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AVS CMP User Group Meeting

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4/16/15

"Advances in Ceria Slurries to Address Challenges in Fabricating Next Generation Devices"

Outline

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- Introduction to Ferro
- Historical Products
- Rate Accelerants
- Fast Oxide CMP Slurry
- Path to Next Generations of STI and Fast Oxide Slurries

We are a leading, global producer of performance materials and chemicals

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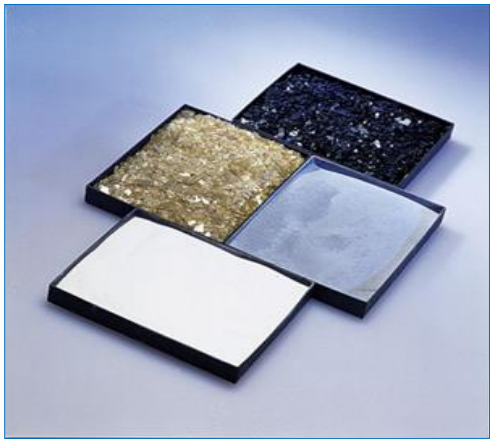
- Ferro was founded in 1919 in Cleveland, Ohio. Porcelain enamel was the Company's original business and it remains an important product line today.
- We are a leading, global producer of performance materials and chemicals sold to manufacturers worldwide.
- Our customers represent more than 30 industries and span 100-plus countries.
- We have manufacturing facilities in The Americas, Europe/North Africa and Asia-Pacific.
- Approximately 4,600 employees work at sites in 26 countries.
- Ferro is publicly-owned; our shares trade on New York Stock Exchange under the symbol FOE.

Ferro's Core Technologies

- Particle Engineering
- Color and Glass Science
- Surface Chemistry and Surface Application
- Formulation



Penn Yan Site

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- ✓ Located on 63 Acres
- ✓ Lake Frontage of 1100 feet
- ✓ 320,000 Ft^2 Under Roof
- ✓ Global R&D Center: Dielectrics and Surface Technologies
- ✓ Customer Service Center for:
  - Cleveland, OH
  - Vista, California
  - Penn Yan, NY

Penn Yan Products

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- **Manufacturer of ceramic powders and slurries**

Dielectrics

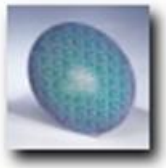
- **High purity engineered powders and formulations for the multi-layer ceramic capacitor (MLCC) industry**

Surface Finishing Material

- **Zirconia, Ceria and Alumina based powder and slurry formulations for the LCD glass, glass ceramic hard disk, flat glass, cover glass, precision glass, sapphire, plastic lens, metals and automotive polishing applications**

CMP

- **Ceria based powders and formulations used in semiconductor applications**



Ferro's Historical Ceria STI Slurrys

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	Dmean (nm)	D0 (nm)	LPC's > 0.5 um	% Ceria	HDP Removal Rate (A/min.)	Nitride Removal Rate (A/min)
1st Gen STI Slurry	145	450	500,000	4	2000	<20 A/min.
2nd Gen STI Slurry	145	450	400,000	4	2700	<20 A/min.

New Device Requirements

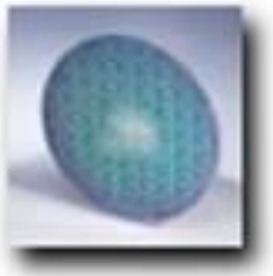
- As devices get more complex, the demands (in addition to the basic planarity requirement), on the CMP slurries that enable their construction increase:

  Defects

  - Continuous push for reduction in defects
  - LPC control has been demonstrated to be key

  Rate

  - More complex designs require:
    - An increase in removal rate due to the number/thickness of layers requiring polishing
    - The ability to polish multiple wafer/layer types with the same slurry



How do we get there?

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- Fundamental understanding is key!

Ceria Polishing Mechanism: Surface Chemical Action

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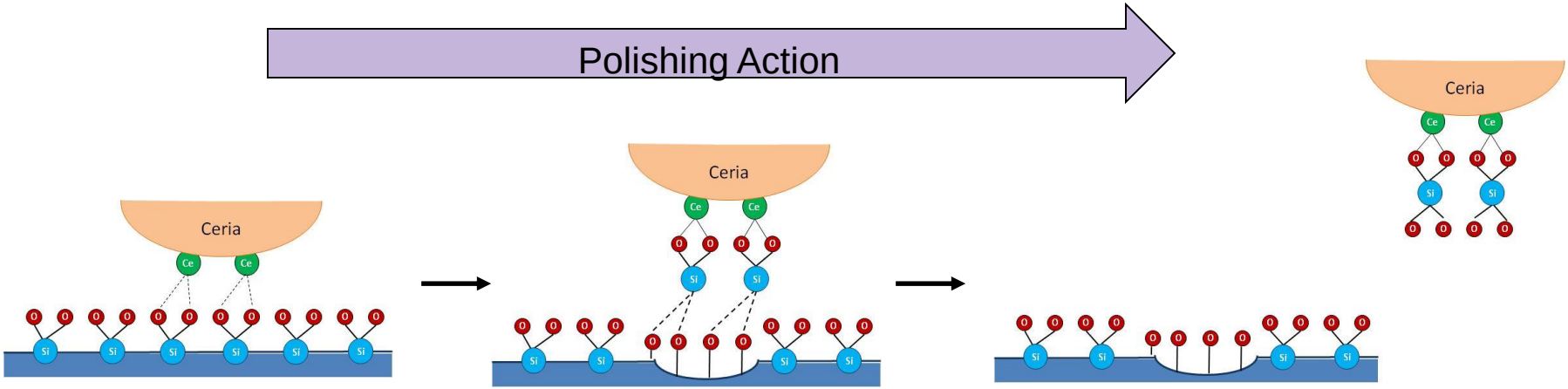
- As opposed to other abrasive types (ie. Silica, alumina, zirconia, etc.), ceria abrasives have a large surface chemical action during glass polishing



- Lee Cook, Journal of Non-Crystalline Solids 120 (1990), p. 152-171

- By control of the ceria particle characteristics and the surface active chemical components in a formulation, ceria systems can be highly tunable in terms of oxide removal rates

Ceria Polishing Mechanism: Surface Oxidation State

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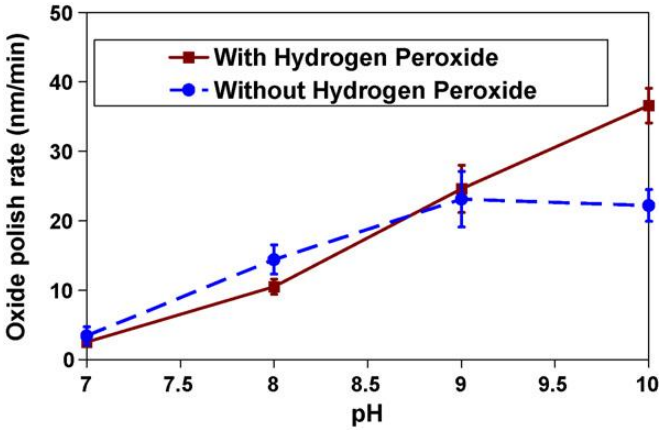
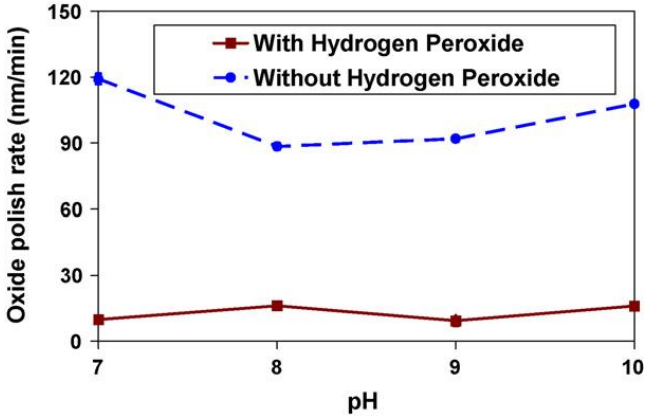


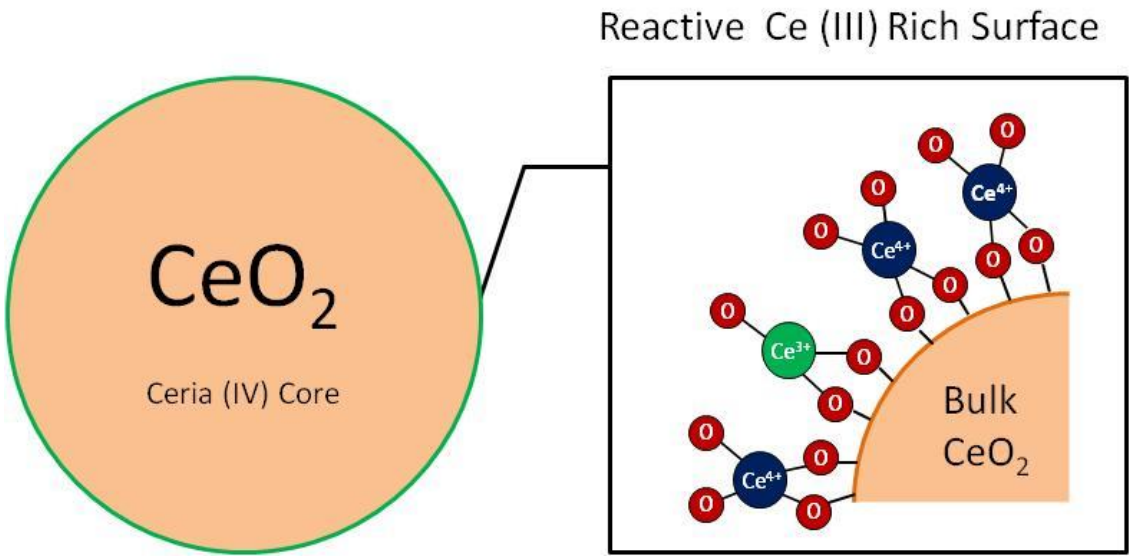
Silica abrasive



Ceria abrasive

- H_2O_2 can shut down oxide removal rates using ceria slurries (more Ce^{4+} on the surface shuts down oxide removal rates)
  - Effect not seen with other abrasives (silica, zirconia, alumina, titania)
    - R. Manivannan, S. Ramanathan, Applied Surface Science 255 (2009), 3764-3768.
- Further studies have shown that Ce^{3+} sites on the surface of ceria particles is critical for the silicon dioxide removal rate
    - Veera Dandu (Clarkson thesis, also presented at 17th Annual International Symposium on Chemical Mechanical Planarization, August 12th-15th, 2012, Lake Placid, NY)

Cerium Surface Oxidation State



- Ferro has developed an additive that stabilizes the Ce^{3+} on the surface of the ceria, leading to a higher population of Ce^{3+} sites and the acceleration of the oxide removal rate
  - Additive is stable in solution (beyond 12 month shelf life)
  - Additive also buffers pH in low regime (pH=3-4)

Novel Rate Accelerant Chemistry

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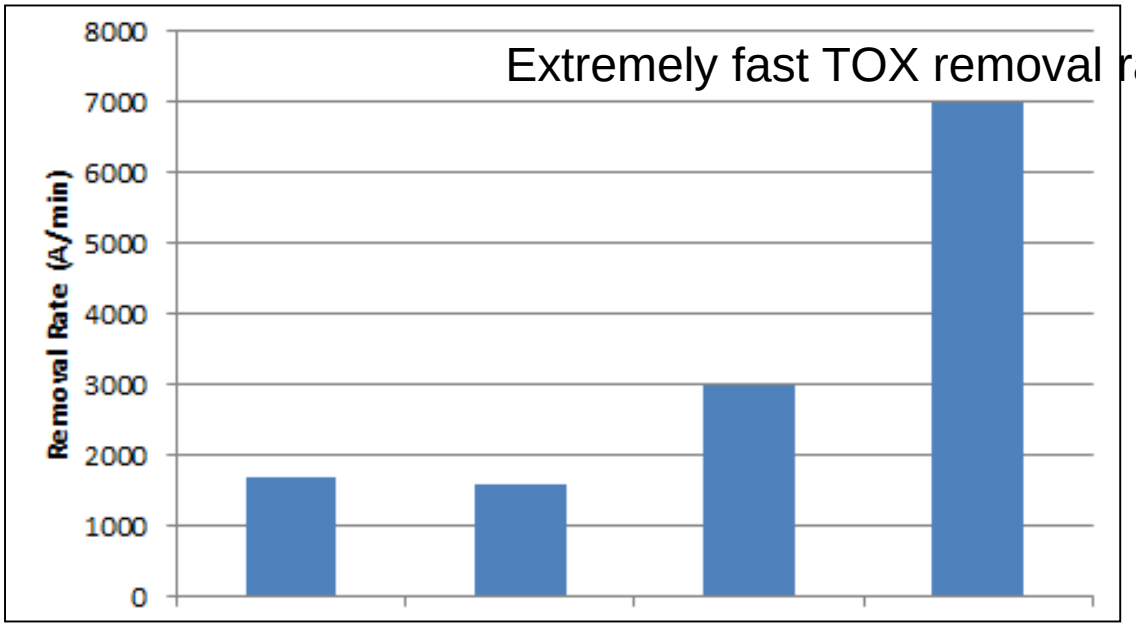

Particle	145 nm ceria	130 nm ceria	130 nm ceria	120 nm ceria
pH	low	low	high	low
Accelerant Package	no	no	no	yes

All systems tested at 3 wt. % ceria

Current HVM Fast Oxide Slurry

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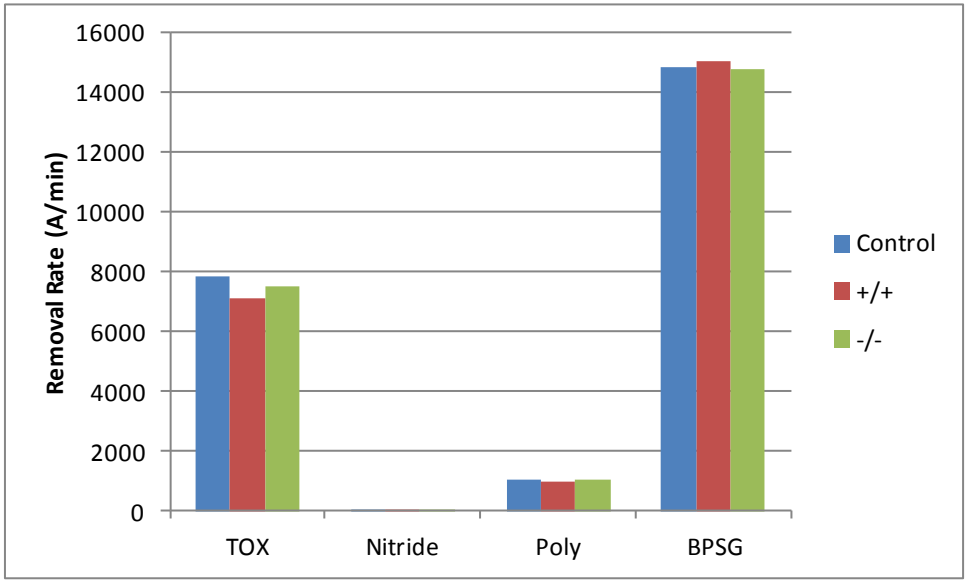

>15,000 Angstroms/minute BPSG removal!

- Fast Oxide Slurry was formulated with extra ceria and accelerant (+/+) and reduced ceria and accelerant (-/-) and compared to standard
- Formulation proven to be robust across formulation space studied

Ferro's Ceria STI Slurry Evolution

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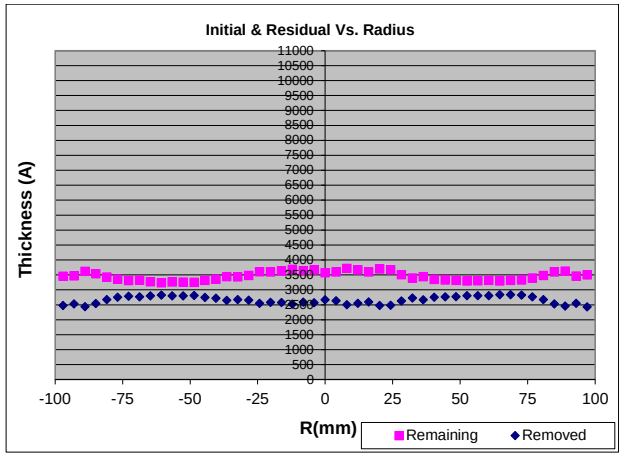
	Dmean (nm)	D0 (nm)	LPC's > 0.5 um	% Ceria	HDP Removal Rate (A/min.)	Nitride Removal Rate (A/min)
1st Gen STI Slurry	145	450	500,000	4	2000	<20 A/min.
2nd Gen STI Slurry	145	450	450,000	4	2700	<20 A/min.
3rd Gen STI Slurry	130	300	<40,000	3	3500	<20 A/min.
4th Gen STI SRS-2092	130	300	<10,000	<0.5	2700	<20 A/min.

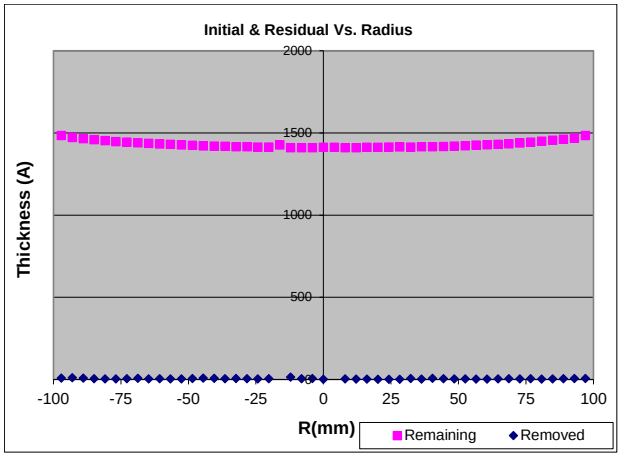
Continuous improvement toward lower ceria loading and lower LPC's for lower wafer level defectivity and lower Fab cost of ownership

SRS-2092: Low Solids STI Slurry

- Ferro has designed its next generation STI slurry
- It is designed to be diluted (typically 1 part slurry : 2 parts water)
  - Lower COO at <0.5% ceria loading
  - Lower Defectivity at smaller particle sizes



HDP
2658 A/min RR



Nitride
4 A/min RR

SRS-2092 Over-Polish Behavior

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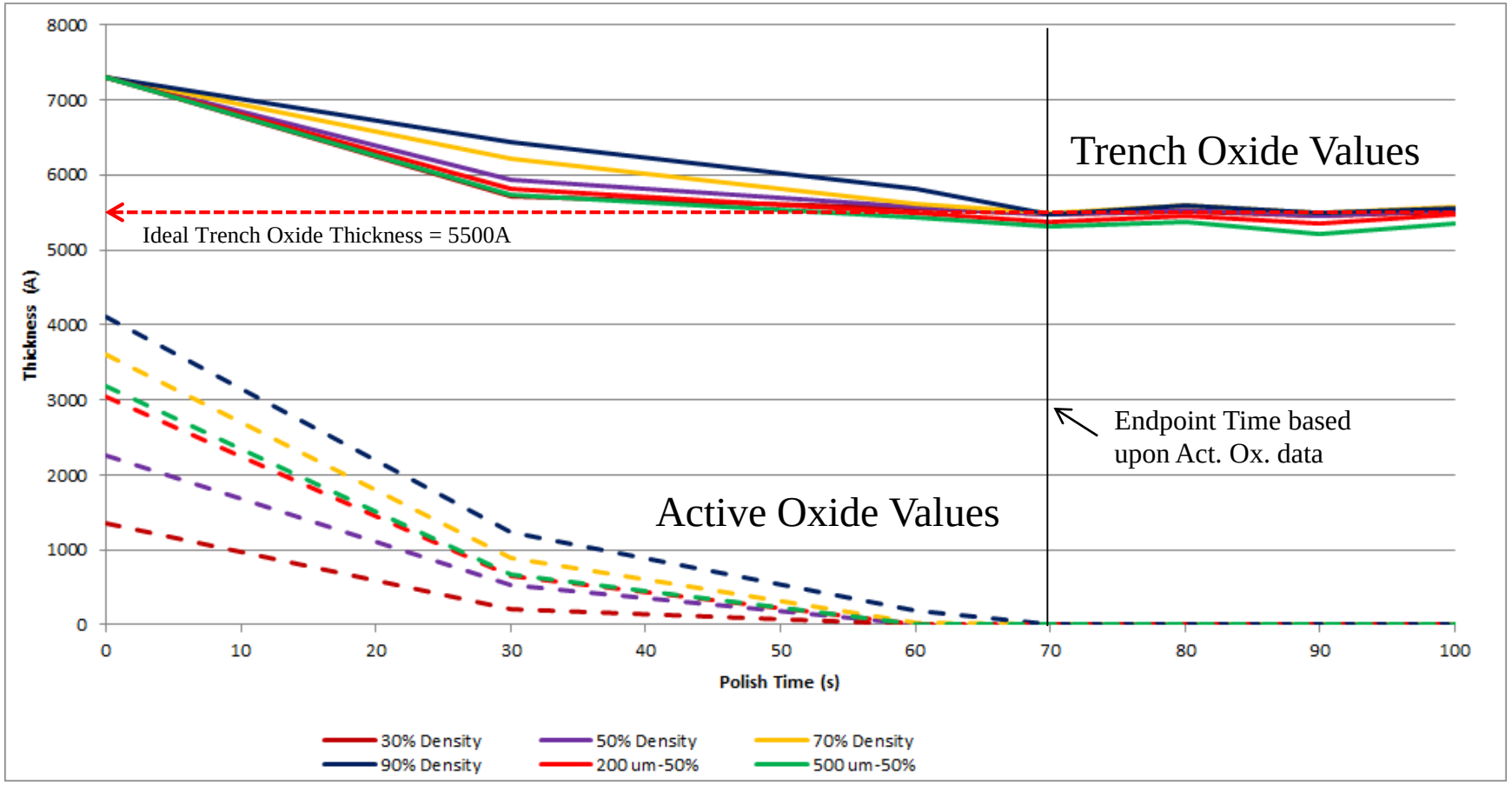

- Extremely long overpolish window with excellent dishing performance!

Where to next?

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- Reduced LPC's/smaller particles to further reduce defects

Next Generation Fast Oxide Slurry

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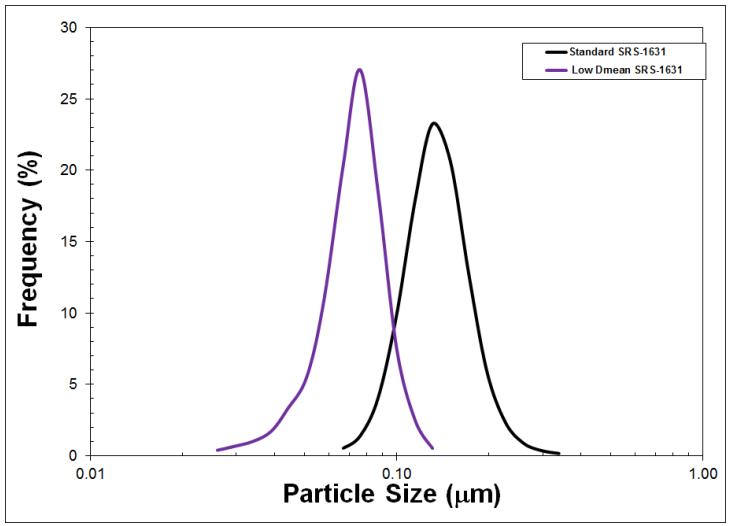
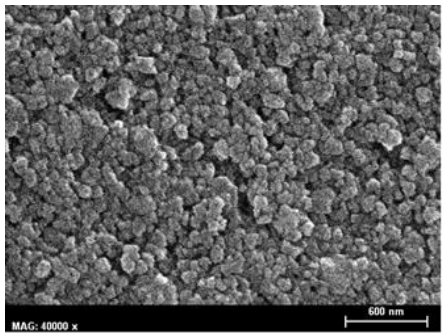
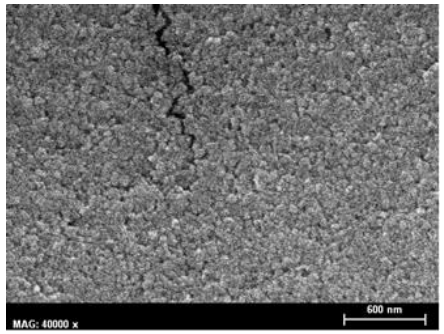




130 nm ceria



70 nm ceria

	Dmean (nm)	D0 (nm)	LPC's > 0.5 um	TOX RR (Ang./min)	TEOS RR (Ang./min.)	BPSG RR (Ang./min.)
Std. Fast Oxide	130	296	100,000	7189	12,250	14,821
Low Dmean	69	131	1,700	6139	11,651	11,352

70 nm ceria with extremely fast removal rates

Low Dmean SRS-2092

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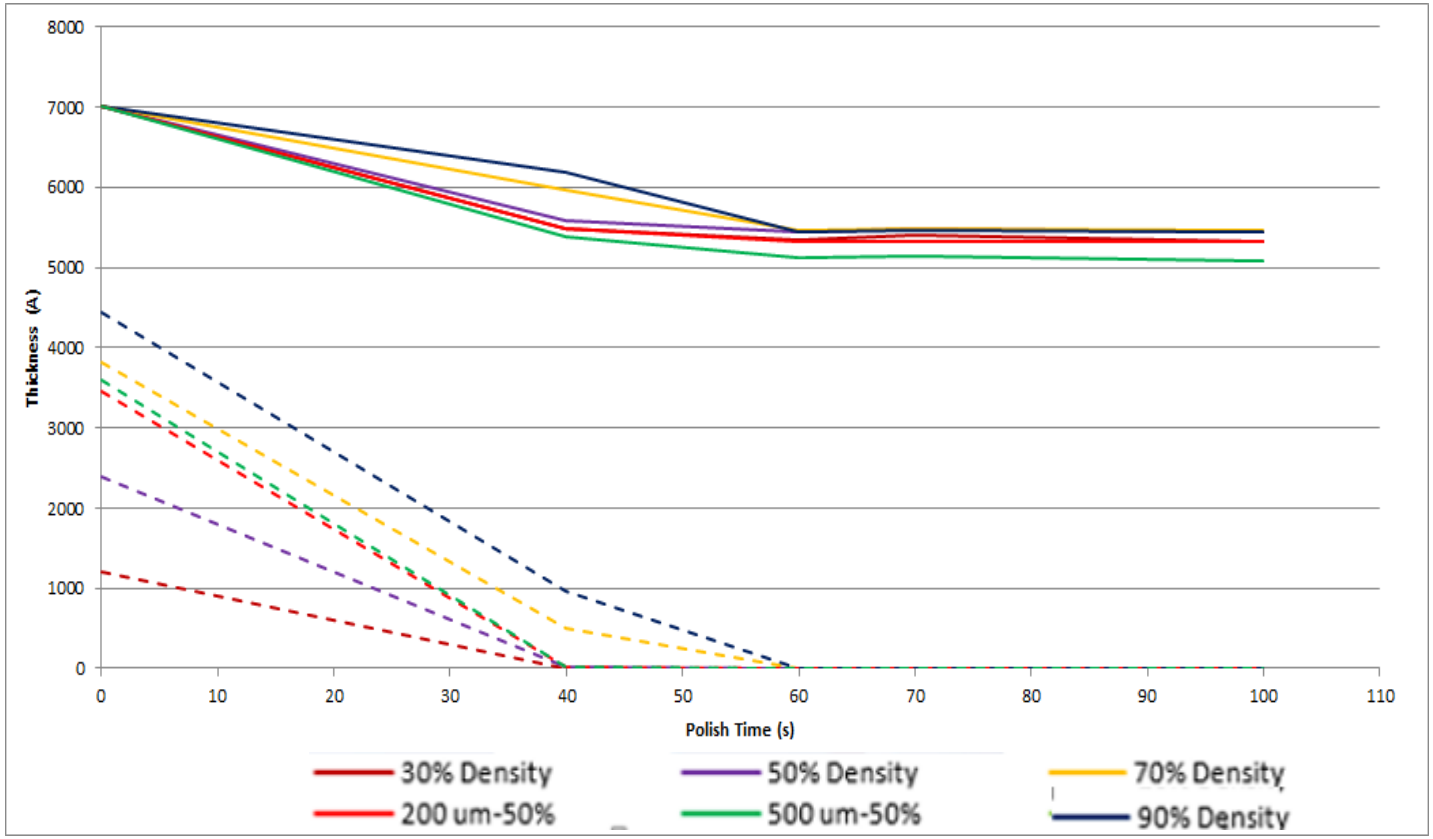
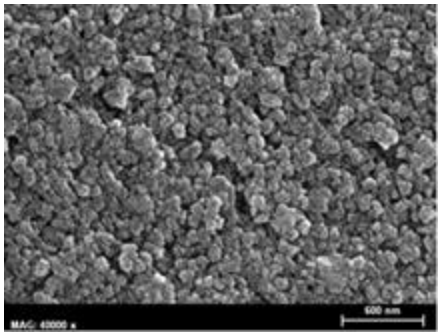
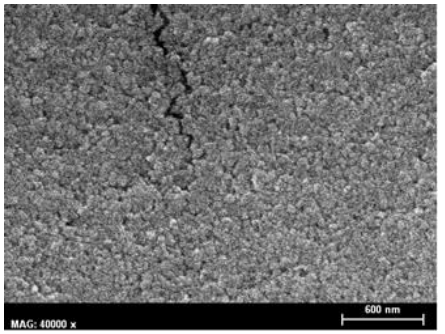
- Ferro has developed a low Dmean version of SRS-2092 that has similar polish behavior at approximately half the particle size





SRS-2092
~ 130 nm



LDM SRS-2092
~ 70 nm

Where to next?

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- Further removal rate improvements
  - How will we get there?

Ferro's Rate Increase Developmental Program

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- Ferro is in the middle of a large rate increase developmental program
- A fundamental 3 path approach is being taken:
  - Alternate Ceria's
  - Alternate Processing
  - Alternate Accelerants

Current State

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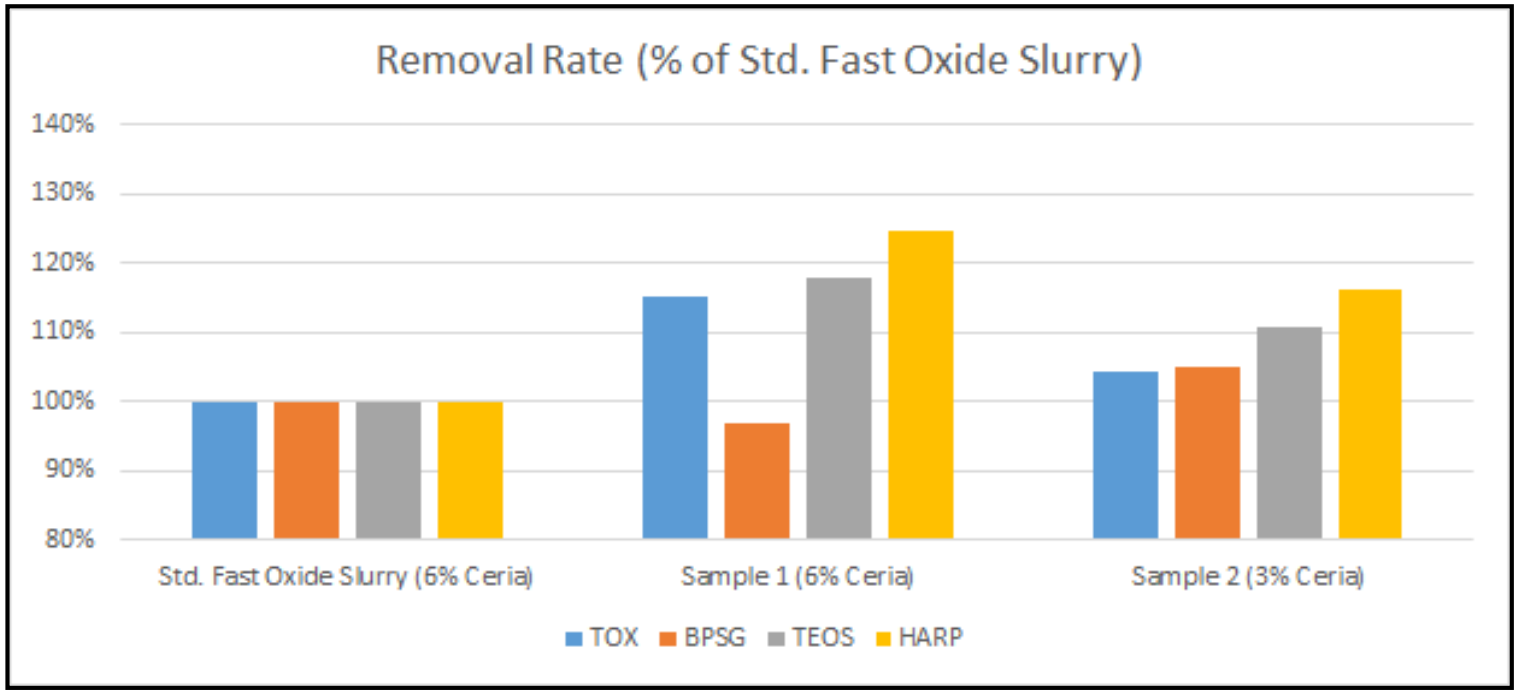
- Based upon 120 nm Dmean
  - With the intent that defects will be reduced compared to Std. Fast Oxide Slurry
  - LPC's are a similar order of magnitude as the sub 70 nm particles
- Combination of alternate processing and alternate accelerants
  - Increase in oxide removal rates with smaller particles (even with a reduction in ceria %)



Path Forward

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- Removal Rate Improvement:
  - Optimize best options to date to achieve greater than 40% increase in removal rate vs. Std. Fast Oxide Slurry with improved defect levels
  - Continue fundamental work to lead to breakthroughs necessary to increase removal rates greater than 80% vs. Std. Fast Oxide Slurry while further improving defect levels
- Defect Improvement:
  - Integrate the learnings above with 70 nm and smaller particles
  - Incorporate the learnings above in next generation STI Slurries to enable the use of 70 nm and smaller particles and further reduce ceria levels

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Acknowledgements

- Bob Her
- Brian Santora
- Nate Urban
- Mohammed Megherhi
- Mike Maxwell
- Dave Walker