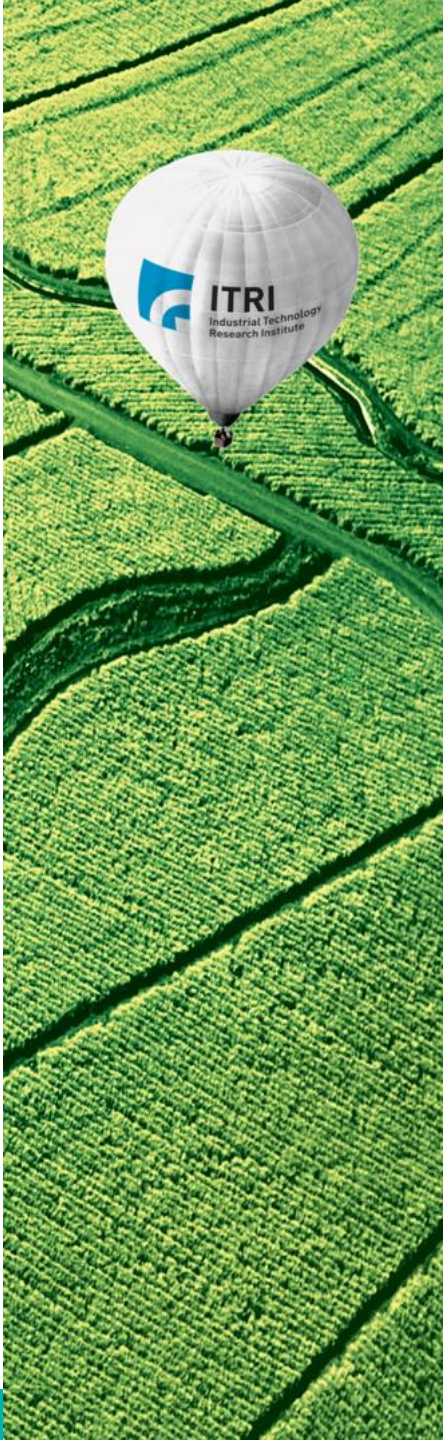
ITRI
Industrial Technology
Research Institute



Nanoparticle Measurements and Applications in Semiconductor Manufacturing

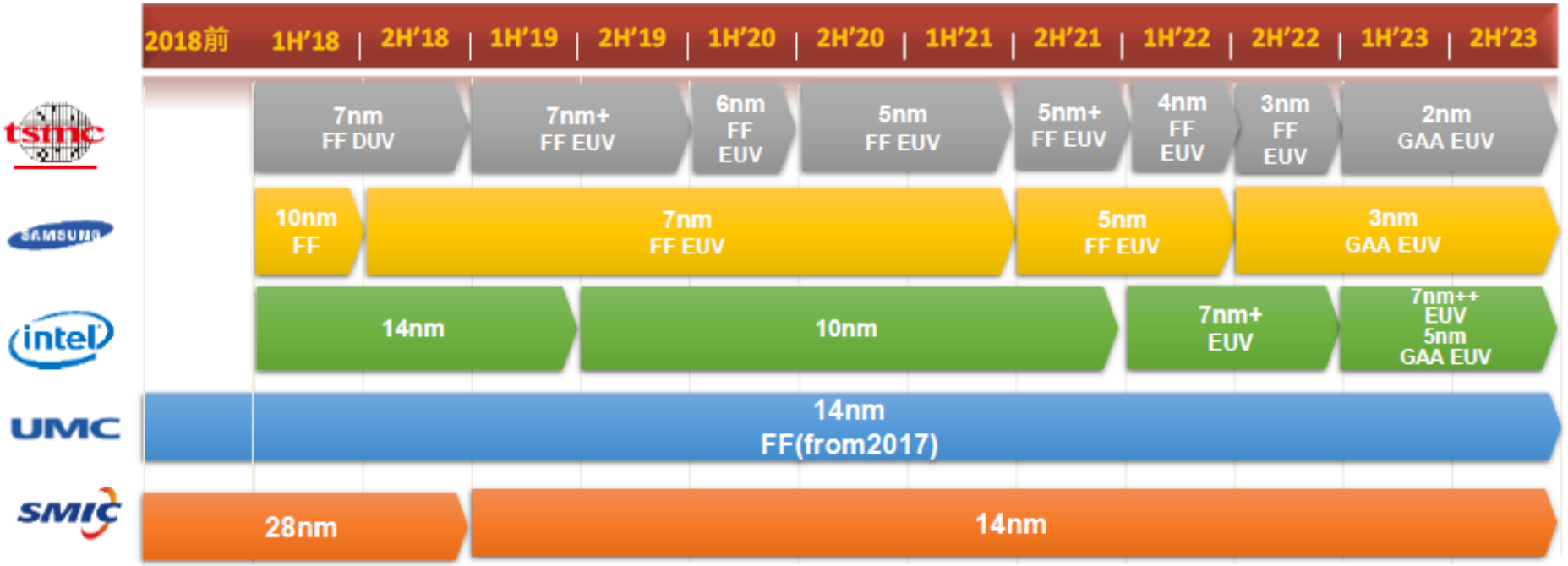
Wei-En Fu, Division Director
Measurement Standards and Precision Instrumentation Division
CMS/ITRI

2022.10.26

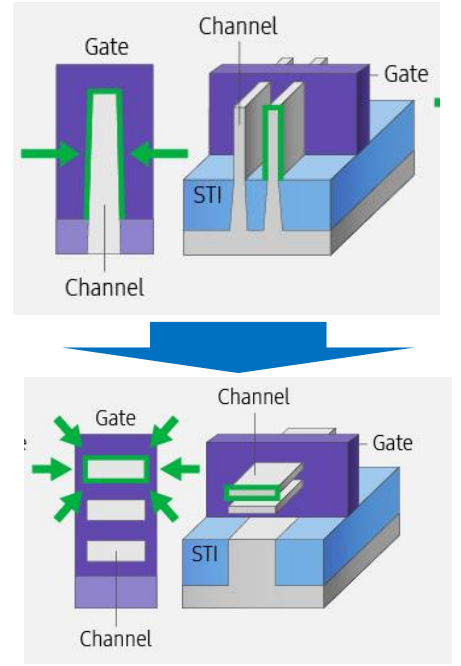
Outline

- Demands for Nanoparticle Metrology in Semiconductor Manufacturing
- Nanoparticle Metrology Development
  - Measurement technology
  - SEMI Taiwan- WG for Purity And Particle Analysis for Semiconductor Raw Materials
- Summary

More 'Moore' Continues to Drive …



Gate-All-Around, GAA
FinFET, FF

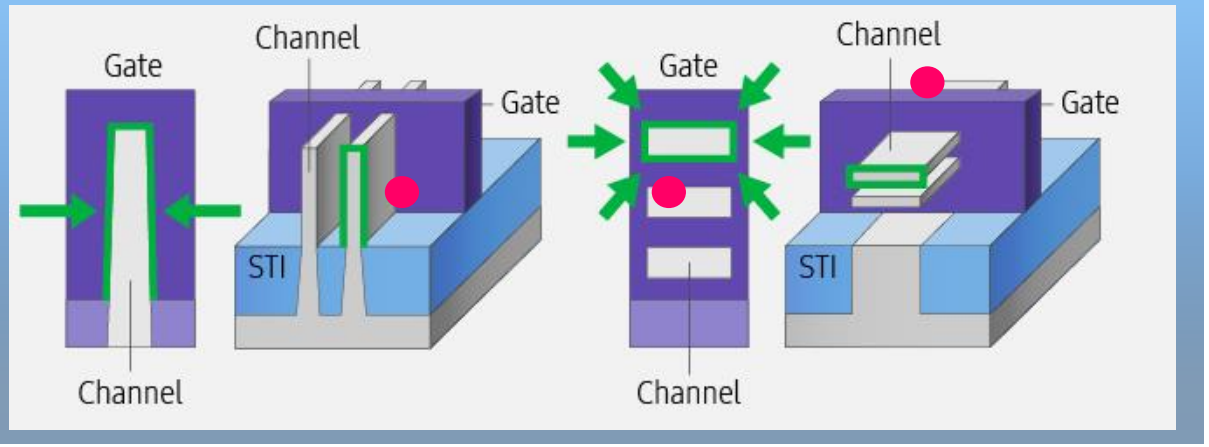


- Moore's Law continues to drive into **2 nm technology node** using gate-all-around (GAA)
- GAA metrology **challenges**: **size** shrinkage, **new materials**, 3D complex structure, and **atomic resolution** (≤ 0.1 nm) for more than 30 key parameters

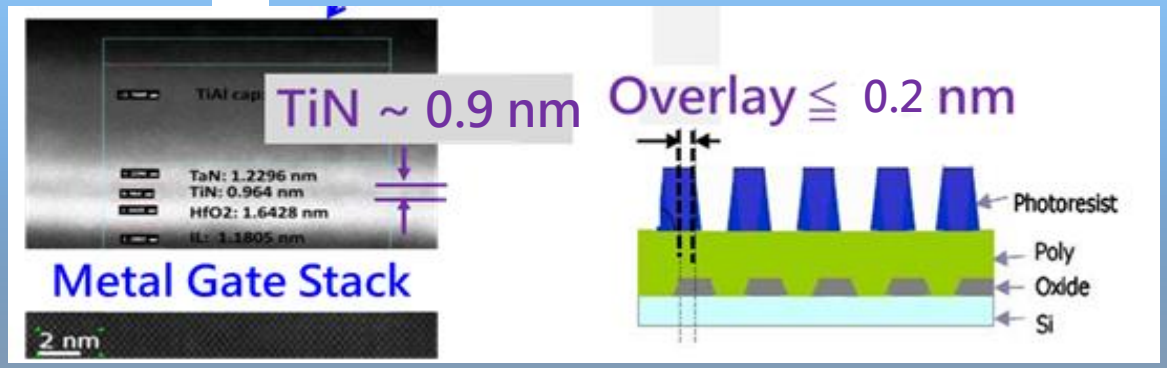
Two Key Directions for Semiconductor Standards

Nanocsale CD Metrology

CDs: 3D profiles for FinFET and GAA

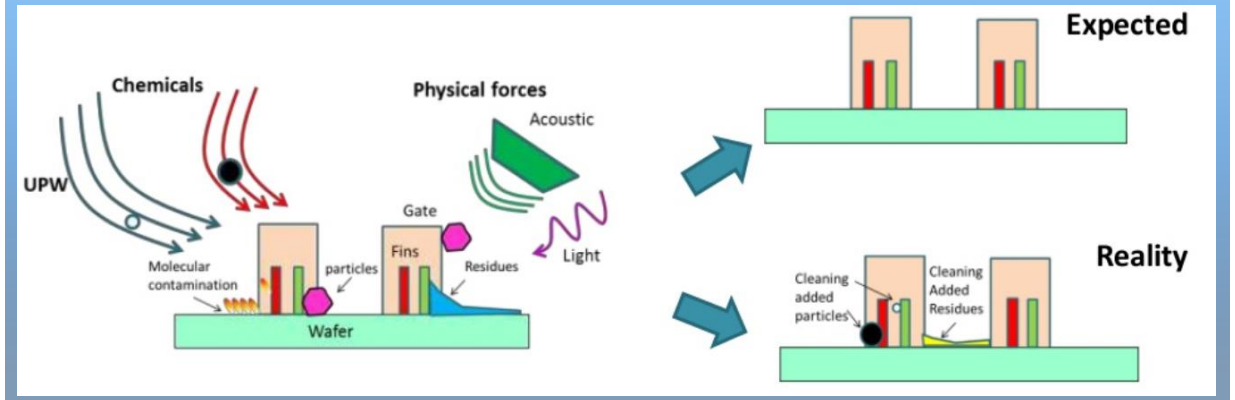


Film thickness, Overlay



Nanoparticle Metrology

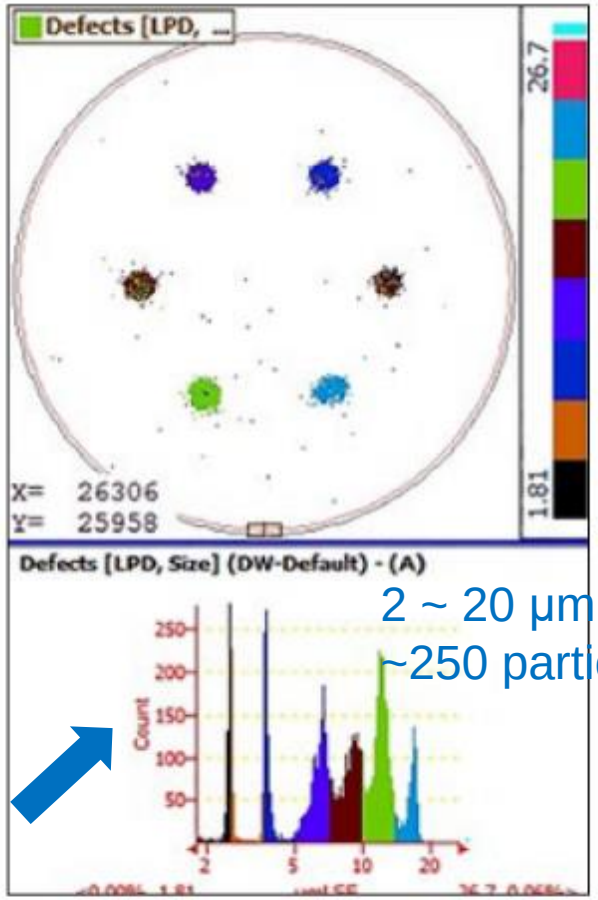
Particle and Impurity



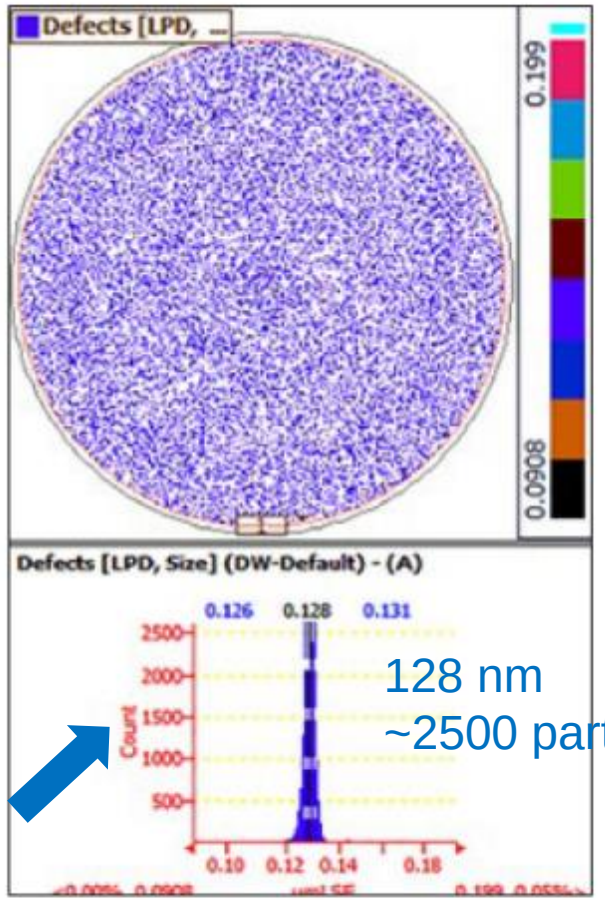
Parameter	Spec.
Metal pitch	20.0 nm
Gate width	7.0 nm
Film thickness	≦ 0.9 nm
Overlay	≤ 0.2 nm
Particle and Impurity	Size < 20 nm Number <10^4 #/mL Composition

On Wafer Particle Defect Inspections

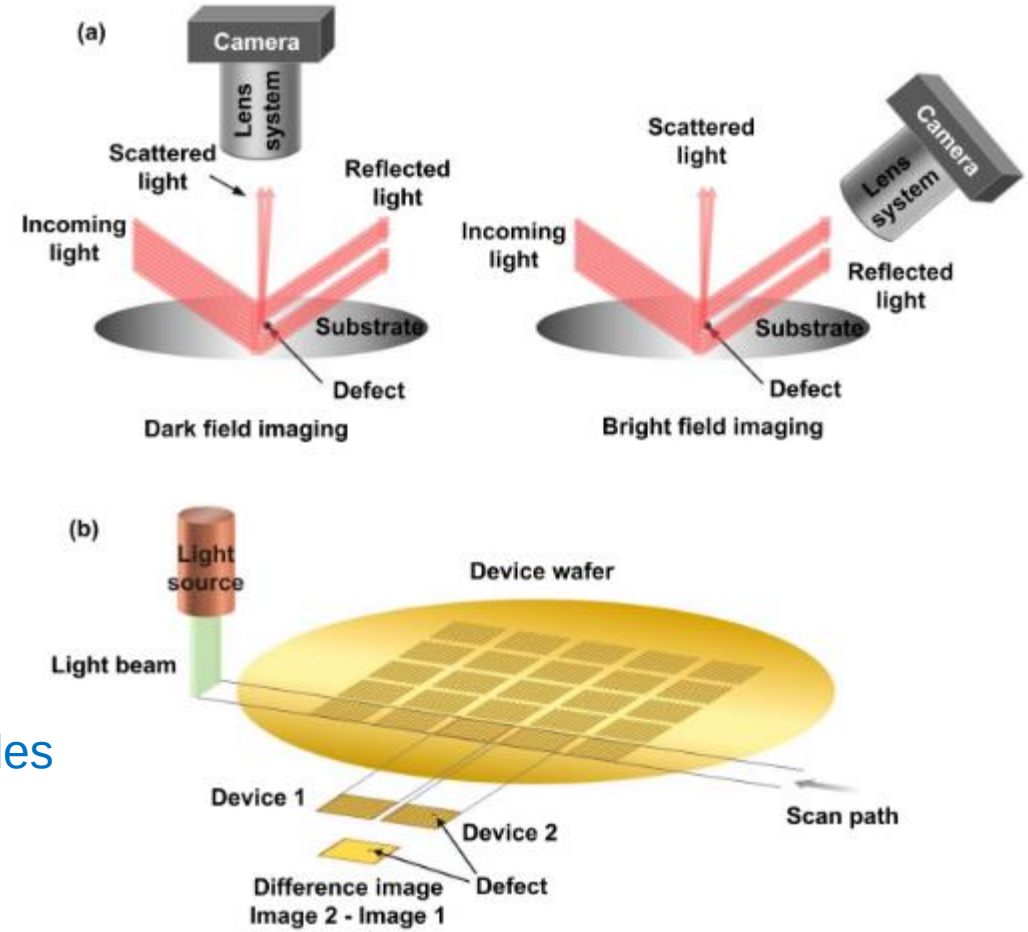
➢ Calibrated particles deposited on wafer



Spot deposits of PSL spheres (2-20 µm)



Full deposit of PSL spheres (modal diameter: 128 nm)

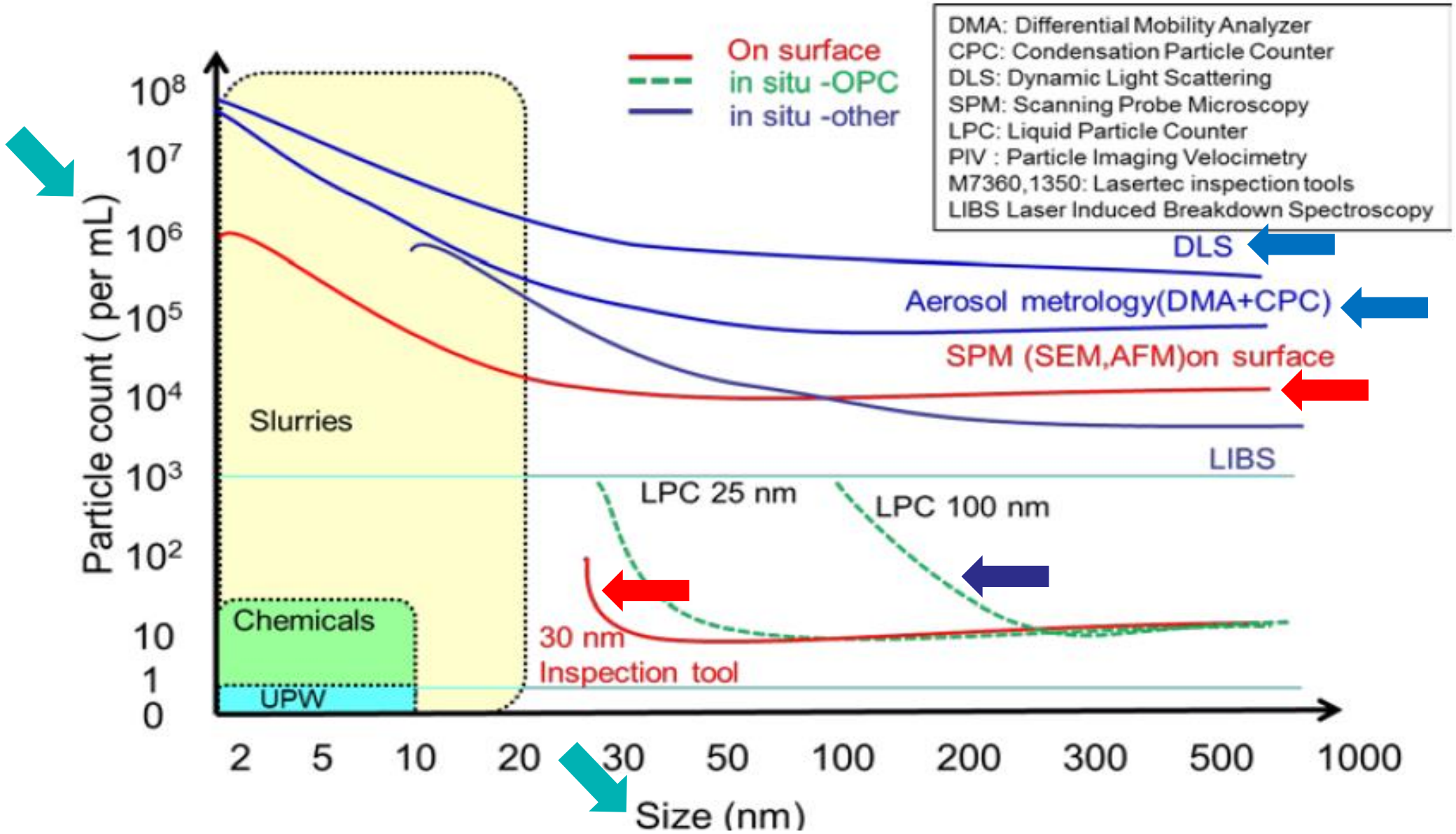


Optical wafer defect inspection at the 10 nm technology node and beyond, Zhu et al, 21 April 2022, International Journal of Extreme Manufacturing

Standards for Particles on Wafer Inspections

MSP (www.mspcorp.com), a division of TSI Cooperated.

Metrology Challenges for Nanoparticles



Metrology requirement for particles, International Technology Roadmap for Semiconductors, 2017.

APMP.L-S5, 2012

APMP.L-S5, 2012
Length, Dimensional Metrology, Nano particles measurements
Joint Comparison with TCMM in APMP

KCDB

Pilot laboratories	**CMS/ITRI, NMIJ**
Participants	**CENAM, CMS, DFM, INMETRO, INRIM, KRISS, LNE, METAS, NIM, NIMT, NMIA, NMISA, NMIJ, PTB**
Methods	**AFM, SEM, TEM, DLS, DMA, XRD, SAXS**

No.	Material	Nominal size [nm]	Volume [mL]	Number concentration [particles/mL][1]	Manufacturer
G1	Nano Gold	10	2	5.7×10^{12}	BBInternational
S2	Nano Silver	20	2	4.0×10^{11}	nanoComposix
P3	Polystyrene latex	30	1	7.0×10^{14}	JSR
P4	Polystyrene latex	100	1	1.8×10^{13}	JSR
P5	Polystyrene latex	300	1	7.1×10^{11}	JSR

Other Than Size and Number Concentration?

3000 Series, 15 mL, 1% Solids	
Diameter	**Cat. Number**
Aqueous Suspensions, Calibrated by Photon Correlation Spectroscopy (PCS)	
20 nm	3020A
30 nm	3030A
40 nm	3040A
Aqueous Suspensions, Calibrated by Transmission Electron Microscopy (TEM)	
50 nm	3050A
60 nm	3060A
70 nm	3070A
80 nm	3080A
90 nm	3090A
100 nm	3100A
125 nm	3125A
150 nm	3150A
200 nm	3200A
220 nm	3220A
240 nm	3240A
270 nm	3269A
300 nm	3300A
350 nm	3350A
400 nm	3400A
450 nm	3450A
500 nm	3495A
500 nm	3500A
560 nm	3560A
600 nm	3600A
700 nm	3700A
800 nm	3800A
900 nm	3900A

- Size
- Size Distribution
- Number Concentration?
- Materials (Composition)?

Urgent Requirements for NP

- Reference Standards
  - Sizes of nanoparticles ≤ 20 nm
  - Number distribution ≤ 10^4 #/mL

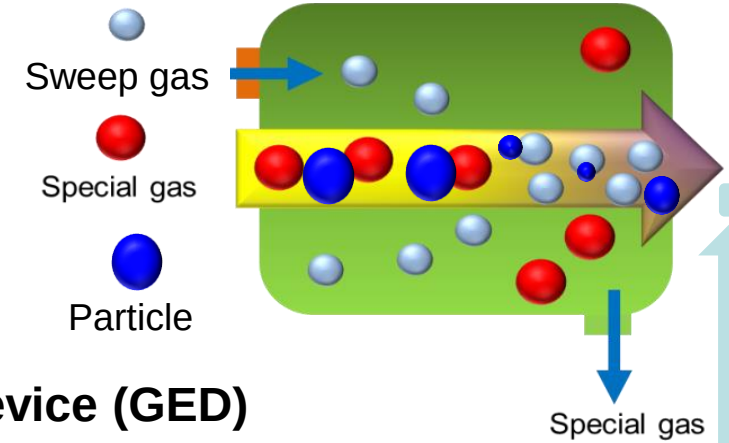
- Measurement Technology
  - Sizes of nanoparticles ≤ 5 nm
  - Number distribution ≤ 10 #/mL
  - In-line calibration

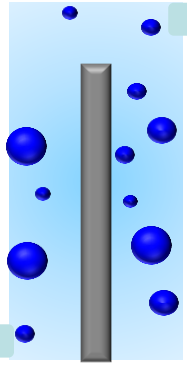
Nanoparticle Metrology in Front End Processes

Particle monitoring in specialty gases

Specialty gas

Gas exchange device



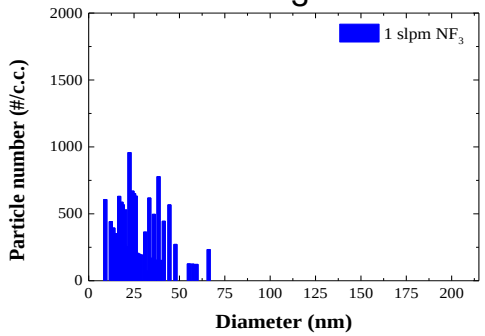


DMA

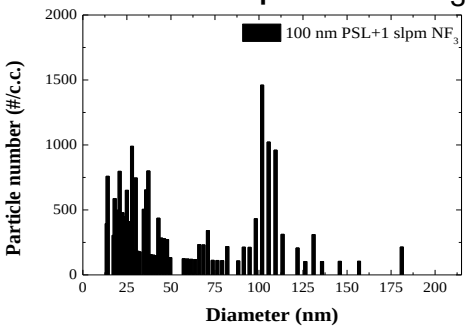
CPC

splCP-MS

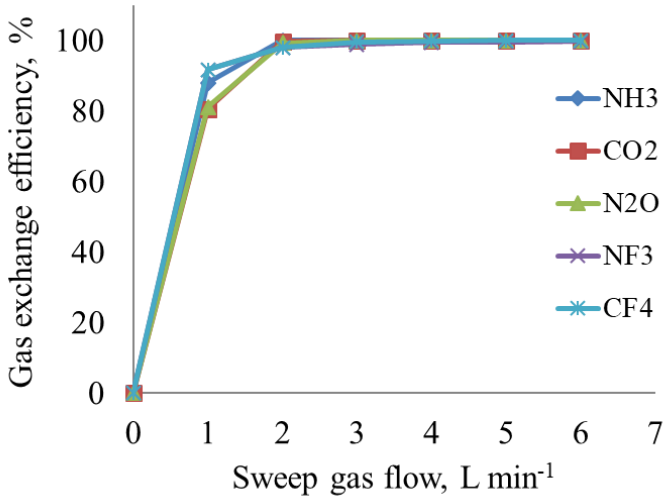
NF_3



100 nm PS spike in NF_3

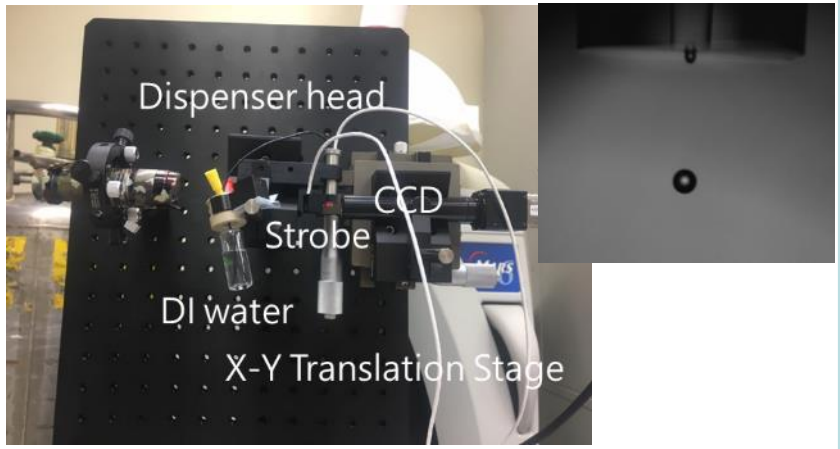


Gas exchange device (GED) Performance test



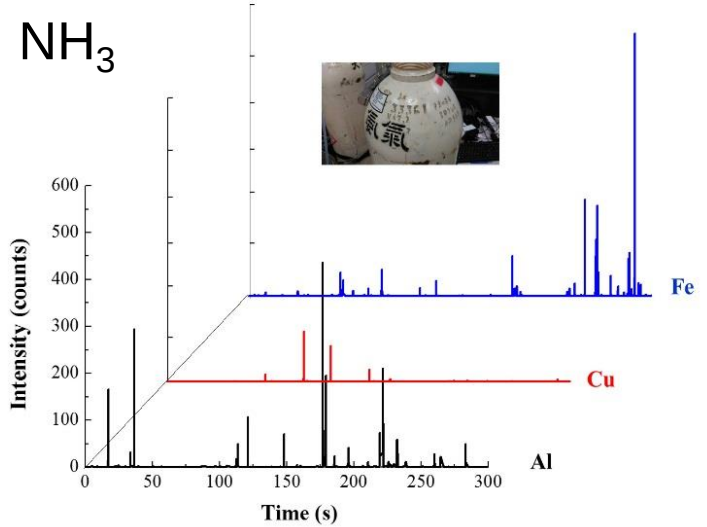
(N_2, CDA, or Ar)

Online calibration system Performance test



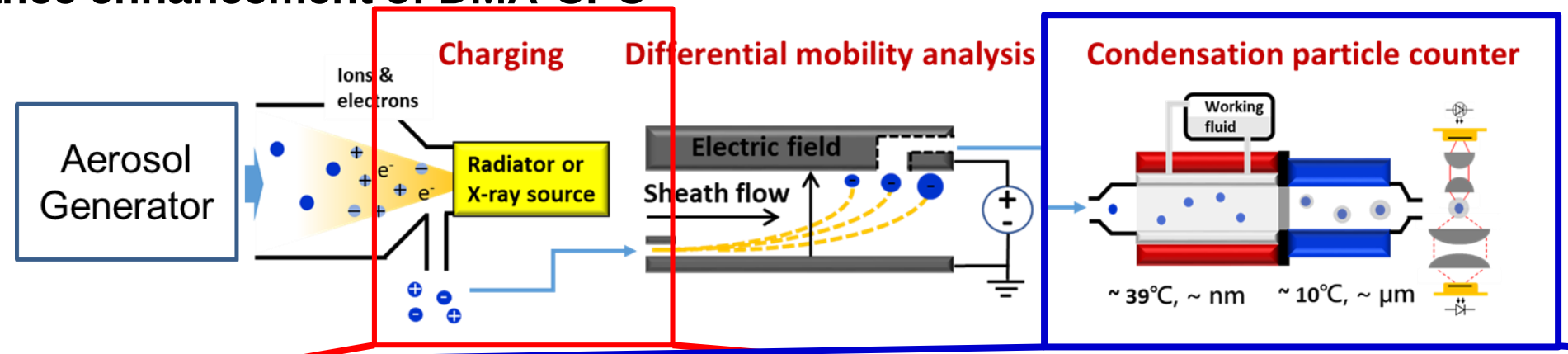
Composition analysis of different-sized particles

NH_3



Particle Monitoring in Ultrapure Reagents

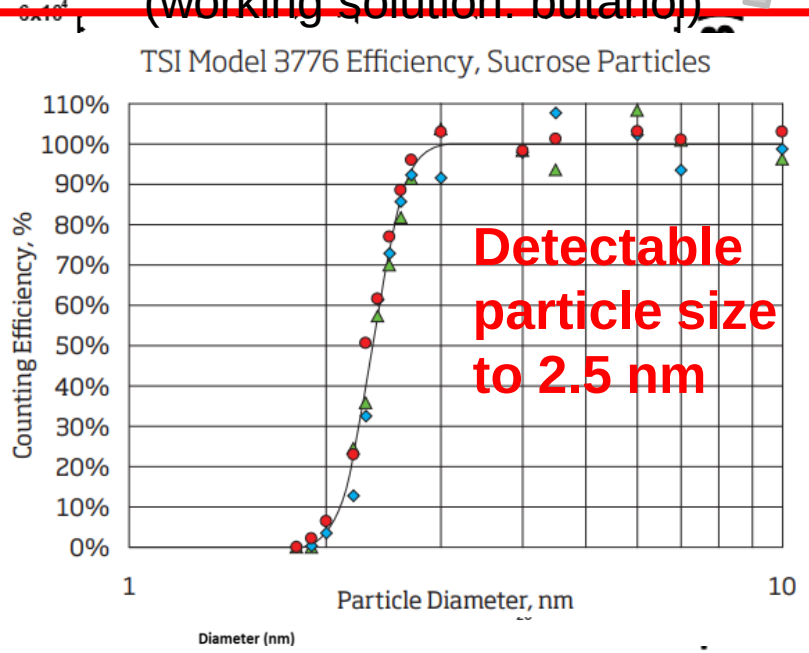
Performance enhancement of DMA-CPC



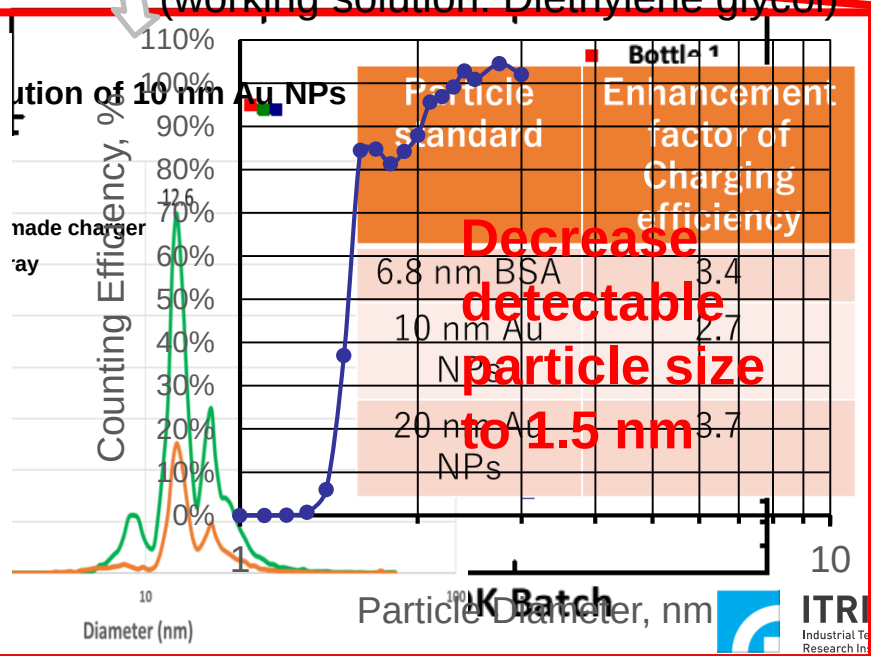
Home-made enhancer:

Enhance charging efficiency ↑

Commercial CPC
(working solution: butanol)

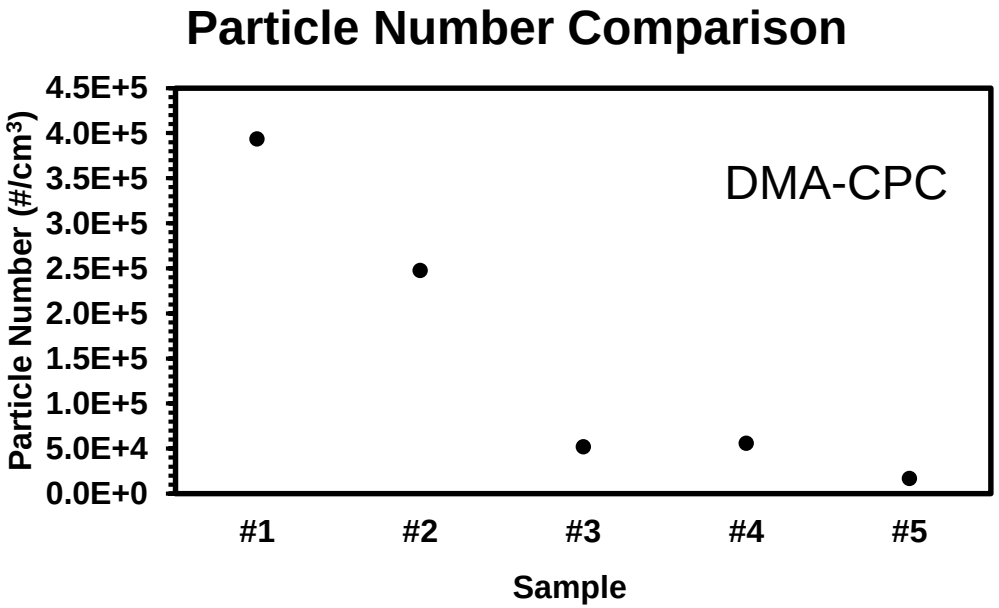


Enhancer + CPC efficiency
(working solution: Diethylene glycol)

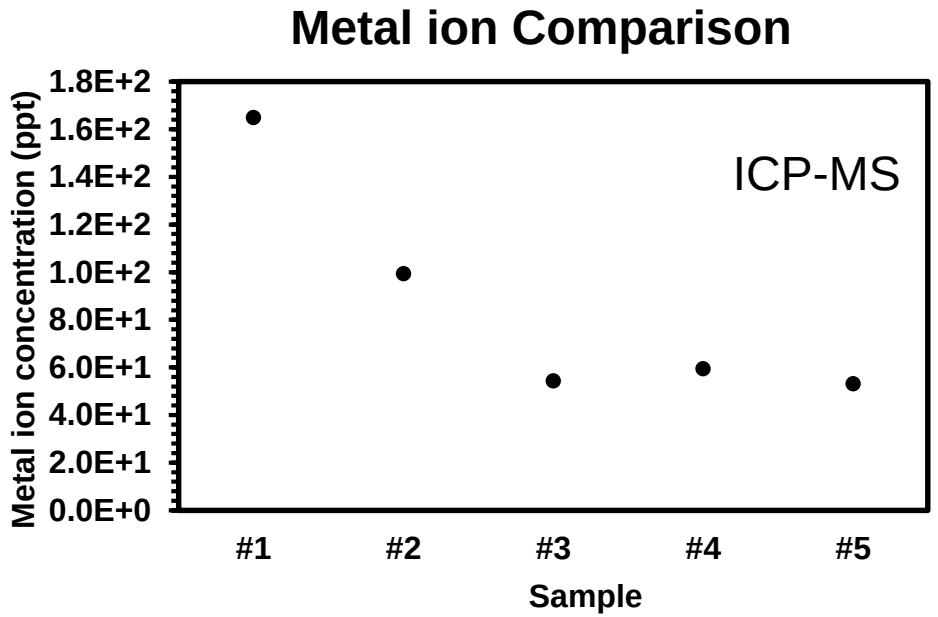


Particle Monitoring in Ultrapure Reagents

Complementary information by DMA-CPC and ICP-MS

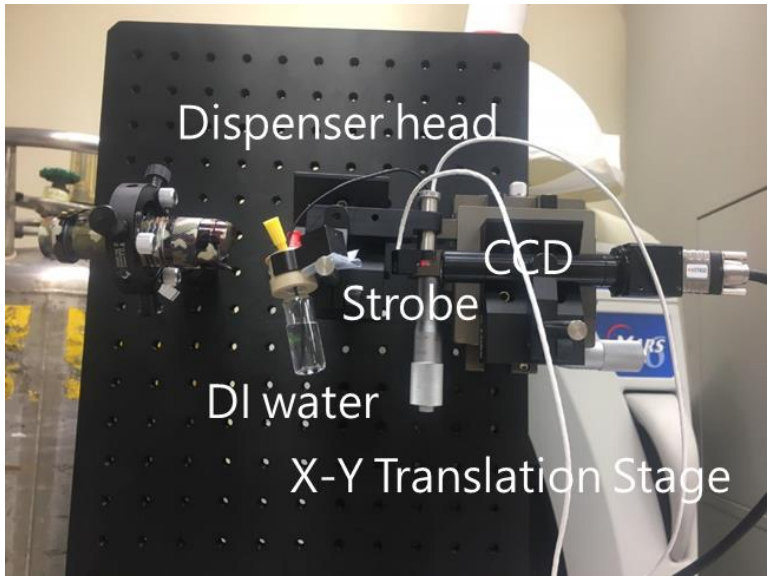


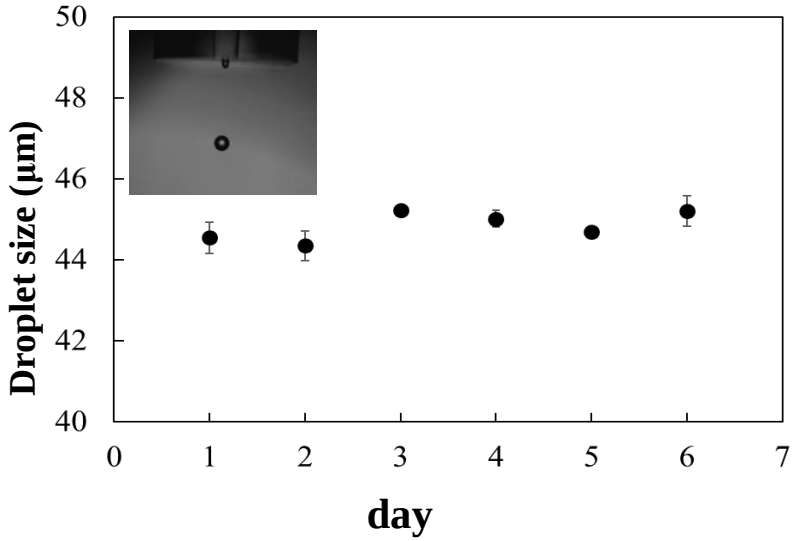
similar trends



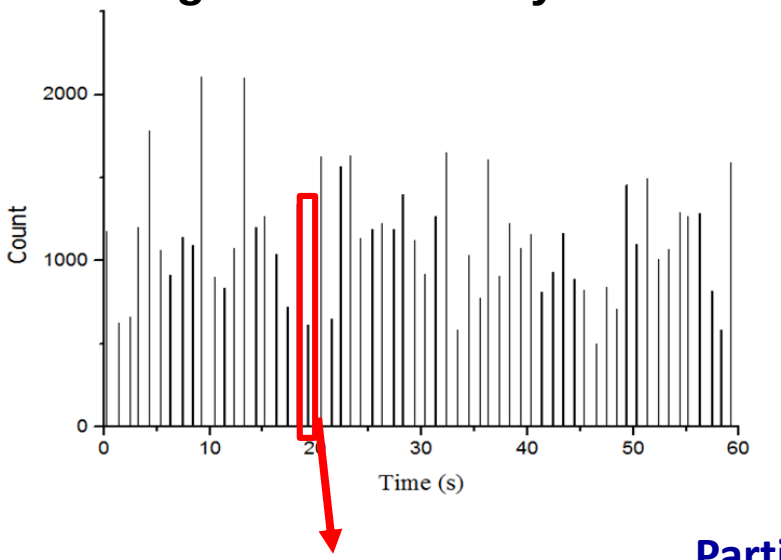
Bottle	Ag	Al	Ca	Co	Cr	Cu	Fe	K	Li	Mg	Na	Ni	Pb	Total ion (ppt)
#1	10.6	1.9	5.2	1.2	13.8	15.6	67.1	1.9	0.1	1.4	37.9	7.6	0.7	164.9
#2	15.4	5.9	0.4	0.3	2.3	19.1	15.0	3.6	0.1	0.4	34.0	1.5	1.4	99.3
#3	9.8	0.4	1.1	0.1	1.9	7.2	2.7	1.4	0.2	0.3	27.3	0.8	1.1	54.3
#4	11.5	0.5	1.8	0.2	1.7	5.8	4.9	2.4	0.1	0.2	28.5	1.1	0.7	59.4
#5	14.7	4.5	0.1	0.1	1.5	1.8	1.1	1.4	0.2	0.2	26.6	0.2	0.7	53.1

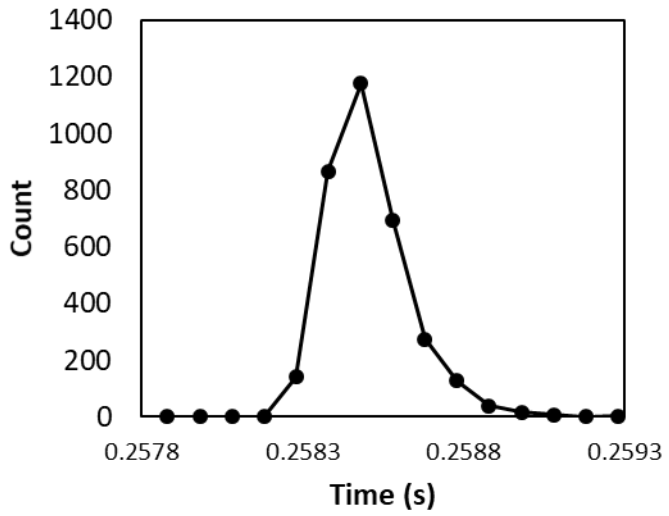
spICP-MS calibration by MDG



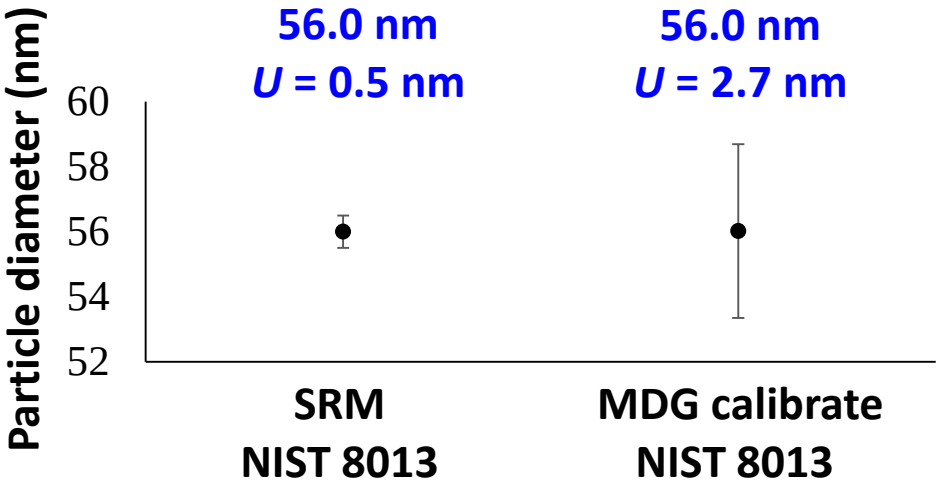


Signal obtained by ICP-MS





Method validation



Particle equivalent diameter

$$D = \sqrt[3]{\frac{R^3 * C_a}{\rho}}$$

Symbol	Meaning
D	Particle equivalent diameter(nm)
ρ	Particle density(g/cm^3)
R	Droplet diameter(μm)
C_a	Metal ion concentration (ng/cm^3)

$$D = \sqrt[3]{\frac{(48.8\ \mu m)^3 * 35.91\ ng/cm^3}{19.32\ g/cm^3}} = 60.0\ nm$$

U_D = 2.1 nm

SEMI Inspection and Metrology Committee

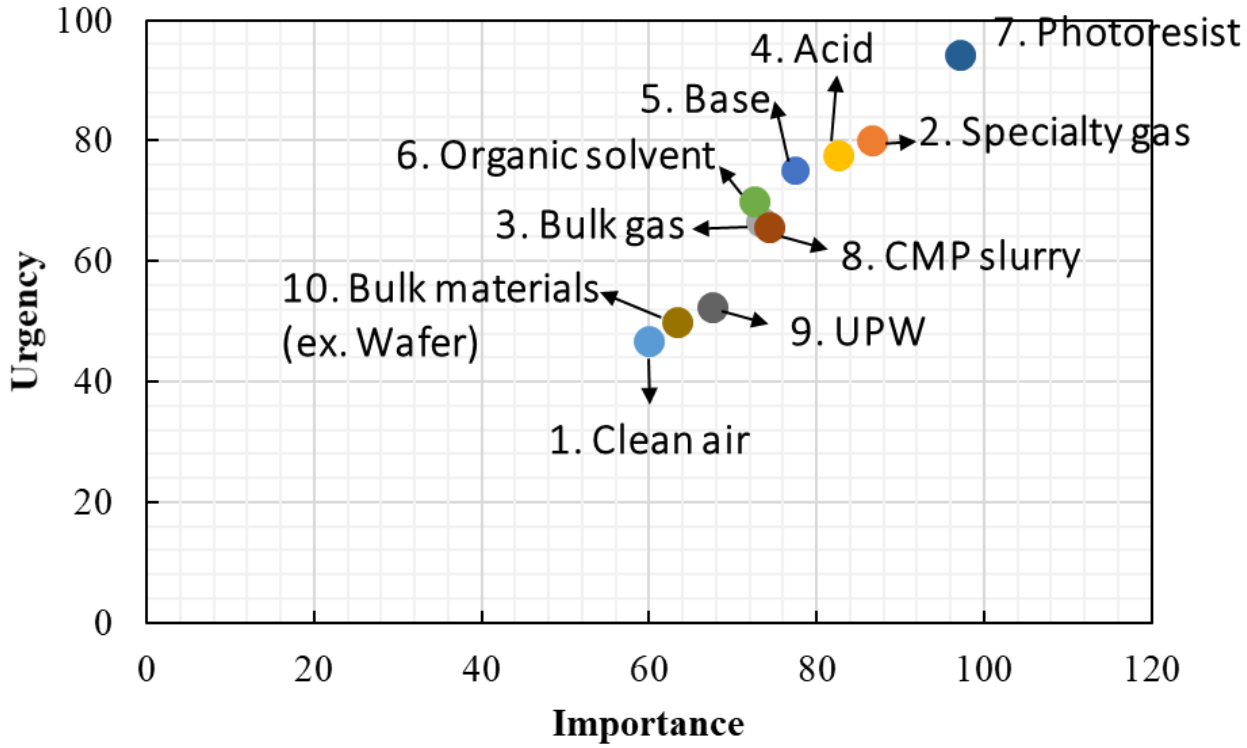
SEMI- Semiconductor Equipment and Materials International

- **Missions**
  - To develop innovative **measurement** technique/method for determination of
    - ✓Particle (size/number/composition)
    - ✓Anion/cation
    - ✓Organic (TOC/speciation)
  - To build a Correlation between on-line and off-line inspection tool
  - To provide strategic advices in overcoming purity analysis problem
  - To establish cooperation among research institute, vendor, and end users

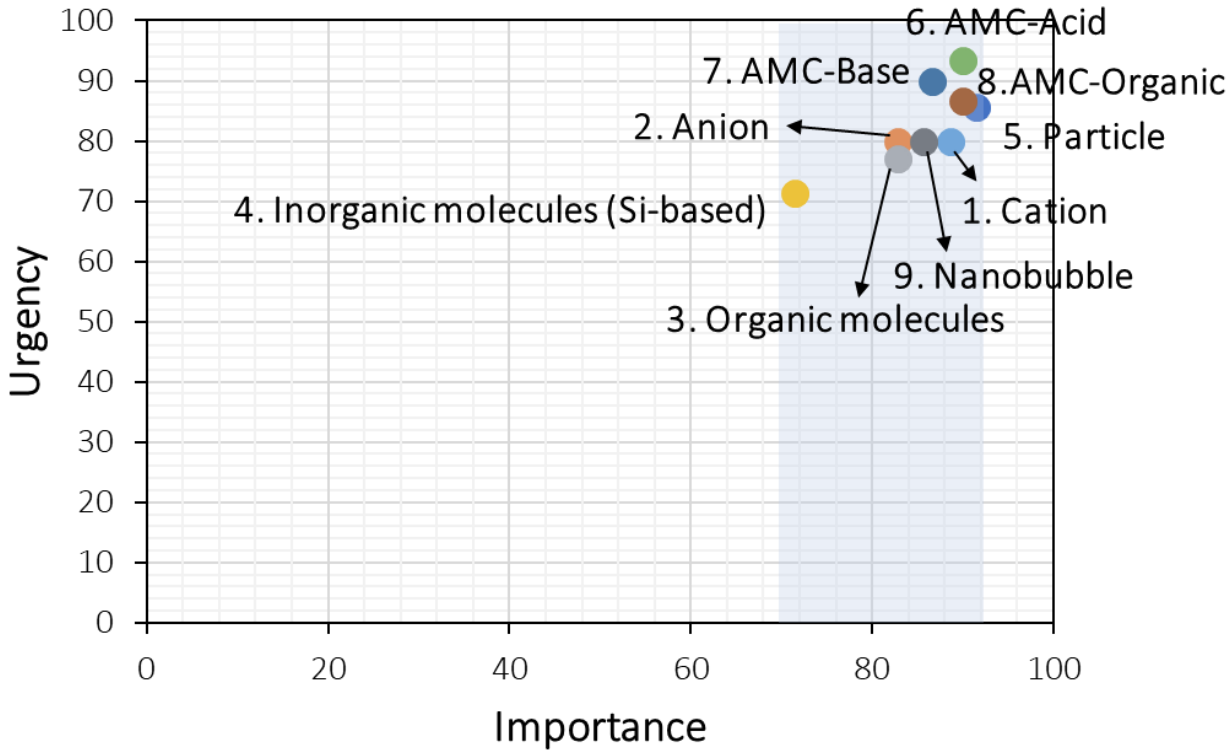
Preliminary Survey for Nanoparticle Metrology

- Questionnaire for Needs in Purity and particle analysis for semiconductor raw materials

A. Raw material



B. Impurity type



Summary

- Raw materials
  - Top 3 importance: Photoresist, specialty gas, acid
  - Top 3 urgency: Photoresist, base, acid
- Impurity type
  - Top 3 importance: Particle, cation, AMC-base
  - Top 3 urgency: Particle, cation, AMC-base
- Analytical method
  - Meet expectation: cation, inorganic, AMC,
  - Not meet expectation: anion, organic molecule, Particle, nanobubbles

Summary

- CMS/ITRI have established the measurement technology for size, number, and composition analysis of nanoparticles, particularly for Ultra-Fine Particles/Impurities monitoring in process gases and chemicals.

- CMS/ITRI have demonstrated the possibility of DMA-CPC for AMC monitoring by converting the gas molecule to particle.

Acknowledgements

- Nanoparticle Group
  1. Dr. Fan-hsin Lin
  2. Dr. Ching-Hsuan Chang
  3. Ta-Chang Yu
  4. Hsiang-Hung Chen
  5. Chen-Fang Jian
  6. Yu-Hsien Wu
  7. Yi-Hung Liu
  8. Yi-Hsuan Pan
  9. Chia-Yun Tsao
  10. Shu-Han Hung