TOKYO ELECTRON

Improved Cryogenic Gas Cleaning for Nanoparticle Removal

SPCC 2016

April 19-20, 2016

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Outline

- Nanoparticle Removal Roadmap and Challenges
- Dry Particle Removal Using Cryogenic Aerosol Technology
- Recent Advances in Cryogenic Aerosol Technology for Nanoparticle Removal
- Conclusions

Nanoparticle Removal Roadmap and Challenges

- **ITRS 2015 roadmap critical size = 11 nm in 2016, 7.5 nm in 2020**
- **Consideration of agglomeration and/or fragmentation**
- **Multi-patterning defectivity → quad-patterning = "quad defects"**

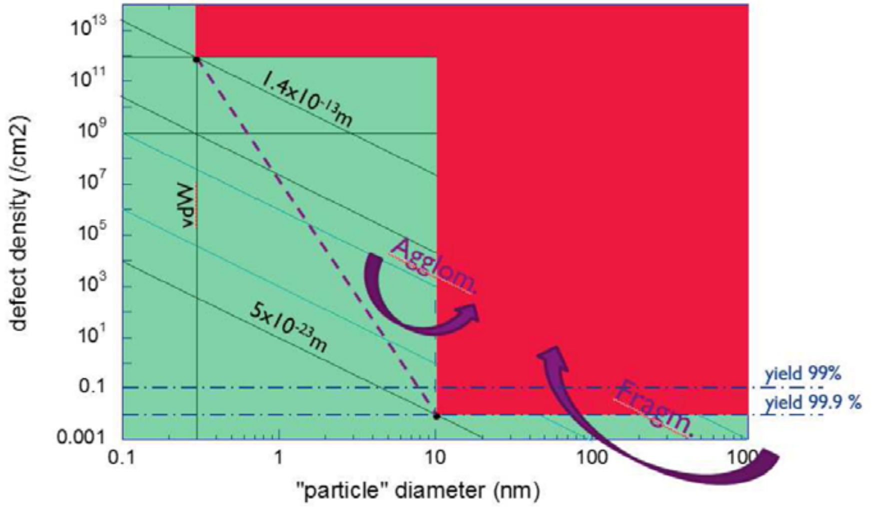


Figure 2: Diagram showing the surface concentration versus diameter of contamination particles. 2 yield lines are added for the case of an active area of 0.1 cm^2. The particle specification is represented by the point (10nm, 0.01 /cm^2). The specification for O and C on the surface is represented by the point (0.3nm, 10^{12}/cm^2). The color red indicates out of specification, while green means within specification. The slanted (power 1/3) lines represent contamination isochores.

P.W. Mertens, Contamination Specifications, an Overall Perspective, In ECS Trans. 69(8), 87-93(2015).

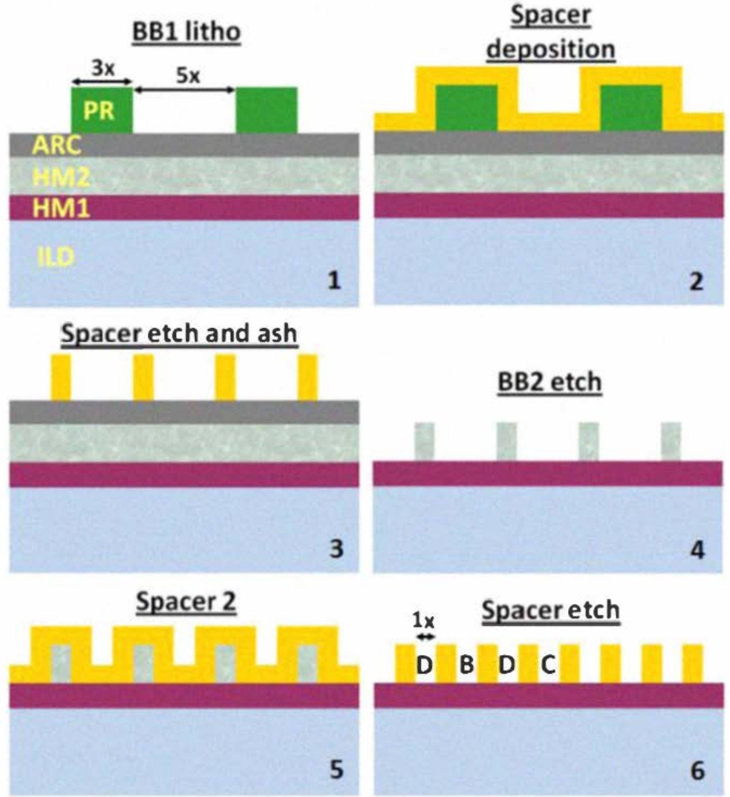


Figure 1: Schematic of a pitch quartering flow using two spacer depositions. The sequential processing steps are labeled 1-6.

M. van Veenhuizen et al., Demonstration of an electrically functional 34nm metal pitch interconnect in ultralow-k ILD using spacer based pitch quartering, in Proc. IITC, 2012, pp. 1–3.

Motivation for Chemical-Free Dry Particle Removal

- No Corrosion / No Material Loss
  – No Photon Induced Copper Redistribution
  – No Copper Corrosion
  – No Galvanic Corrosion
  – No Fin Loss

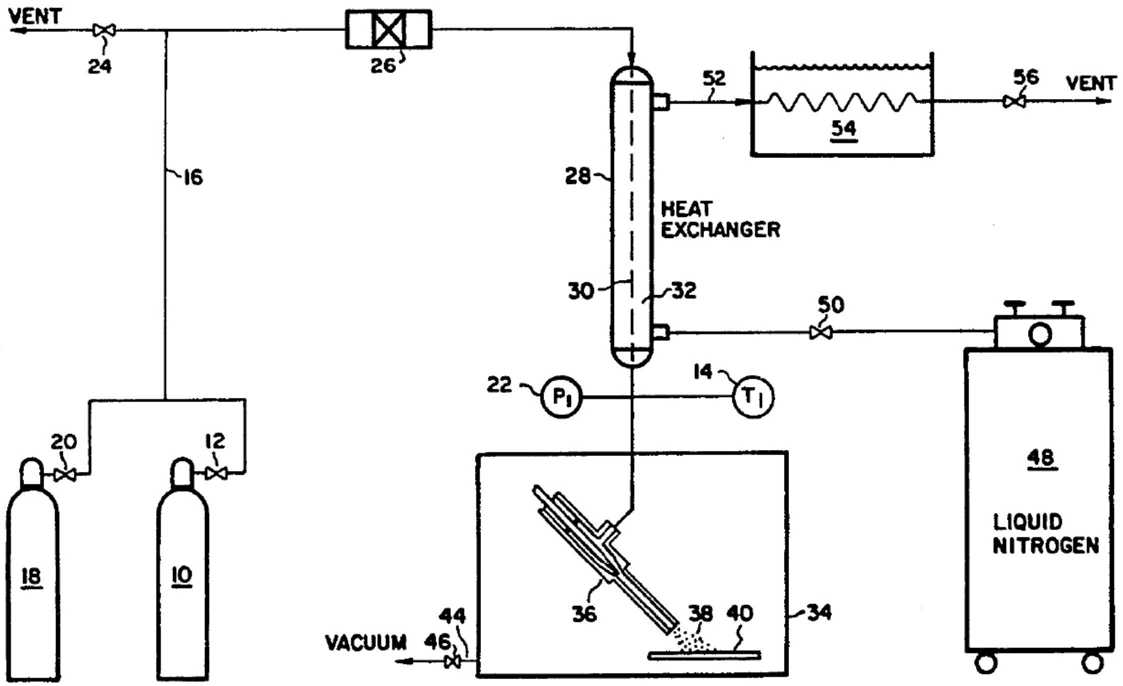
- Effective on Hydrophobic Surfaces

- No Adverse Effects on Low-k Films

- No Wetting Issues for Narrow Features

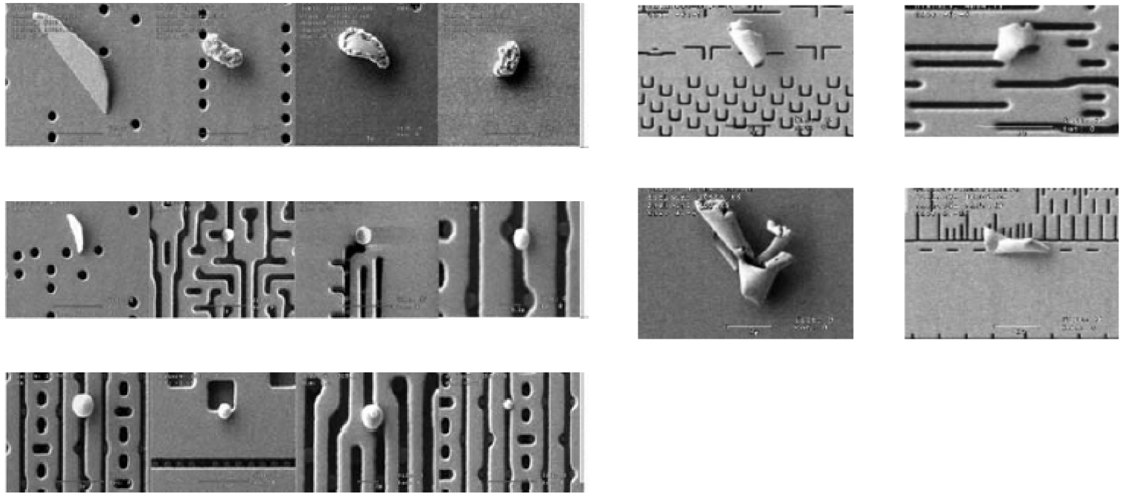
Cryogenic Ar/N_2 Aerosol Cleaning

- Concept developed in 1990



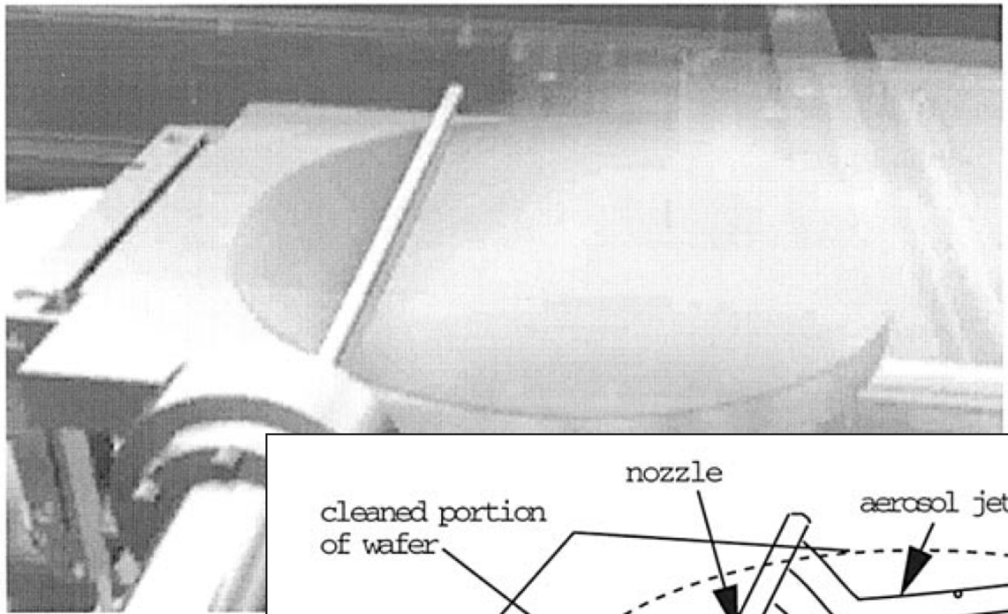
W.T. McDermott et al, US Patent 5,062,898 (1991)

- Applied in IC Manufacturing
  150 nm - 2000 nm size particles removed

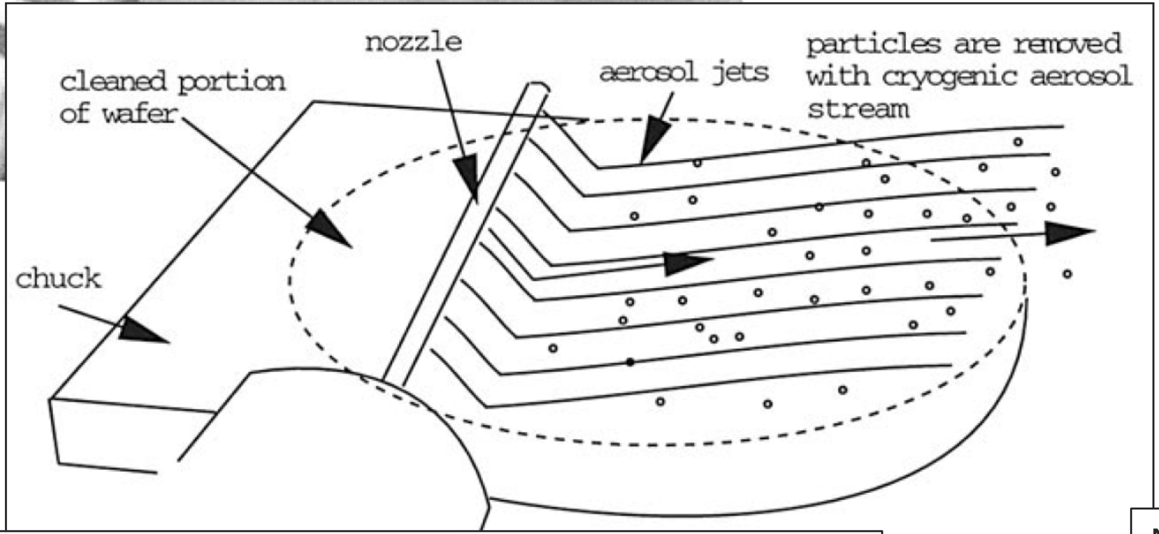


J. Lauerhaas et al., Yield Improvement Using Cryogenic Aerosol for BEOL Defect Removal, in ECS Trans 11(2), 33-39(2007)

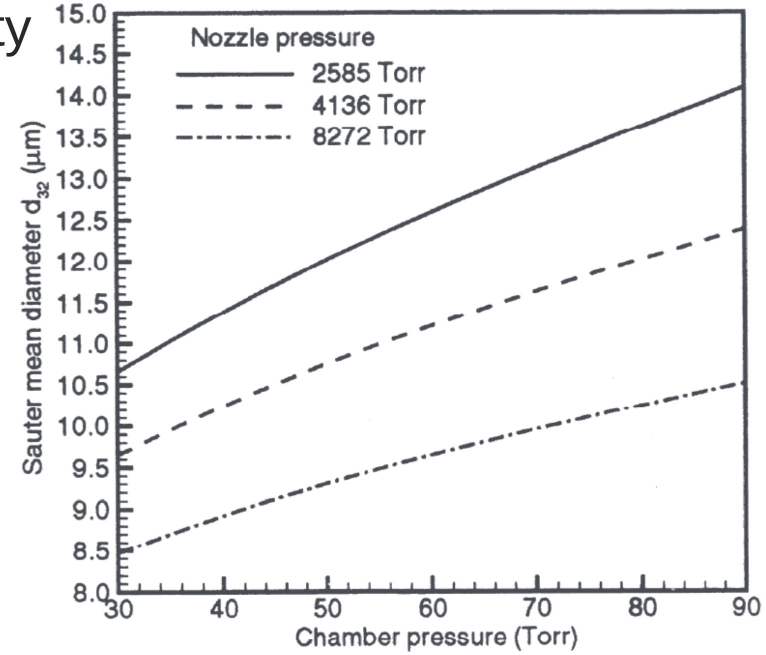
Current Cryogenic Ar/N_2 Aerosol Cleaning Principle



- Partially liquefied gas stream
- Expanded through linear spray nozzle
- Evaporative cooling causes solidification
- ~0.5-10 micron aerosol size
- ~50-100 m/s aerosol velocity

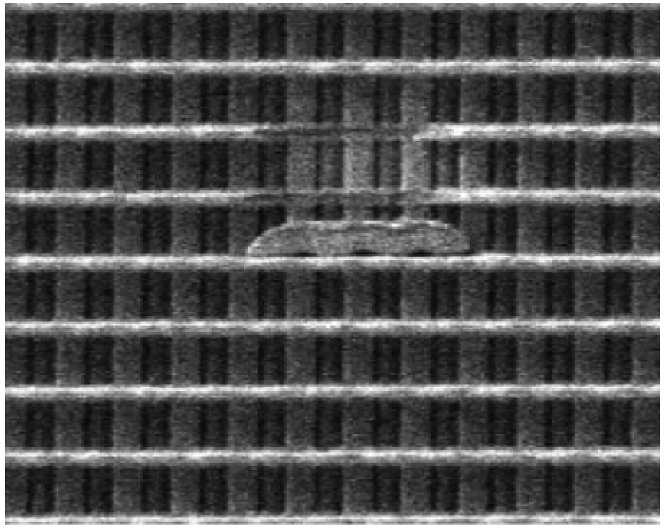


N. Narayanswami, Theoretical Analysis of Wafer Cleaning Using a Cryogenic Aerosol, in J. Electochem. Soc. 146(2), 767(1999)



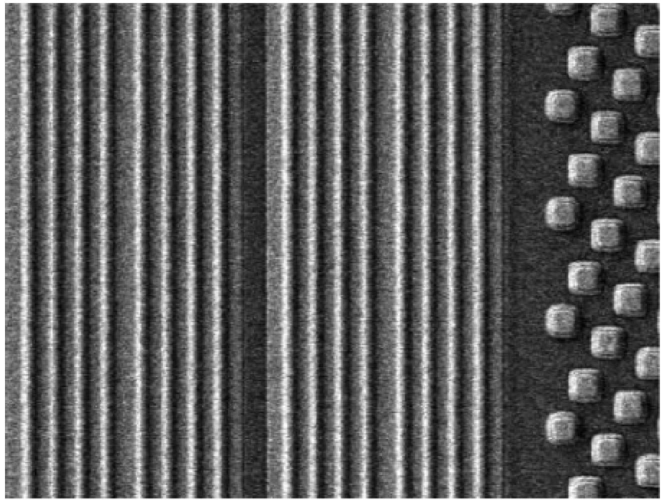
N. Narayanswami et al., Development and Optimization of a Cryogenic Aerosol-Based Wafer Cleaning System, in Particles on Surfaces 5&6: Detection, Adhesion and Removal, 251(1999)

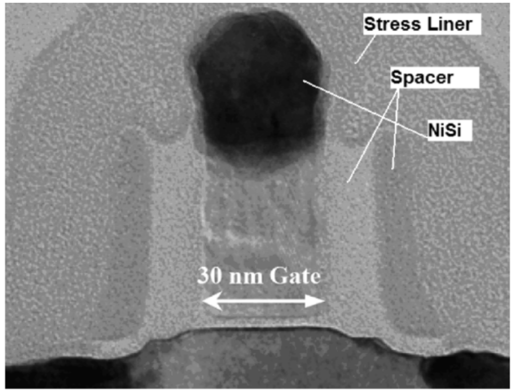
Damage-Free Particle Removal Window – Cryogenic Ar/N_2 Aerosol

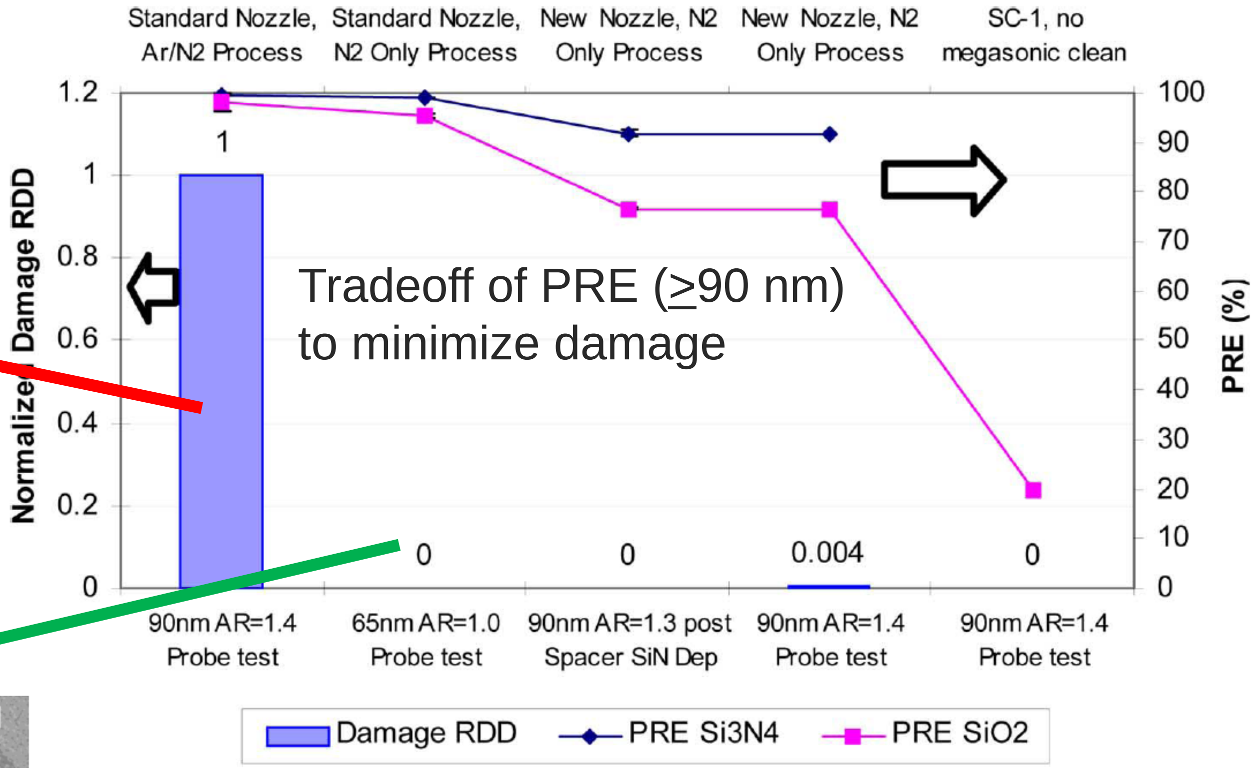


90nm
AR = 1.4:1

65nm
AR = 1:1







Tradeoff of PRE (≥90 nm) to minimize damage

(RDD = Random Defect Density)
(PRE = Particle Removal Efficiency)

H. Lin et al., Damage-Free Cryogenic Aerosol Clean Processes, in IEEE Trans Semi Manuf 20(2), 101(2007)

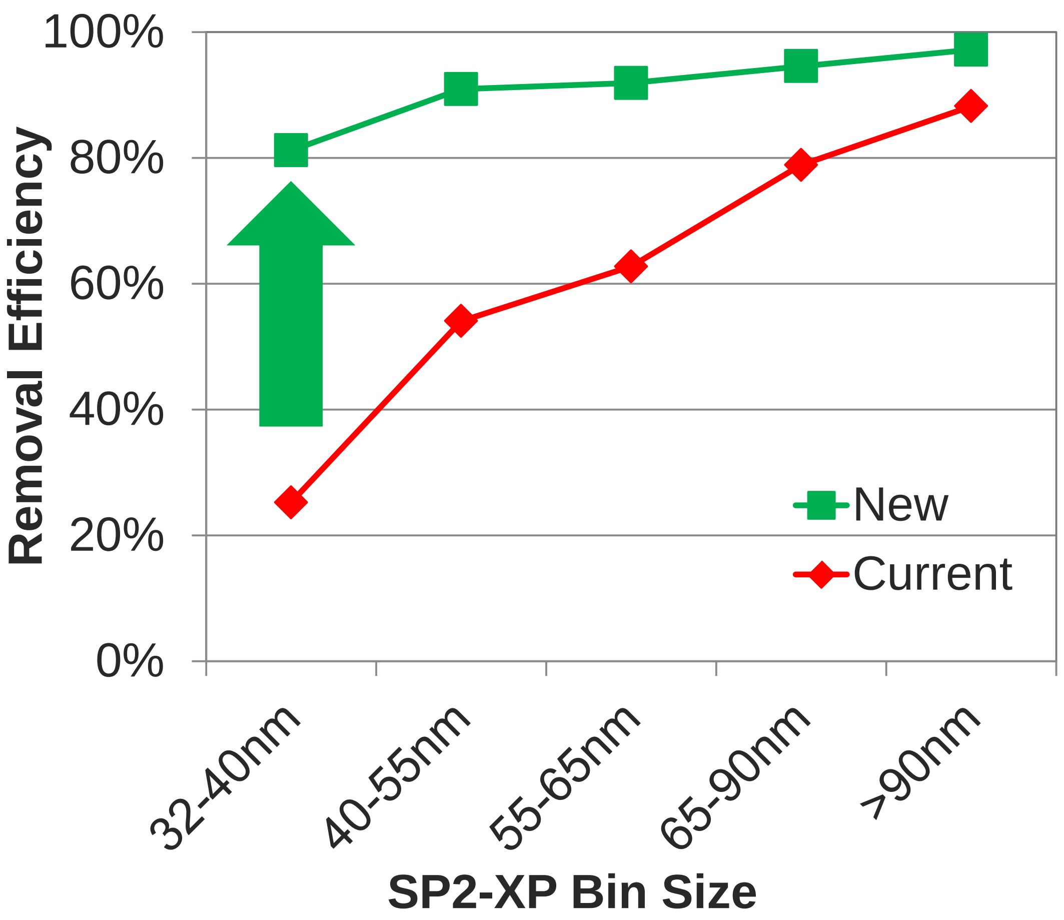
New Cryogenic Aerosol Process

- Goals:
  – Increase removal efficiency for <40 nm particles, extend to 10 nm and beyond
  – Damage-free for <40 nm features, extend to 10 nm and beyond
  – Remove particles between patterns

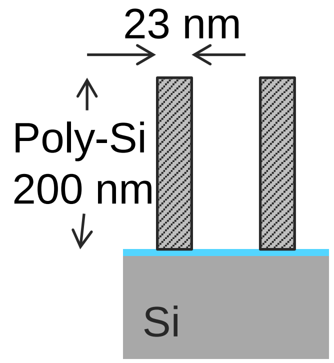
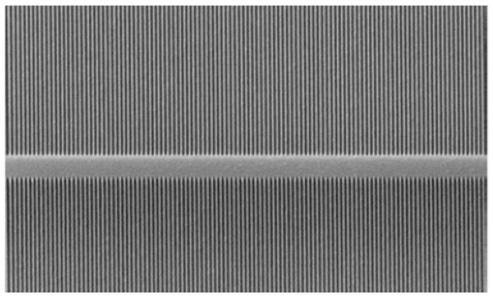
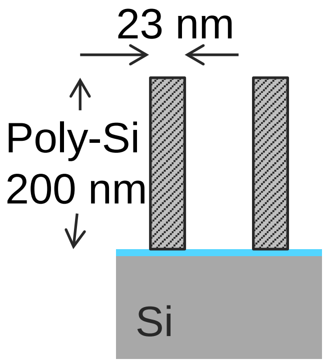
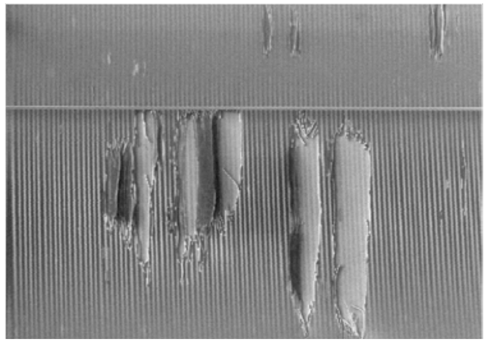
- Develop Nozzle and Process Conditions to Achieve:
  – Smaller aerosol size
  – Narrower aerosol size distribution
  – Higher aerosol velocity

New Process Increases Nanoparticle Removal without Damage

- Nanoparticle Removal Efficiency
  (Dry Deposited Si_3N_4 particles , 36-hour aged)

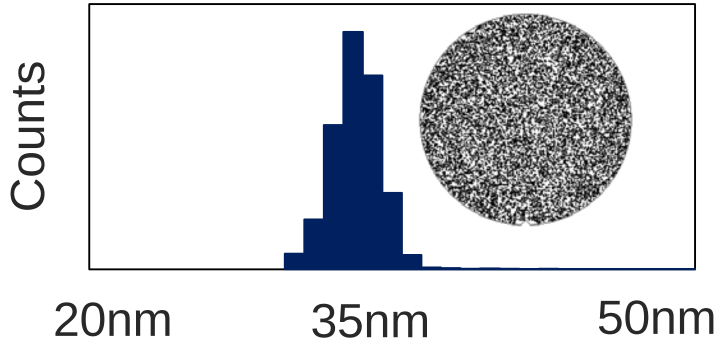
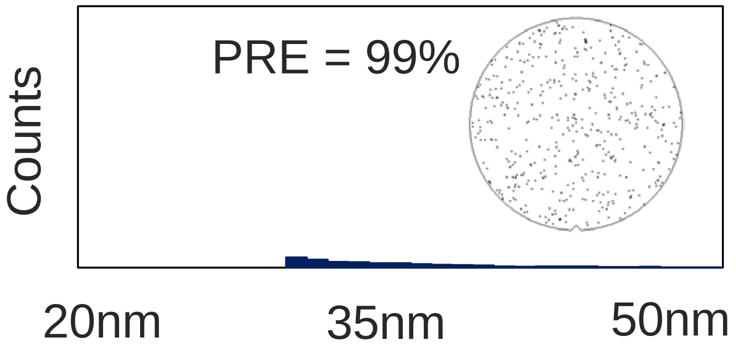
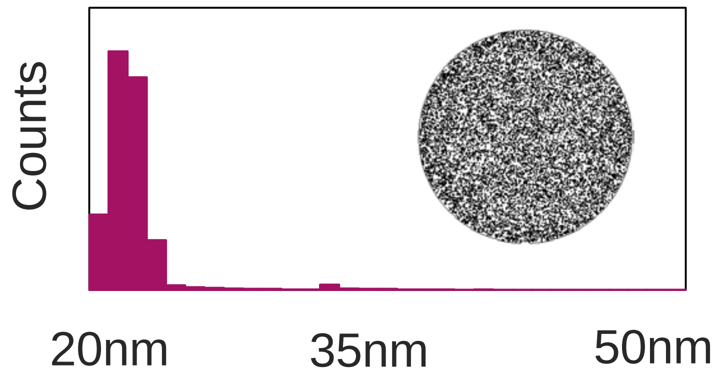
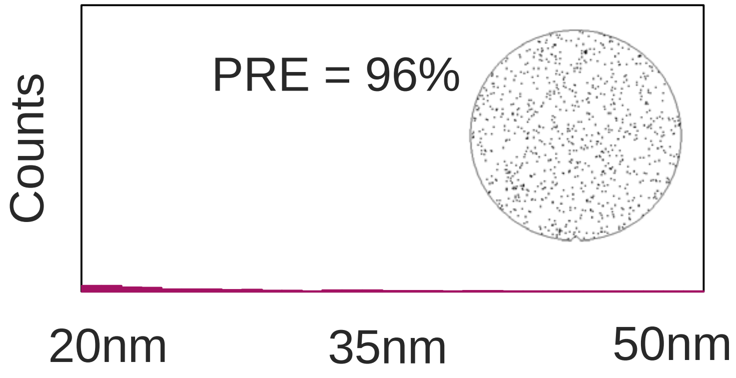


- Pattern Damage Performance

Process	Pattern Features	Post-Process
New		
Current		

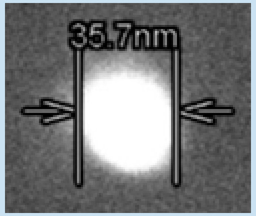
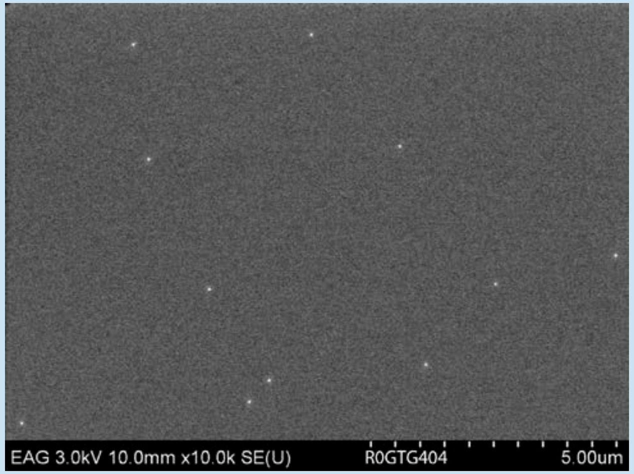
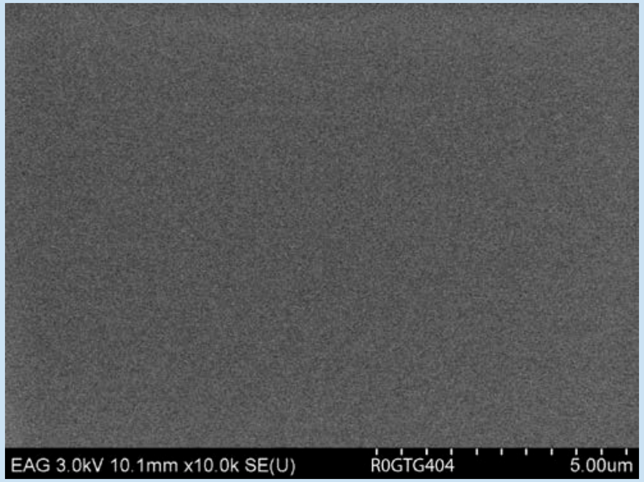
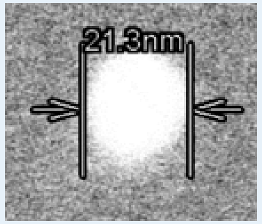
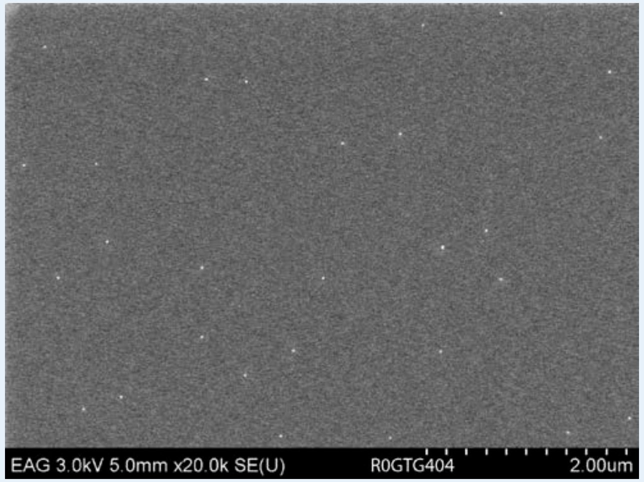
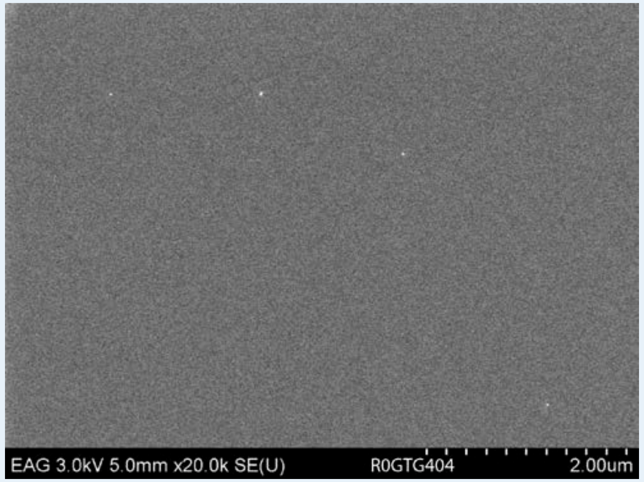
Nanoparticle Removal Efficiency Based on KLA Surfscan® Measurement

- > 90% removal efficiency as measured by KLA SP2-XP for 40 nm Silica
- > 90% removal efficiency as measured by KLA SP5 for 30 nm Silica

Silica Particle Size	Contaminated Sample (Wet Deposited Silica Particles)	6-Hour Silica Challenge + New Process
40 nm Silica	Particle Size Distribution 	Particle Size Distribution 
30 nm Silica	Particle Size Distribution 	Particle Size Distribution 

Nanoparticle Removal Efficiency Based on SEM Inspection

- > 90% removal efficiency as measured by multiple SEM FOV counting
- > 80% removal efficiency as measured by multiple SEM FOV counting

Silica Particle Size	Contaminated Sample (Wet Deposited Silica Particles)	6-Hour Silica Challenge + New Process
30 nm Silica 		
18 nm Silica 		

Light Scattering "Haze" Used for Sub-Resolution Particle Detection

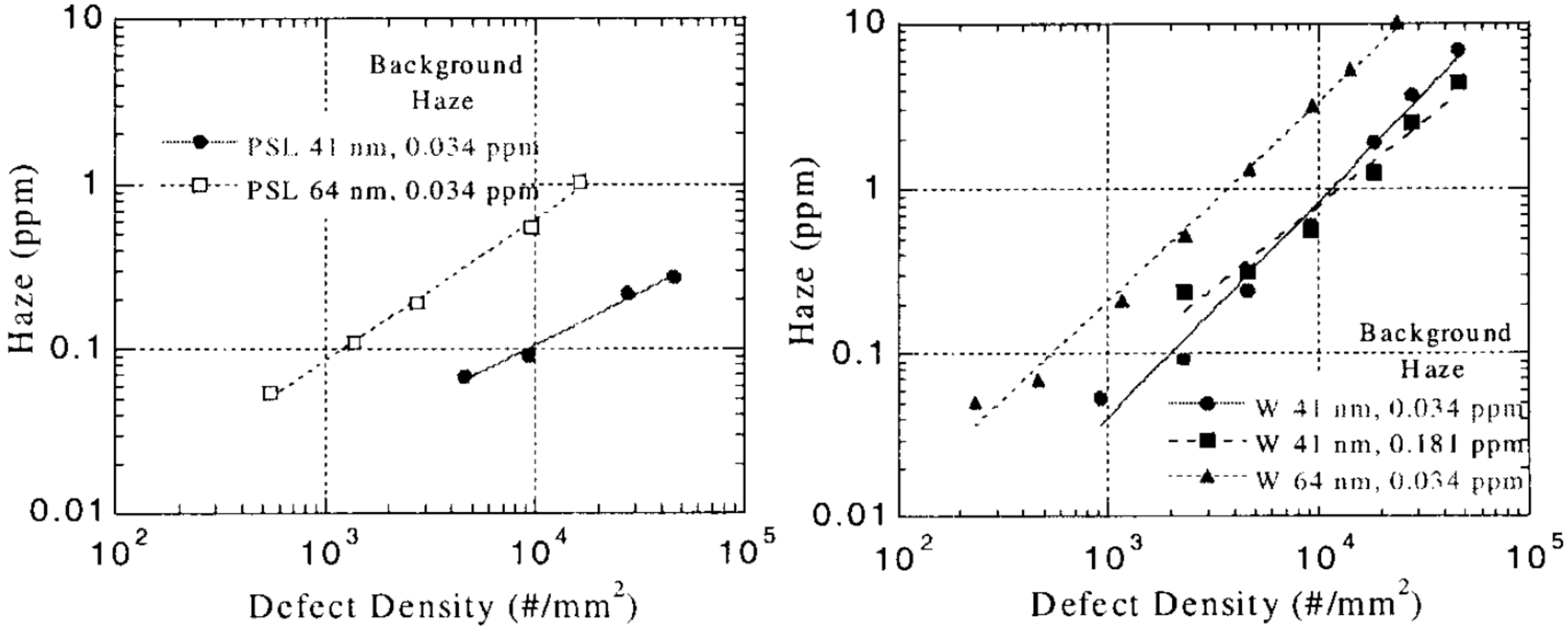
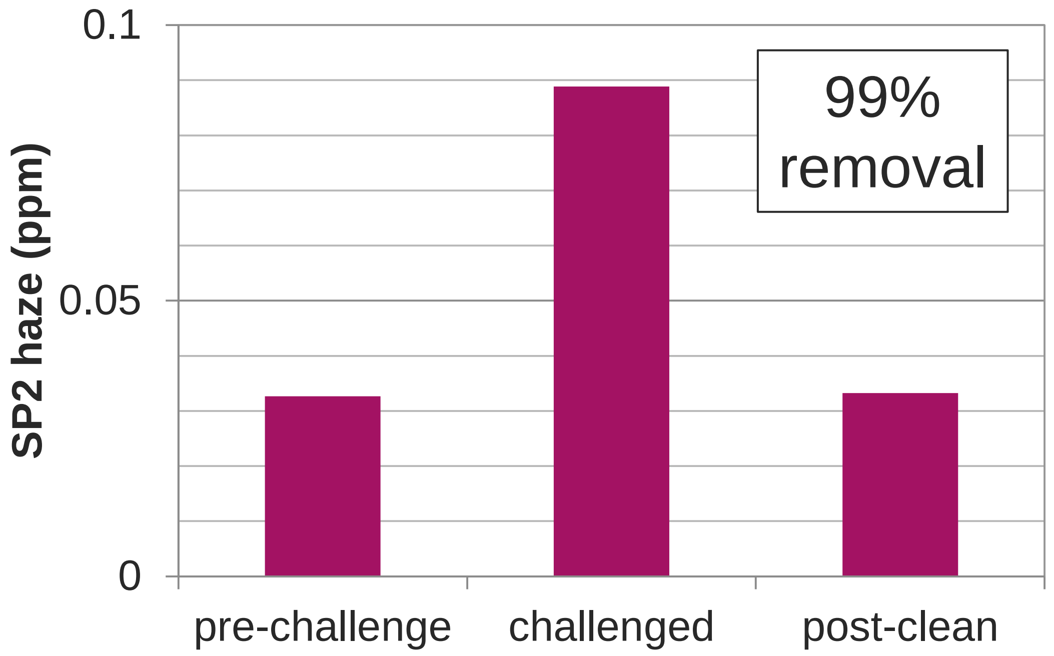


Figure 2. Haze Calibration Curves for PSL Spheres (left) and W Particles (right)

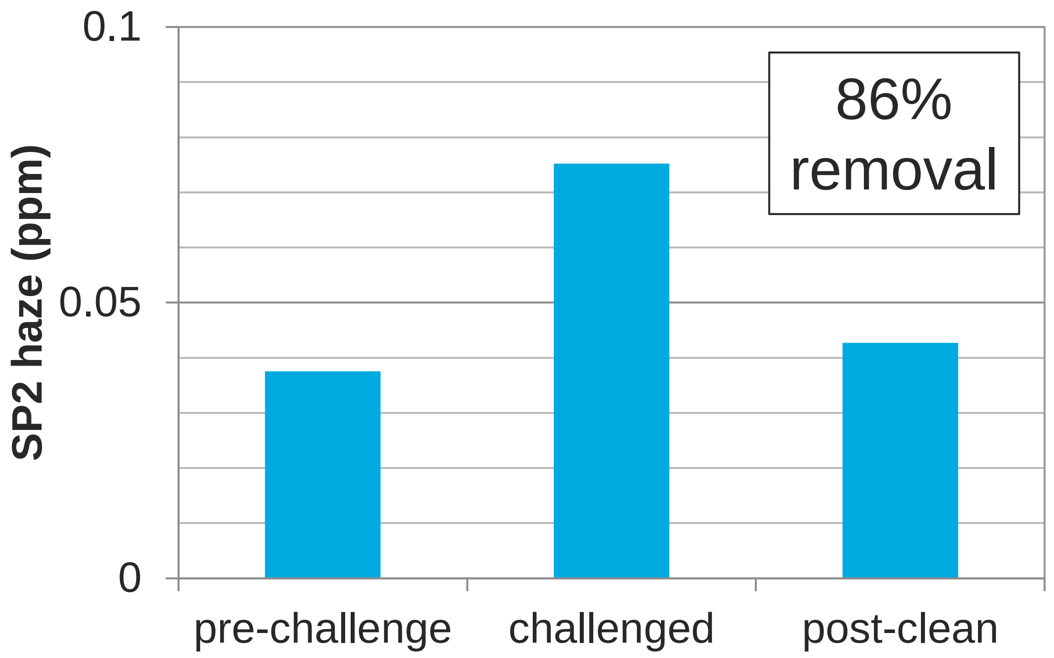
S.H. Yoo et al., Particle Removal Efficiency Evaluation at 40nm Using Haze Particle Standard, in Solid State Phen. Vol 76-77, 259-262(2001)

Nanoparticle Removal Efficiency Based on Haze Response

- 30 nm Silica, wet deposited, 6-hour aged



- 18 nm Silica, wet deposited, 6-hour aged

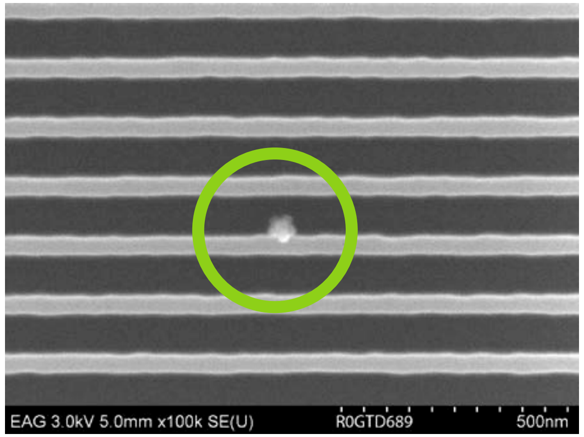


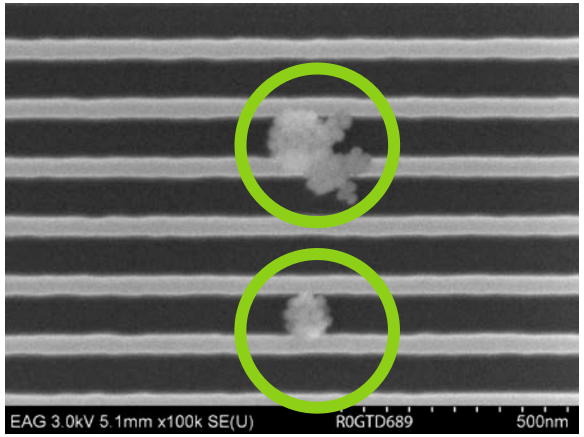
Particle Cleaning from Patterned Si Trenches

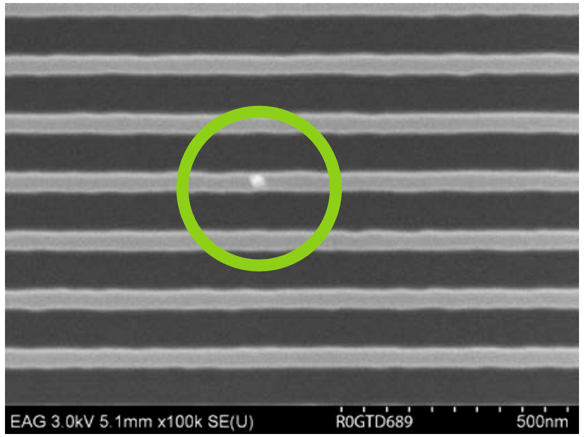
- 30 nm Silica particle clusters were dry deposited on patterned Si wafer

Line Width (nm)	Line Space (nm)	Line Height (nm)
45 nm	45-90 nm	100 nm

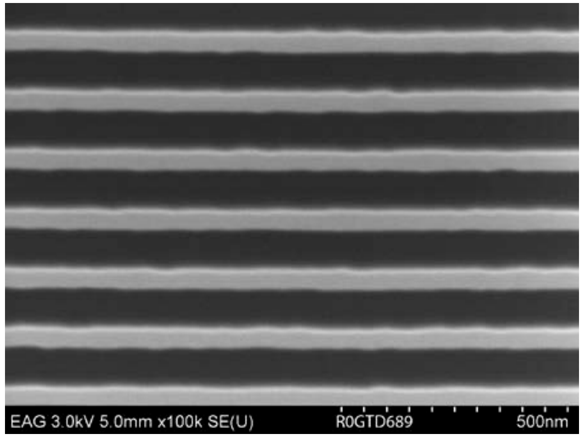
Particle clusters on patterned silicon surface

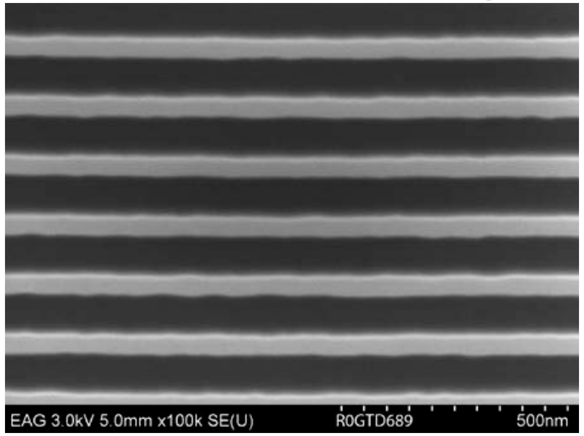


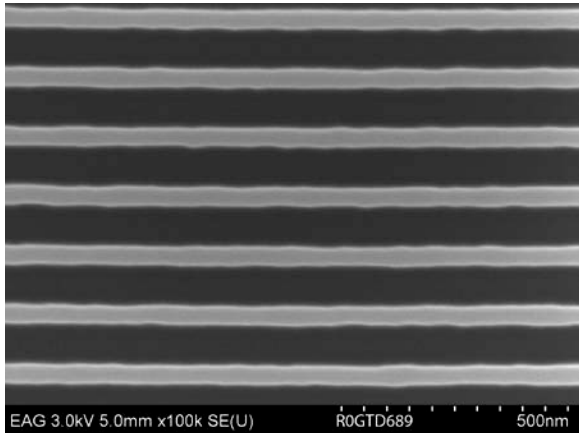




Particle clusters removed after cleaning

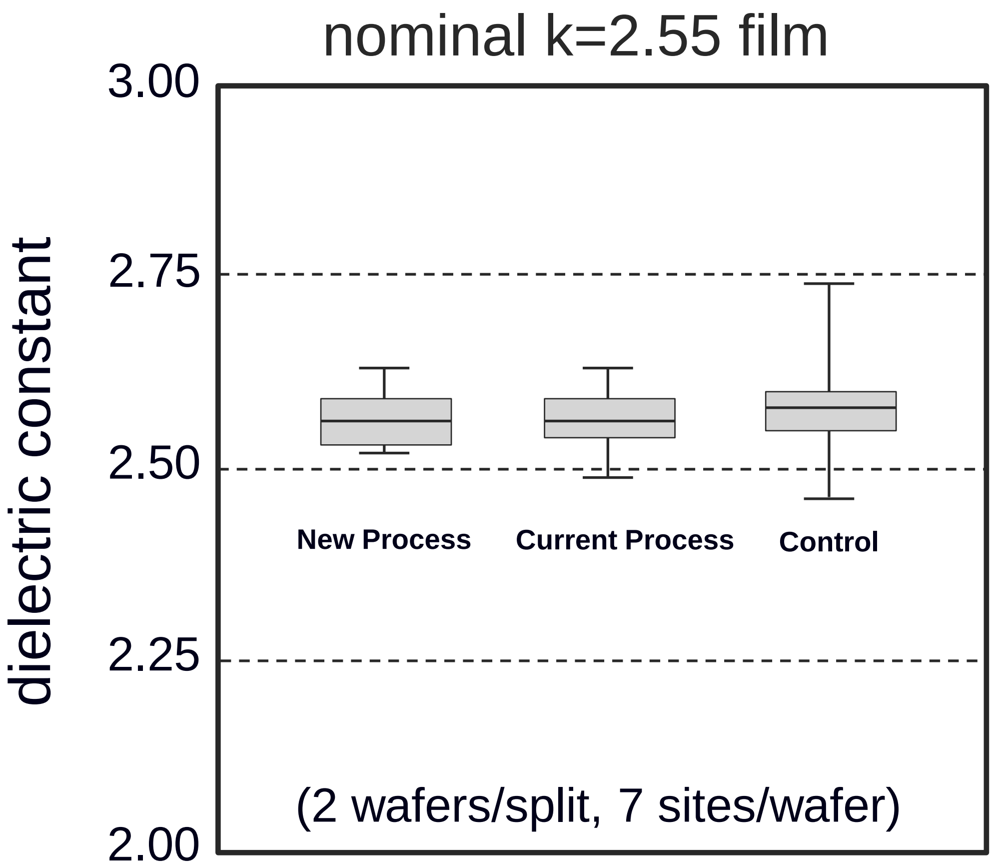






New Cryogenic Process Maintains Compatibility with Low-k Films

- Low-k wafers were processed with cryogenic aerosol processes
- Low-k wafers unaffected after cryogenic aerosol processing



Summary

- IC ground-rules continue to shrink, creating particle removal challenges
- The damage-free cleaning window is becoming narrower
- Cryogenic aerosol cleaning is a chemical-free, non-corrosive particle removal technology that is proven in production
- New cryogenic nano-aerosol cleaning technology is effective for <40 nm particles and is damage-free for advanced IC manufacturing.

Acknowledgements

- Greg Thomes, Brent Schwab, TEL FSI, Inc.
- Kazuya Dobashi, Tokyo Electron Limited, Process Development Center
- Koji Kagawa, Tokyo Electron Kyushu Limited, SPE Process Technology Dept.
- Wallace Printz, Derek Basset, Antonio Rotondaro, Tokyo Electron America, Inc. Advanced Technology Group

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