Challenges of
Particle Control Technology
in the Nano-scale Device Manufacturing

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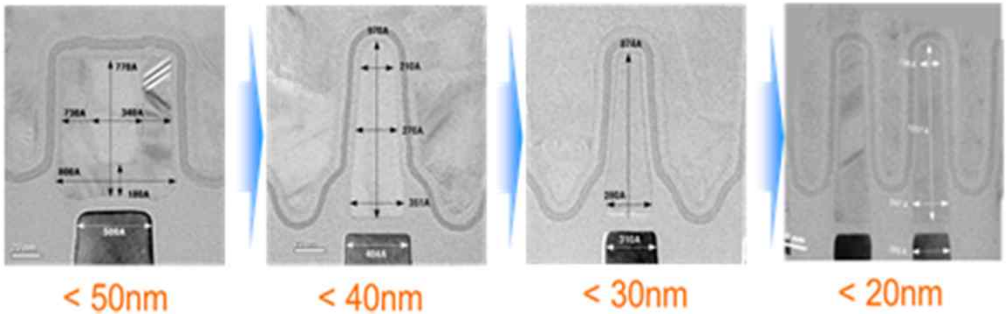
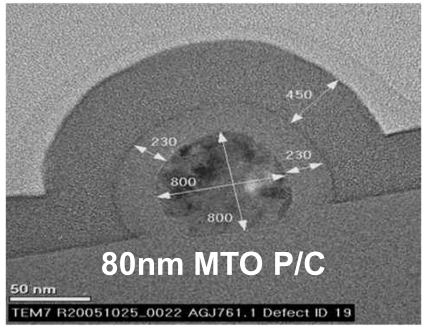
Outlines

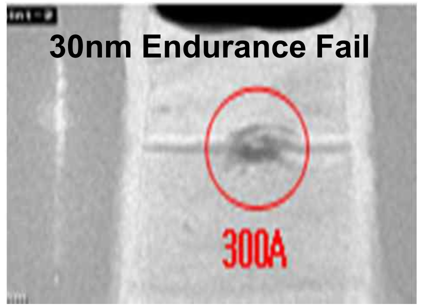
- **Nano-Scale Device and Nano-Particle**
- **Characteristics of Particle Behavior in the Nano-Size Range**
  - Particle Deposition, Wafer Inspection and Cleaning
- **Particle Control Technology in the Device Manufacturing**
  - Particle Generation and Control inside the Process Equipment
  - Cleanroom Environment
  - Precursor Material, Liquid Chemical and Slurry Particle Control
  - In-situ Chamber Cleaning and Exhaust Gas Abatement System
- **Conclusions**

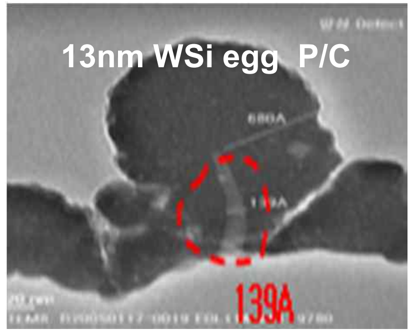
Nano-scale Device and Critical Defect Size

- NAND-Flash Memory Cell Structure

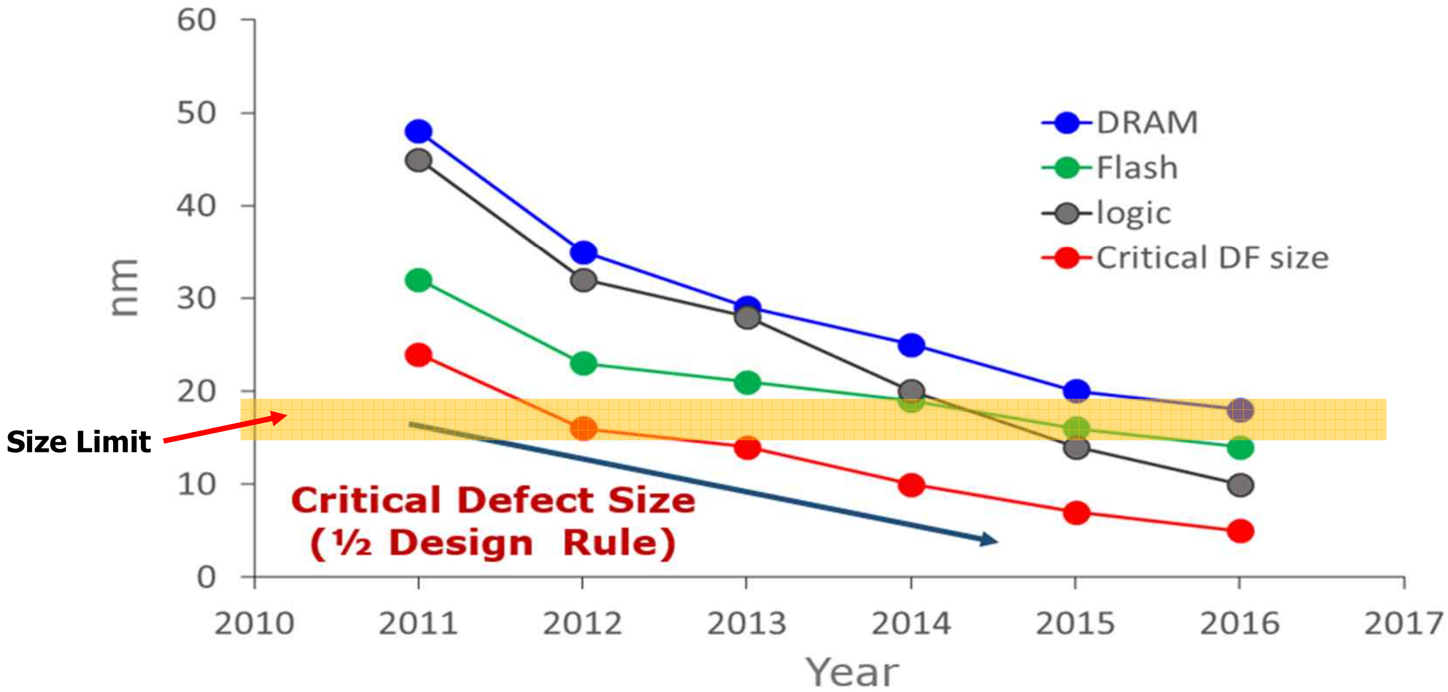








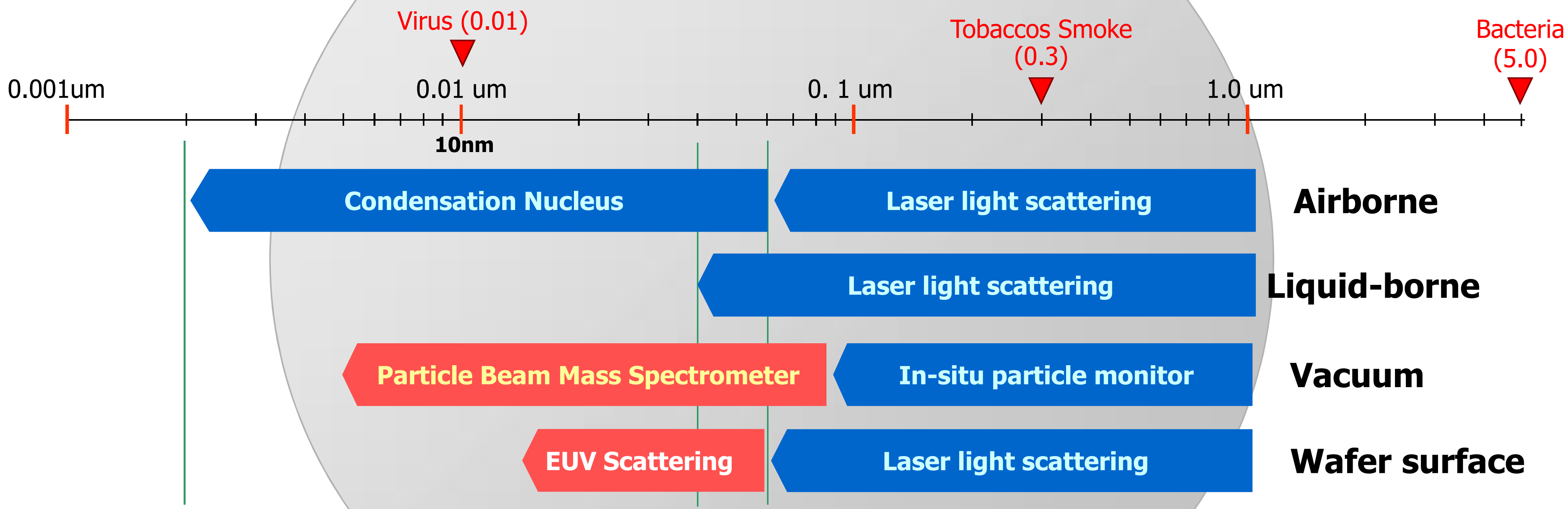
- Design Rule & Critical Defect Size



Particle Size and Measurement

■ Challenge of Metrology: Nano-particle

- Particles : 0.002 μm (2 nm) < D_p < 100 μm
- Nanoparticle : D_p < 0.1 μm (100 nm)

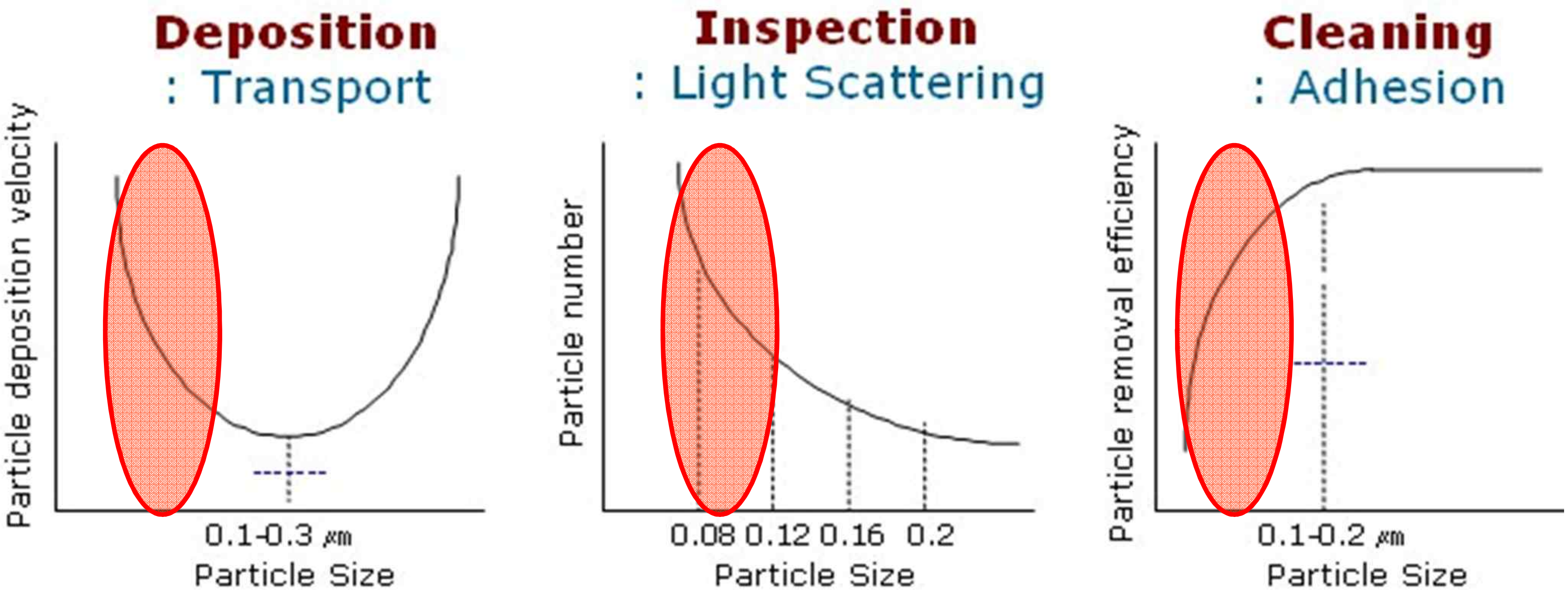


Particles in Semiconductor Manufacturing Process

➔ Yield drop, Productivity Loss (Throughput, PM, Tool Utilization)

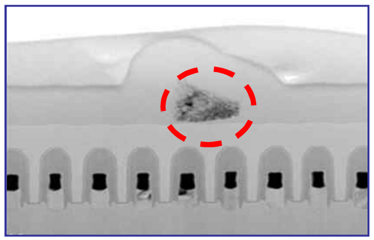
Characteristics of Nano-Particles on the Wafer Surface

■ Characteristics of Nano-Particles



Nano-Particle in the Semiconductor Manufacturing Process:

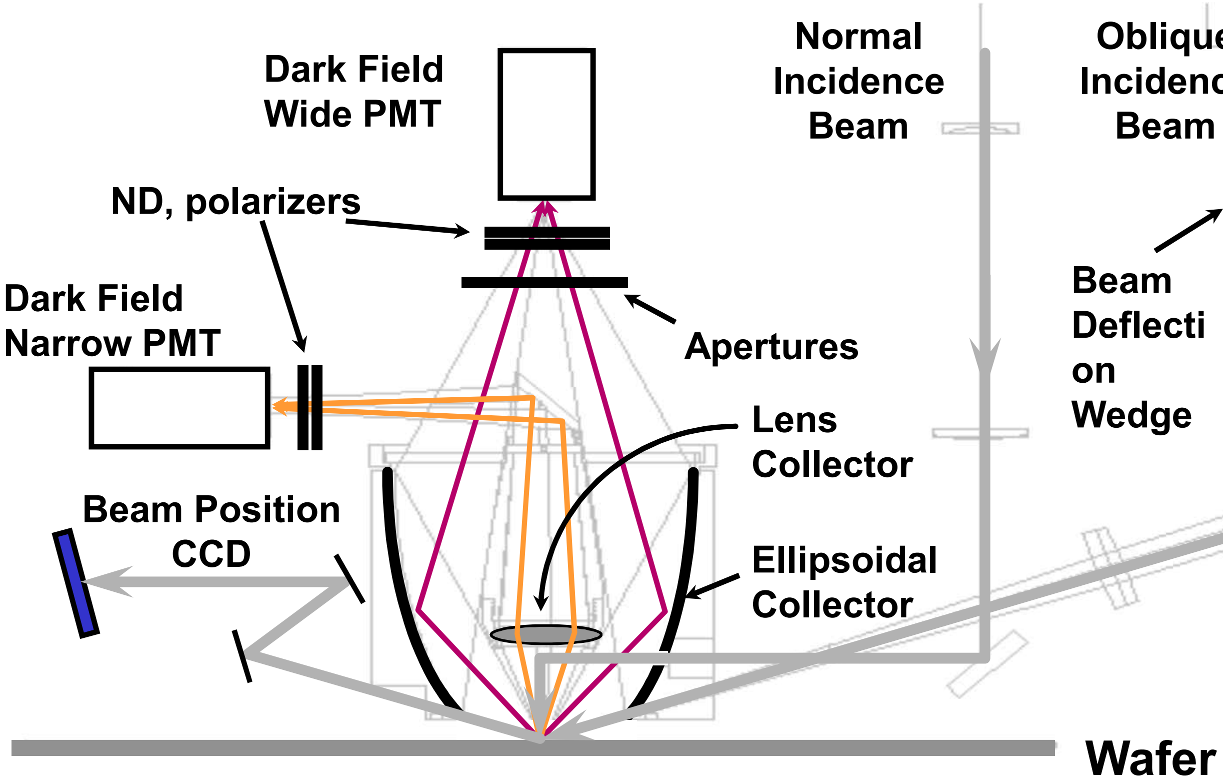
- **Higher number concentration**
- **easily deposited on wafers**
- **Difficult to detect and analyzed**
- **Difficult to remove once deposited**

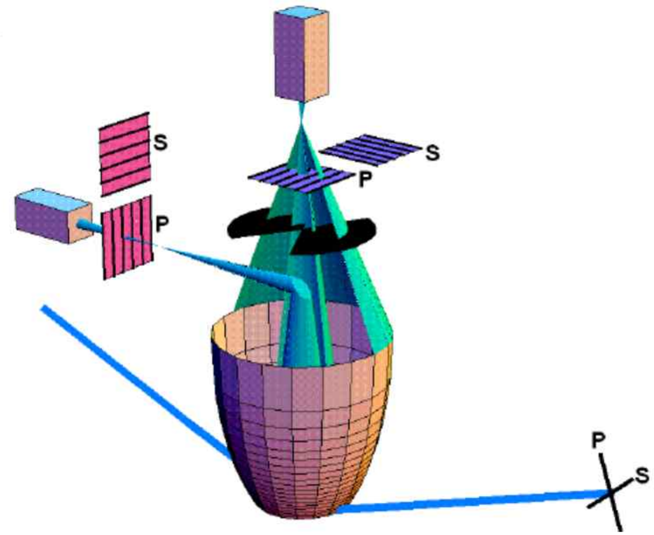


Particle Inspection on the Wafer Surface

■ Optical Particle Inspection Equipment – Wafer Surface Scanner : SP1/2

- Ar(488 nm)/ DUV(365 nm) laser beam : normal & oblique incidence, s & p polarization
- Two PMT detectors : wide and narrow scattered light collection
- Rotational angular scanning of wafer



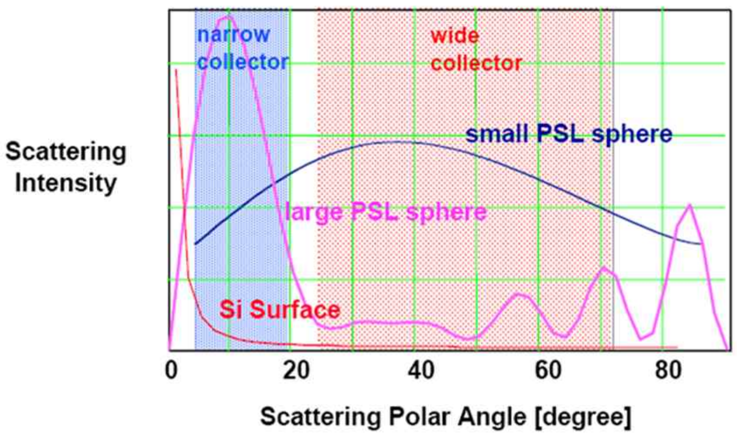


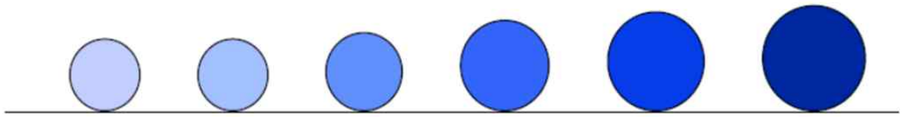
(Source: KLA Tencor)

Particle Standard on the Wafer Surface

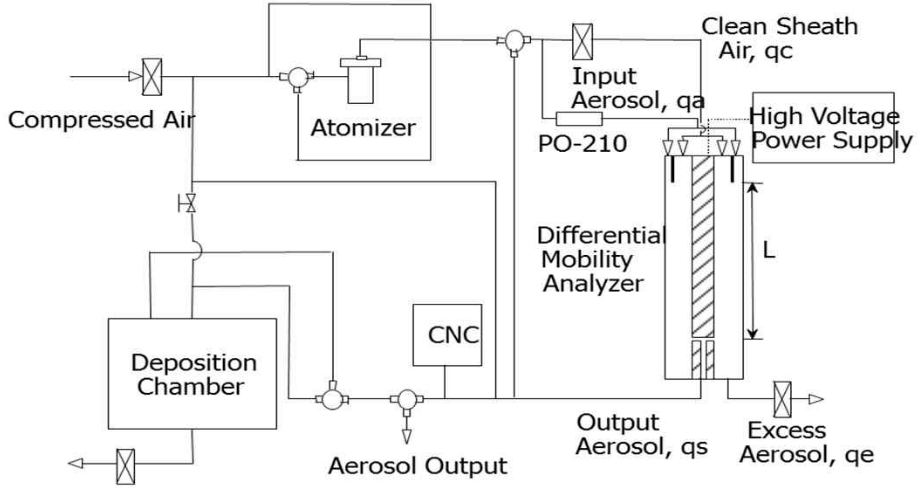
■ Standard PSL Sphere Particle – SP1/2

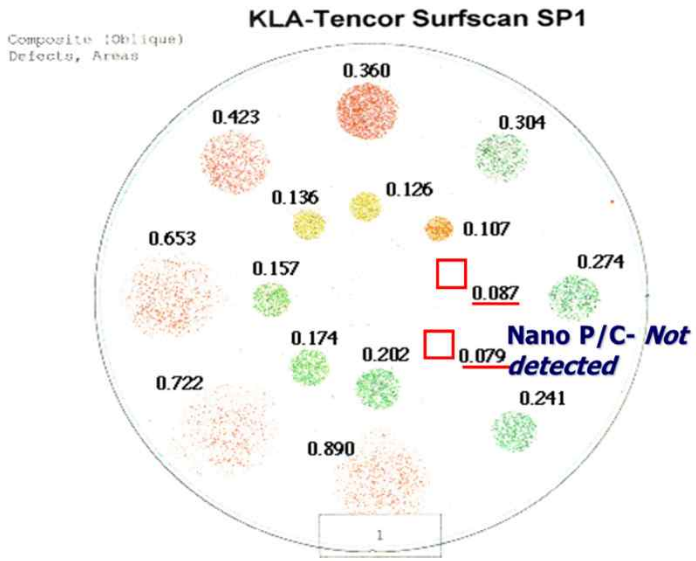
- Wafer calibration particle standard
Particle deposition system (spherical PSL)





	Si	Cu	Al	Si3N4	PSL	SiO2
Index	3.88	1.14-2.52i	0.75-5.75i	2.04	1.60*	1.47
LSE	72 nm	72 nm	75 nm	90 nm	100 nm	105 nm





Ref.) S.K.Chae, J.Sun, B.Y.H.Liu and S.H.Yoo," Particulate Contamination in the Next Generation Fab.: Standardizing Defect Inspecting Tools," Future Fab International 6, p. 229-237, 1999

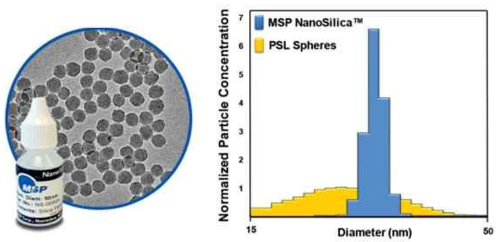
Recent Wafer Surface Scanner and Particle Standard

KLA-Tencor
Surfscan SP5

MSP
Particle Deposition System

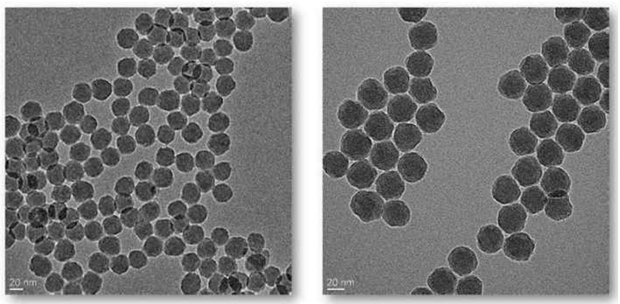
- The latest tools use extreme ultra-violet (EUV: 266 nm) lasers, which damage PSL spheres, noticeably decreasing their size with repeated inspection.

Sensitivity	Throughput
26 nm	87 wph
19 nm	19 wph



Nano-Silica Production

TEM images of MSP NanoSilica™



30nm **50nm**

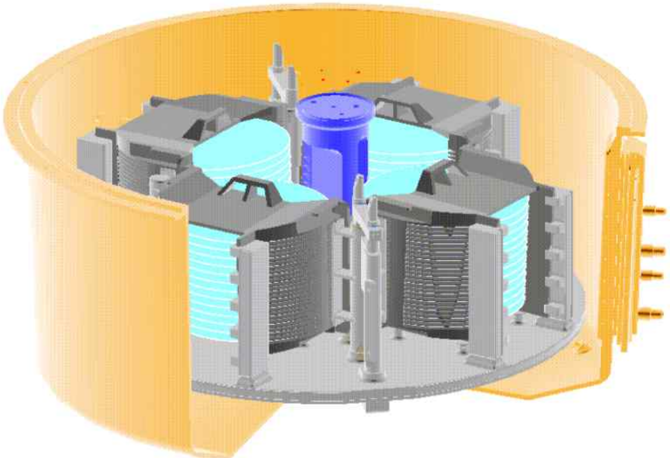
- SiO_2 spheres can be the industry-preferred replacement for PSL spheres.

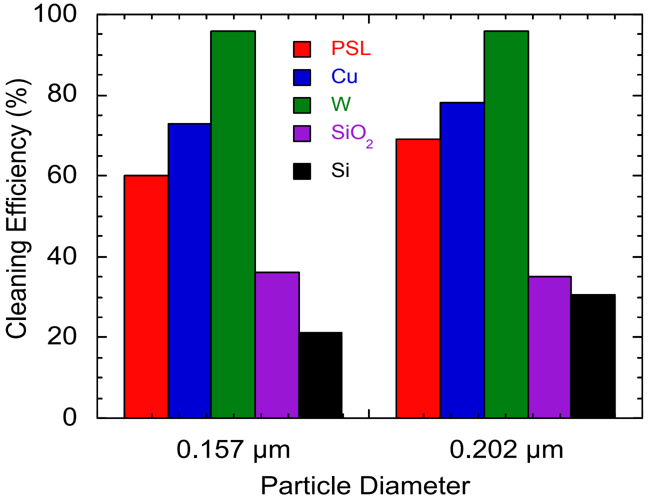
15 nm, 18 nm, 20 nm, 24 nm
30 nm, 35 nm, 40 nm, 50 nm

Particle Removal and Cleaning

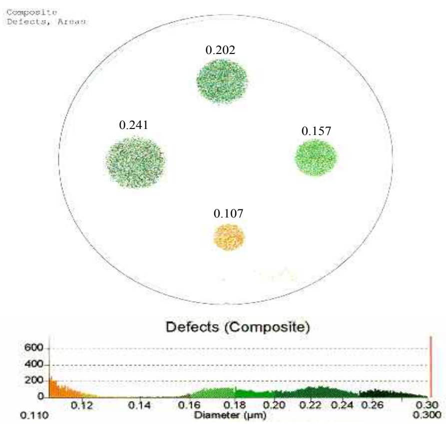
■ Wet Particle Cleaning Technology

Wafer Cleaning Equipment (Spin Spray Processor)





Spot Deposition
of Tungsten Particles



<u>Chemical Cleaning</u>
High Temperature Concentration

- ➢ SPM (H_2SO_4, H_2O_2)
- ➢ APM (NH_4OH, H_2O_2, H_2O)
- ➢ DHF (HF, H_2O)
- ➢ Rinse
- ➢ IPA Dry

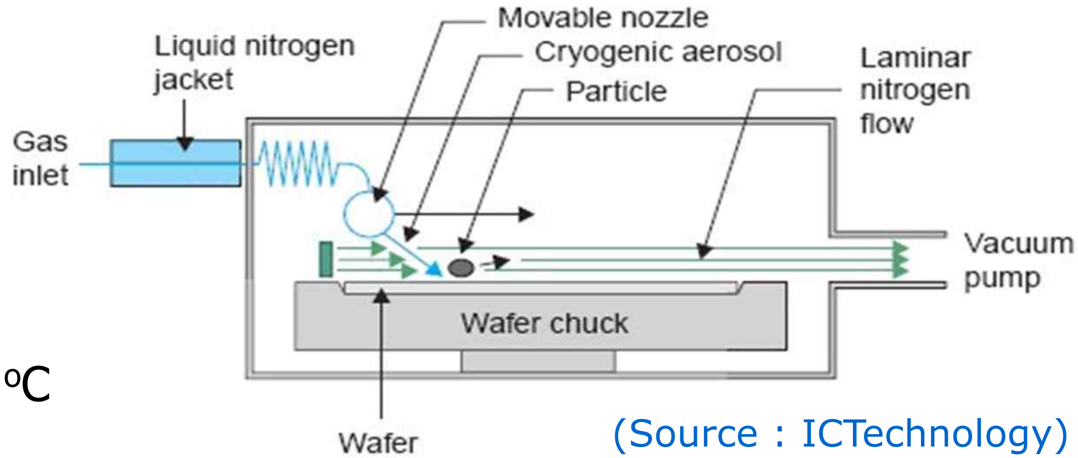
- FSI Mercury Spray processor
- Rinse and dry only process
- Monodisperse process particles on bare wafers
- Cleaning Efficiency

= 1- (Nclean-Ninitial)/(Ndepo.-Ninitial)

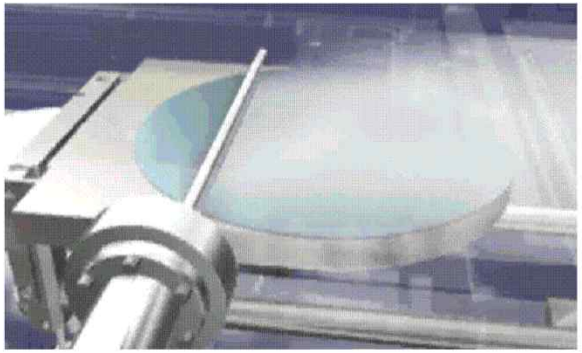
Particle Cleaning Technology

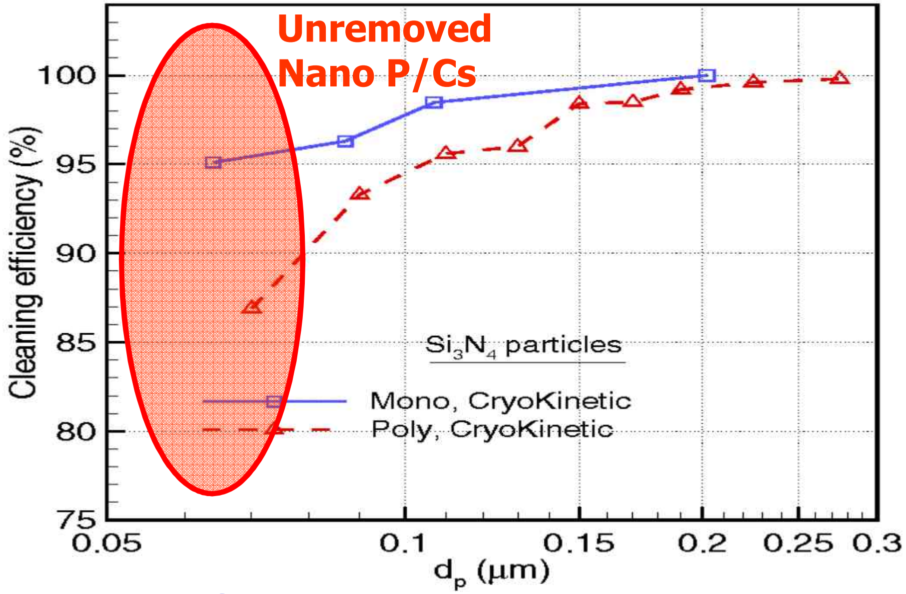
■ Aerosol Cleaning Technology

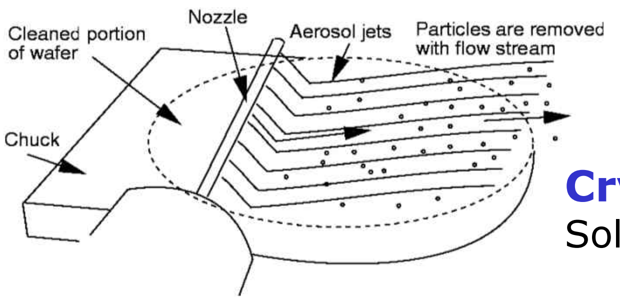
- Merits of Dry Cleaning
  - Environmentally Friendly
  - Easier Integration
  - Better Uniformity than Megasonic
- Cryogenic Aerosol
  - Super-cooling Gases less than -150 °C
  - Solid Aerosol Cluster
  - Removal by Momentum Transfer



(Source : ICTechnology)







Cryo-Kinetic Aerosol Wafer Cleaning

Solid CO_2 (snow), H_2O (Ice), Ar (higher momentum), N_2

Particle Control Technology in the Device Manufacturing

■ Particle Control Technology in the Semiconductor Device Manufacturing

Identification
(Root-Cause Analysis)

- Particle Composition Analysis
  (FIB, EPMA, AES etc.)
- Process Chemistry Analysis
- Equipment Part/Kits Material Analysis

Wafer Inspection

- Patterned/Non-pattern Wafer
  (particle size, number,shape review)

Cleaning & Removal

- Mechanical Scrubbing
  (spin, megasonic, brush, aerosol etc.)
- Wet Cleaning (chemical etching)
- Process Chamber In-situ Gas Cleaning
- Equipment Parts Cleaning

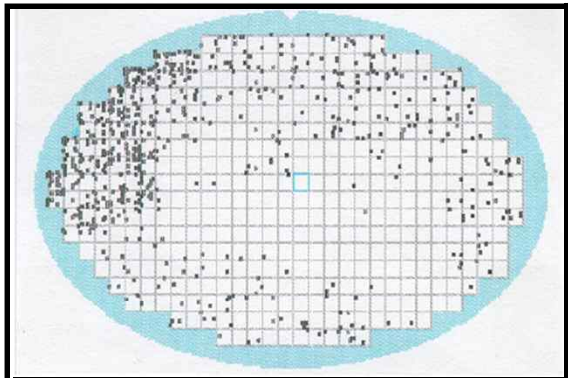
Preventive Monitoring

- Monitoring Wafer
- In-situ Particle Monitoring
- Equipment Cleaning Periods

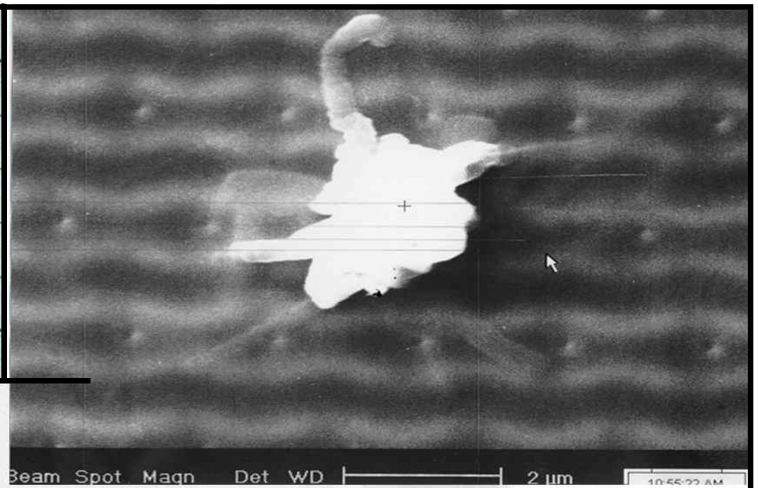
Patterned Wafer Particle Inspection and Analysis

■ In-line Patterned Wafer Particle Inspection and Analysis

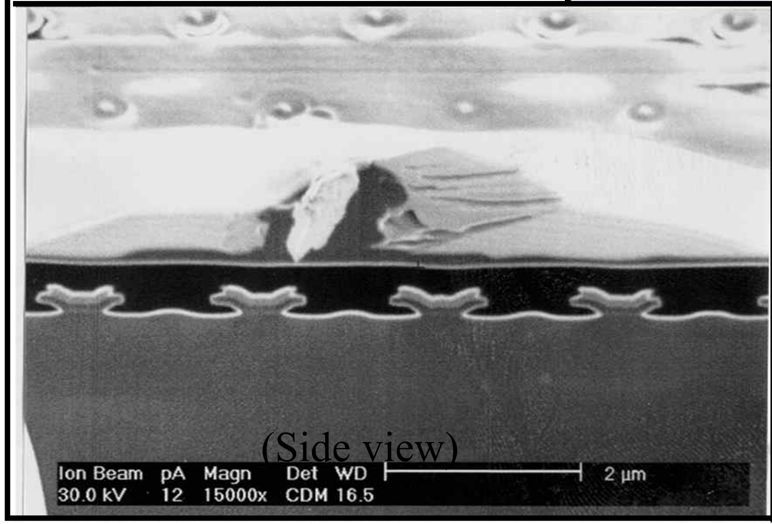
- Example on LPCVD Process Particles
- Patterned wafer inspection, SEM review and FIB / EDX composition analysis



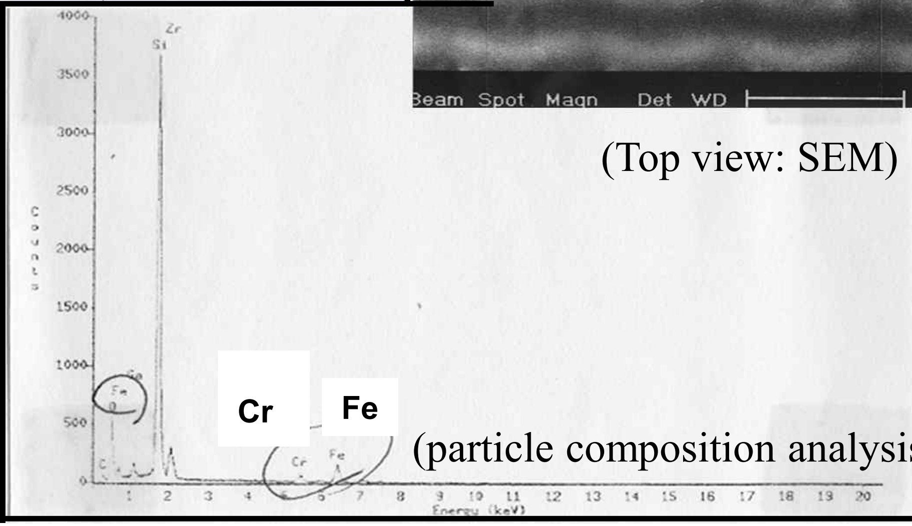
Size	Defect Count
< 1㎛	12
1 ~ 2㎛	142
2 ~ 3㎛	79
3 ~ 5㎛	53
> 5㎛	37
TOTAL	713



(Top view: SEM)



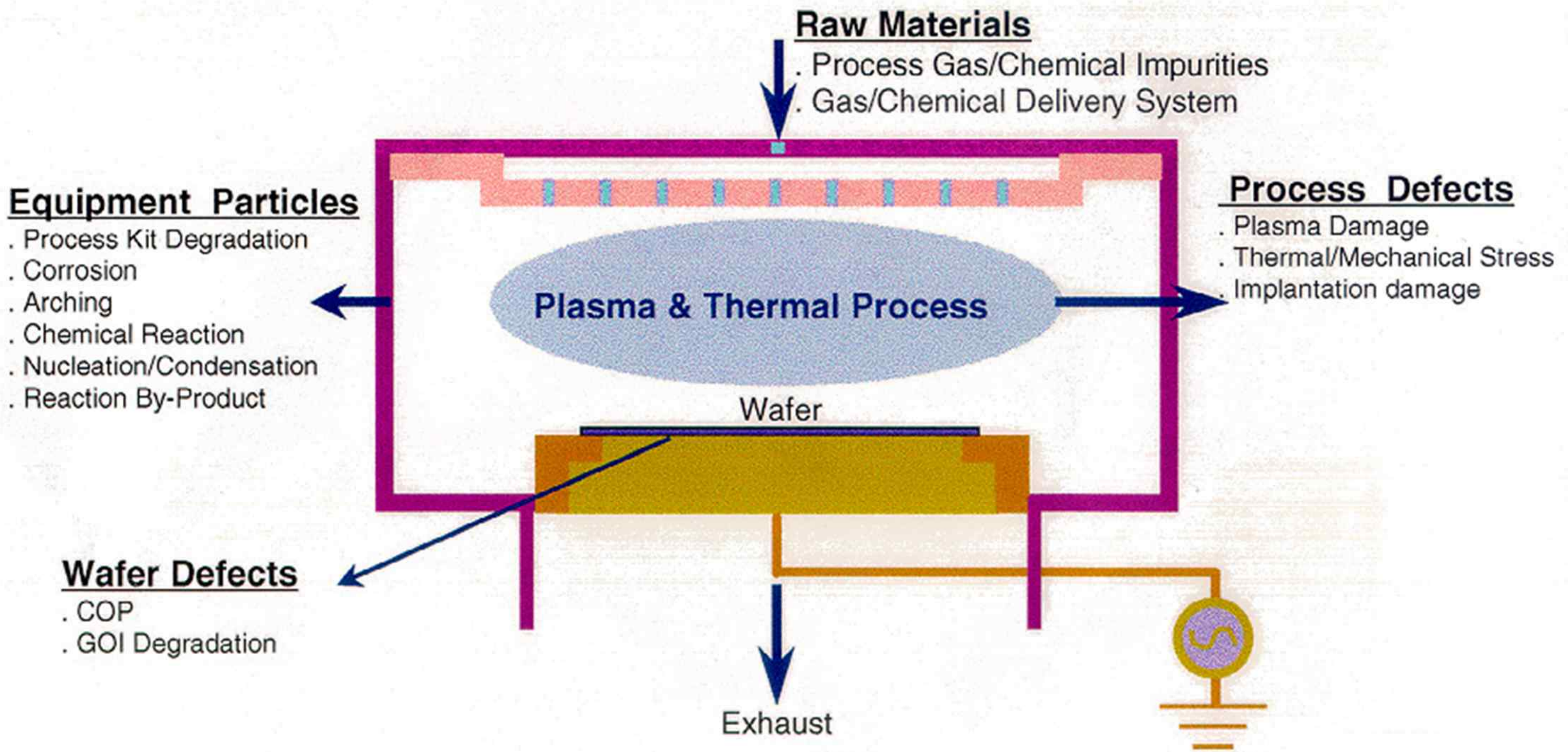
(Side view)



(particle composition analysis : EDX)

Particle Sources in the Process Equipment

■ Particle Contamination Sources



Ref.) S.K.Chae, "Defect-Free Process in Semiconductor Manufacturing," Materials Characterization Strategy for the Giga-Bit DRAM Era II, SEMICON West 98

Generation, Transportation and Deposition of Particles to the Wafer Surface in Process Chamber

Mechanism

- Gas-phase nucleation
- Condensation
- Erosion/ Corrosion
- Arcing
- Hardware Degradation

- Flow field
- Thermal
- Plasma
- Electric field
- Magnetic field

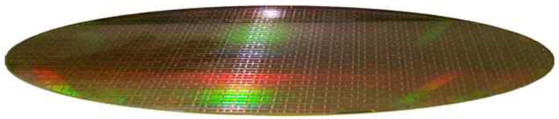
- Gravitational
- Electrostatic, Diffusion
- Thermophoretic
- Inertial Impaction

Process

Generation

Transportation

Deposition



Control

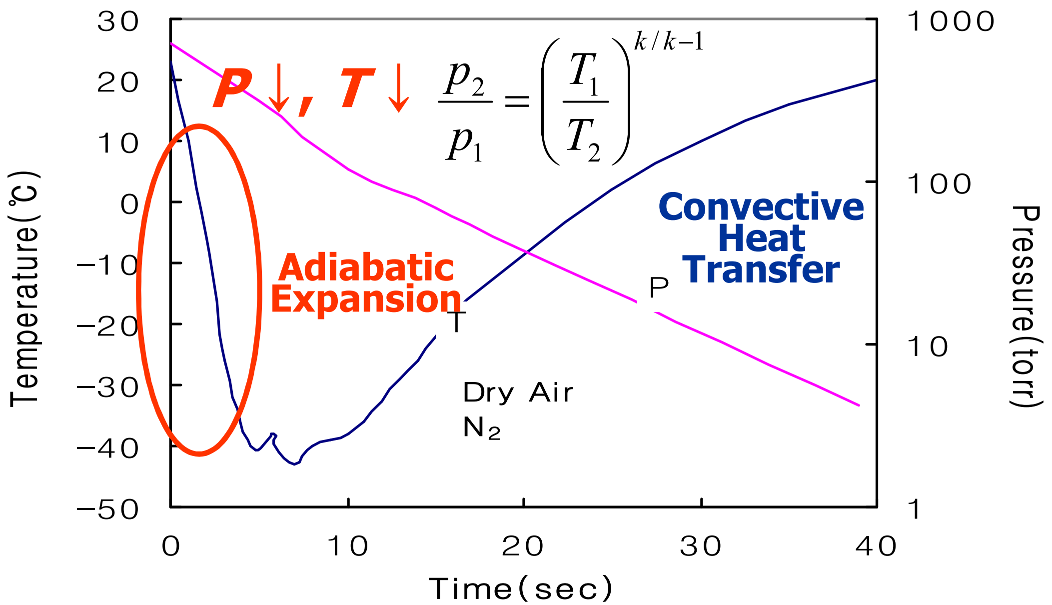
- Chemistry modification
- Material compatibility
- Slow pump and vent

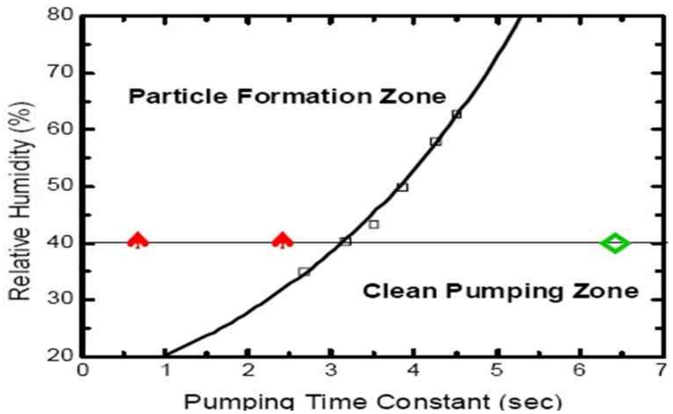
- Pump-purge management
- Flow management
- Magnetic Field management
- Pressure management

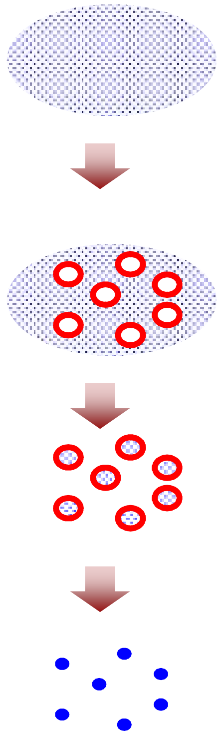
Ref.) A.Gupta, "Particle Behavior and Reduction in a Plasma Process Chamber," Applied Materials, Inc, 1994

Particle Generation during Vacuum Pump Down

■ Particle Generation at the Load Lock during Pumping Down







Gas Phase Precursors

Rapid Pump Down
Adiabatic Expansion
Super-saturation
Homogeneous Nucleation

Liquid Droplet

Condensation

Liquid droplets with dissolved gases

Evaporation

Residue Particles

temperature abruptly decreases at initial pumping

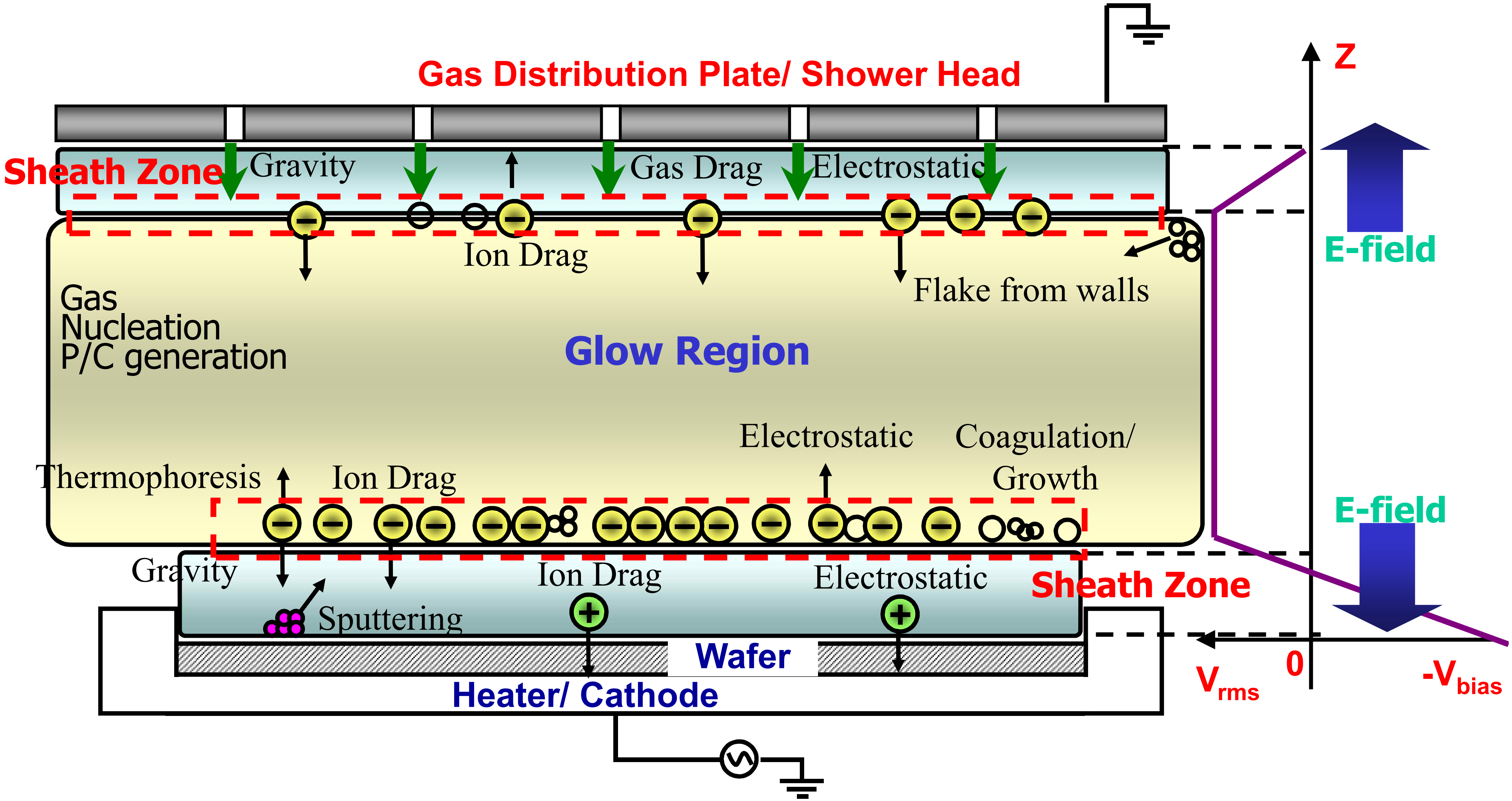
→ super saturation → particle formation

- Slow pumping
- Dry N_2 purge & pumping
- L/L wall heating

Ref.) Y.Ye et al, J. Electrochemical Society, 140 (1993) 1463

Particle Behavior in Plasma

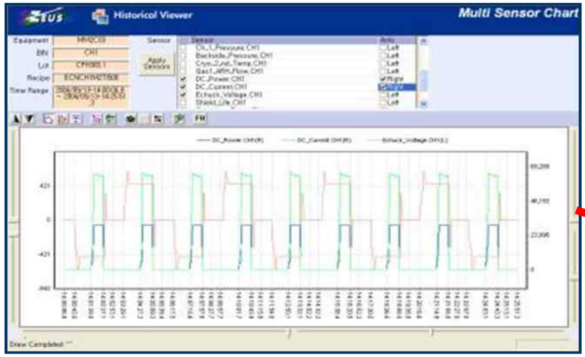
Dusty Plasma – Force Balance in a Plasma Reactor



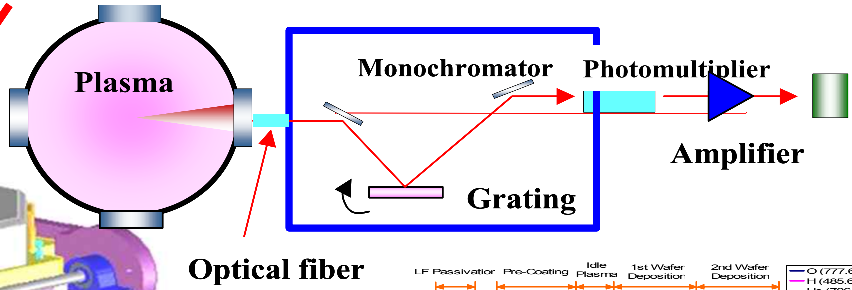
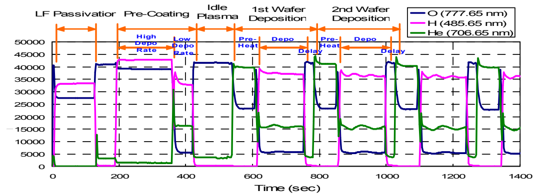
Particle Monitoring and Simulation

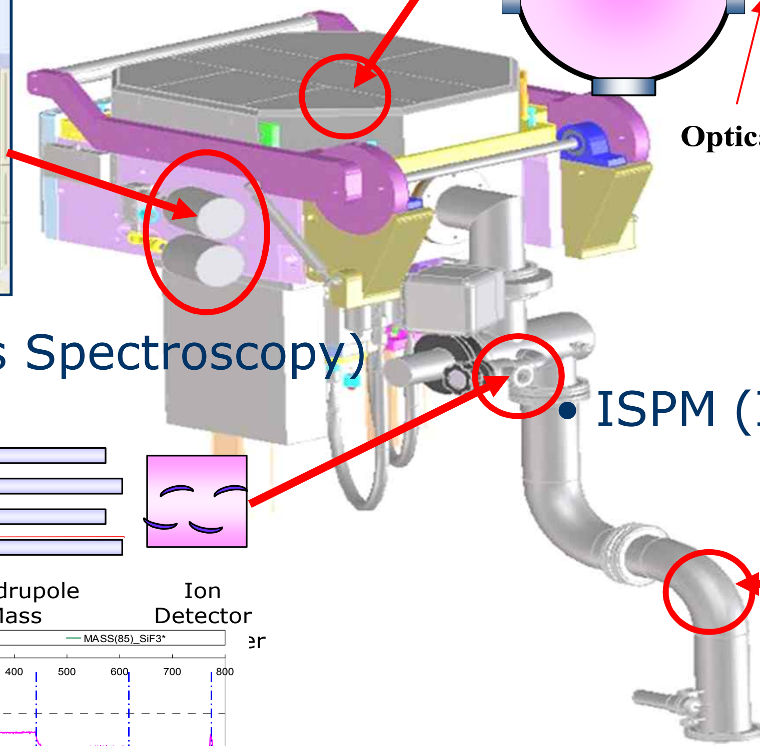
■ In-Situ Process Monitoring Technology

- Sensor signal analysis

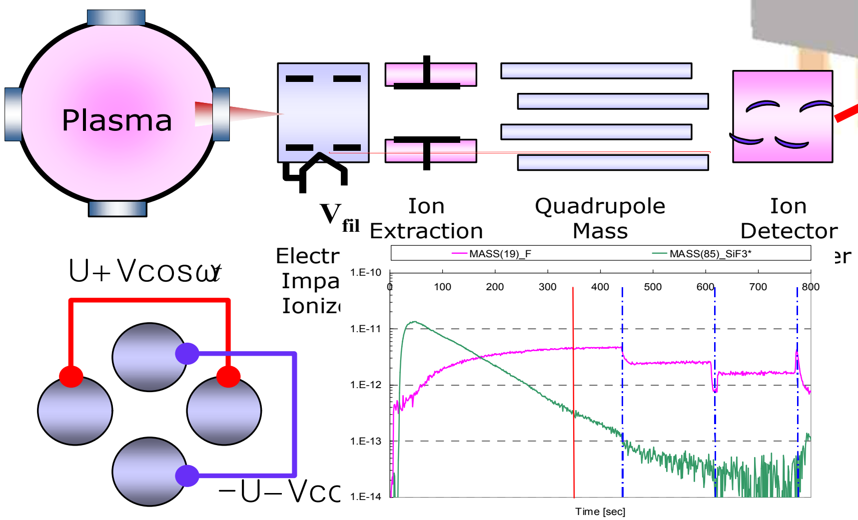


- OES (Optical Emission Spectroscopy)

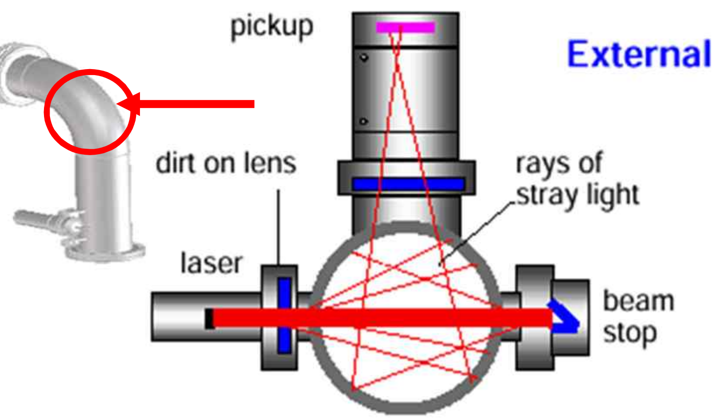





- QMS (Quadrupole Mass Spectroscopy)



- ISPM (In-Situ Particle Monitoring)



Design of Particle-Free Process Equipment

- **Simplified Design of Process Chamber**
  - Less Number of Process Kits
  - Particle-transport Control in Fluid Flow, Thermal, Plasma and Electromagnetic Field

- **Careful Selection of Component Design and Materials**
  - Particle-Free Material including Reaction with Process Chemicals
  - Longer Component Lifetime, especially Particle Generation Point of View

- **Prevention of Sudden Process Parameter Change**
  - Simplification of Process Steps
  - Damping Capability for Sudden Change

- **Easy Access for In-Situ Process Diagnostic Tools**
  - Access for Diagnostic Tools and Ports for In-Situ Monitoring
  - Easy Control through Main-Equipment Software

Contamination Control for Cleanroom

Airborne particle

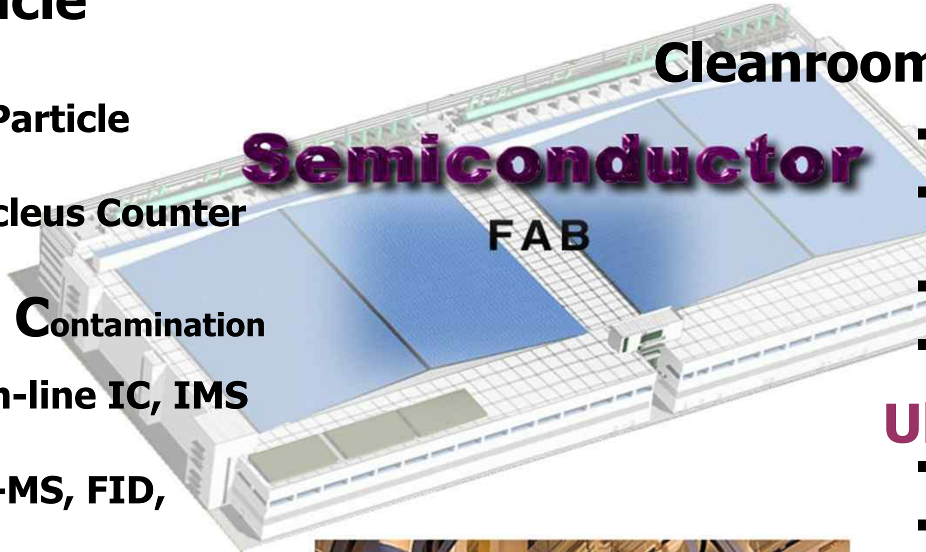
- Laser-scattering Particle counter
- Condensation Nucleus Counter

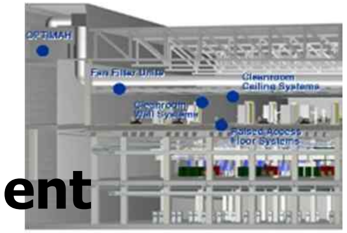
Airborne Molecular Contamination

- Acids } HPIC, In-line IC, IMS
- Bases }
- Condesnible : GC-MS, FID, FTIR
- Dopants : ICP-MS

Surface Molecular Contamination

- VPD-ICP-MS
- Surface Acoustic Sensor
- TDS GC-MS, TD-API-MS
- ATR-FTIR, RAMAN





Cleanroom Environment

- Temperature/Humidity
- Differential Pressure, Air velocity
- ESC, ESD, EMI
- Vibration & Noise

Ultra Pure Water

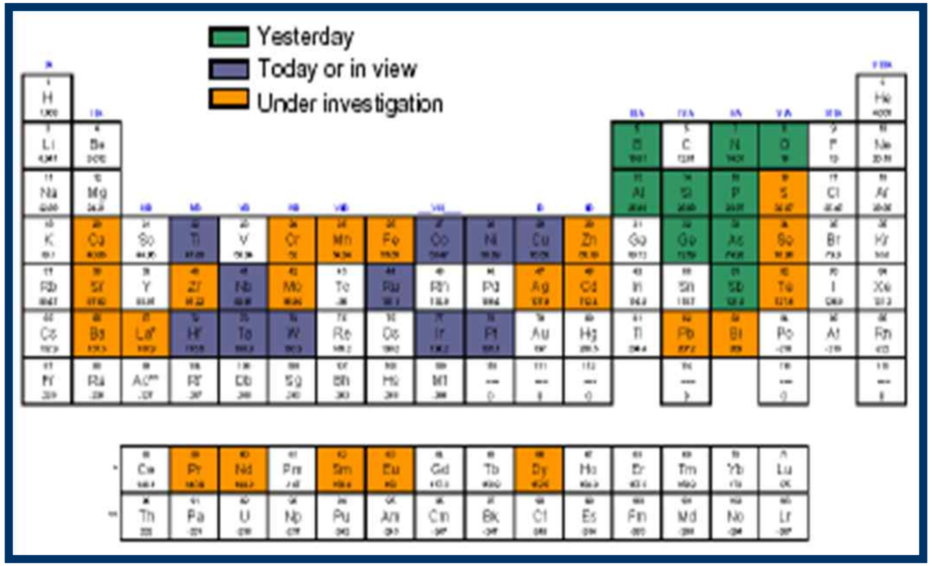
- Liquid Particle counter
- Total Organic Contamination
- Dissolved Oxygen
- Resistivity
- Ion, Metal Impurity

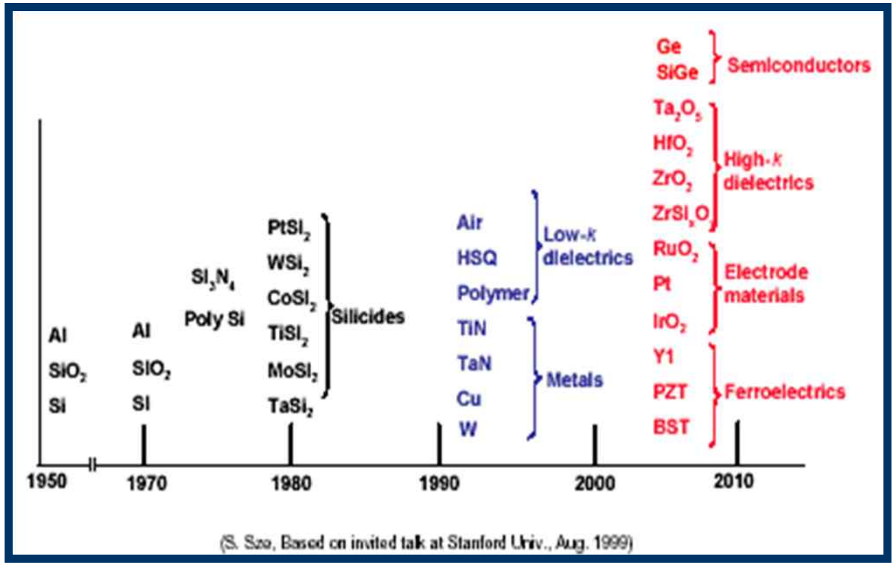
Bulk-Gas

- Gas particle counter
- Dewpoint
- Moisture
- Ion/Metal impurity

New Materials for Nano-Devices

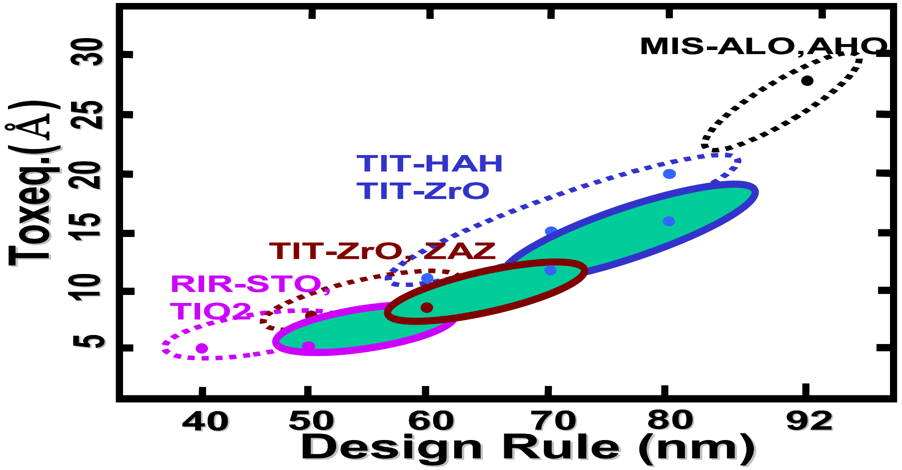
■ New Materials for Future Devices





(Source: Stanford University)

■ Capacitor Trend & Materials



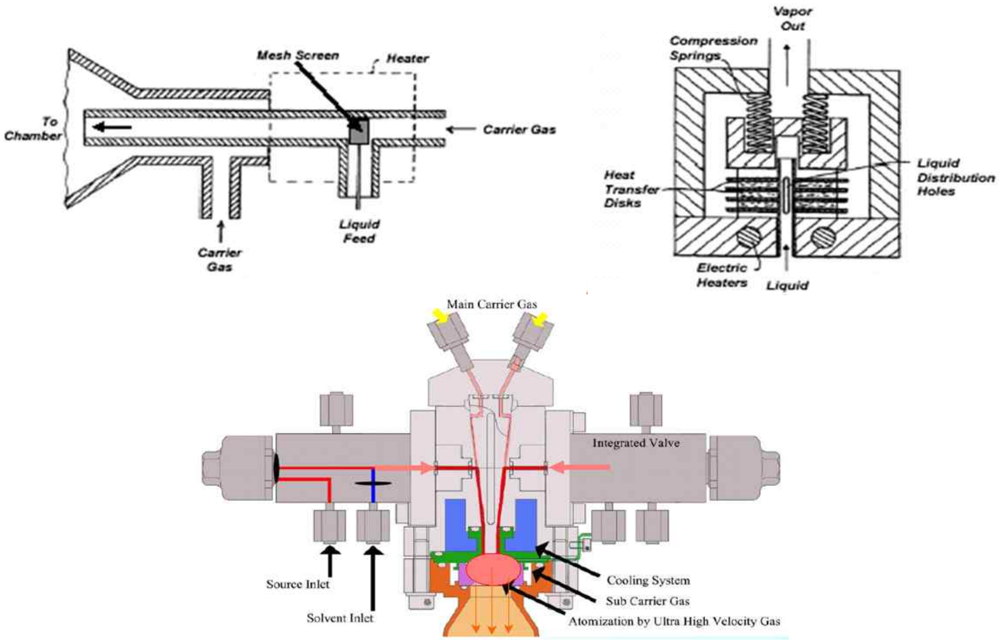
Item	Hf	Zr			Ru
	TEMAHf	TEMAZ	NNZ-22	Kc-Zr	RuDER
Film	HfO_2 (ALD)	Zr_2O_3 (ALD)			Ru (ALD)
Vis-cosity	2.3 cP	3.4 cP	-	-	6 cP

Particle Control for Novel Liquid Precursors

■ Vaporizer (Liquid Droplet Generator) Technology

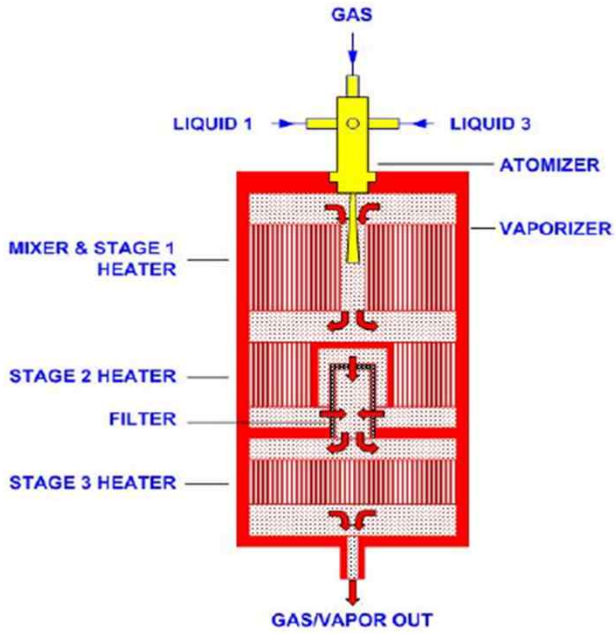
- High-k HfO_2 Liquid Precursor (TEMAH)

Previous Design



- Current Liquid Source Vaporization Tool
- Large Liquid Droplet

New Vaporizer

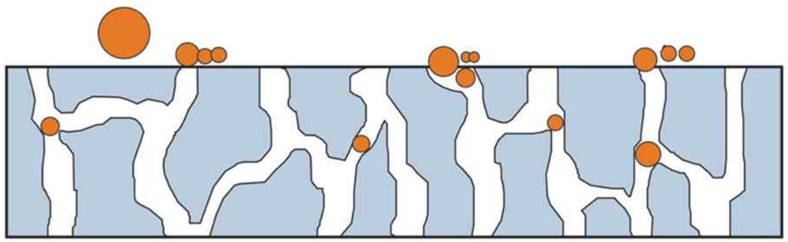


- Atomizer Technology
- Fine and Uniform Size Liquid Droplet
- Enhance Film Quality and Particle Control

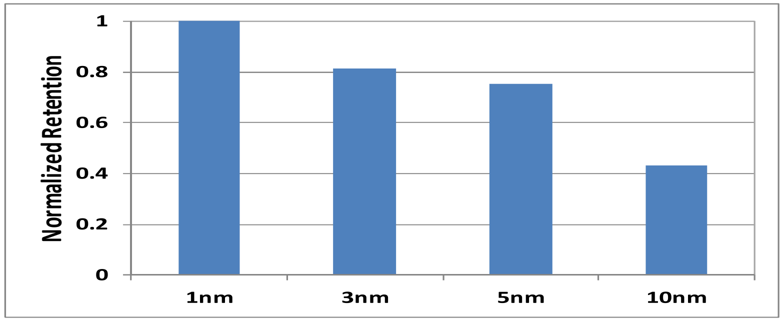
Liquid Chemical Filtration – Material Quality Control

Sieving Removal – Filtration Based on Size Exclusion

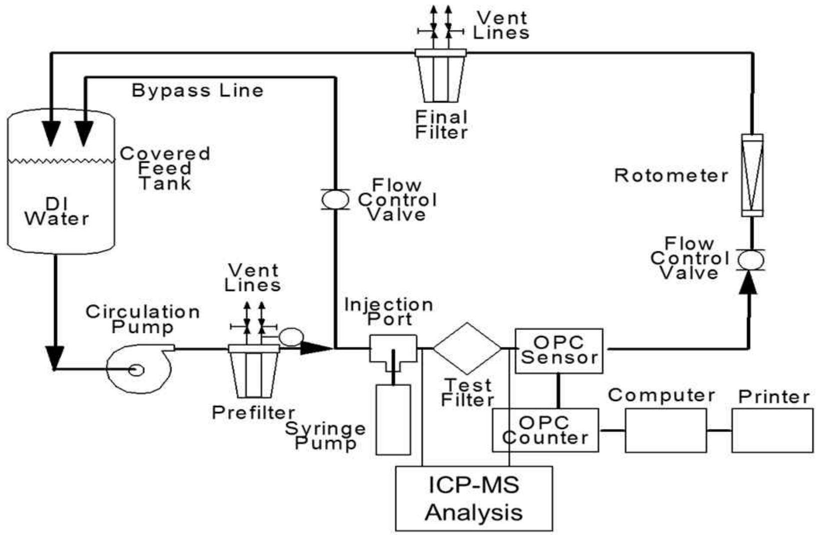
- In sieving (size exclusion), particles are too large to pass though the pore structure.
- They are either captured on the surface or in smaller passages inside of the structure.
- The smaller the pore size, the better sieving efficiency



Retention using 5 nm Au Nano-particles in PGME (Unmodified UPE membrane)



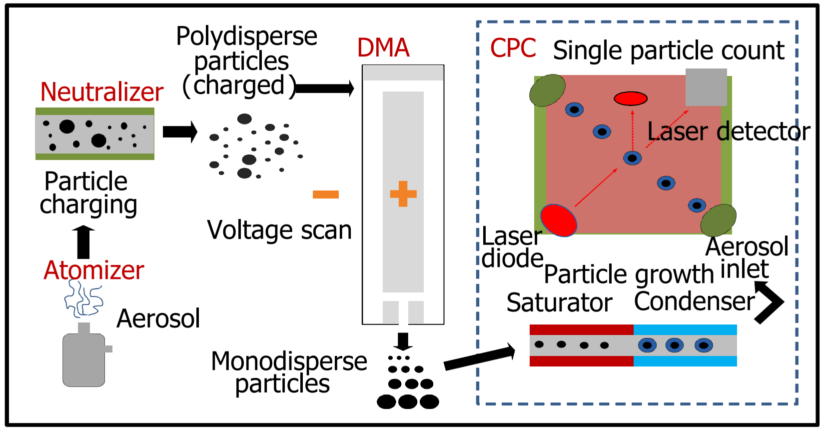
Retention Test Stand Schematic



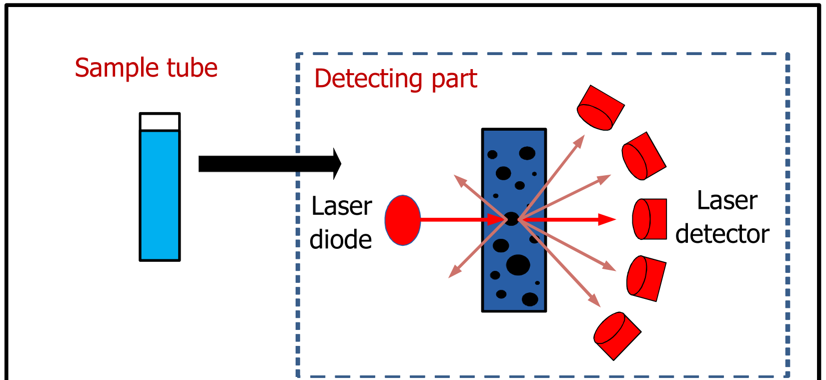
Particle Size Characterization for CMP Slurry

■ Nano particle size distribution

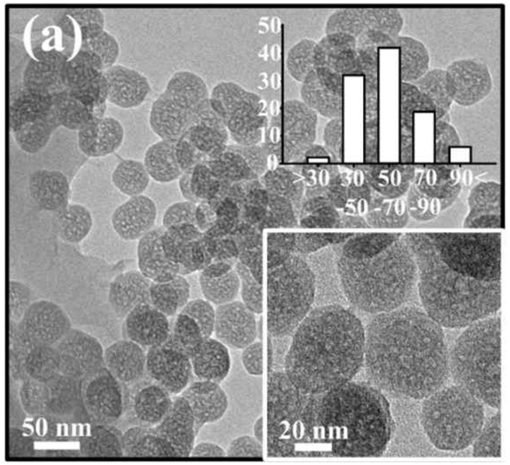
Scanning Measurement Particle Sizer (SMPS)



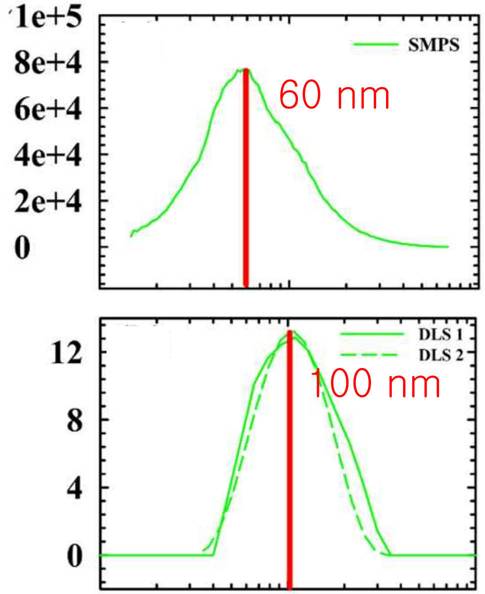
Dynamic Light Scattering (DLS)

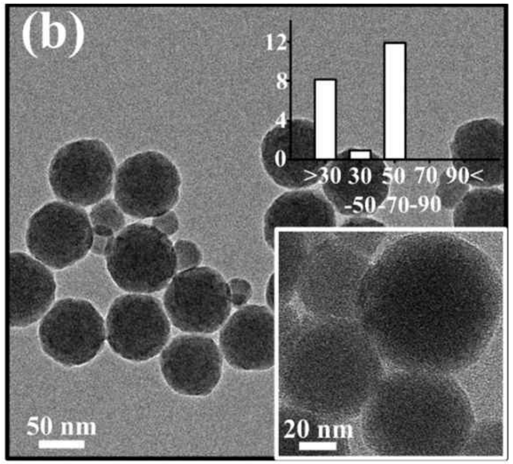


Sunjae Jang et al. Evaluation of Slurry Particle Size Analyzers for Chemical Mechanical Planarization Process (2016)

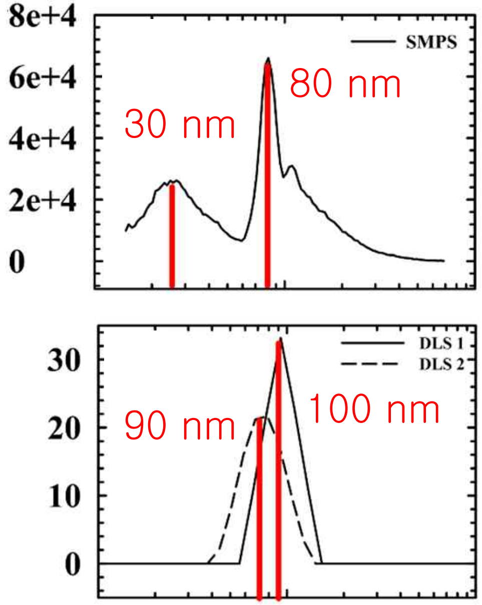


Colloidal ceria



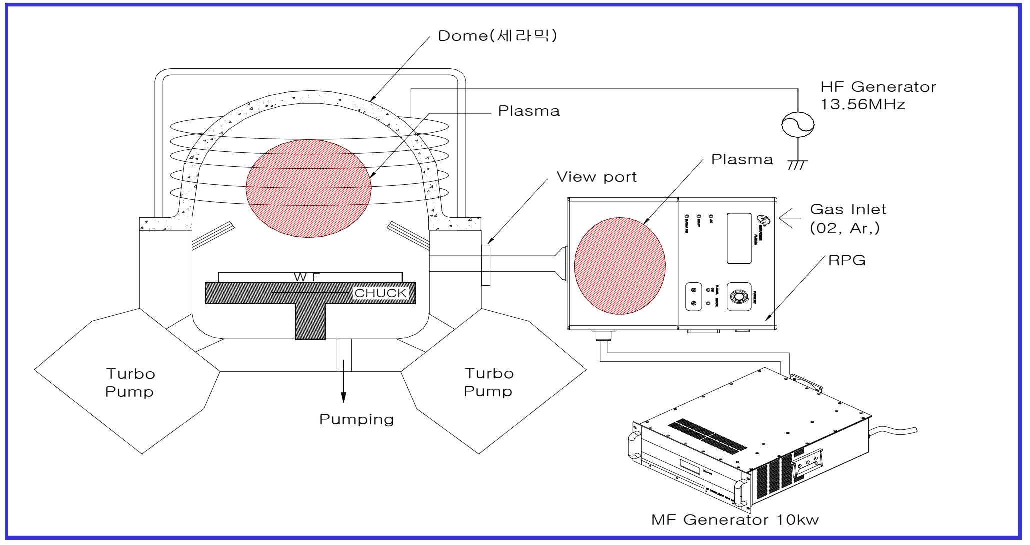


Colloidal silica



In-situ and Remote Plasma Chamber Cleaning

■ In-Situ Chamber Cleaning



RPC (Remote Plasma Clean)

- Merits
  - No Physical Damage Inside Chamber
  - High Cleaning Rate
- Demerits
  - Temperature Dependency of Cleaning Rate

- Application in Dry Etcher, CVD, LPCVD
- Chamber Cleaning Optimization
  - Process Optimization for Film Material and Thickness
  - Reduction of Gas Usage
  - Particle Reduction
- Trends of Cleaning Gas Change
  - PFC Emission Reduction
  - $ClF_3 \rightarrow F_2$
  - $CF_4/C_2F_6 \rightarrow C_3F_8 \rightarrow NF_3$
- In-situ/ Remote Plasma Cleaning

PFC Emission Reduction Technology

■ Global Warming due to PFC (Perfluoro Compound) Emission

● PFC Emission Reduction Goal in World Semiconductor Council

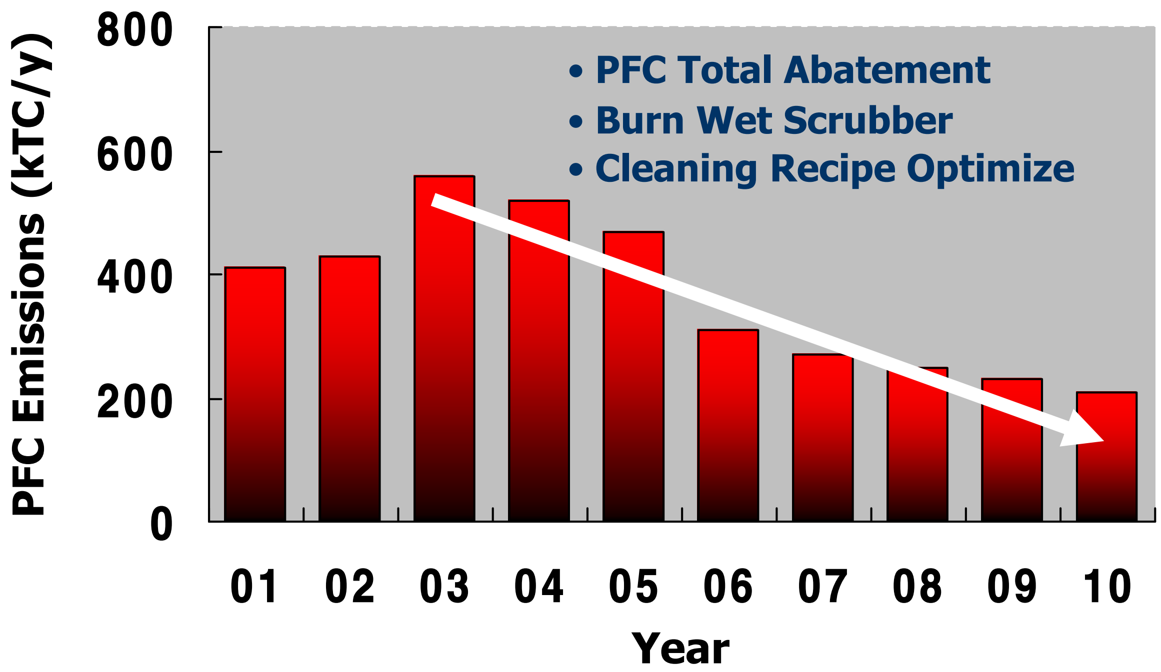
2010, 10% Reduction in Absolute Emissions (MMTCE) Based on 1995 (1997)

Process	PFC Gas in Usage
Etching	CF_4, CHF_3, C_3F_8, C_4F_8, SF_6
CVD	C_2F_6, C_3F_8, NF_3

● Methodology

- Alternative Chemistry
- Abatement Technology
- Capture / Recovery
- Process Optimize
- Emission Monitoring Quantitative Analysis

● PFC Emission Reduction in Samsung



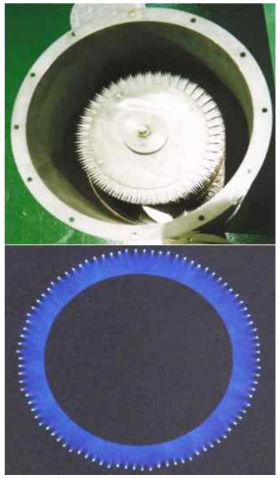
PFC Abatement System Technology

■ Abatement Control Technology for PFC Emission Reduction

Process Tool

Vacuum Pump

POU Scrubber



PFC Total Scrubber

Acid House Scrubber

Ref.) W.S. Kim, S.G.Lee and S.K.Chae, "New Large-Scale End-of-Pipe PFC Abatement System Using a High Efficiency Atmospheric Discharge Technology," SEMI Technology Symposium, Semicon West 2004.

Abatement System Efficiency Analysis

FT-IR

QMS

Conclusions

- Recent semiconductor device has the design rule of 1x ~ 2x nm and needs defect control down to 1x nm size range.
- Current bare wafer inspection metrology can detect particles down to 1X nm and needs different wafer particle standard for calibration.
- To understand the 1x ~2x nm particle formation in the process equipment, it continuously needs the proper development of in-situ process contaminants monitoring tools.
- Process chemical needs advanced filtration technology and new precursors needs the development of vaporizers.
- Zero emission of gaseous contaminant from the Fab needs continuous developments of various process abatements systems.