Particle Removal Using Cryogenic Aerosols

Thomas J. Wagener
FSI International, Inc.
Chaska, Minnesota USA 55318
thomas.wagener@fsi-intl.com

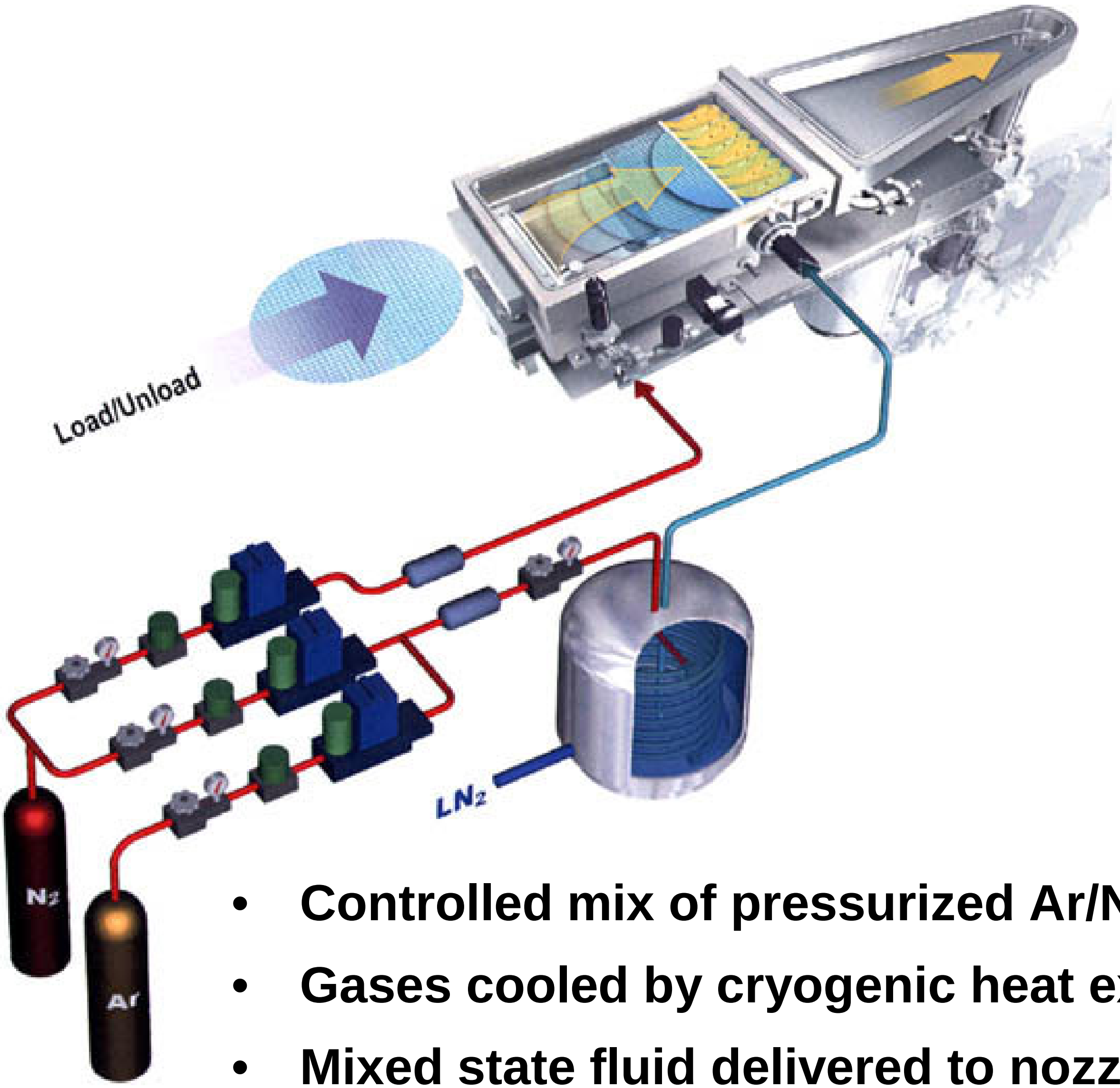
Outline

- **Overview of Cryogenic Aerosol Process**
  - **Definitions**
  - **Cryogenic Aerosol Basics**
- **Advantages of Cryogenic Aerosol Process**
  - **No Material Loss**
  - **No Change to Film Properties**
  - **No Charging**
  - **Superior Particle Removal Efficiency on Phobic Surfaces**
  - **Aggressiveness Control to Avoid Damage to Sensitive Structures**
- **Device Wafer Results**
  - **Typical Particles Removed**
  - **Damage Free Processing**
  - **Split-Lot Yield Results**

Definition of “Cryogenic Aerosols”

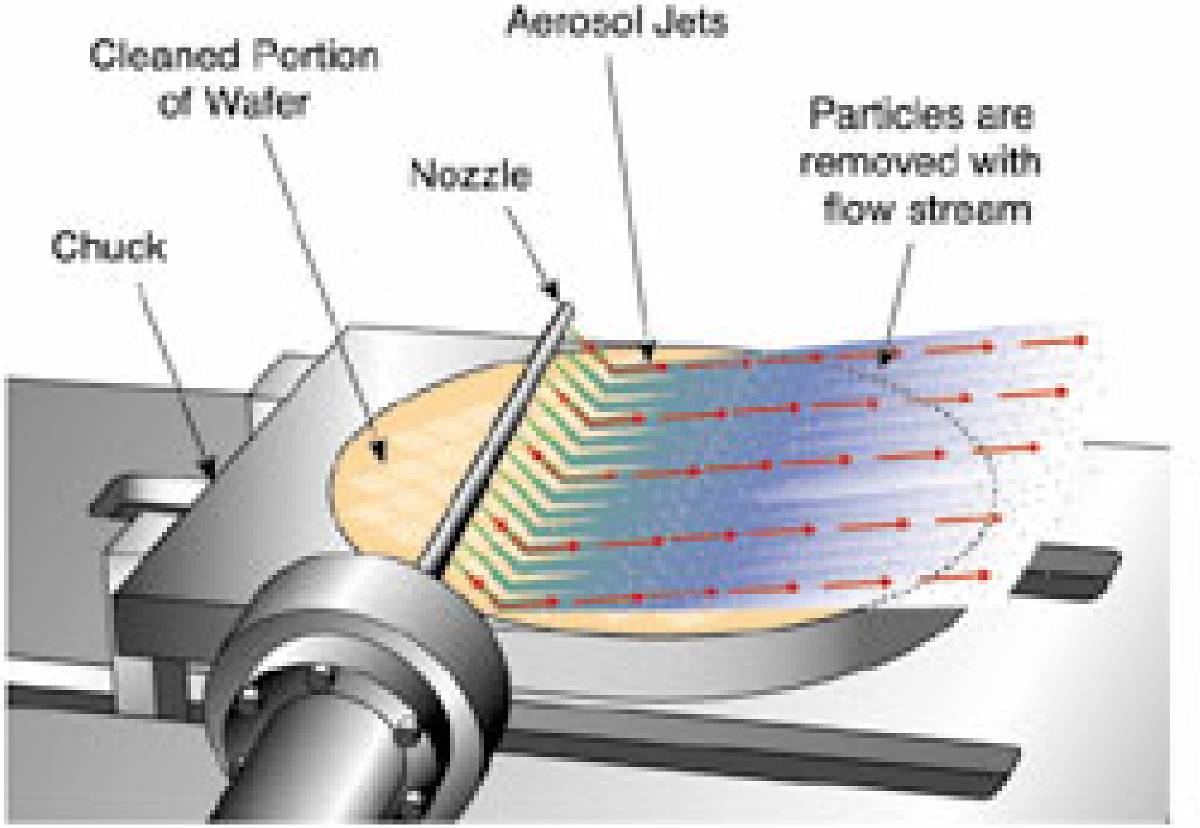
- "The cryogenic temperature range is from -238°F (-150°C) to absolute zero.“ (www.britannica.com)
- National Institute of Standards and Technology has suggested that the term cryogenics be applied to all temperatures below -150° C
- Some scientists regard the normal boiling point of oxygen (-183° C or -297° F), as the upper limit (see Absolute Zero)."
- CO_2 freezes at -78.5C.
- Why care? Many attributes described in this paper (e.g. charging and damage control) are not the same when comparing Ar/N_2 aerosols and CO_2 aerosols.

Cryogenic Aerosol Process



- Controlled mix of pressurized Ar/N_2 gases
- Gases cooled by cryogenic heat exchanger
- Mixed state fluid delivered to nozzle

Cryogenic Aerosol Process

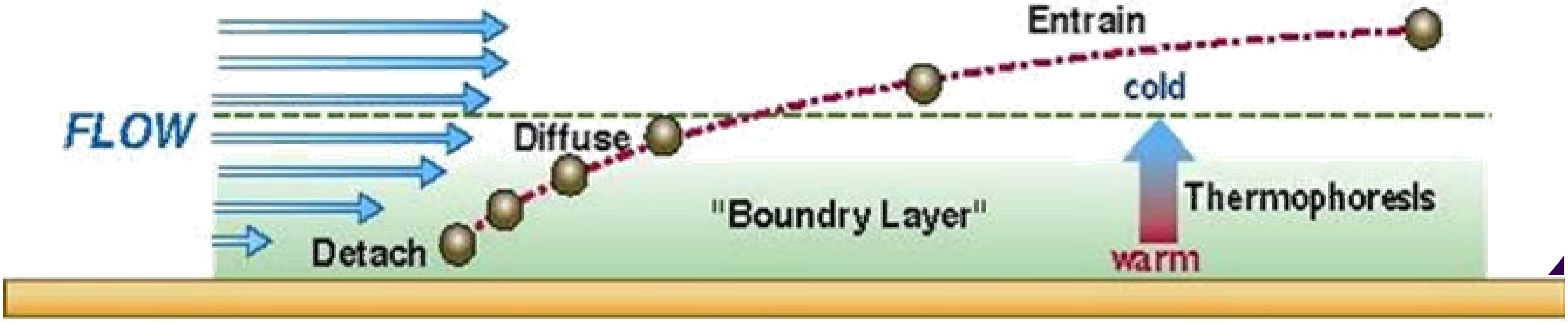


- **All-dry, non-reactive, brushless**
- **Uses inert, high-velocity cryogenic aerosols to dislodge and remove particles from wafer surfaces**
- **Laminar flow carries particles away**

Particle Removal Steps

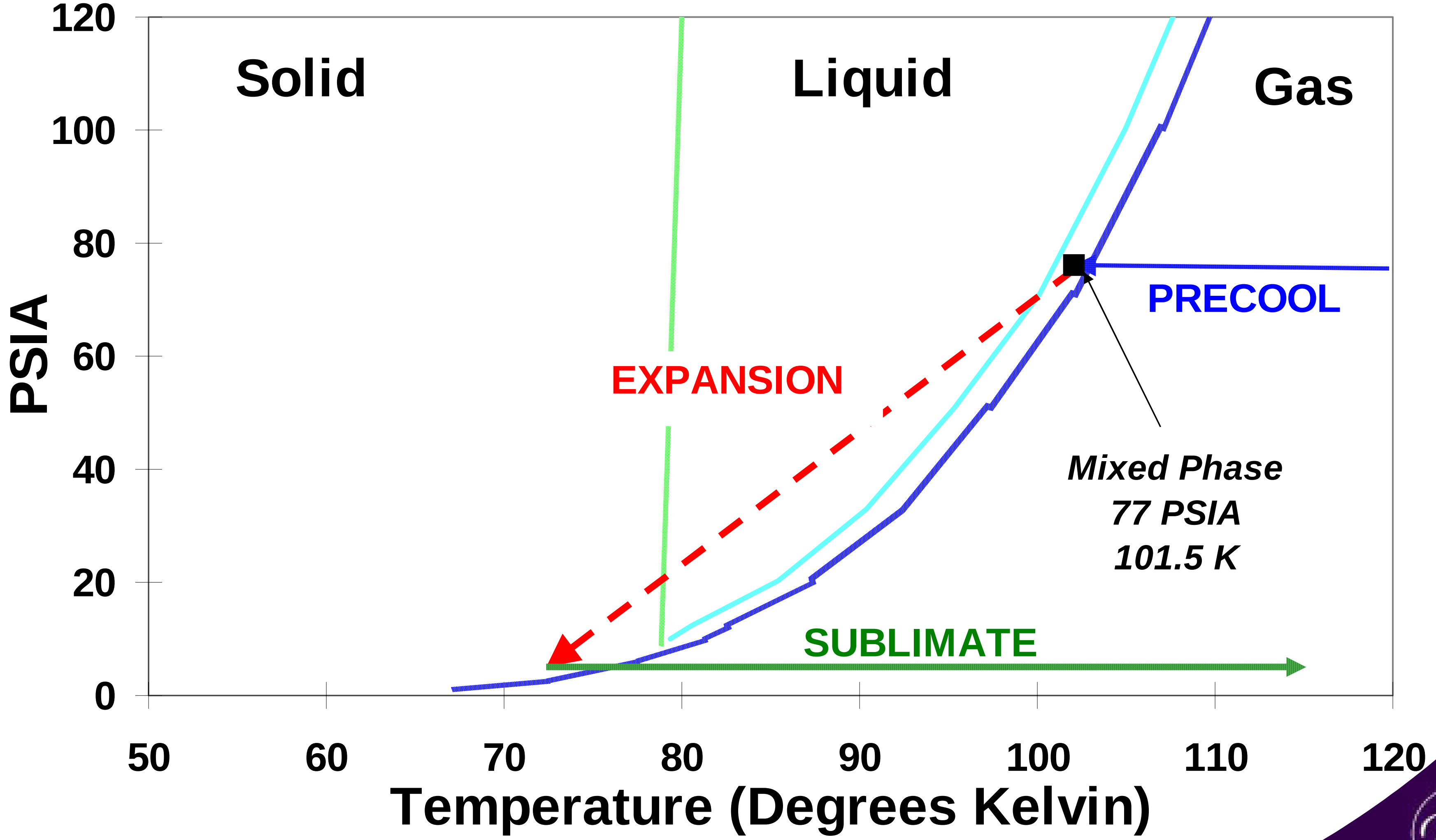
1. Detach
2. Diffuse
3. Entrain

Avoid Redeposition



Cryogenic Aerosol Process

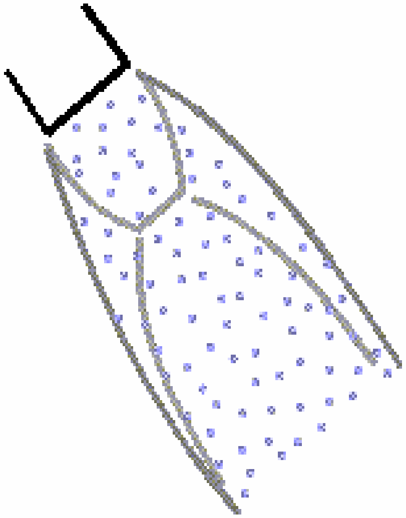
Phase Diagram - 3:1 Ar:N_2 Ratio



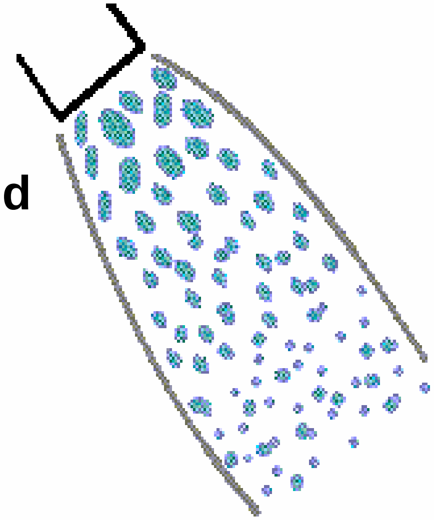
Aerosol Process

Formation Mechanisms

- **Homogenous Nucleation**
  - **Aerosols form from expanding Ar and/or N_2 gas**
  - **Results in aerosols ~10 nm in size**
  - **Non-measurable contribution to particle removal (down to 30 nm)**

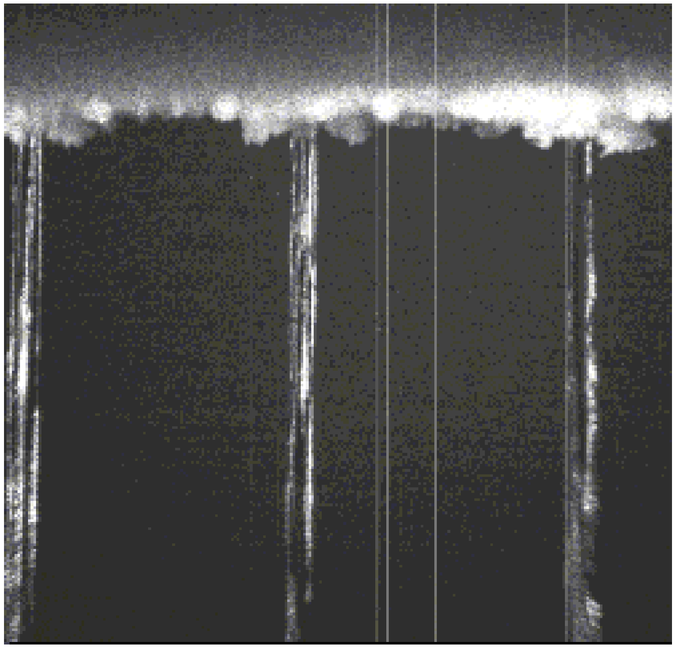


- **Liquid Stream Breakup With Evaporative Cooling**
  - **Aerosols form from micron size liquid droplets of Ar and/or N_2 gas**
  - **Results in aerosols ~micron in size**
  - **Dominant contributor to particle removal (down to 30 nm)**



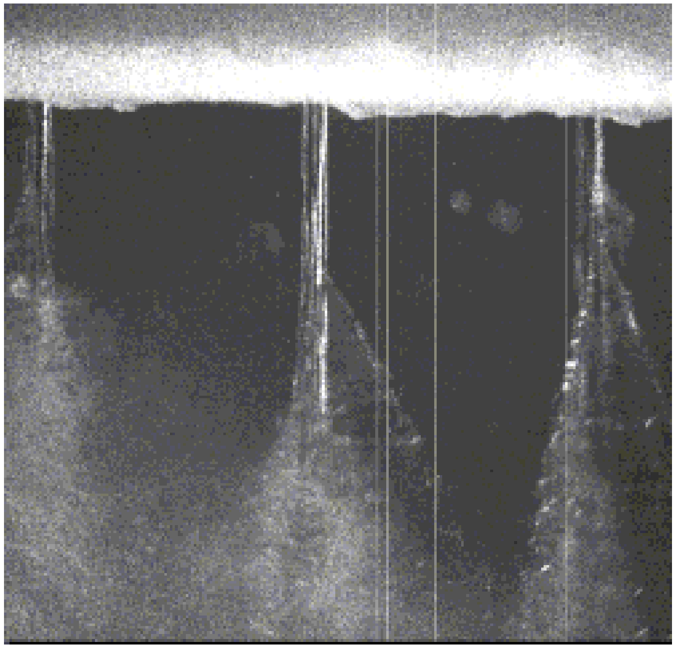
Aerosol Formation

Liquid Breakup Mechanisms



Hydrodynamic Breakup

- Dominant at higher chamber pressures (e.g. 300 Torr)
- Large, slow aerosols
- Small spray divergence



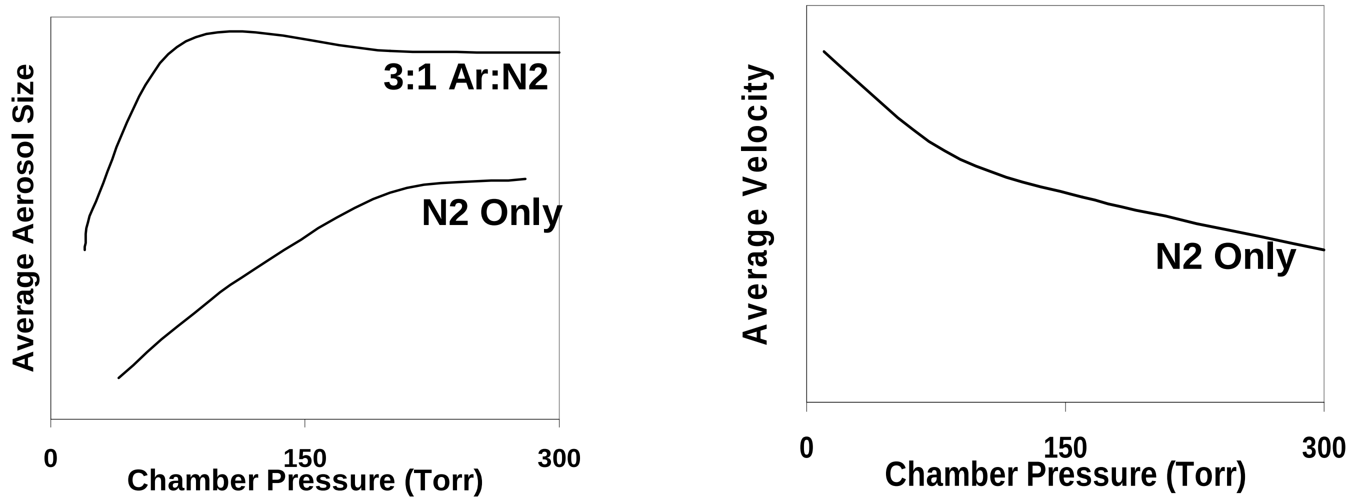
Effervescent Flashing

- Dominant at lower chamber pressures (e.g. 50 Torr)
- Small, fast aerosols
- Large spray divergence

Eliminate Larger Aerosols

Improved Particle Removal and Reduced Damage

- **All Nitrogen Process Produces Smaller/Faster Aerosols**
    - **Measured by Phased Doppler Particle Analysis (PDPA)**



-
    - **Smaller aerosols have lower momentum that cause less damage**
    - **Smaller aerosols result in higher cleaning efficiencies for smaller particle sizes**
- **Lower Liquid Fraction Further Reduces Damage (Called AspectClean™)**
    - **On-wafer studies show that liquid-lean processes further reduce damage**
    - **No damage observed on many devices including 60x225nm polysilicon lines**

Cryogenic Aerosols

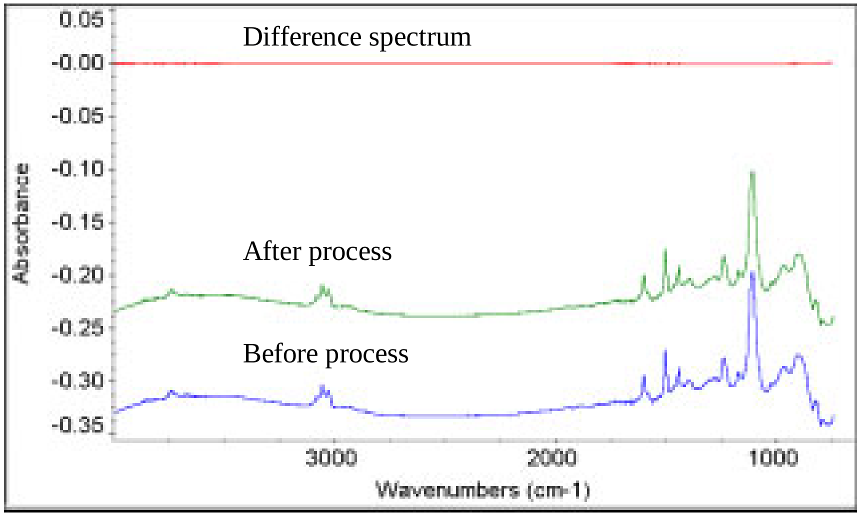
Do Not Alter Thickness or Refractive Index of SiLK® or p-MSQ

Sample	Thickness (Å)	Refractive Index
SiLK® as-deposited	5739.4 ± 7.1	1.636 ± 0.001
SiLK® after ANTARES® process	5738.6 ± 6.7	1.636 ± 0.001
p-MSQ as-deposited	3951.7 ± 3.9	1.253 ± 0.001
p-MSQ after ANTARES® process	3949.4 ± 3.3	1.254 ± 0.001

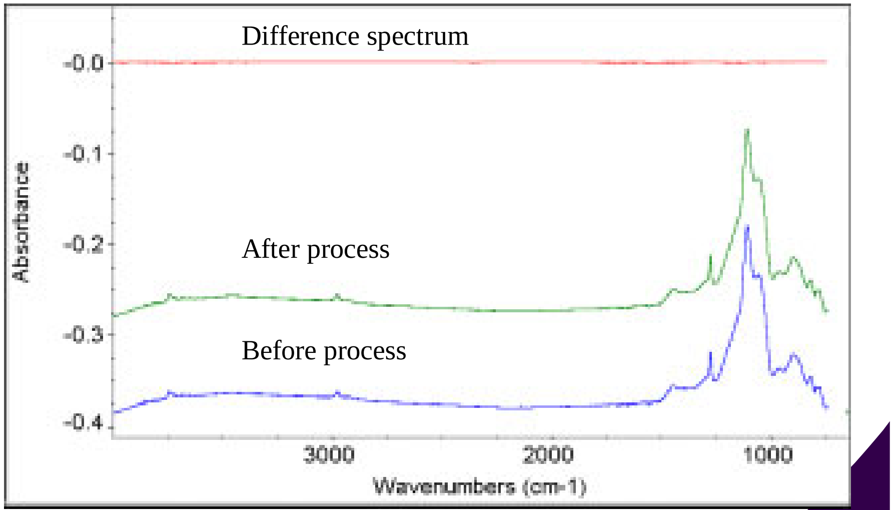
Cryogenic Aerosols

No Change to Film Properties

- **No Measurable Change in Film Thickness or Refractive Index Dense SiLK® or Porous MSQ (via Ellipsometry)**
- **No Measurable Change in FTIR Spectra**



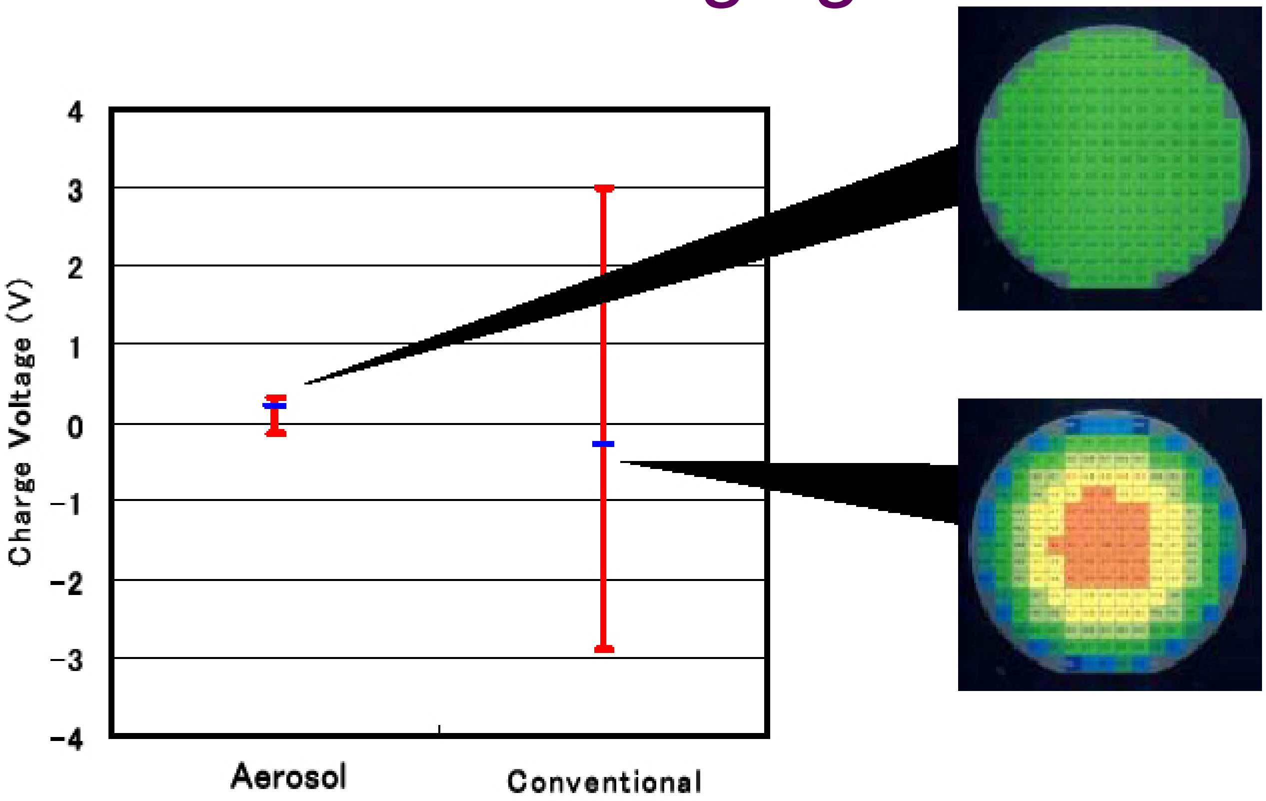
Dense SiLK®



Porous MSQ

Cryogenic Aerosols

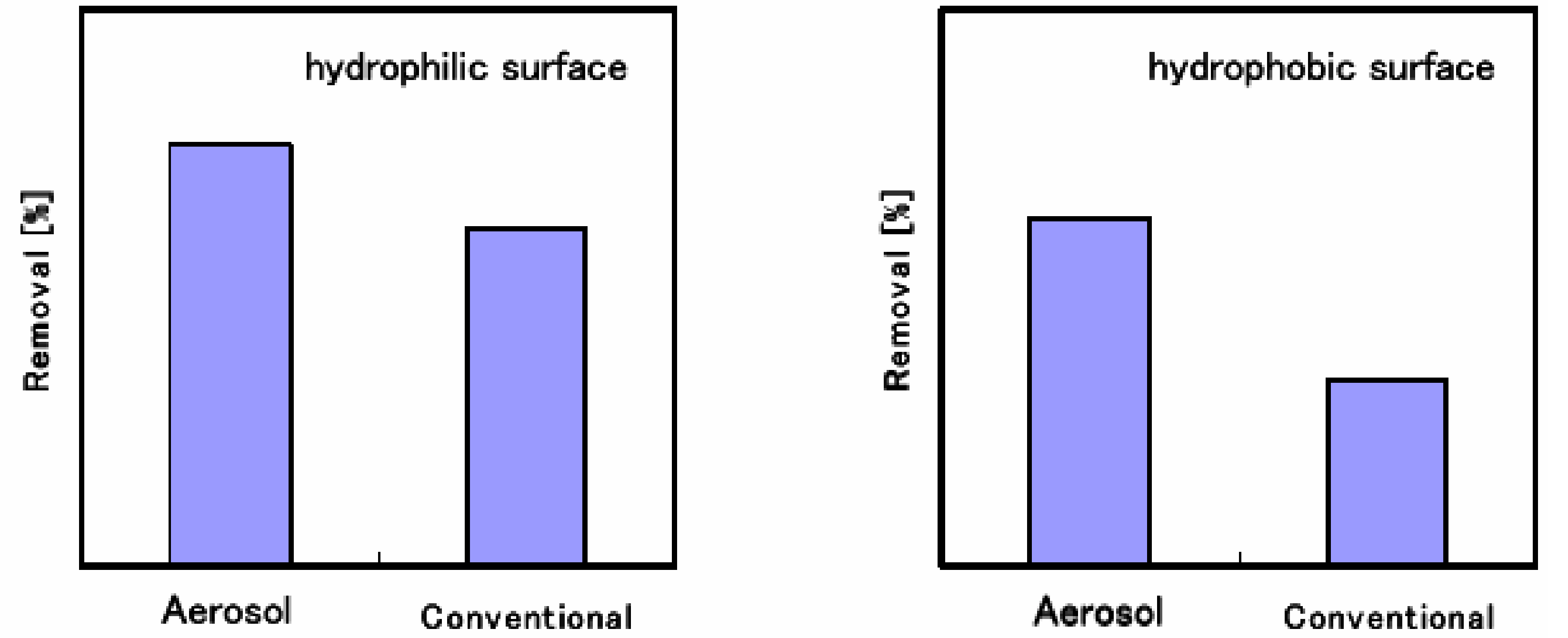
No Charging



Originally Published by H. Iwamoto, et. al, "Environmental Friendly Cleaning Technology for Next Generation Device," 5th Surface Contamination Control Seminar, SEMICON Japan, December 4, 2003.

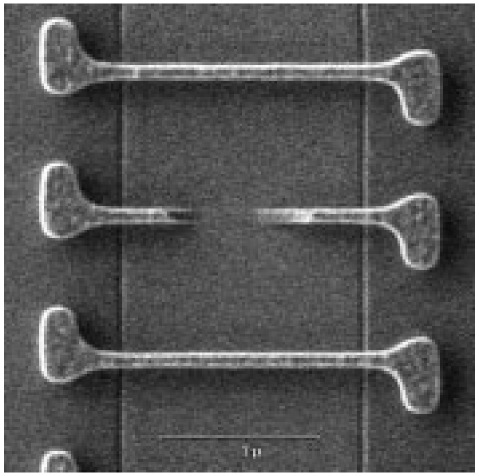
Cryogenic Aerosols

Superior Removal Efficiency on Phobic Surfaces

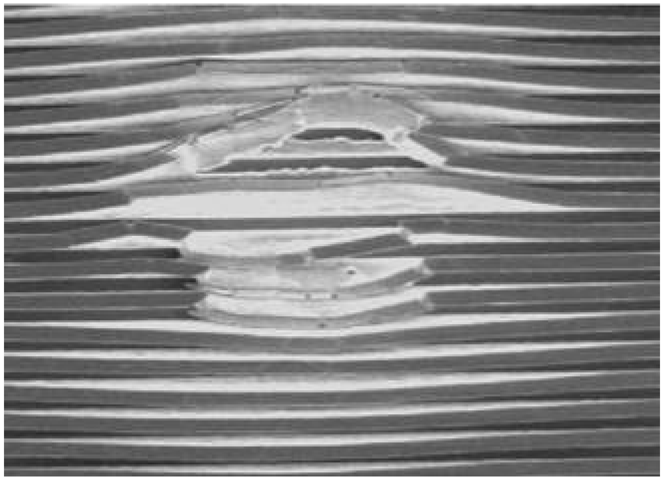


Originally Published by H. Iwamoto, et. al, "Environmental Friendly Cleaning Technology for Next Generation Device," 5th Surface Contamination Control Seminar, SEMICON Japan, December 4, 2003.

Damage of Sensitive Structures

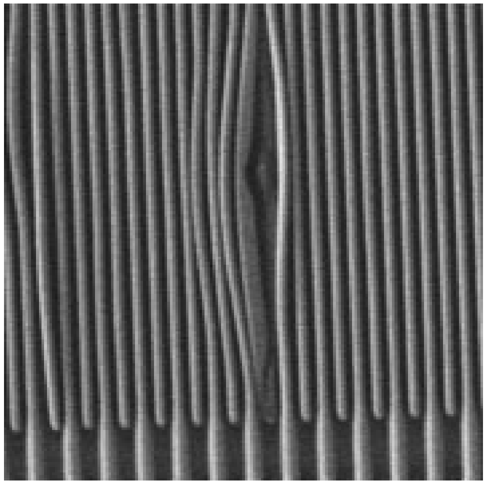


110nm Poly Lines



(Photo Courtesy of IMEC)

300 nm Al Lines

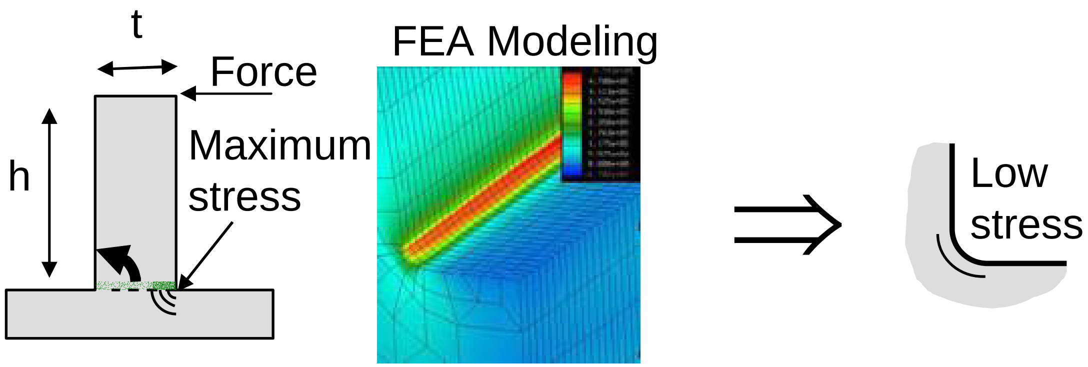


Patterned Low-k

Energetic particle removal techniques (e.g. megasonics, atomized spray, etc.) can damage sensitive structures if not properly controlled.

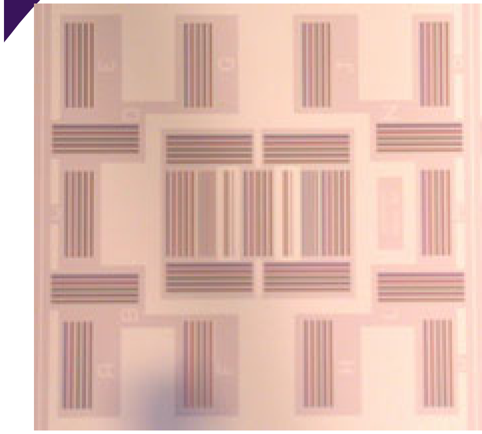
Damage Susceptibility Factors

- **Pattern width and aspect ratio**
- **Line spacing**
- **Line shape**

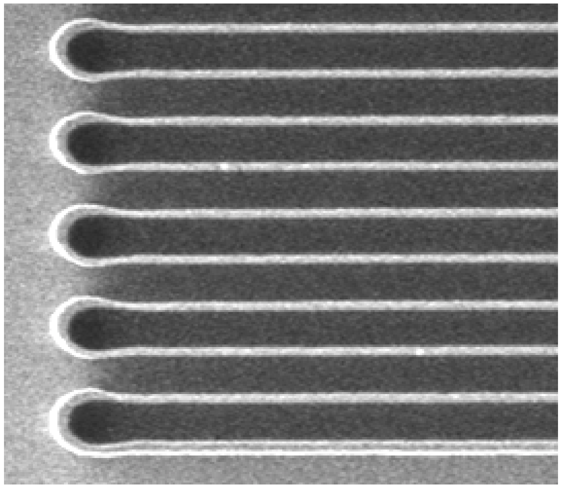


- **Pattern adhesion to surface**
- **Pattern material**
- **Angle of aerosol to pattern direction**
  - **No issue when parallel**
  - **Use caution when perpendicular**

Damage Test Structures

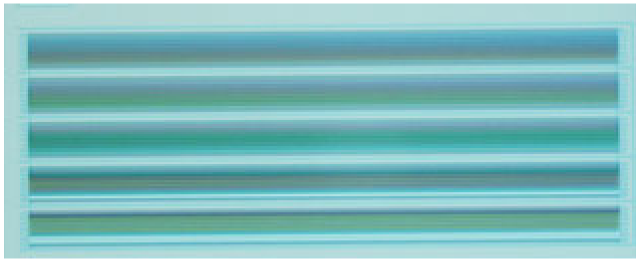


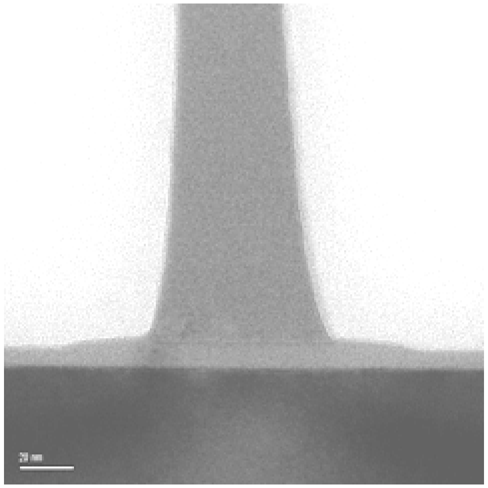
20x20 mm die



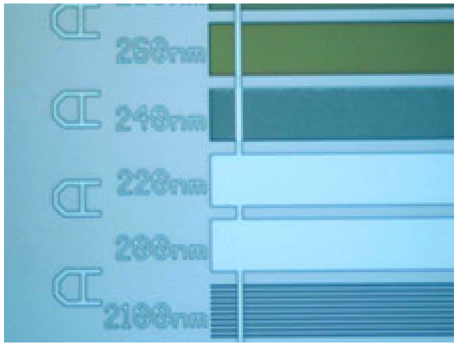
60x230nm poly lines

4 mm long field





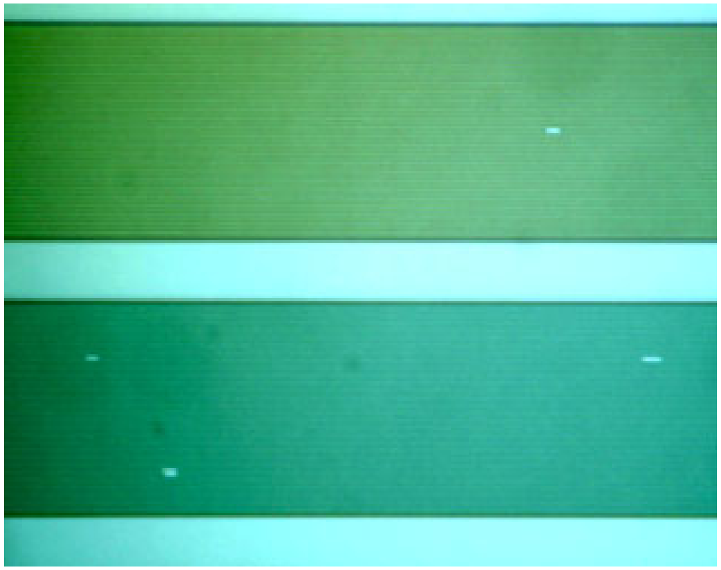
TEM Image ~60nm at base



Arrays of lines with varying pitch

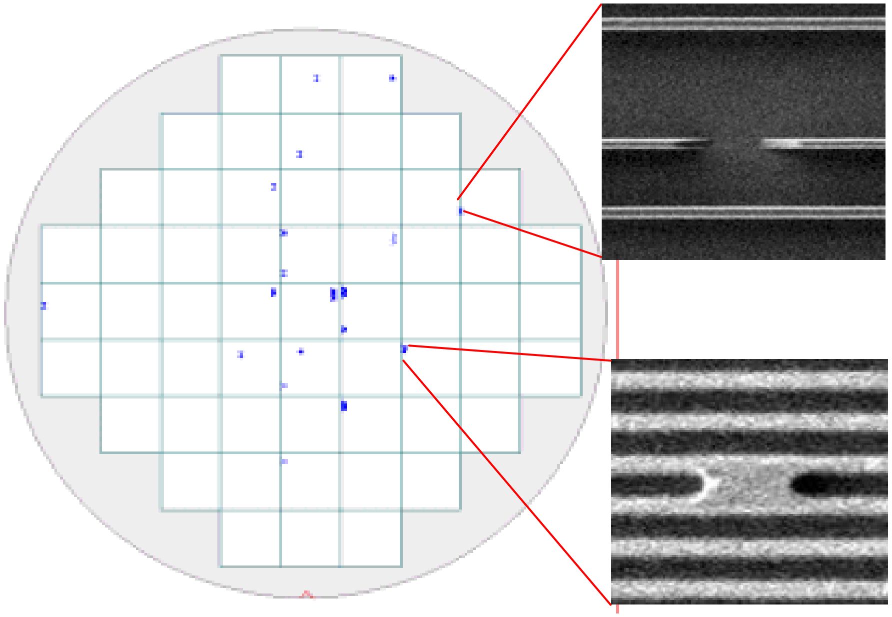
Damage Assessment Methodology

Screening Tests



Manual Optical Review of Individual Die

Final Confirmation Tests



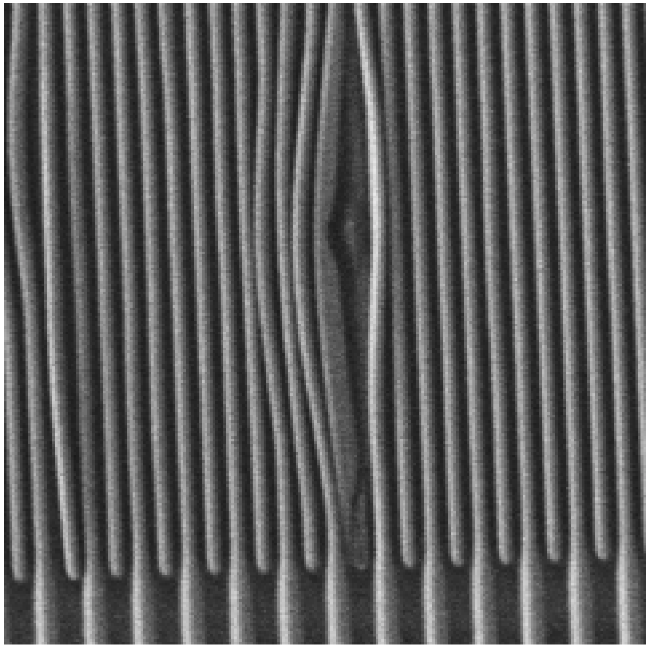
Automated Full Wafer Review Using AMAT ComPlus

Verify With SEM

Cryogenic Aerosols

Gas Concentration Affects Aggressiveness

3:1 Ar:N_2



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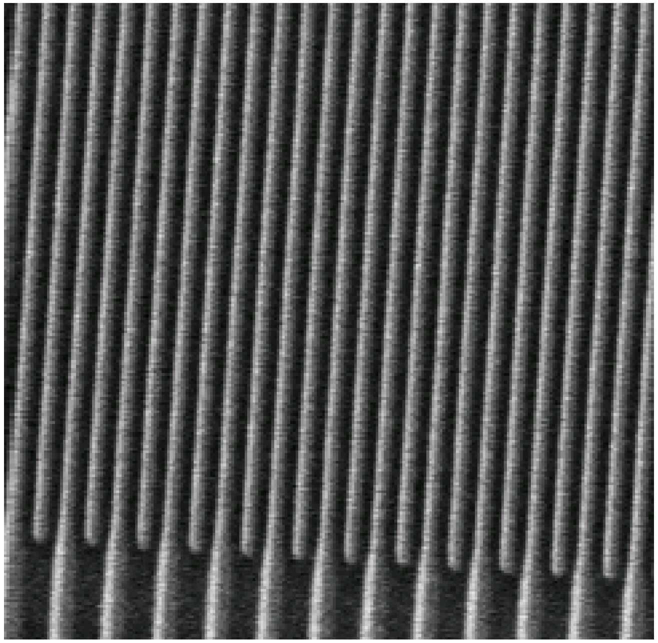
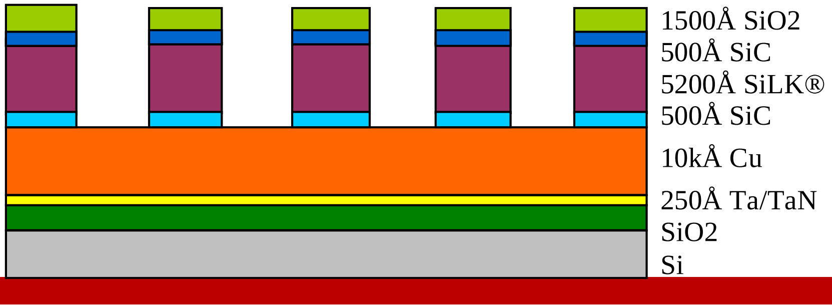
N_2-Only



Eliminates Damage to Dense SiLK®: 0.2µm Line x 0.2µm Trench

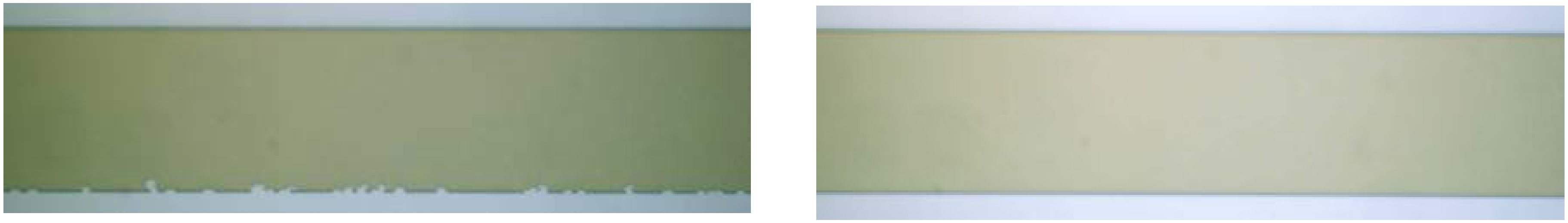


Cryogenic Aerosols

Liquid Content Affects Aggressiveness

3:1 Ar:N_2 – 31% Liquid → **N_2 Only - 16% Liquid**

110nm wide, 225nm thick, 1990nm spacing

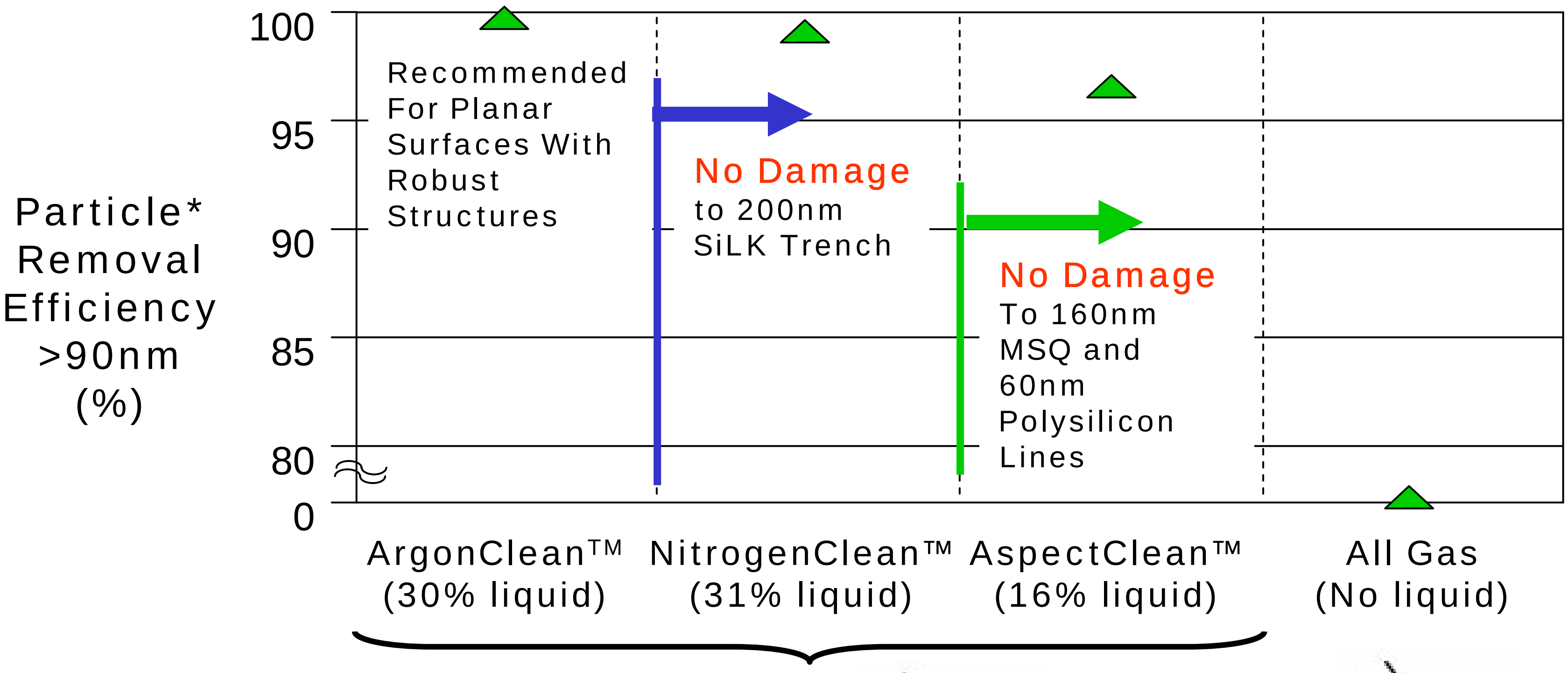


60nm wide, 225nm thick, 240nm spacing

Eliminates Damage to Polysilicon Lines

Cryogenic Aerosols

Aggressiveness Summary



Recommended For Planar Surfaces With Robust Structures

No Damage to 200nm SiLK Trench

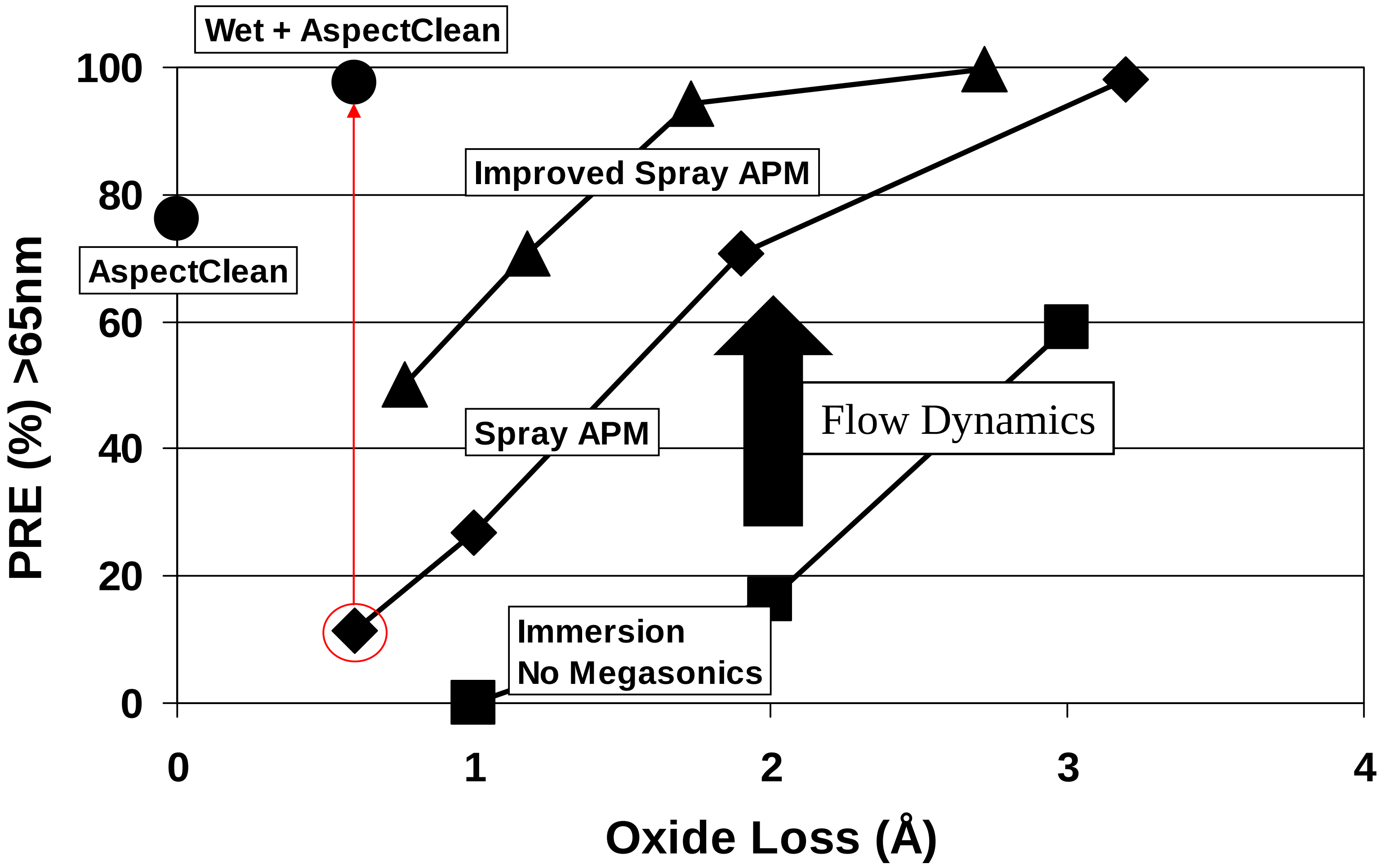
No Damage To 160nm MSQ and 60nm Polysilicon Lines

Cryogenic Aerosols

***Particle removal efficiency with Si_3N_4 challenge wafers (dry deposited and aged 24 hours)**

Particle Removal Efficiency (PRE)

Non-Damaging Cleans

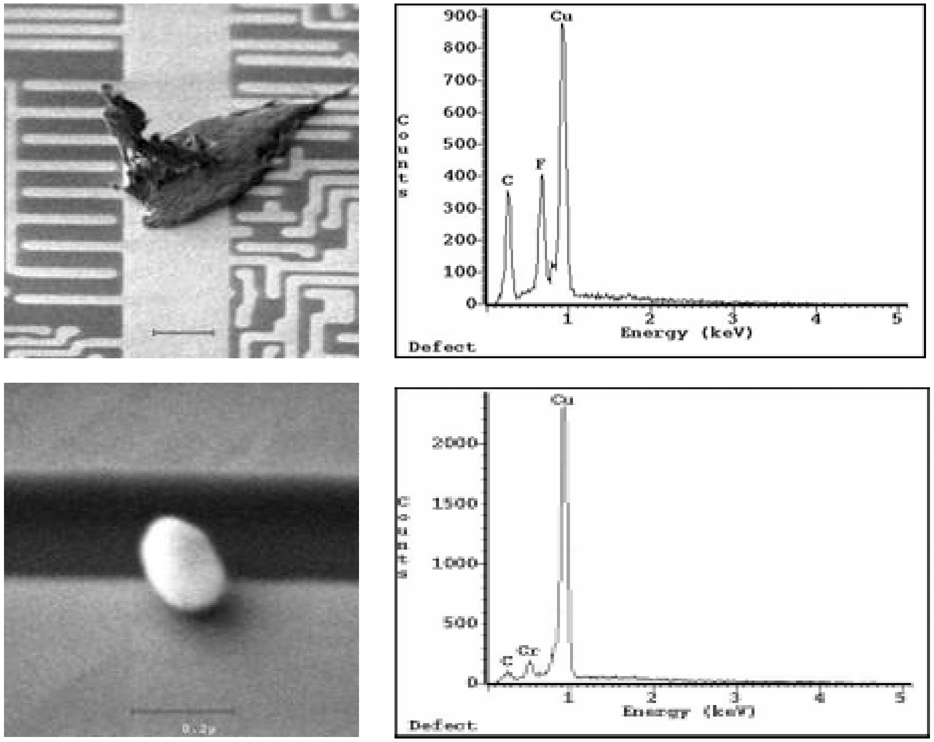


*Particle removal efficiency with Si_3N_4 challenge wafers (wet deposited and aged 24 hours)**

Device Wafer Results

Cryogenic Aerosols

Removes Yield Detracting Defects



10µm Particle

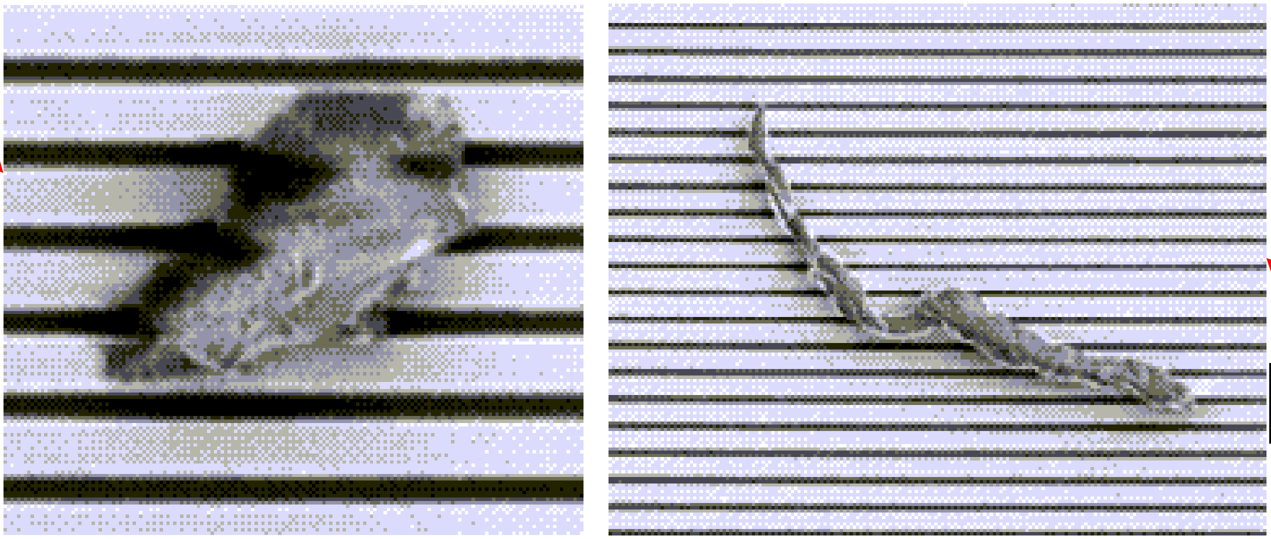
0.2µm Particle

SEM

XPS Chemical Analysis

Cryogenic Aerosols

Particle Removal After Dry Etch

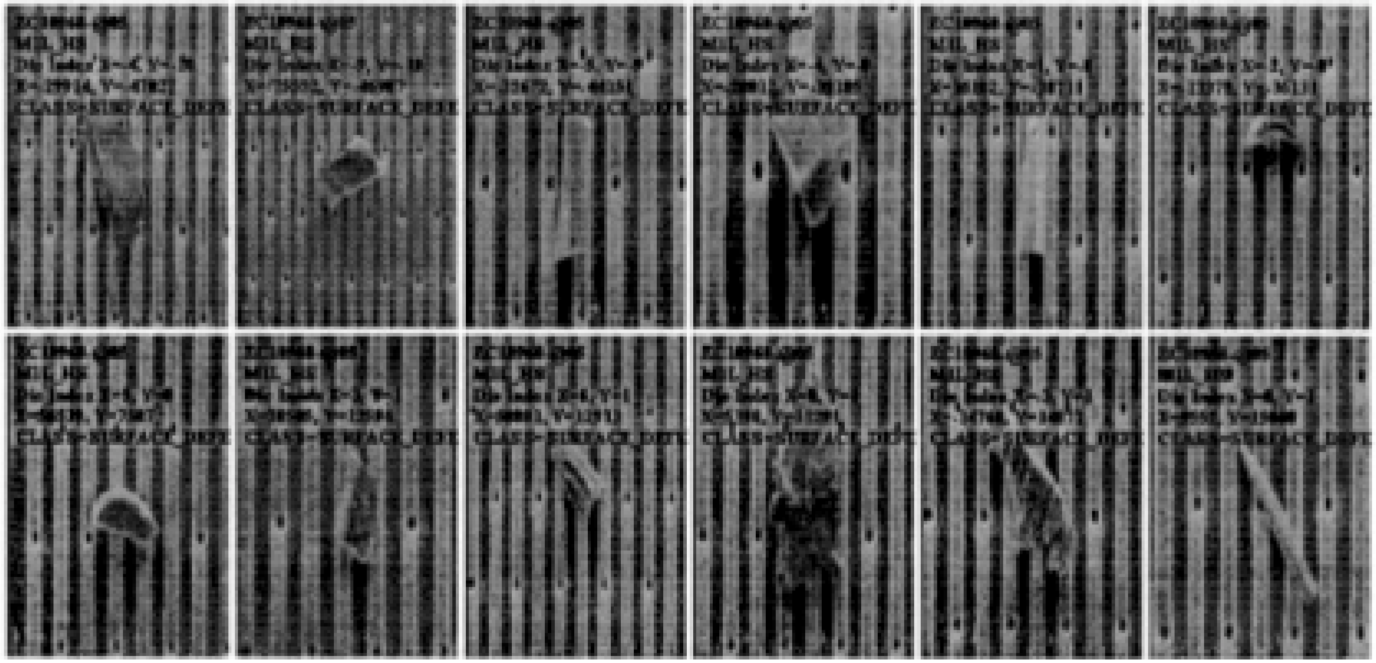


AL Line

AL Line

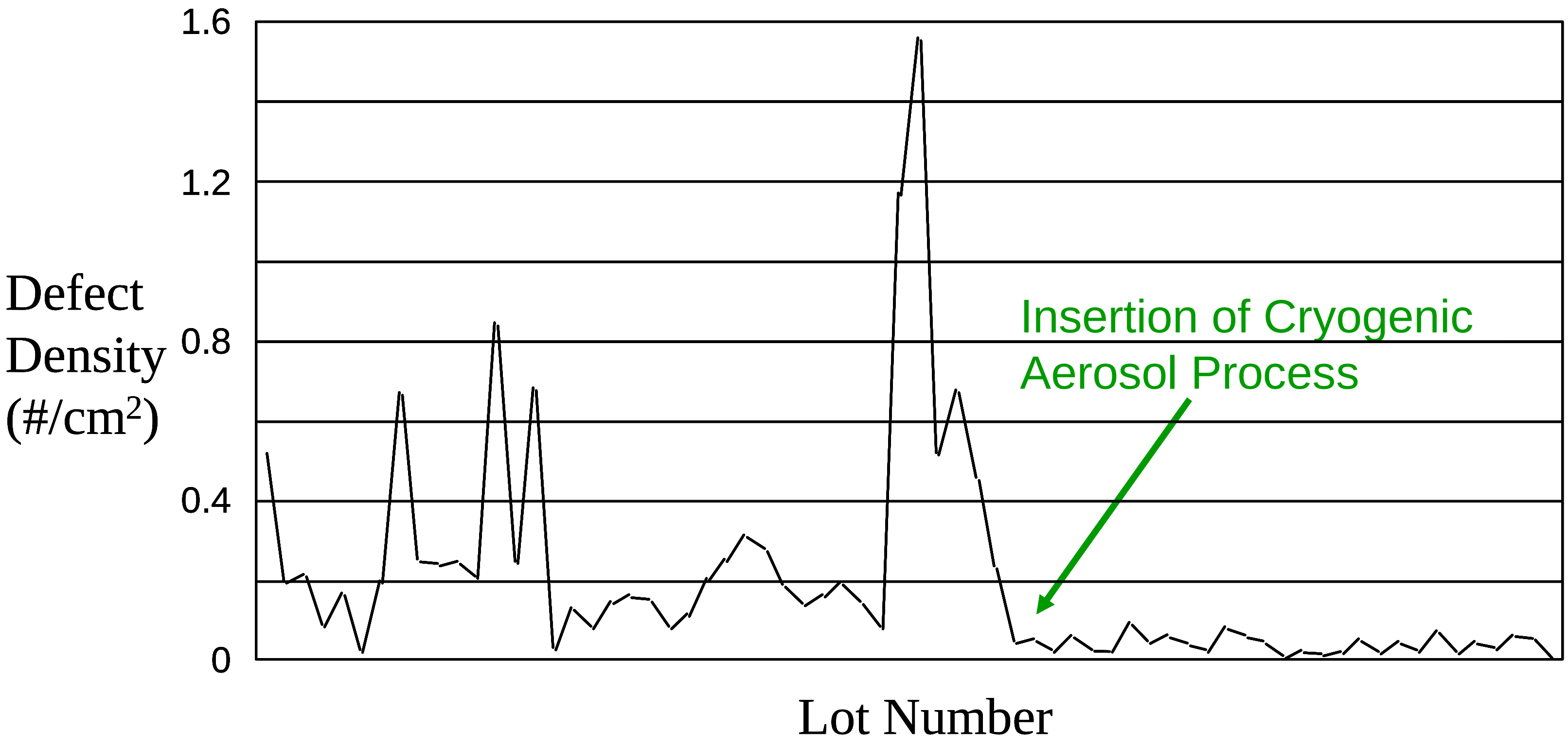
Cryogenic Aerosols

Lot Recovery/Excursion Control



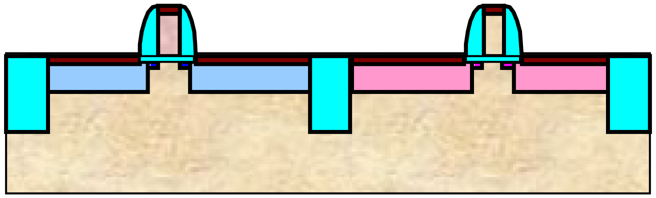
Cryogenic Aerosols

Lowers Defectivity

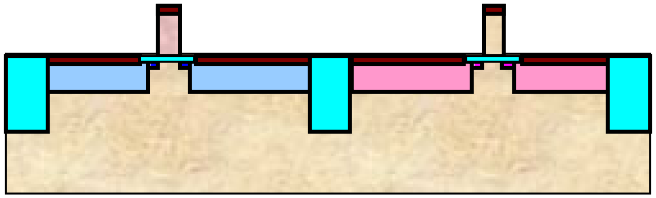


Insertion Of Cryogenic Aerosol Prior to TiN Deposition Controls Defect Excursions

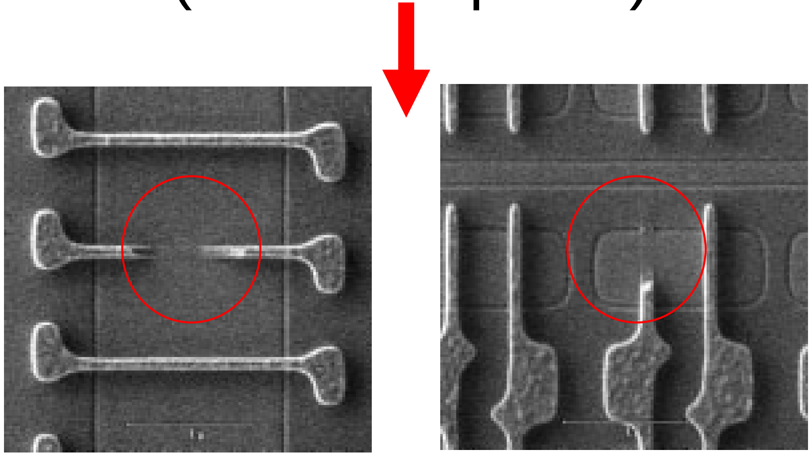
Damage Susceptibility of Poly Gate Structures



No Damage Structure
(With Spacer)



Damage Susceptible Structure
(Without Spacer)



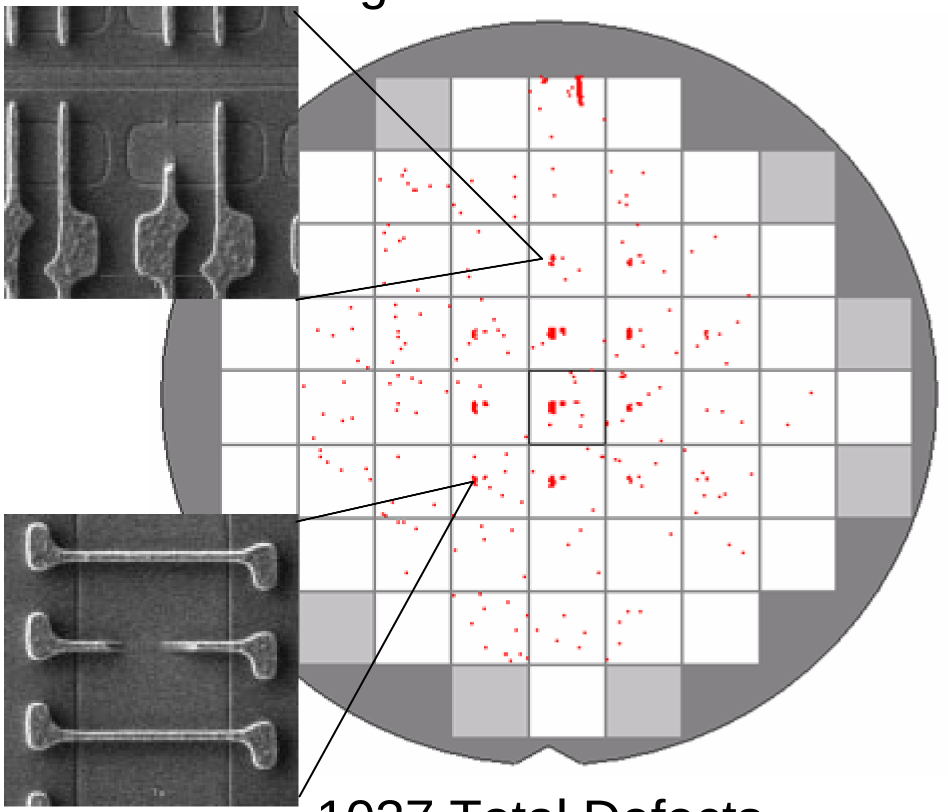
0.11um Poly Lines Without Spacers are Susceptible to Pattern Collapse

<u>Poly Line Dimensions</u>
110nm wide
180nm thick
250nm space (min)

Elimination of Pattern Collapse

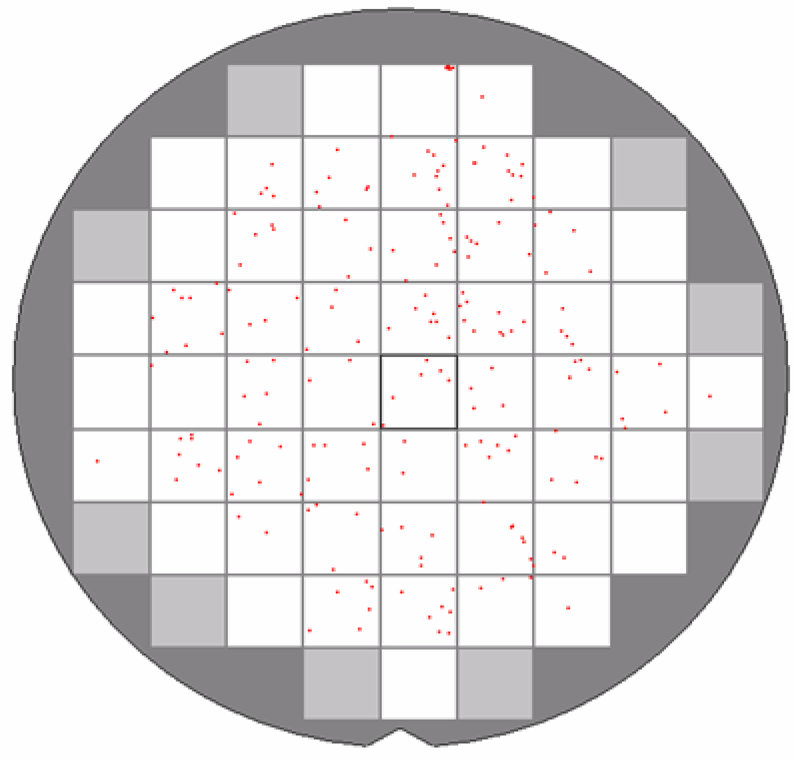
110nm Gates – No Spacer

ArgonClean$^{\text{TM}}$ Process



1037 Total Defects
~900 Due to Pattern Collapse

AspectClean$^{\text{TM}}$ Process



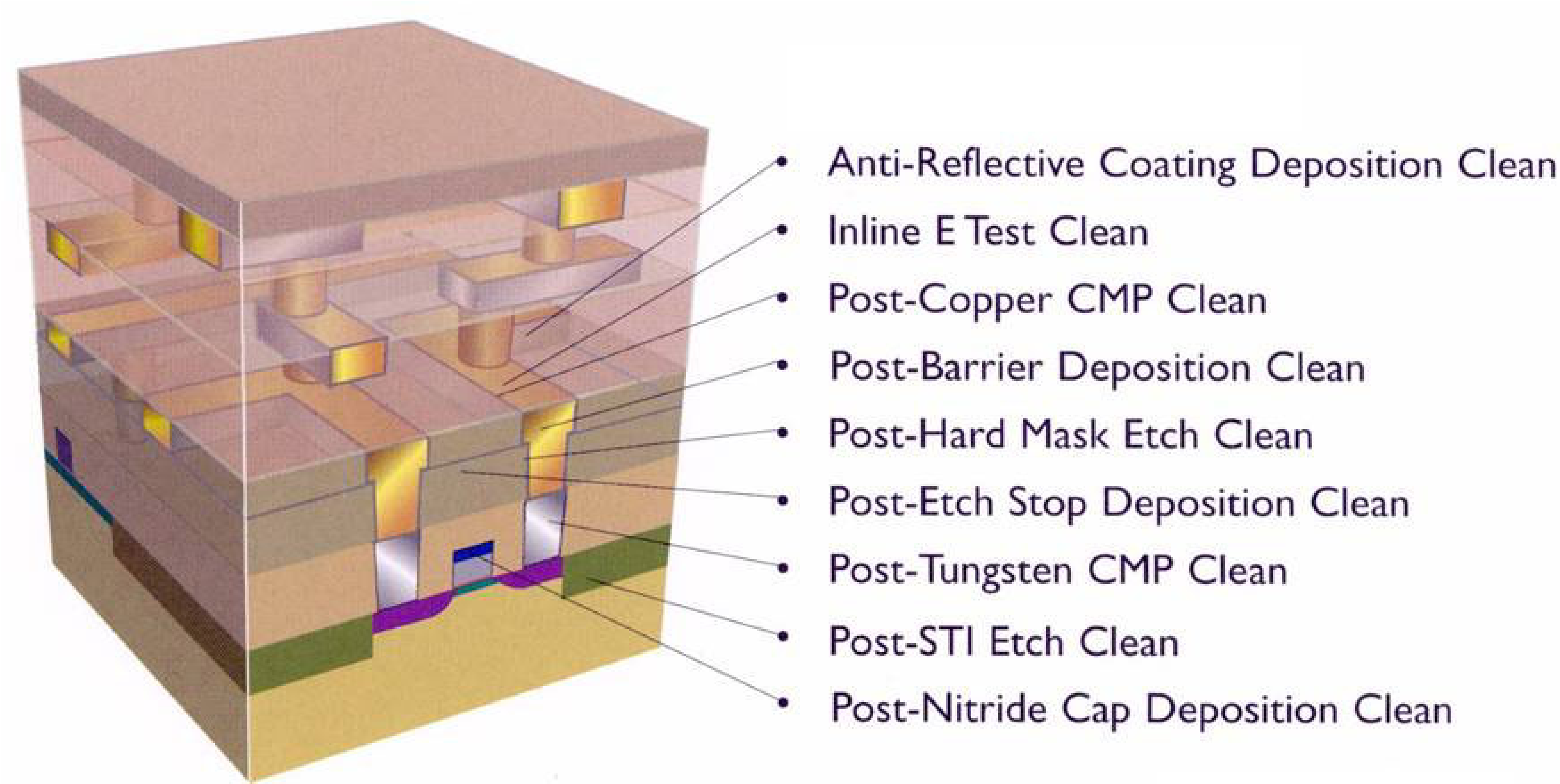
170 Total Defects (Underlying)
No Pattern Collapse

Summary of Device Yield Results

Device	Trial Layer (s)	Recipe	# of Wafers	Percent Yield Improvement
0.18um Logic	4 Cleans – • Post Spacer Deposition, • Post Spacer Etch, • M1 Post Nitride Deposition, • M1 Post SiO Deposition	AspectClean™	12	+1.51 %
	1 Clean • M4 Post Line Etch	AspectClean™	5	+0.65 %
	6 Cleans • Post Line Etch (M1 - M6)	AspectClean™	5	+4.74 %
0.13um Logic	1 Clean • Post Salicide Formation	ArgonClean™	5	+3.11 %
	Multiple FEOL Cleans • Post Spacer Etch, • Post Salicide Formation, • Post Film Deposition	ArgonClean™	6	+12.9 %
	Multiple BEOL Cleans • Post Film Deposition • Post CMP	AspectClean™		

Cryogenic Aerosols

Typical Applications for Defect Reduction



- Anti-Reflective Coating Deposition Clean
- Inline E Test Clean
- Post-Copper CMP Clean
- Post-Barrier Deposition Clean
- Post-Hard Mask Etch Clean
- Post-Etch Stop Deposition Clean
- Post-Tungsten CMP Clean
- Post-STI Etch Clean
- Post-Nitride Cap Deposition Clean

Summary

- **Cryogenic Aerosols**
  - Consists of Frozen Argon and/or Nitrogen Gas
  - No Water, Chemicals, Hazardous Effluents
  - No Modification to Surfaces
    - Material Loss
    - Charging
    - Damage (Physical or Otherwise – e.g. K-Value)

- **Demonstrated Yield Improvements in Production Environment**