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NCCAVS CMP USERS GROUP

Nanoabrasive-based Slurries for Next Generation CMP Applications

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Overview

- Introduction
- Nanoabrasive slurries benefits
  - Surface damage
  - Surface roughness
- Nanoabrasive slurries challenges
  - Dishing
  - Cleaning
  - Particle detection

Introduction

- What CMP proc dev eng needs from slurry:
  - Large CMP process margins (appropriate selectivity, removal rates, planarity control, endpoint capability) and low defects

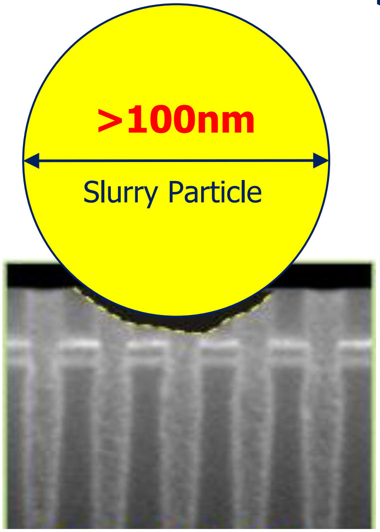
- Defect reduction strategies:
  1. Tightening particle size distribution, cutting tail, LPC reduction
  2. Chemistry formulation to prevent particle agglomeration, deposition / re-deposition to wafer surface
  3. Moving toward chemical polishing rather than mechanical, abrasive content reduction
  4. Decreasing particle size

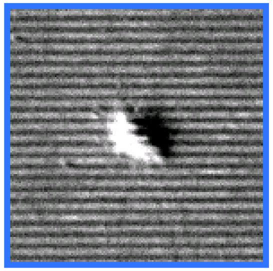
Introduction

- Abrasives Investigated
  - Calcinated ceria, size > 100nm
  - Nanoceria, size < 30nm

- Experimental Techniques
  - CMP: AMAT LK Reflexion 300mm, process conditions: 2-4 psi, 100–150 rpm, 150-300ml slurry flowrate
  - Slurry analysis: Horiba LA-950V2, Malvern Zeatsizer Nano-Zs, AccuSizer 780A
  - Surface analysis: AFM - topographic scans Bruker Nano FastScan Atomic Force Microscope in the tapping mode. The scans measured 2 µm X 2 µm areas. Large area scans (60 µm X 60 µm) were conducted using a ICON-CL tool in tapping mode.
  - Roughness: Rq = $\sqrt{\frac{\Sigma(Z_i)^2}{N}}$ Ra = $\frac{1}{N}\sum_{j=1}^{N}|Z_j|$

Small Abrasive Benefit

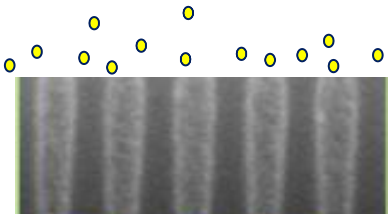


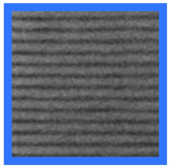


- Abrasive particles larger than STI features are unsuitable to clear dielectric from the array without damaging the structures

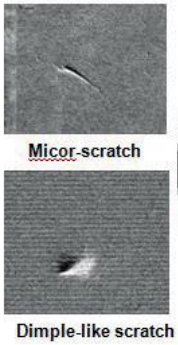
65-90% divot and scratch reduction observed for nanoceria.

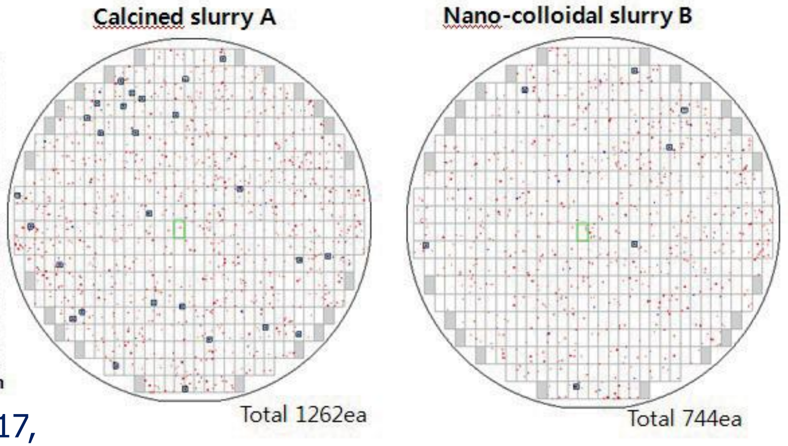
Nanoparticles





- Drastic particle size reduction is needed, no damage observed with nonabrasive based slurries





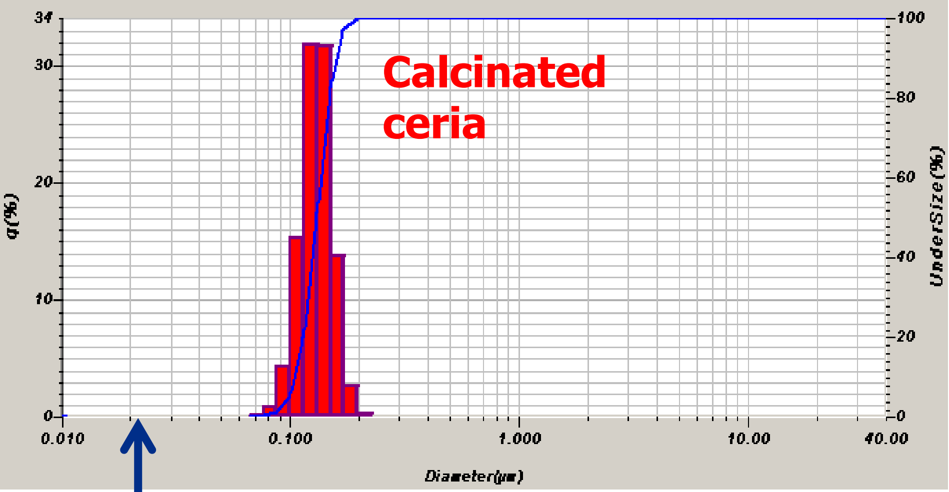
Hyun-Goo Kang et al. ICPT 2012, October, 15-17, 2012, Grenoble, France

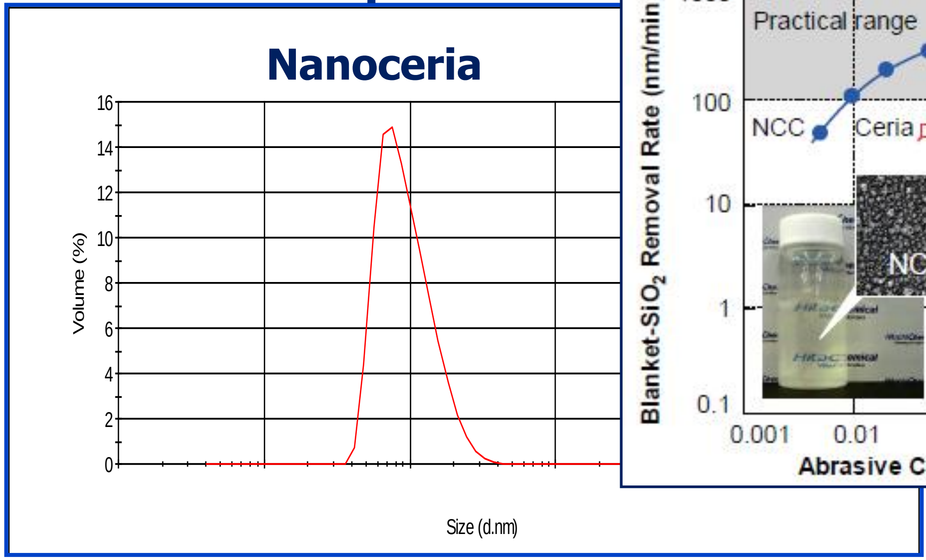
Literature reports similar observations:

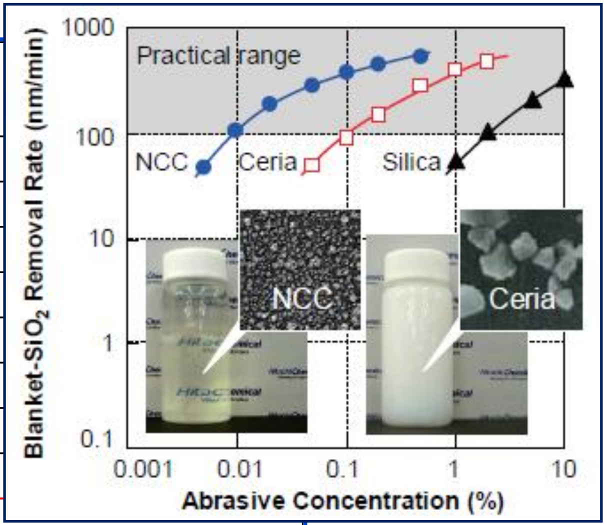
	reviewed defect [100ea]		Total Defect	
	Micro-scratch [ea]	Dimple-like scratch [ea]	Micro-scratch [ea]	Dimple-like scratch [ea]
Calcined slurry A	2	10	25 (2%)	129 (10%)
Nano-colloidal Slurry B	0	3	0	24 (3%)

Particle Size Distribution & LPC Benefit

	Calcinated	Nanoceria
% Solids (wt%)	1.27	0.572
LPC		
Cum Particles / ml >=1.15um	**539233**	**6515**
Cum Particles / ml >=2.01um	**33964**	**1947**





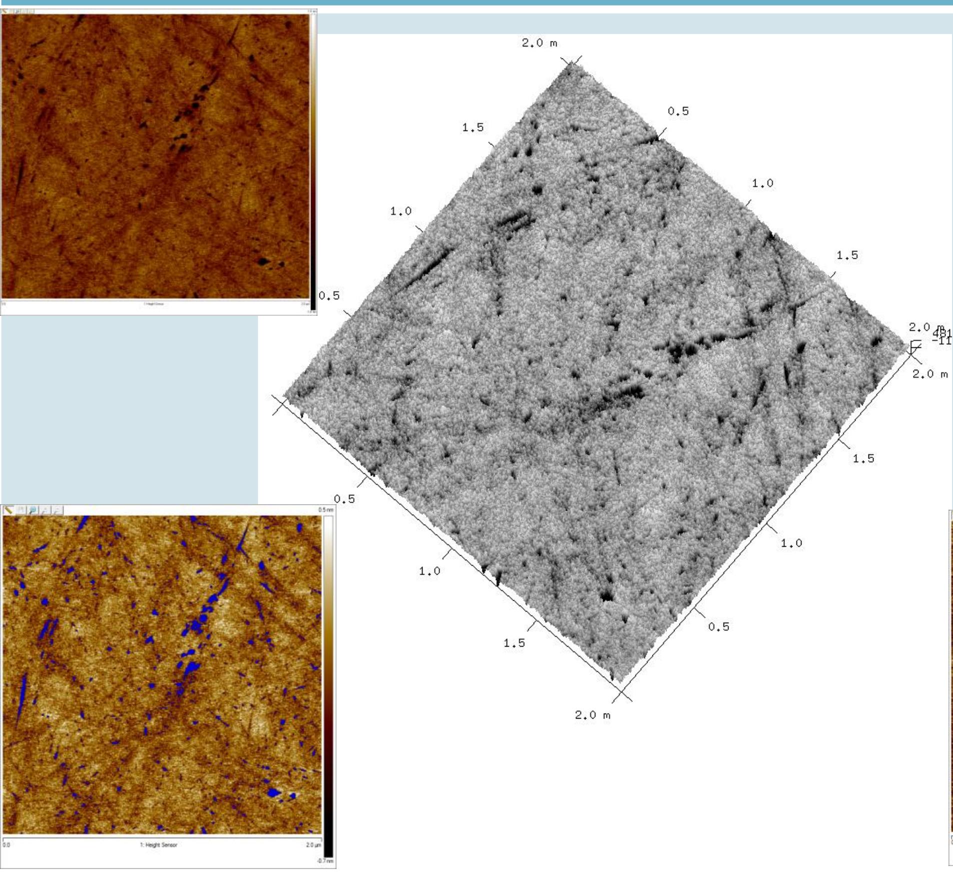


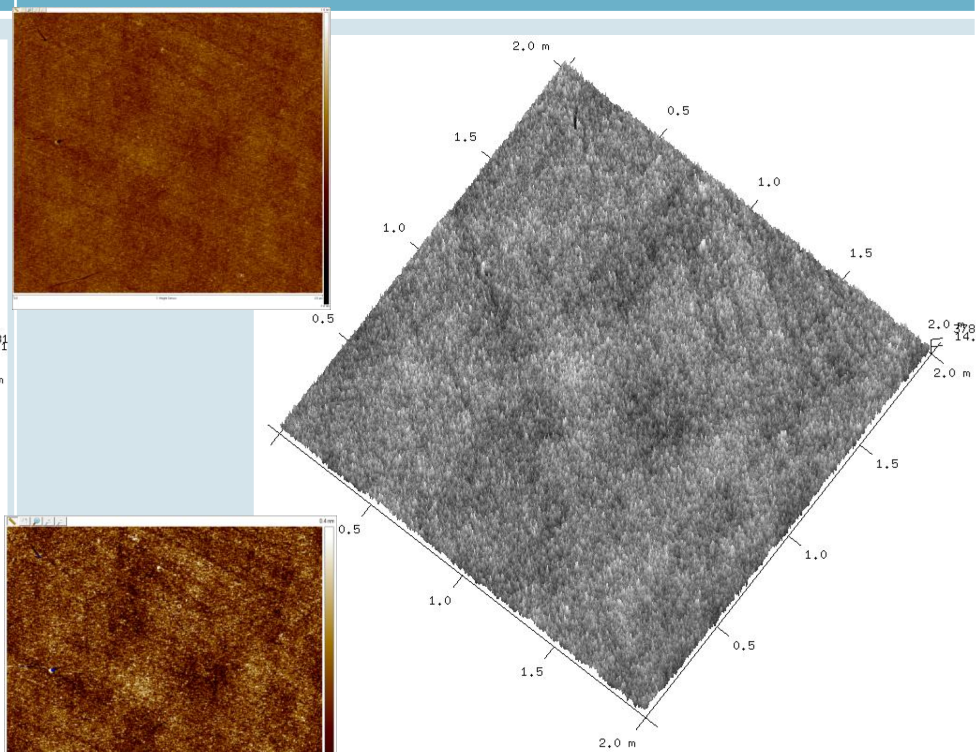
- Moving size distribution toward smaller abrasive particles directly correlates with CMP scratches reduction
- One to two orders of magnitude in LPC reduction
- Abrasive load reduction

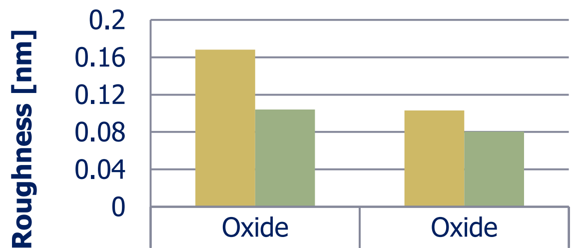
2009 Symposium on VLSI Technology Digest of Technical Papers, 9A-2, p168-169

Oxide Surface

Calcinated ceria - ox	Nanoceria - ox





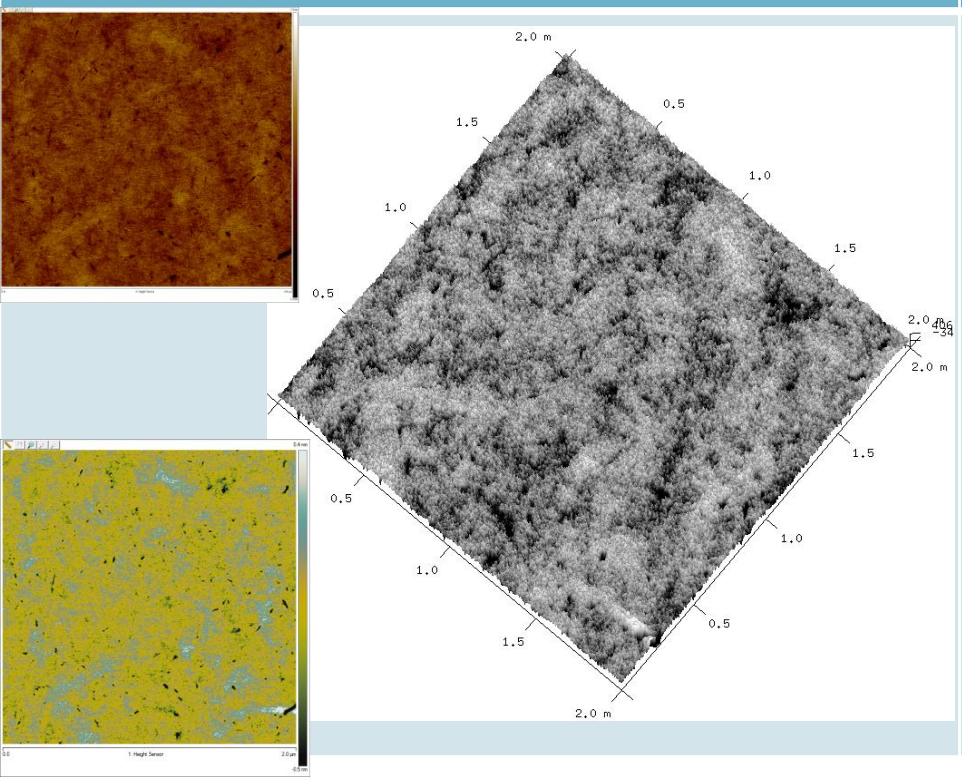


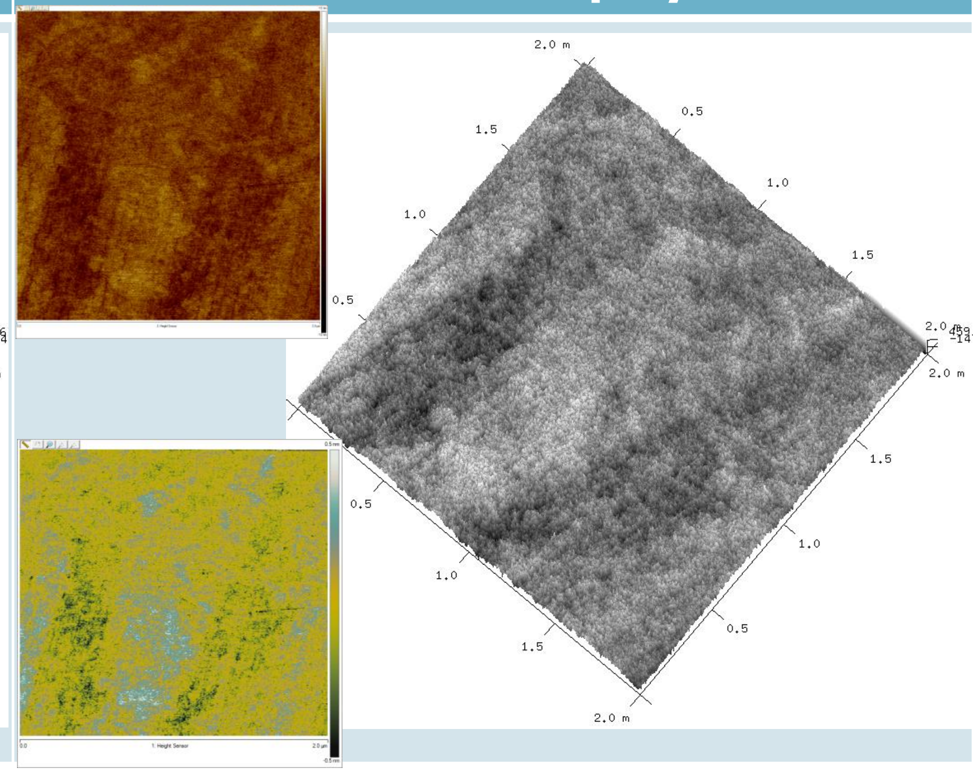
	Oxide Calcinated ceria	Oxide Nanoceria
Rq (nm)	0.168	0.103
Ra (nm)	0.104	0.0805

- Oxide surface damage drastically decreased for nanoceria
- Surface roughness lower for nanoceria

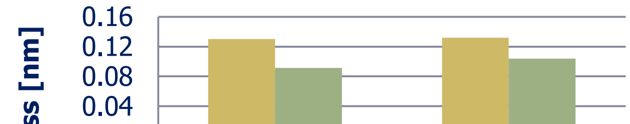
Poly Surface

Calcinated ceria - poly	Nanoceria - poly





- Similarly to oxide surface, less high impact damage observed on poly surface for nanoceria
- Poly surface roughness comparable between calcinated and nanoceria

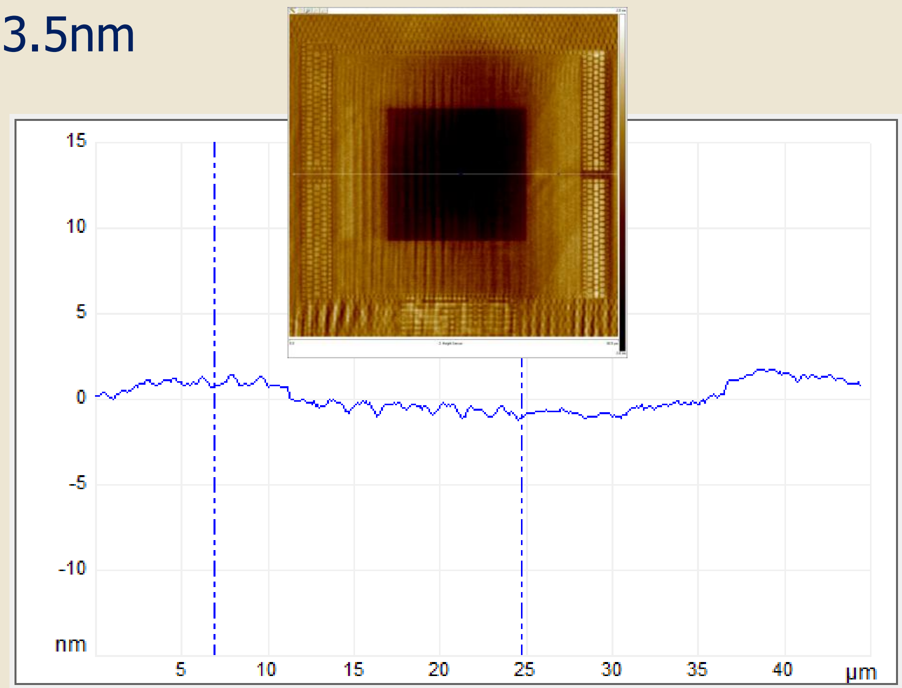


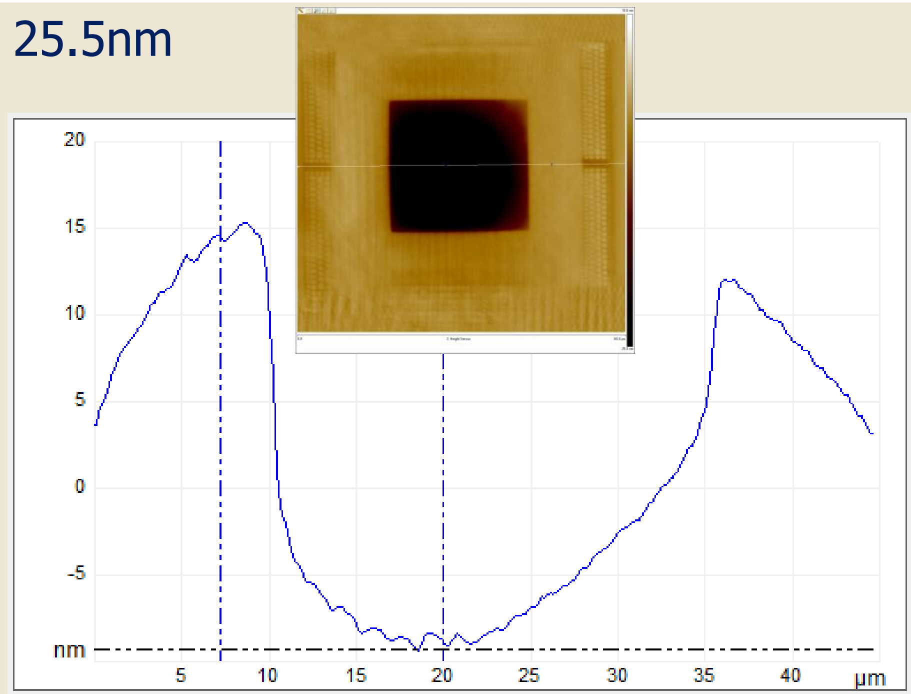
	Poly Calcinated ceria	Poly Nanoceria
Rq (nm)	0.13	0.132
Ra (nm)	0.0916	0.104

Challenges

Dishing

Calcinated ceria	Nanoceria
3.5nm	25.5nm





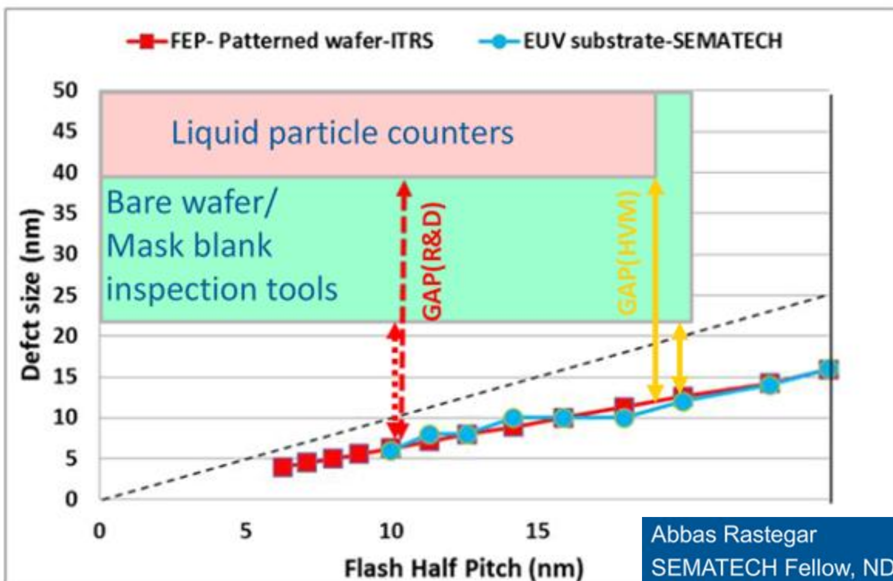
- Dishing is much lower with calcinated ceria. Erosion is greater.
- Nearly order of magnitude difference in dishing between calcinated ceria and nanoceria
- Need additive development with nanoabrasive CMP for “improved planarity”
- Need Good SON/SOP capability (high selectivity)

Cleaning

International Technology Roadmap (2011 edition)

Ref.: http://www.itrs.net

Year of Production		2011	2012	2013	2014	2015	2016	2017
MPU Physical gate length	(nm)	24	22	20	18	17	15	14
Front Surface Critical Particle Size	**(nm)**	**18**	**16**	**14**	**13**	**11**	**10**	**9**
Front Side Critical Particle Count	(#/wafer)	13	13	13	13	13	13	13
Critical GOI Surface Metal	(E10 atoms/cm2)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Other Critical Surface Metals	(E10 atoms/cm2)	1	1	1	1	1	1	1
Max. Silicon and oxide Loss/clean	(Å)	0.1	0.1	0.1	0.1	0.1	0.1	0.1



- Critical particle size that needs cleaning drastically drops
- It is possible that efficient nanoparticle cleaning might be even more urgent than what is predicted in ITRS Roadmap

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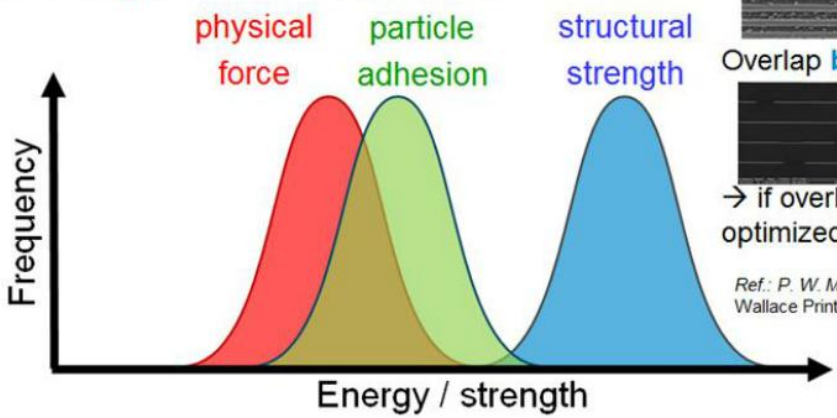
SEMATECH
SST Webcast, May 2013

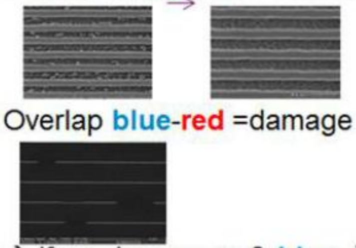
Cleaning

Mechanical cleaning force: force process window



Overlap **red-green** = cleaning

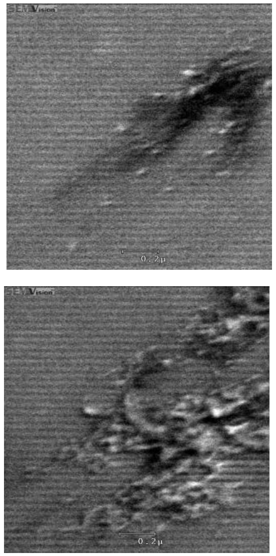
Overlap **blue-red** =damage



→ if overlap **green** & **blue** → non optimized process

Ref.: P. W. Mertens et al., proceeds IEEE VLSI-TSA, 2006; Wallace Printz, Ihsan Simms, Antoine Pacco, SPCC 2013

Frank Holsteyns et. al. , Surface Cleaning and Preparation, SST, May 16, 2013

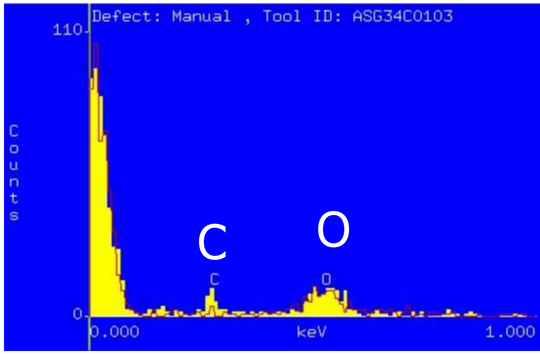


Physical forces:
1. Drag force
2. Water hammer pressure
3. Capillary forces
4. Shock waves,...

Particle adhesion:
1. Van der Waals interaction
2. Electrostatic interaction
3. Solvation forces
4. Aging effects,....

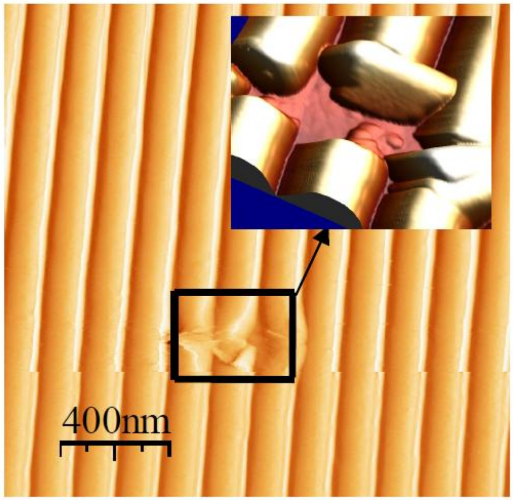
Structural strength:
1. Geometry
2. Interfaces
3. Bulk material properties
4. Surface energy,...

→ Chemical Mechanical cleaning: limited process window shown for patterned substrate cleaning [A.Pacco et al., Electrochem. Solid-State Lett. 2011 14(9):H380-H384]

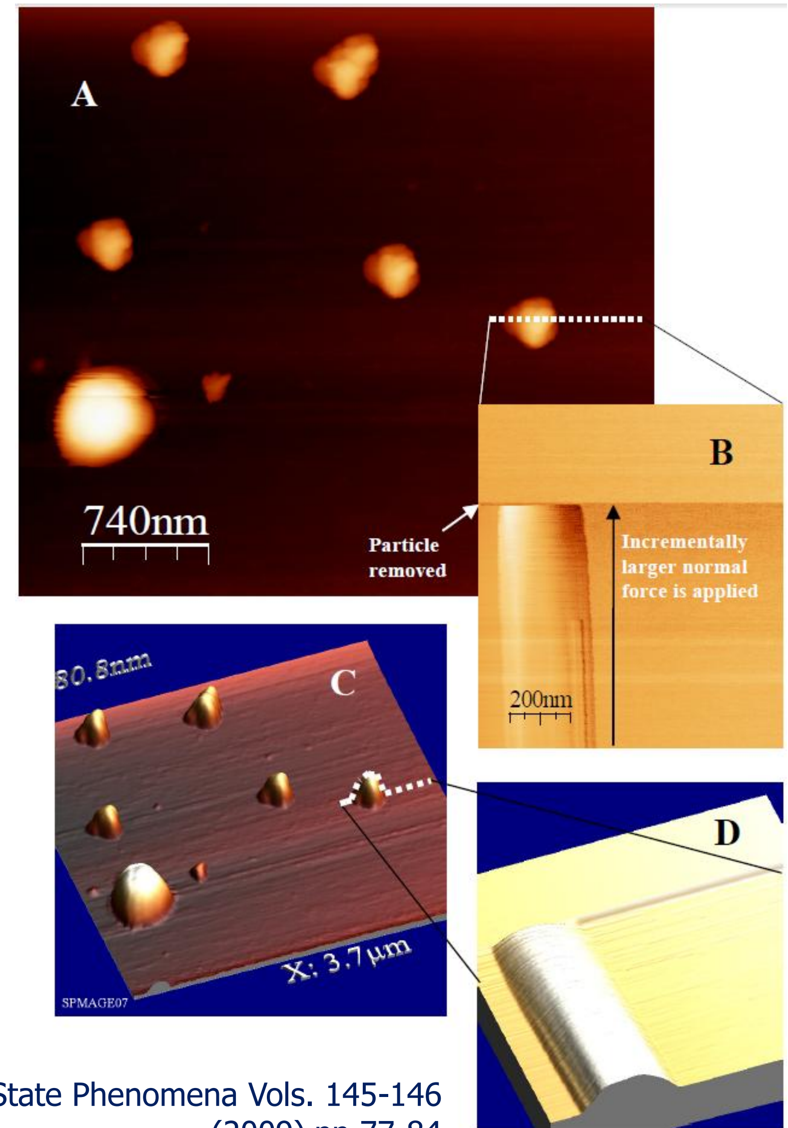


Traditional post CMP cleaning methods are unsuitable for very small particles.

Structural Strength vs. Adhesion



Damage of the spacer oxide structures by the AFM applied lateral force.

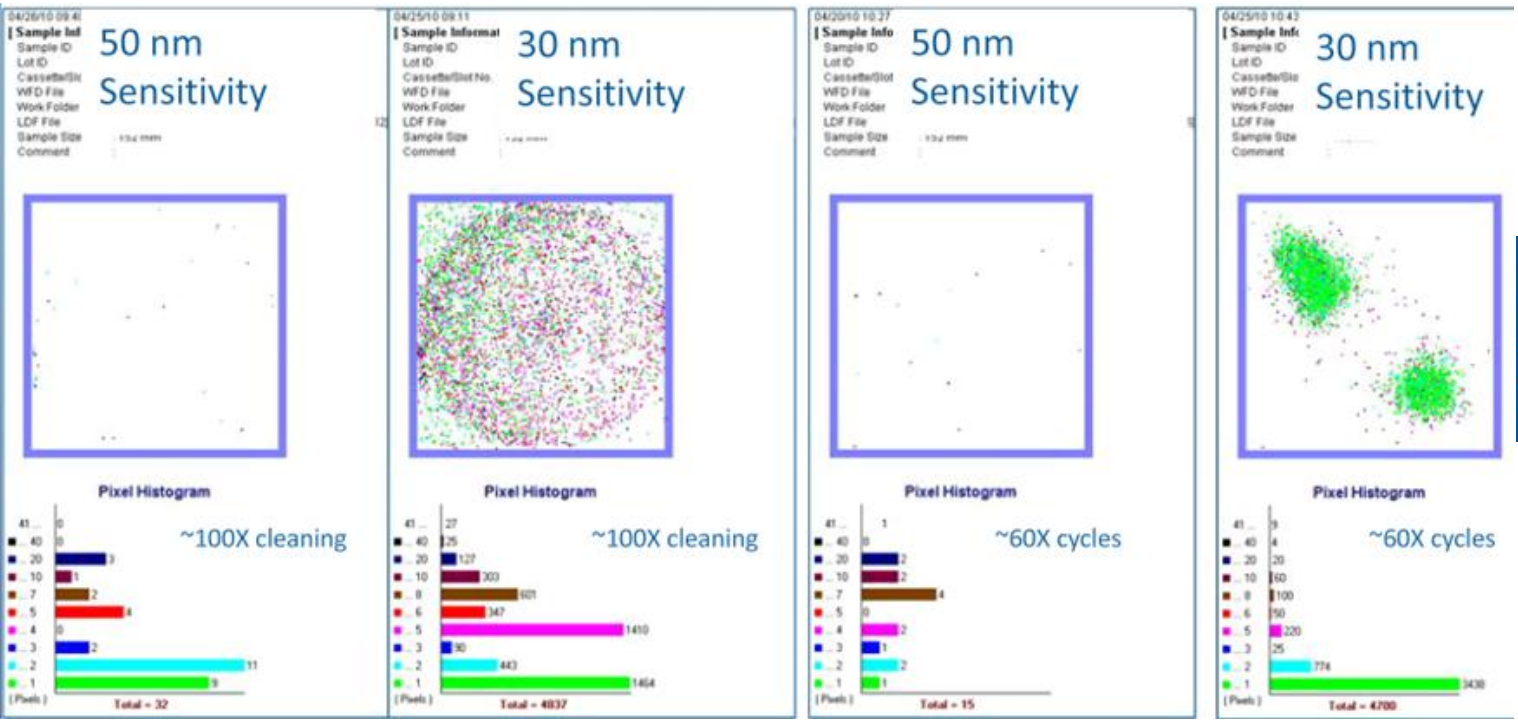


- In the case of 90nm structures the damaging force is ~10x higher than the force required to remove 250nm silica particles.
- The case might be different when dealing with smaller features

Measurement of the lateral force required to slide/roll a contaminant particle. A – spherical silica particles on a wafer surface (topography), B – the indicated particle is scanned repeatedly with increasing normal force until the particle is displaced from its location on the wafer (marked as particle removed), C – 3D image of the 250 nm particles, D - 3D topography image of B

Solid State Phenomena Vols. 145-146 (2009) pp 77-84

Detection



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- Hardly any defects are visible under 50nm sensitivity, this is not the case when recipe is optimized for 30nm sensitivity. Better nanoparticle detection is needed below 30nm size.
- AFM and other probe based techniques are good for academic and research level nanoparticles study
- High throughput , high sensitivity inspection tools are desired for process control

Conclusions

- Abrasive particle size reduction is a great way to reduce post CMP surface damage and defectivity.
- Nanoparticle based slurry formulations need dishing improvement
- Critical particle size that requires cleaning drastically drops, but the adhesion force increases and structural feature strength decreases. Re-design of post CMP cleans might be necessary.
- Manufacturing worthy high sensitivity inspection tools are critical for nanoparticles based CMP technology advancement.

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