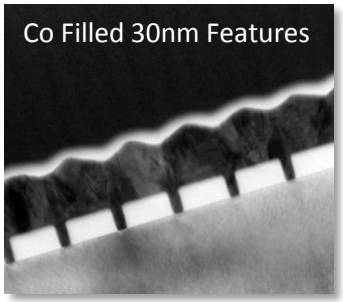
SPC for advanced process flows



Robust baseline process flows

Multi vendor CMP platforms

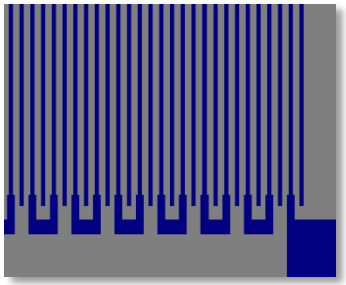
5x AMAT Reflexion LK
1x Ebara F-Rex 300S



Leading edge materials

SUNY Poly CMP

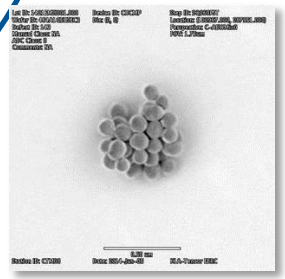
Industry standard mask-set



TEM, SEM, AFM
Surface Spectroscopy
Electrical Testing
Reliability Testing

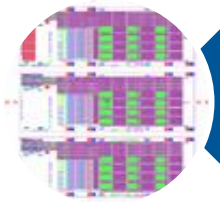
Fundamental analysis

State of the art defect metrology



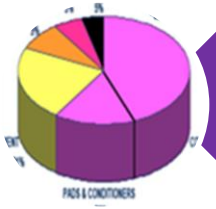
KLA SP3
KLA2915
KLA eDR 7100

SUNY Poly CMP Expertise



Industry Standard Multi-Level Advanced Learning Vehicle

- Structures at relevant critical dimensions for process development, benchmarking, dummy fill sensitivity, e-test and reliability, and advanced metrology characterization

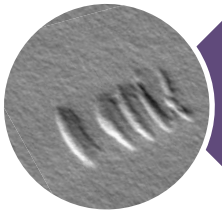


CMP Process Development

- Consumables evaluation, benchmarking and development
- Enabling multi-party engagement for CMP suppliers and customers
- CMP of new materials, scale-up issues

Robust Fully Integrated Baselines

- Process flows for advanced front-end-of-the-line (FEOL) and back-end-of-the-line (BEOL) CMP levels



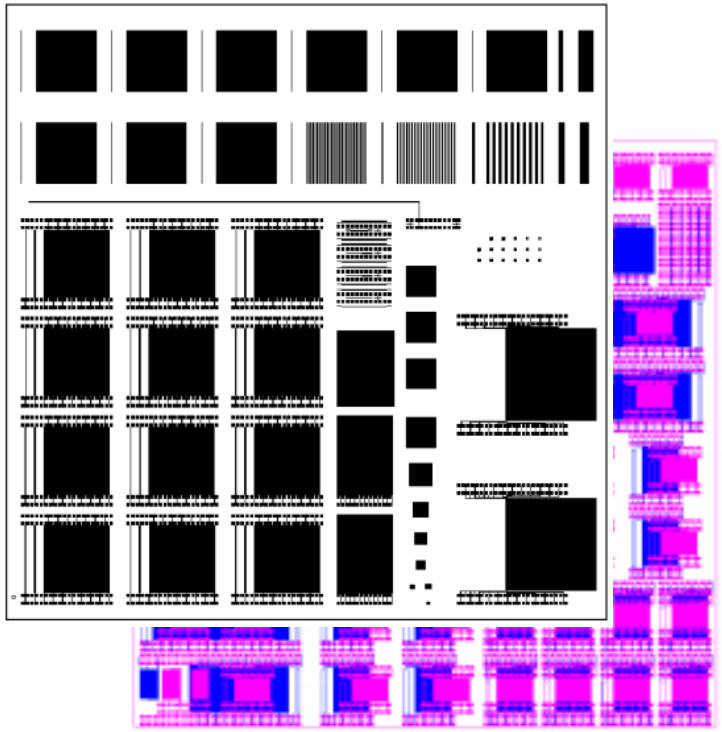
Leading-edge characterization techniques for CMP

- Multi-spectral advanced defect characterization techniques
- Particle/pad/wafer interactions, adhesion measurements, nanomechanics

Development of Advanced Learning Vehicles

SUNY Poly has significant expertise and experience in the development of test vehicles for advanced R&D

- The *de facto* CMP standard for the industry is still the SEMATECH/MIT mask-set developed in the late 90's
  - Process characterization
  - Consumable benchmarking
  - Standardization of results



Need for development of industry-standard multi-level CMP-focused mask-set to meet advanced node challenges

ADK14: New Industry-Standard 14 nm Test Vehicles

- ADK14 FEOL - multi-level vehicle for unit process development and integration at relevant critical dimensions
  - Incorporated design input from CMP community
  - CMP consumable and process benchmarking
  - Advanced metrology characterization and development
  - Single level process characterization
  - Cumulative topography effect assessment

FEOL (26mm×33mm)	CD (nm)	Pitch (nm)
SADP Fin/Active	10	48
Gate	30	90
Contact	40	90
M1 /Fatline	1k	1.09k

ADK14 FEOL Flow

- HM1, HM2 & mandrel dep
- Mandrel litho & etch
- SIT spacer dep and etch
- Cut mask litho & etch
- Block litho
- Etch HM2, HM1 and fin/active
- Oxide fill and Fin **CMP**
- Poly dep & Poly **CMP**
- Gate litho & etch
- Spacer dep & etch
- ILD 0 dep & POP **CMP**
- HK/MG dep & **CMP**
- MG recess, SiN dep & **CMP**
- ILD 1 dep
- Contact litho
- Contact etch & fill & **CMP**
- IMD dep
- M1 litho & etch
- M1 fill & **CMP**

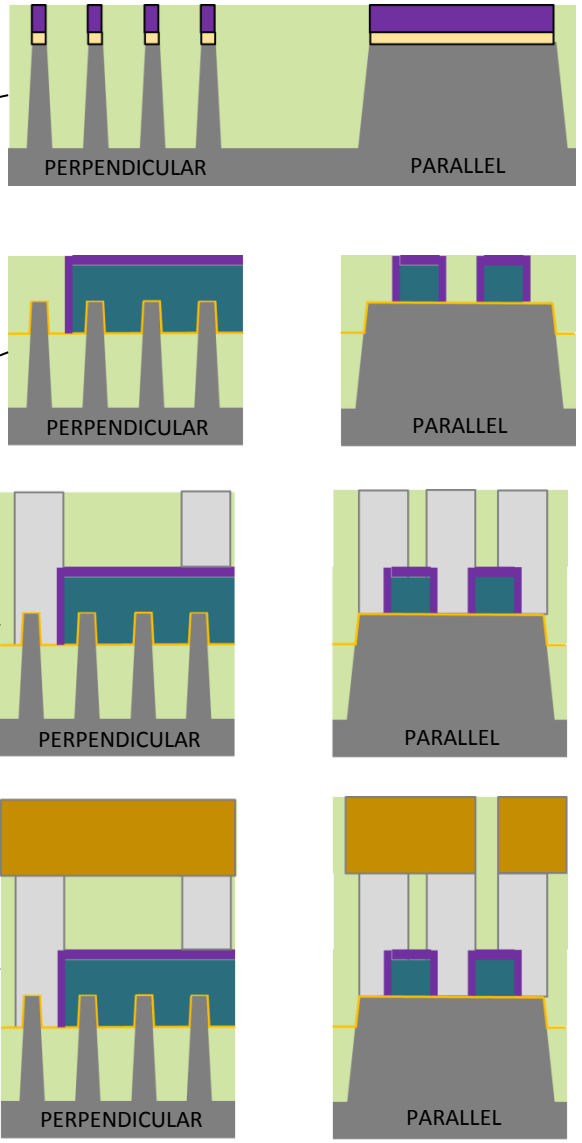
Allows for Development of All Major CMP Processes

Fin/Active

RMG

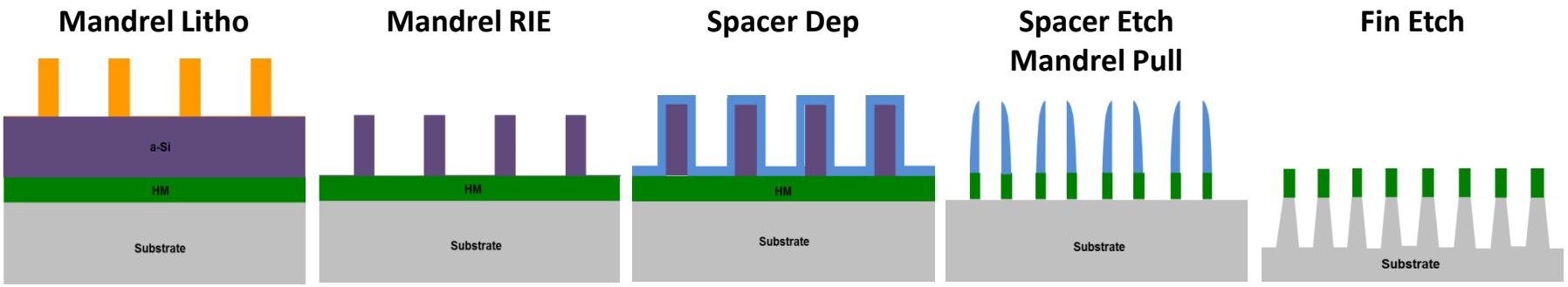
Contact

M1

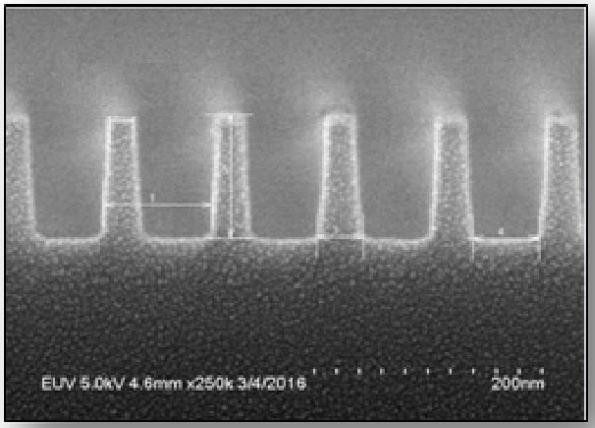


SADP Integration

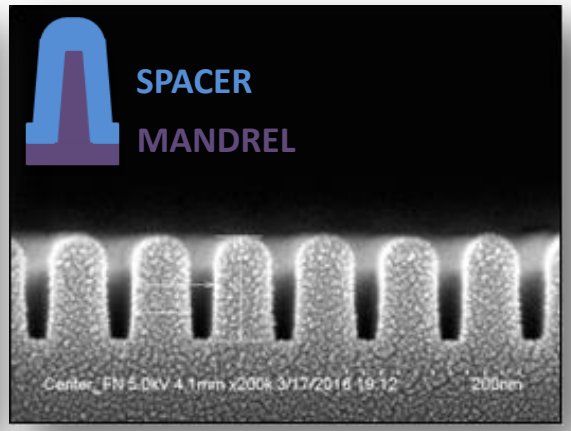
- ADK14 Self Aligned Double Patterning (SADP) Process Flow



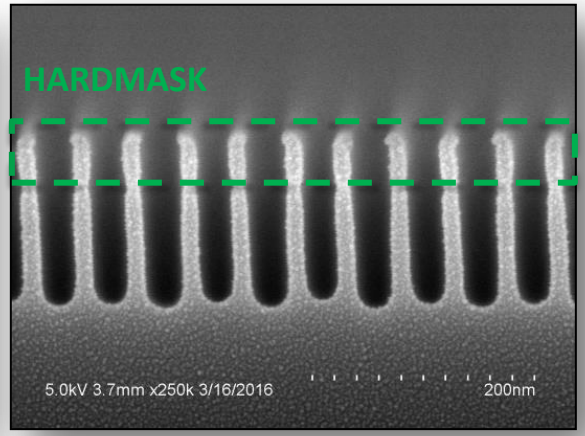
Post Mandrel RIE



Post Spacer Deposition

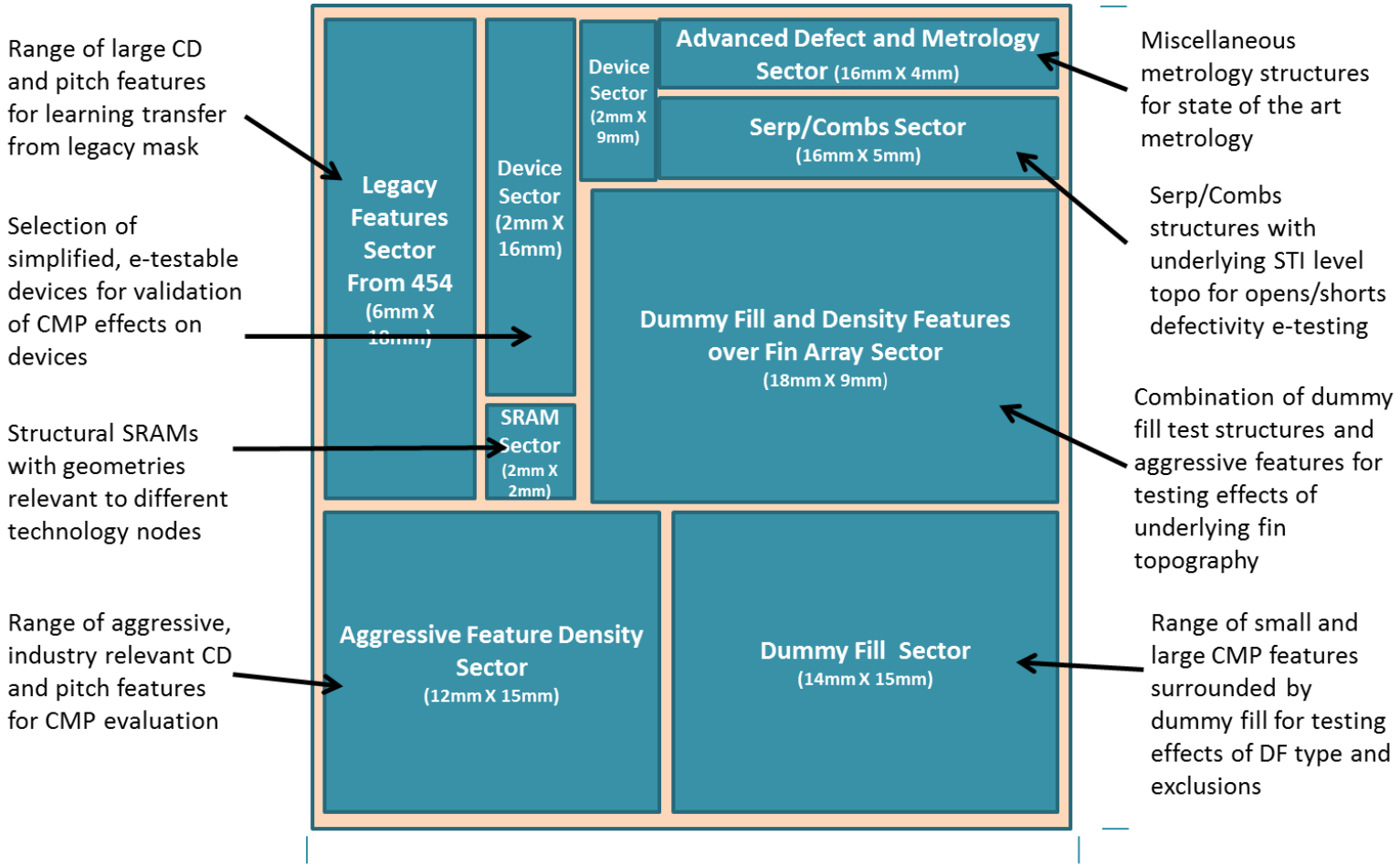


Post Fin Etch SADP



ADK14 FEOL Layout

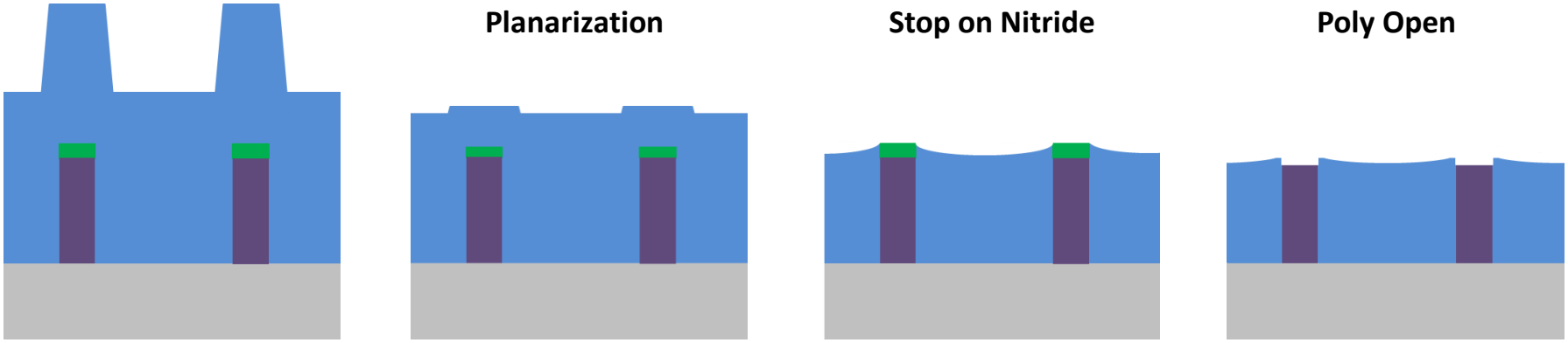
Wide range of topographic and e-testable structures



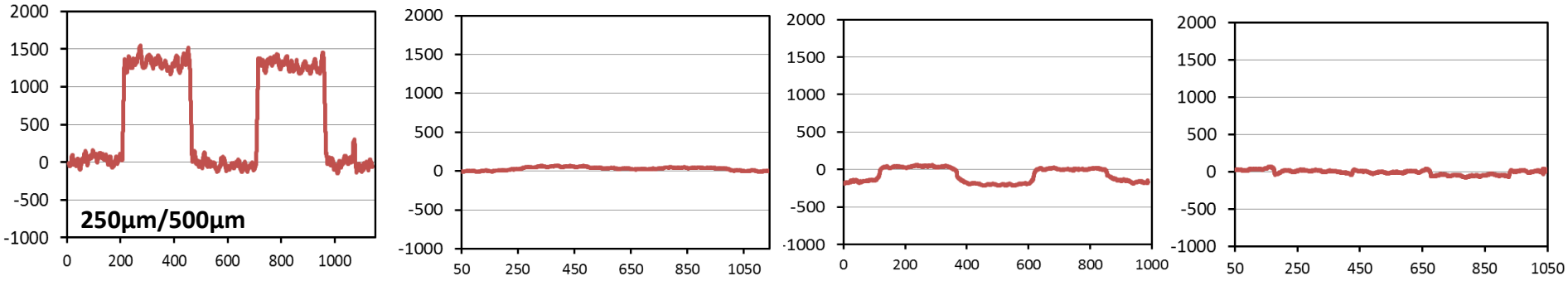
Enables comprehensive process development at relevant critical dimensions

Poly Open Planarization Flow

- POP CMP process for replacement metal gate

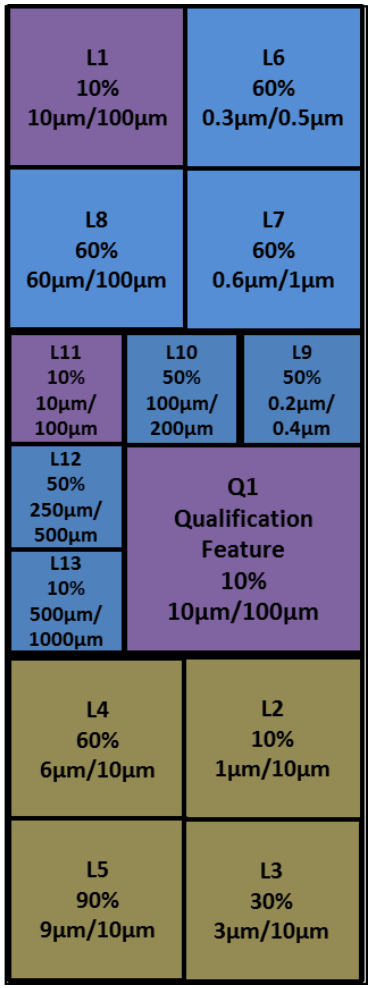


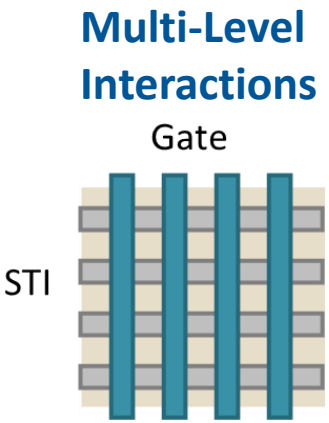
Topography Evolution - Profilometry Data



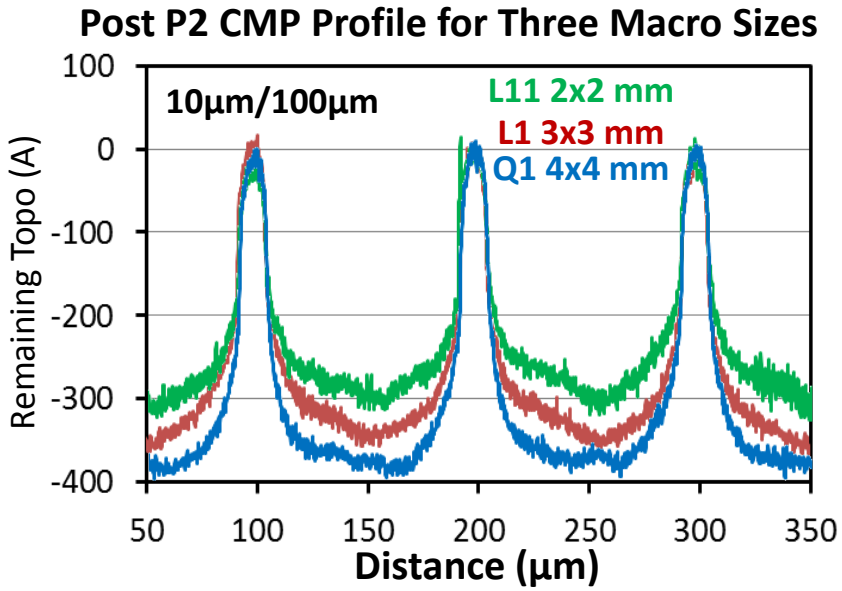
Legacy Features Sector

- Relaxed CD lines and pitches equivalent to SEMATECH/MIT mask
  - Provides a bridge to historical data





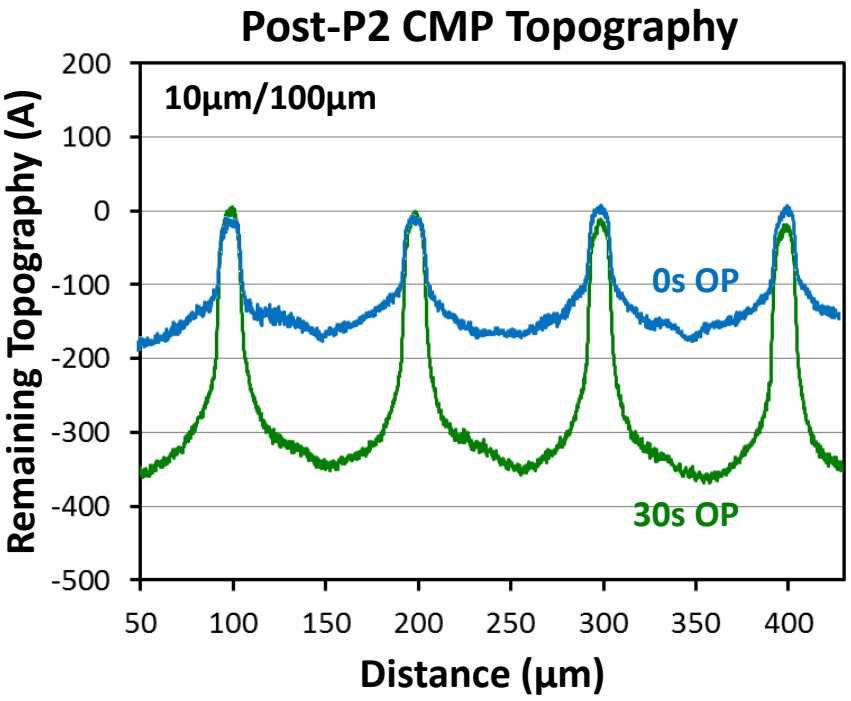
Optical Micrograph of Gate Level

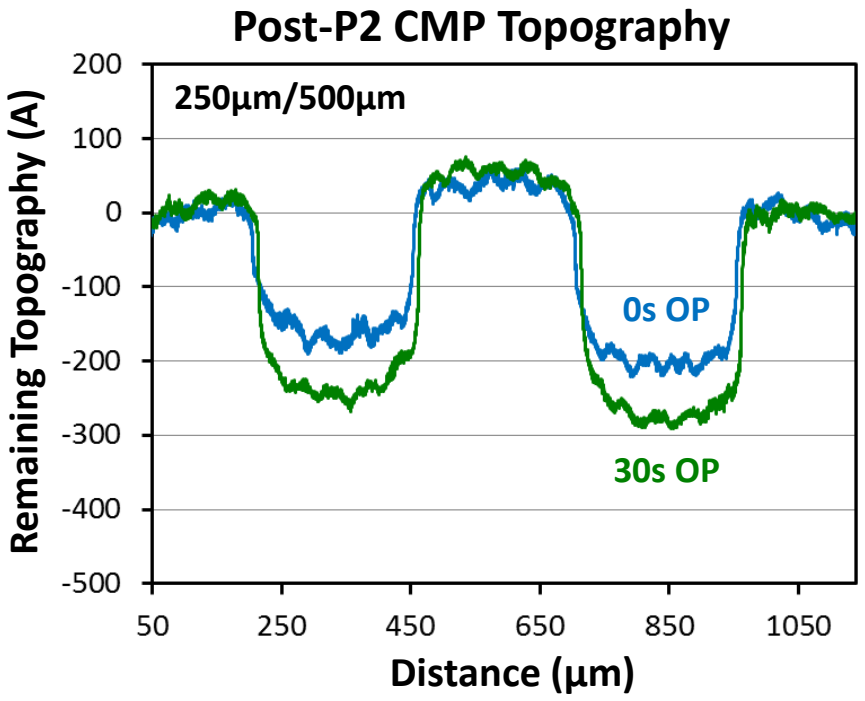


Different macro sizes allow for building transfer function between array size and CMP performance

Structures for Dishing and Erosion Tests

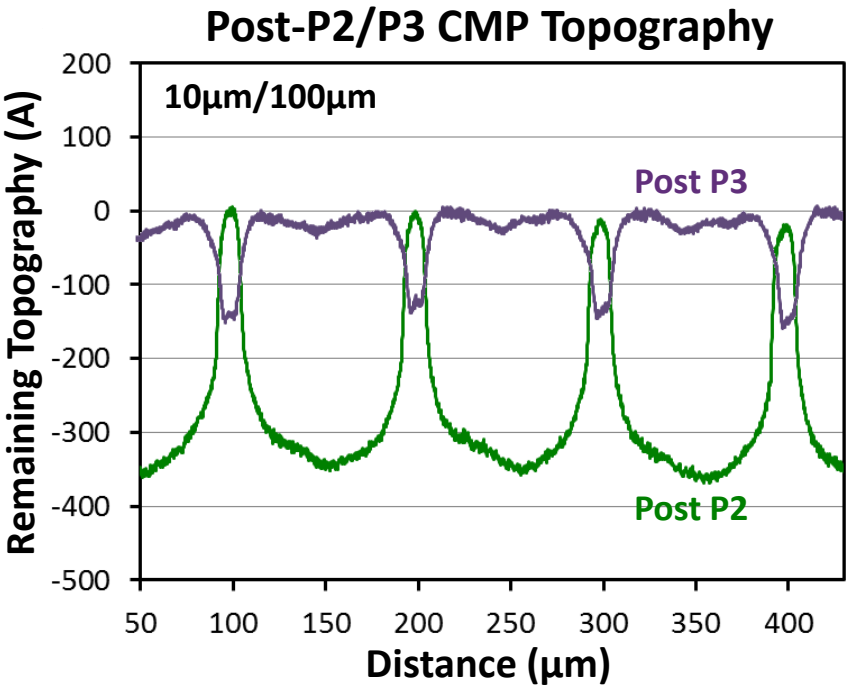
- Wide range of structures to test influence of process conditions on dishing and erosion
- Example: Influence of overpolish time on dishing performance for P2 (stop on nitride) process

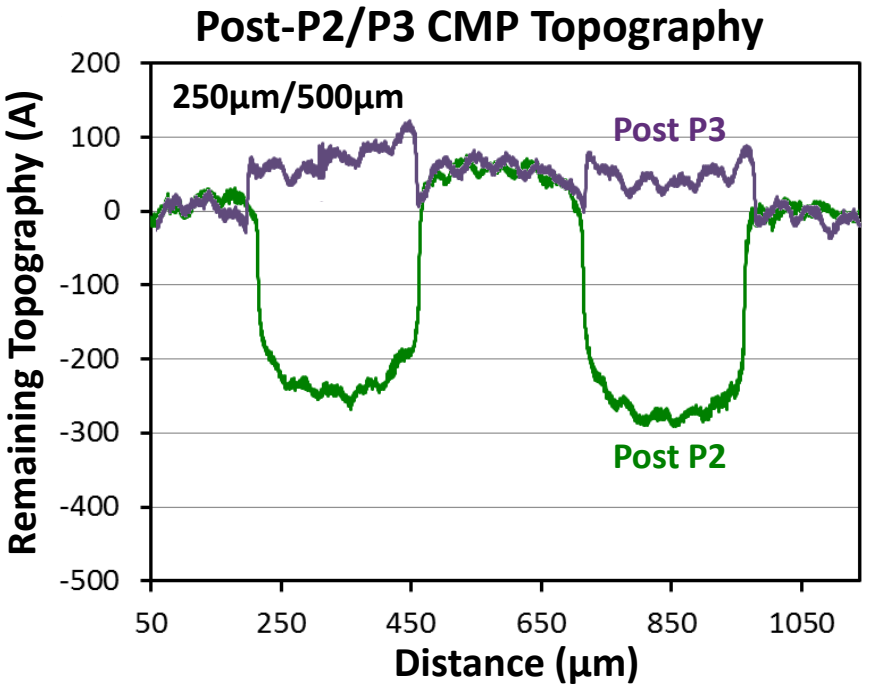




Structures for Dishing and Erosion Tests

- Example: Comparison of post P2 and post P3 topography for POP CMP process





Aggressive Density Macros

- Well defined line arrays with wide range of CD and pitch for characterization of CMP performance

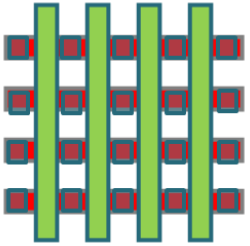
Level-Specific Range of CD and Pitch

S41 100nm 10% 100/1000	S31 70nm 70% 70/100	S21 40nm 5% 40/800	S11 10nm 21% 10/48
S42 100nm 50% 100/210	S32 70nm 5% 70/1400	S22 40nm 18% 40/220	S12 10nm 5% 10/210
S43 100nm 40% 100/250	S33 70nm 30% 70/234	S23 40nm 10% 40/400	S13 10nm 21% 10/48
S44 100nm 25% 100/400	S34 70nm 10% 70/700	S24 40nm 5% 40/800	S14 10nm 9.5% 10/105
S45 100nm 5% 100/2000	S35 70nm 25% 70/280	S25 40nm 15% 40/267	S15 10nm 5% 10/210

Active/Fin Level

Multi-Level Interactions

Hole Contacts



Slot Contacts

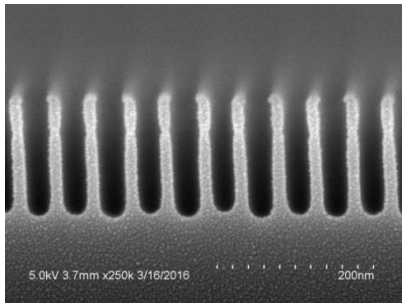
Contact

Gate

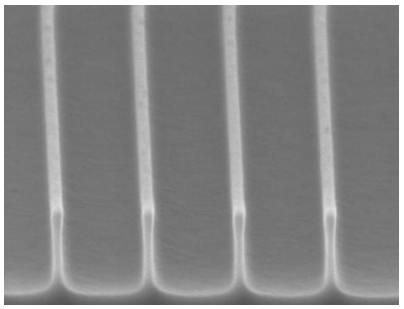
Active

Post-RIE SEM

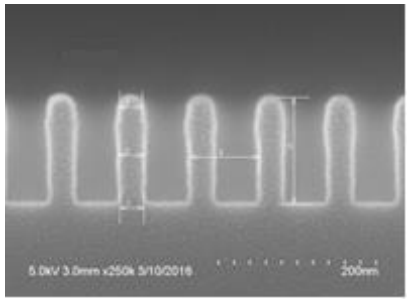
SADP Active 10/48

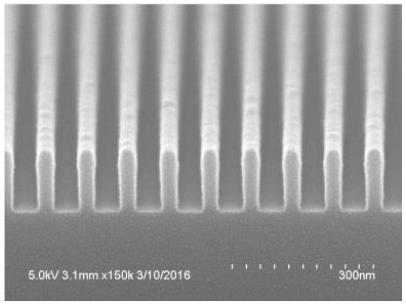


RX Active 40/267



Gate 30/90

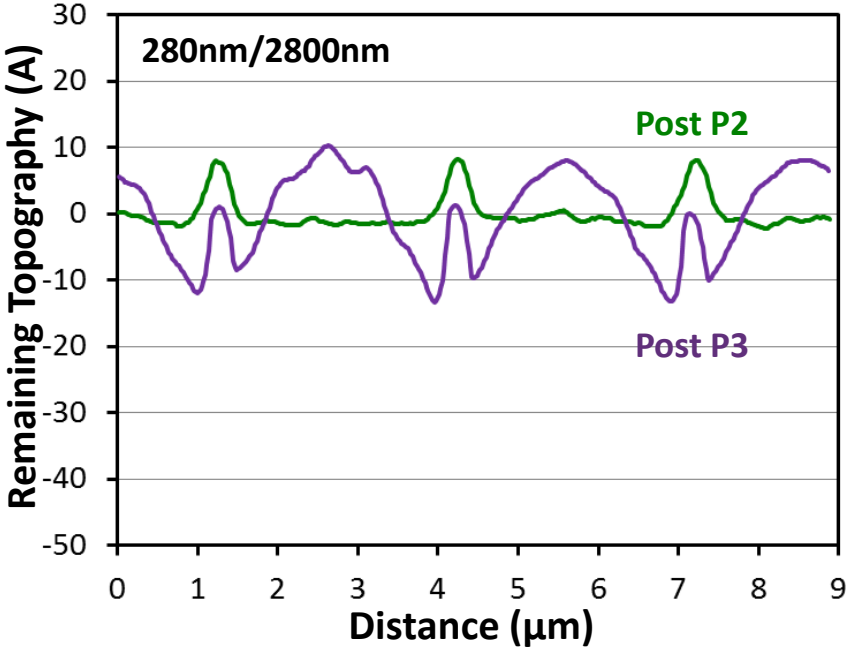


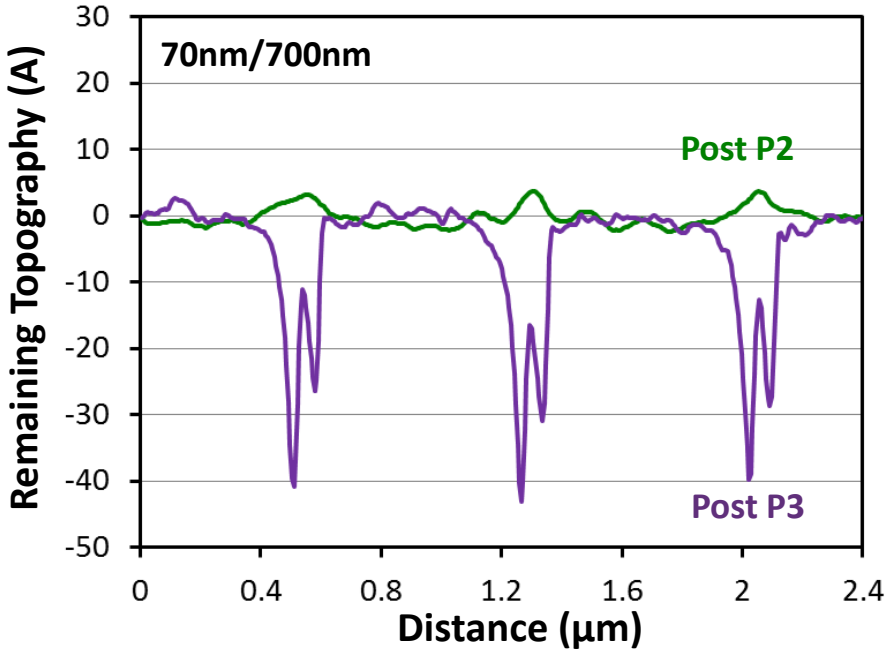


Fine Structures for CMP Performance

- Wide range of aggressive CD and pitch structures to test influence of process conditions on dishing and erosion

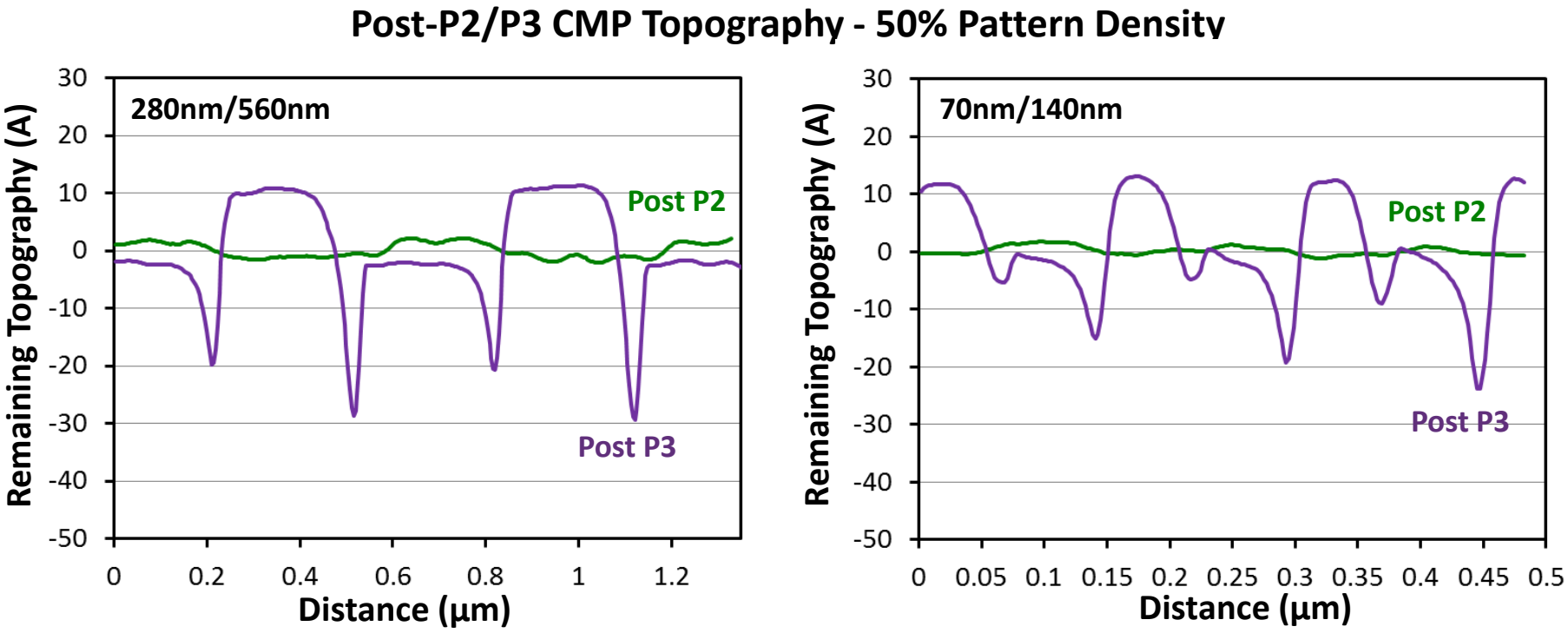
Post-P2/P3 CMP Topography - 10% Pattern Density





Fine Structures for CMP Performance

- Wide range of aggressive CD and pitch structures to test influence of process conditions on dishing and erosion



Maximizing CMP Defect Sensitivity

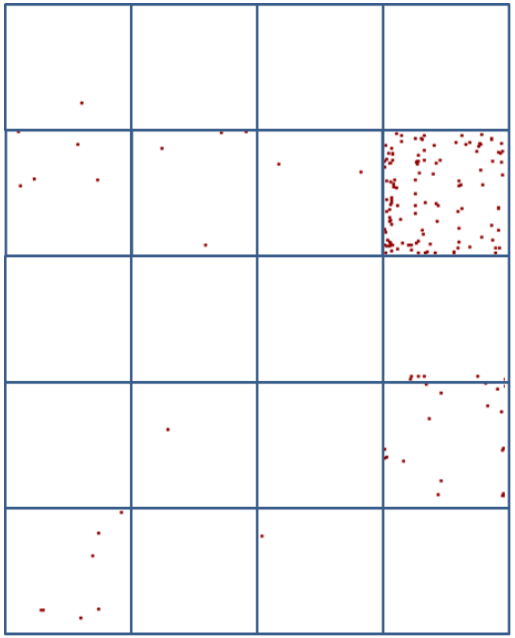
- Reticle designed and processes developed to minimize nuisance defects for higher sensitivity post-CMP defectivity studies
- Defect Source Analysis for targeting of post-CMP defects for CMP performance analysis

Aggressive Density Macro

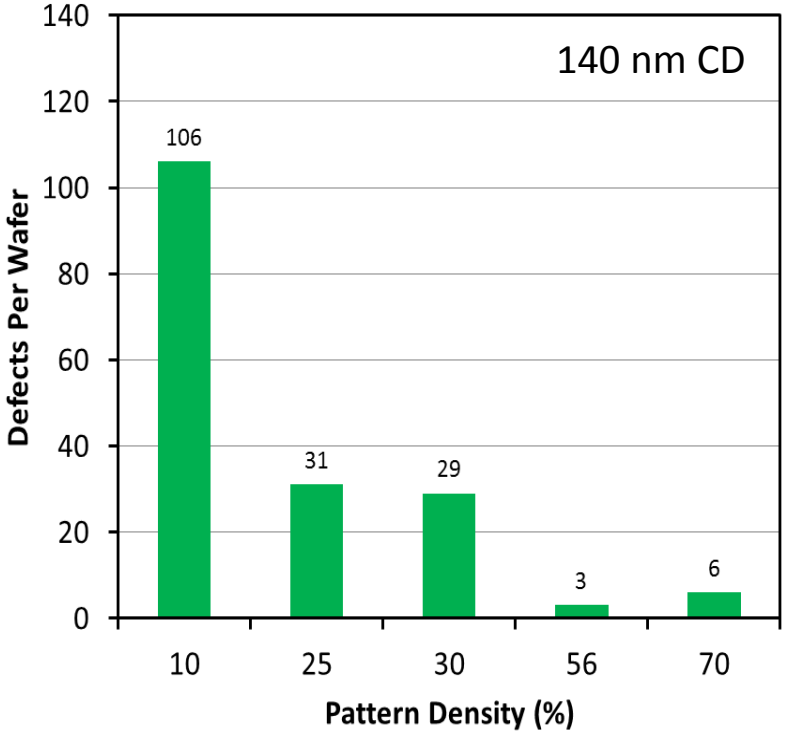
G41 280nm 50% 280/560	G31 140nm 70% 140/200	G21 70nm 10% 70/700	G11 30nm 35% 30/90
G42 280nm 10% 280/2800	G32 140nm 10% 140/1400	G22 70nm 50% 70/140	G12 30nm 5% 30/700
G43 280nm 82% 280/340	G33 140nm 56% 140/250	G23 70nm 30% 70/233	G13 30nm 25% 30/140
G44 280nm 75% 280/373	G34 140nm 30% 140/467	G24 70nm 10% 70/700	G14 30nm 10% 30/350
G45 280nm 25% 280/1120	G35 140nm 25% 140/560	G25 70nm 35% 70/200	G15 30nm 30% 30/117

Gate Level

Post RIE Die Defect Map



Post RIE: Total Defects Per Wafer



Maximizing CMP Defect Sensitivity

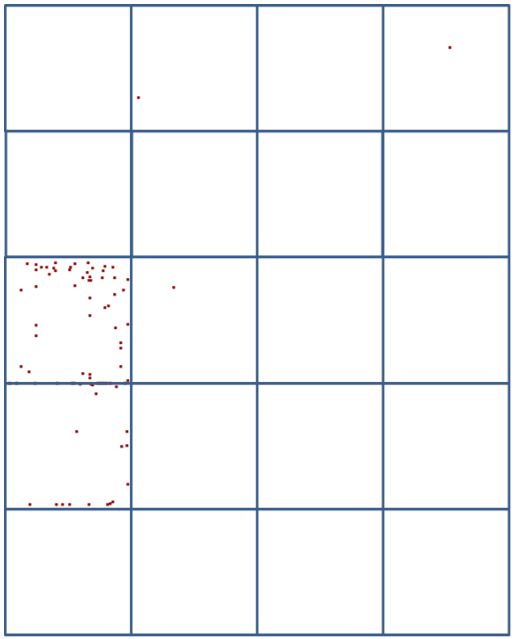
- Good sensitivity to post CMP defectivity on aggressive density macros
- Further enhancements to defect sensitivity in progress

Aggressive Density Macro

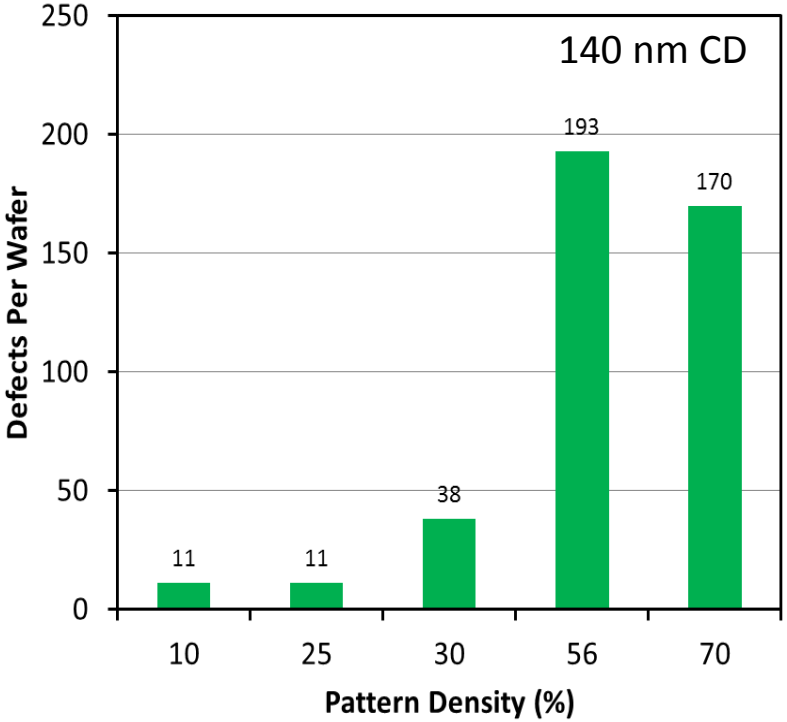
G41 280nm 50% 280/560	G31 140nm 70% 140/200	G21 70nm 10% 70/700	G11 30nm 35% 30/90
G42 280nm 10% 280/2800	G32 140nm 10% 140/1400	G22 70nm 50% 70/140	G12 30nm 5% 30/700
G43 280nm 82% 280/340	G33 140nm 56% 140/250	G23 70nm 30% 70/233	G13 30nm 25% 30/140
G44 280nm 75% 280/373	G34 140nm 30% 140/467	G24 70nm 10% 70/700	G14 30nm 10% 30/350
G45 280nm 25% 280/1120	G35 140nm 25% 140/560	G25 70nm 35% 70/200	G15 30nm 30% 30/117

Gate Level

Post CMP Die Defect Map



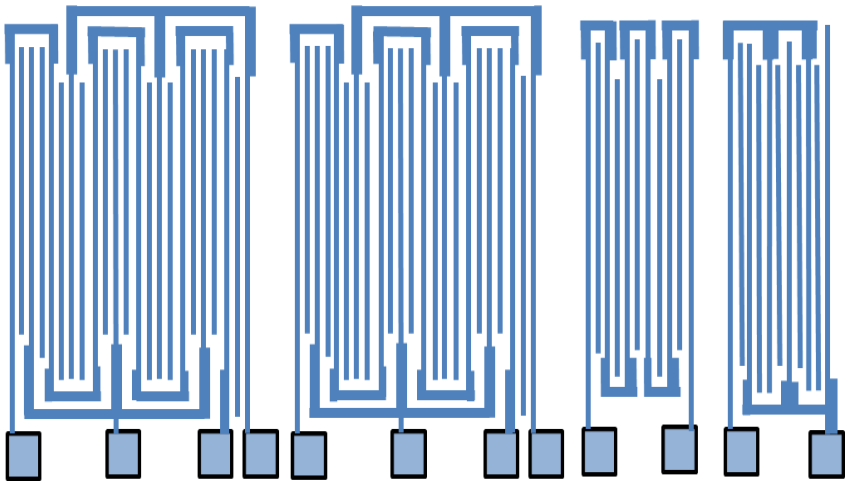
Post CMP: Total Defects Per Wafer



Structures for Resistance and Leakage Tests

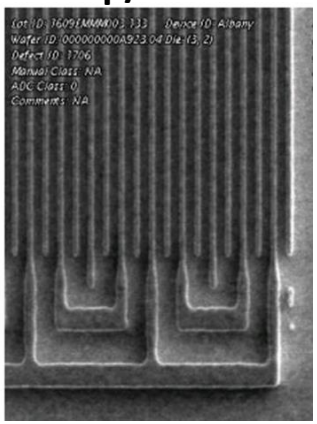
- E-testable structures at gate level for leakage characterization
  - Range of line CD, pitch and area for opens/shorts detection
  - Allows for electrical and optical defect data correlation

Serp/Comb Macro Design

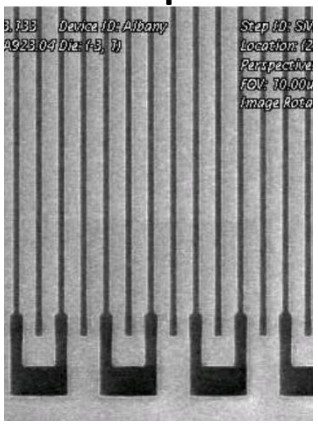


Post Gate RIE SEM

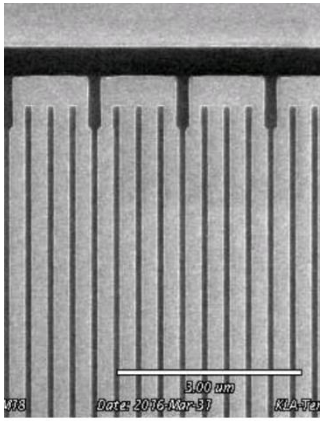
Serp/Comb



Serp



Comb



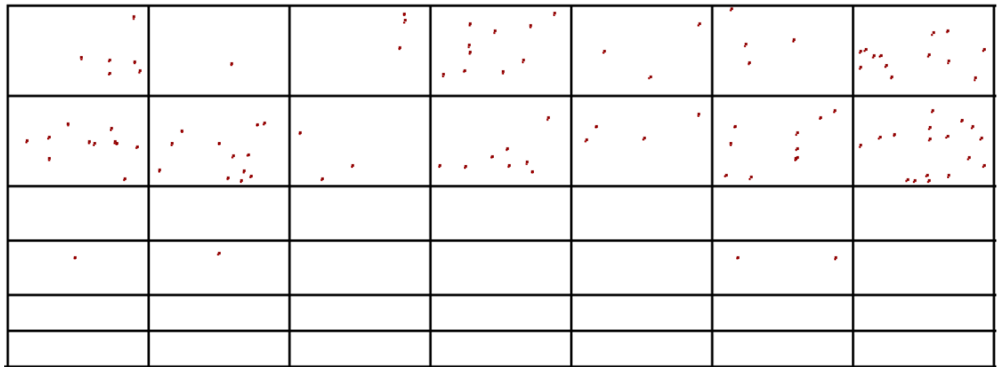
Sensitivity for Electrical to Defect Correlation

- Gate level structures designed for defect inspection and electrical testing
  - Low nuisance defects to enable high sensitivity to post-CMP defect studies

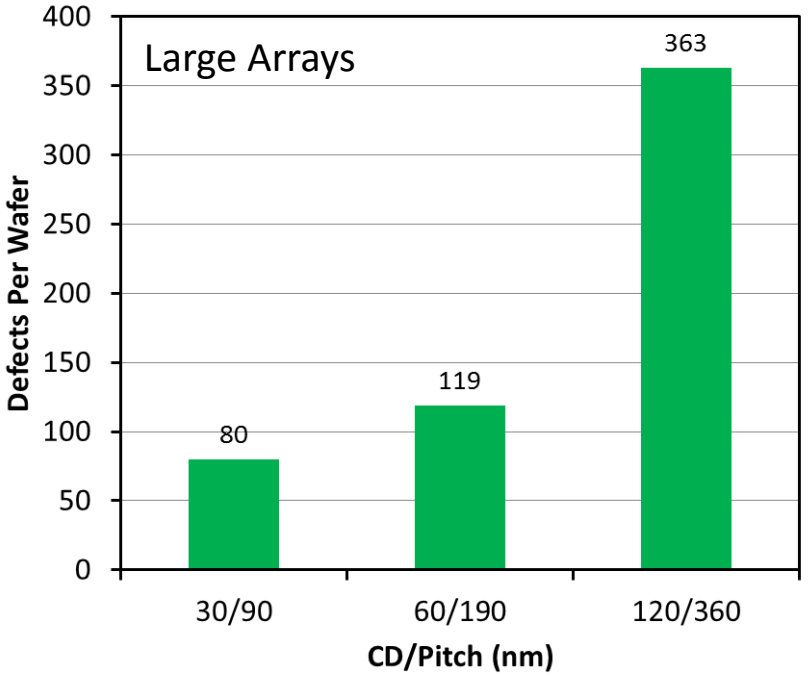
Serp/Comb CD and Pitch

30/90 120/360	30/90 120/360	30/90 30/90	60/190 30/90	60/190 60/190	60/190 120/360	120/360 120/360
30/90 120/360	30/90 120/360	30/90 30/90	60/190 30/90	60/190 60/190	60/190 120/360	120/360 120/360
30/90 120/360	30/90 120/360	30/90 30/90	60/190 30/90	60/190 60/190	60/190 120/360	120/360 120/360

Post RIE Die Defect Map



Post RIE: Total Defects Per Wafer



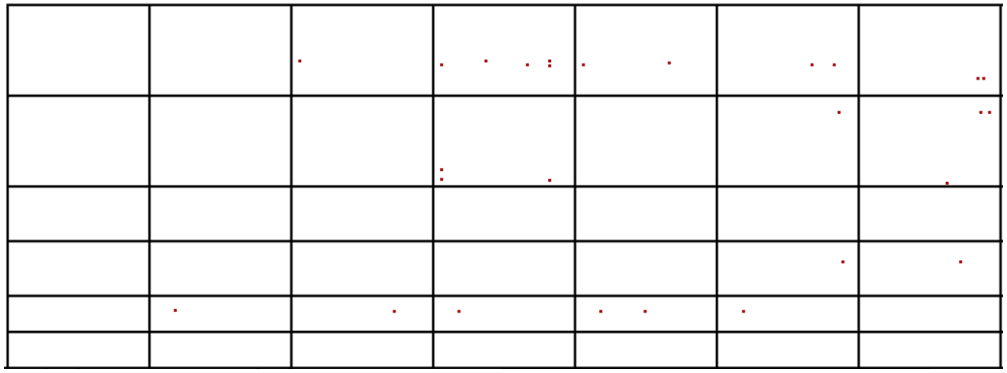
Sensitivity for Electrical to Defect Correlation

- Optical defect inspection shows good sensitivity to post CMP defects
  - Allows for slurry/cleaner evaluations with good signal to noise ratio
  - Further enhancements to sensitivity in progress

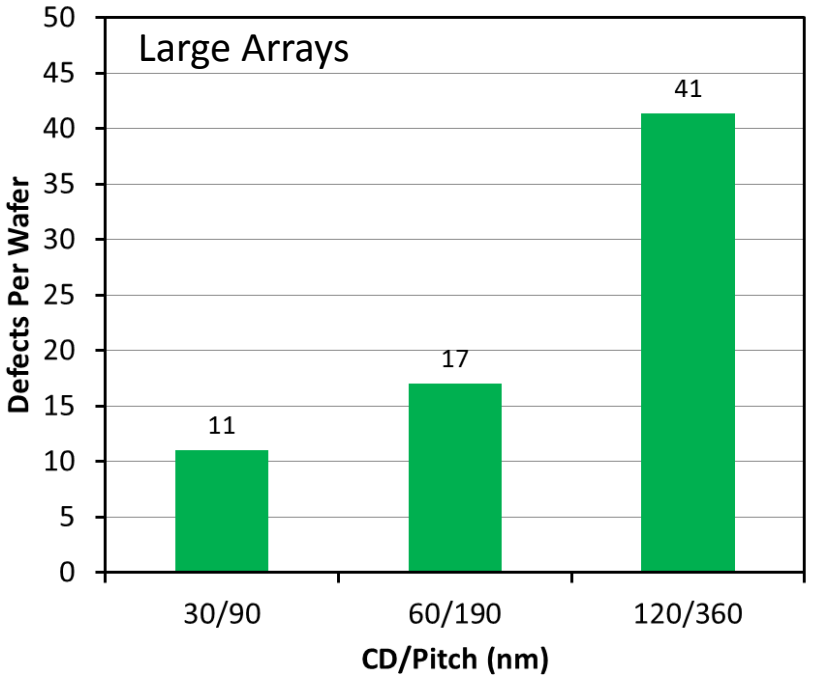
Serp/Comb CD and Pitch

30/90 120/360	30/90 120/360	30/90 30/90	60/190 30/90	60/190 60/190	60/190 120/360	120/360 120/360
30/90 120/360	30/90 120/360	30/90 30/90	60/190 30/90	60/190 60/190	60/190 120/360	120/360 120/360
30/90 120/360	30/90 120/360	30/90 30/90	60/190 30/90	60/190 60/190	60/190 120/360	120/360 120/360

Post CMP Die Defect Map



Post CMP: Total Defects Per Wafer



ADK14 BEOL - 14 nm Test Vehicle

- ADK14 BEOL - CMP oriented multi-level vehicle for CMP process development and reliability studies
  - Enables CMP consumable and process benchmarking, dummy fill sensitivity evaluations, advanced metrology characterization and development
  - Novel e-testable structures for reliability studies (TDDB, VSM) and fundamental film properties characterization
- Currently in design phase

BEOL (13mm×33mm)	CD (nm)	Pitch (nm)
M1 (LELE)	38	64
Via1	38	128
M2 (LELE)	38	64
Via2	38	128
M3/Fatline	1k	1.09k
Al Cap Layer	1k	1.09k

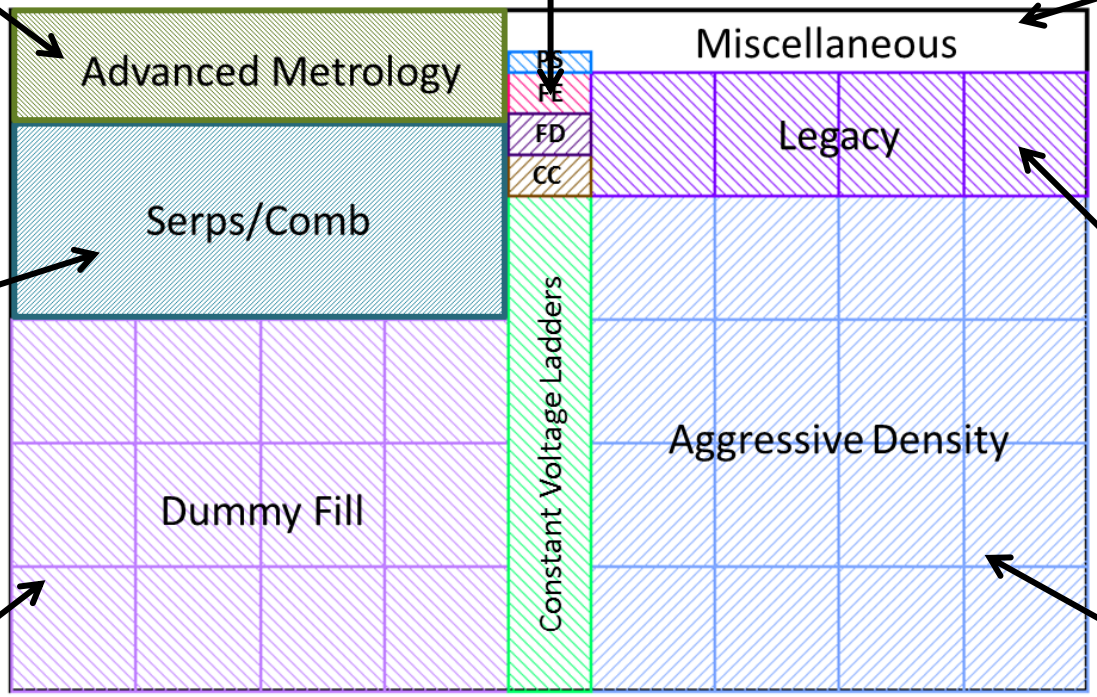
ADK14 BEOL Layout

Wide range of topographic and e-testable structures

Advanced metrology structures for state of the art metrology

Advanced reliability and material characterization structures for e-testing

Miscellaneous test structures



Serp/Comb structures for TDBB and opens/shorts defectivity e-testing

Range of large CD and pitch features for learning transfer from legacy mask

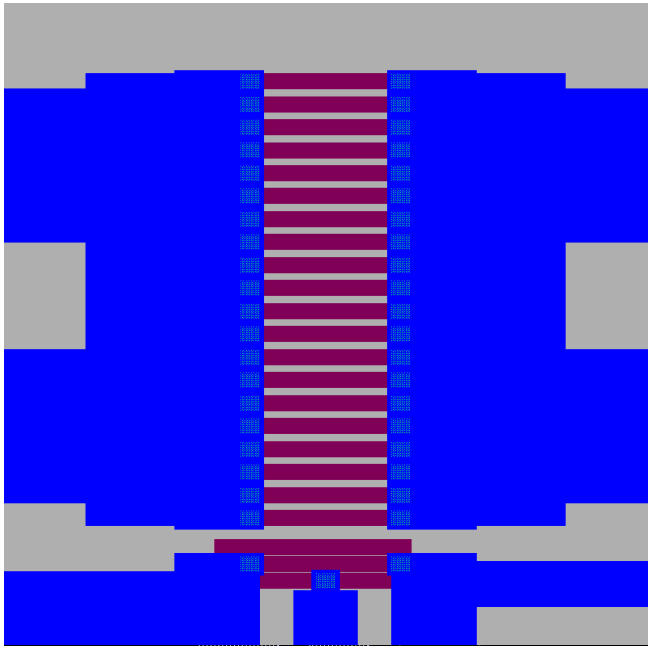
Range of small and large CMP features surrounded by dummy fill for testing effects of DF type and exclusions

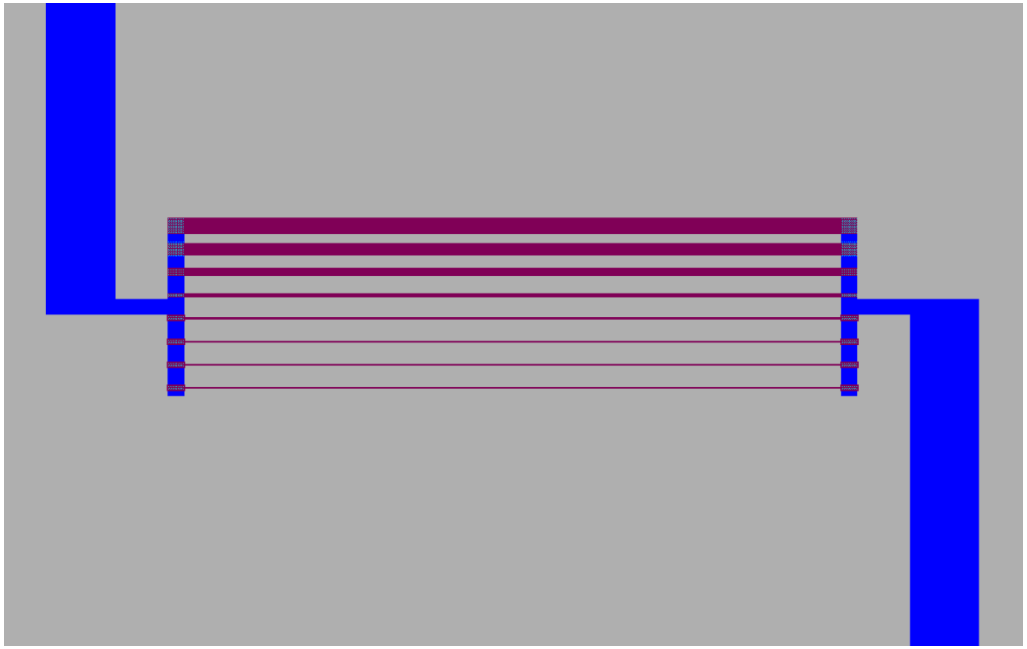
Range of aggressive, industry relevant CD and pitch features for CMP evaluation

Reliability testing capable learning vehicle

ADK14 BEOL Reliability Test Structures

Constant Voltage and Constant Current Electromigration Test Structures





Structures with different line CD and line length to test reliability and failure mechanisms at metal levels

Wide range of e-testable (serp/comb) and topographic structures with CD from 38nm to 500nm and varying pattern density

Summary

- CMP-oriented, IP-neutral, state-of-the-art 14nm test vehicles for FEOL and BEOL process characterization
- Variety of topographic and e-testable structures for post-CMP testing across wide range of CD and pitch, open/shorts detection and reliability studies (BEOL)
- Supported by robust baseline process flows with focus on defectivity
- Health-of-the-line (HOL) will be maintained, monitored, and recorded by SPC
- SUNY Poly offers access to industry standard CMP tools, defect analysis, materials and processes with well-characterized baselines