Influence of Particle and Particle Precursor Contamination from High-Purity Polymer Components on On-wafer Particle Defectivity

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Introduction

- Particle precursors (PPs) are medium to high-molecular weight organics that can form particles on the wafer surface during drying.
- Potential sources are high surface area components like ion exchange resin, filters, membrane contactors, and polymer piping.
- The IRDS UPW and Critical Components Task Force have successfully associated PP concentration to on-wafer particle defects.
- Ongoing testing is focused on developing a standard test method to assess the defectivity risk of PP contamination from various sources.
- If successful, this method will provide a tool for material and component suppliers to improve products, prioritize development, and manage PP risk to semiconductor yield.

Presentation Outline

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- Foundational background
- Key findings from the IRDS Critical Components Phase 2 study.
- Test plan for Phase 3
- Phase 3 results to date and interpretation

What is the risk of PPs to device yield?

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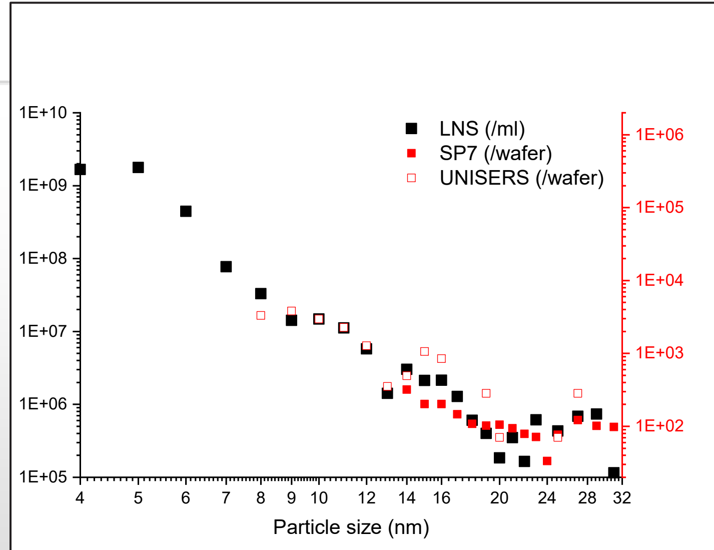
Source: 2021 IRDS UPW White Paper

KLA SP5 Analysis Courtesy of Screen (Japan)

UNISERS Analysis Courtesy of UNISER AG (Switzerland)

LNS Analysis by CT Associates (USA)



Increasing concentration of IX resin PPs resulted in an increasing in particle concentration on the wafer.

How do we measure PPs and sub-20 particles?

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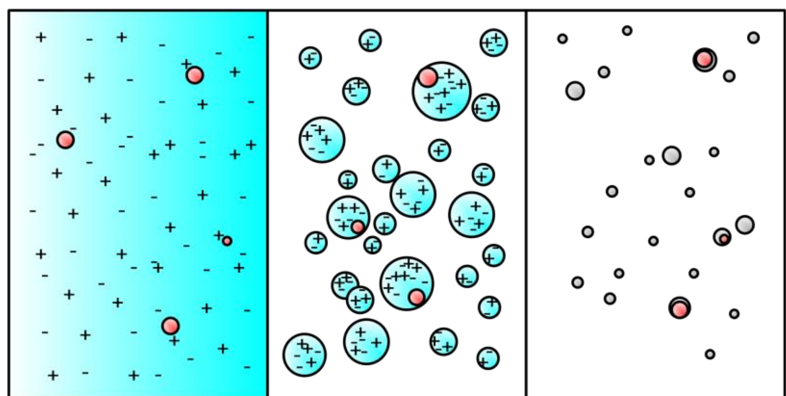
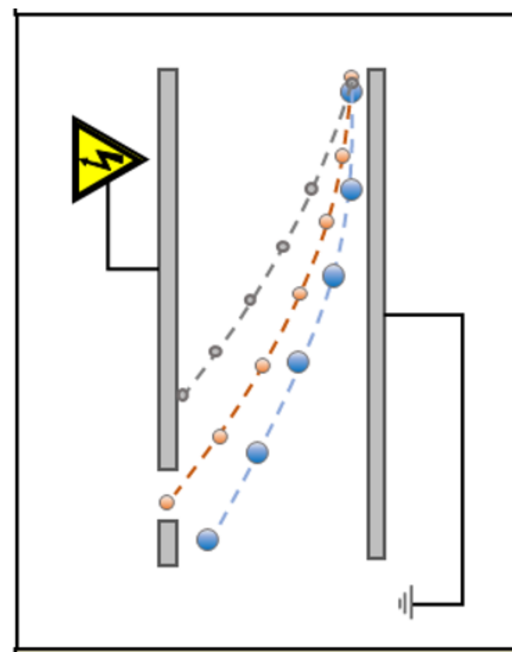
Liquid to Aerosol Conversion



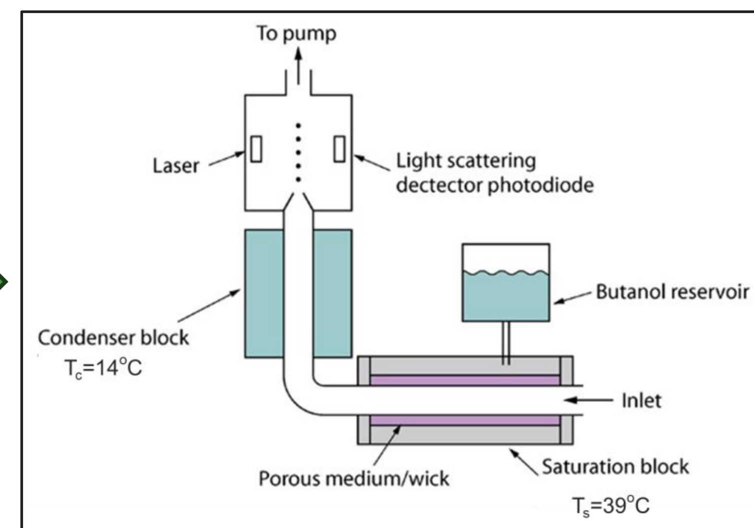
Courtesy of Kanomax FMT

Aerosol Size Selection by EM



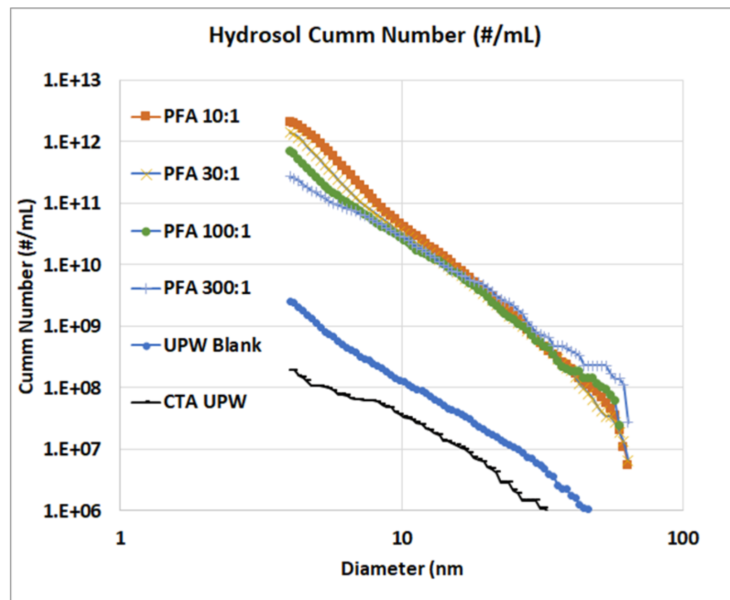
Electrical Mobility ∝ Dp

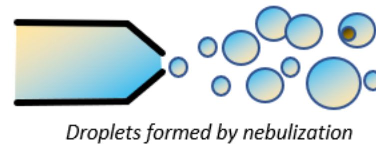
Condensation Particle Counting

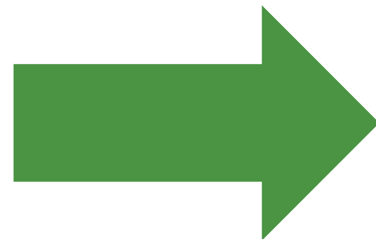


Nebulization combined with condensation particle counting is the only technology currently available that can detect and quantify particle precursors found in process liquids (aka: Liquid Nanoparticle Sizing (LNS))

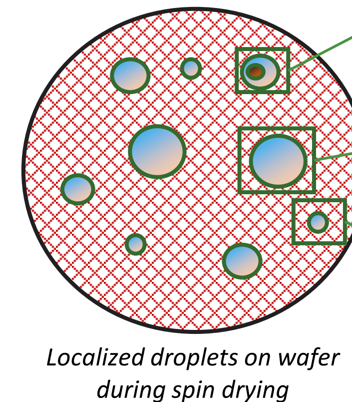
Why is nebulization relevant?

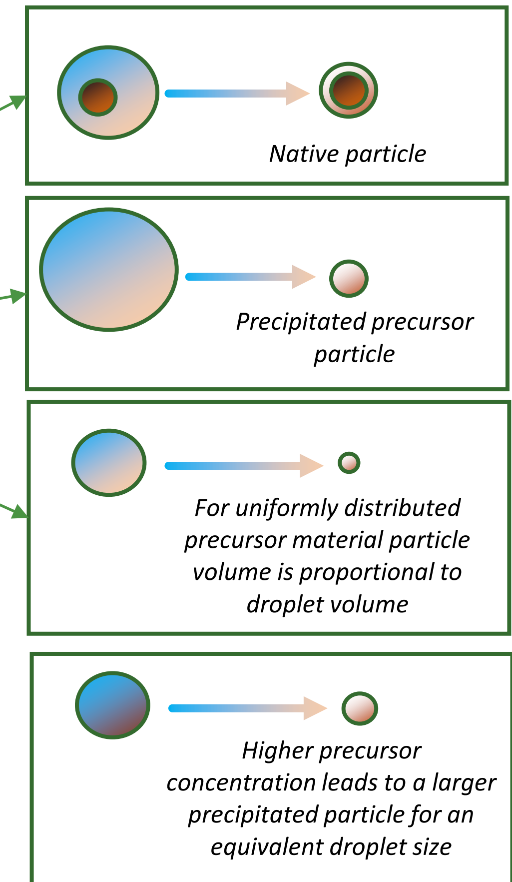






Nebulization mimics the drying process on the wafer surface





Source: Oberreit, et al, Solid State Phenomena, vol. 346.

How do we distinguish PPs and Native Particles?

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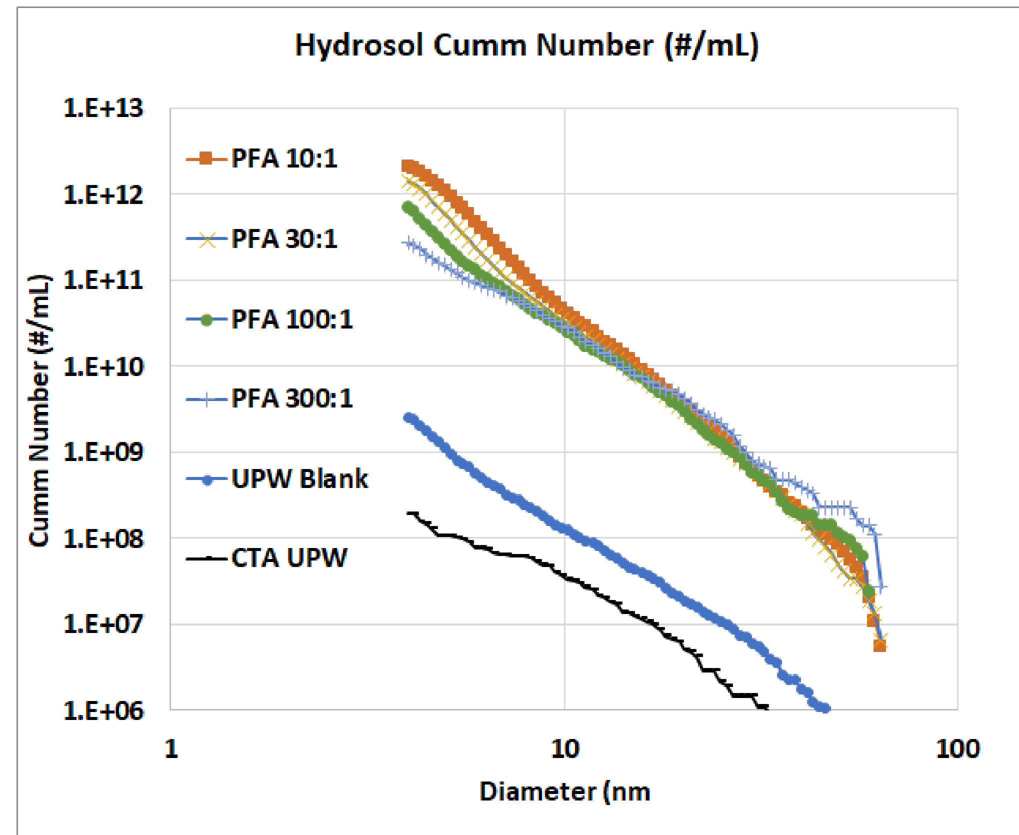
Hot UPW (85°C) Extract from PFA (Dilution Normalized)

Extract is measured at multiple dilution ratios. Results are dilution normalized to separate the native particle and particle precursor signals.



Source: Van Schooneveld, et al, Ultrapure Micro 2022

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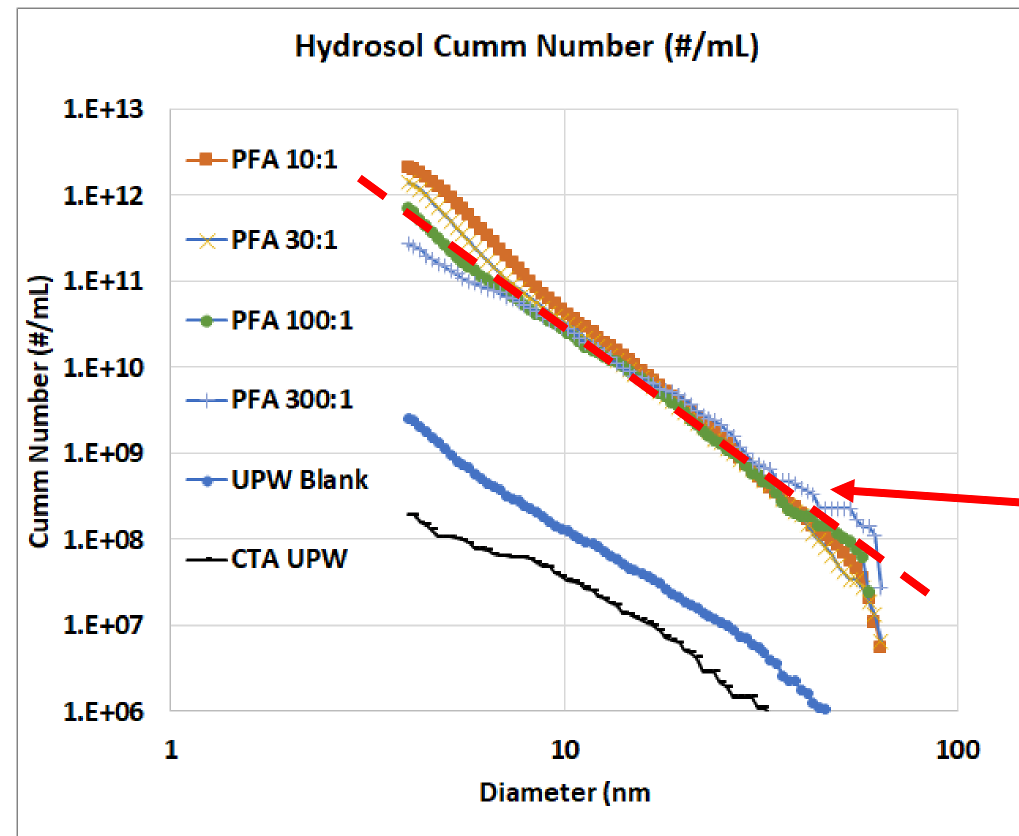

Native particle distribution (linear log-log)

Source: Van Schooneveld, et al, Ultrapure Micro 2022

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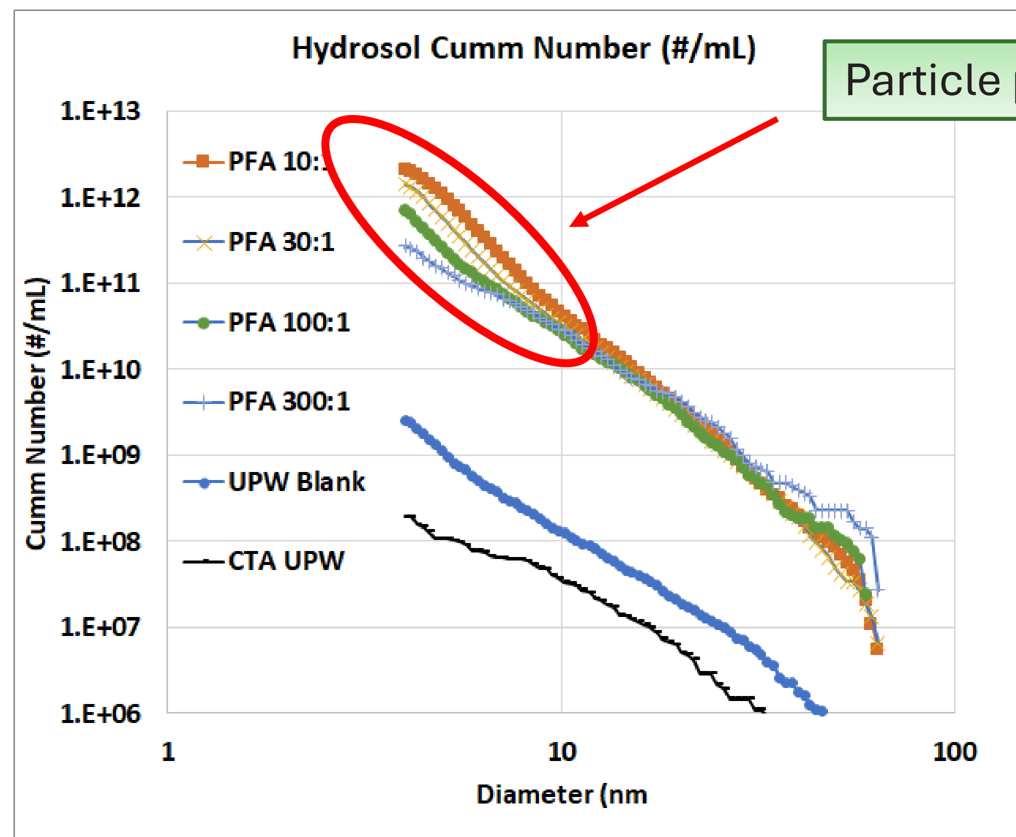


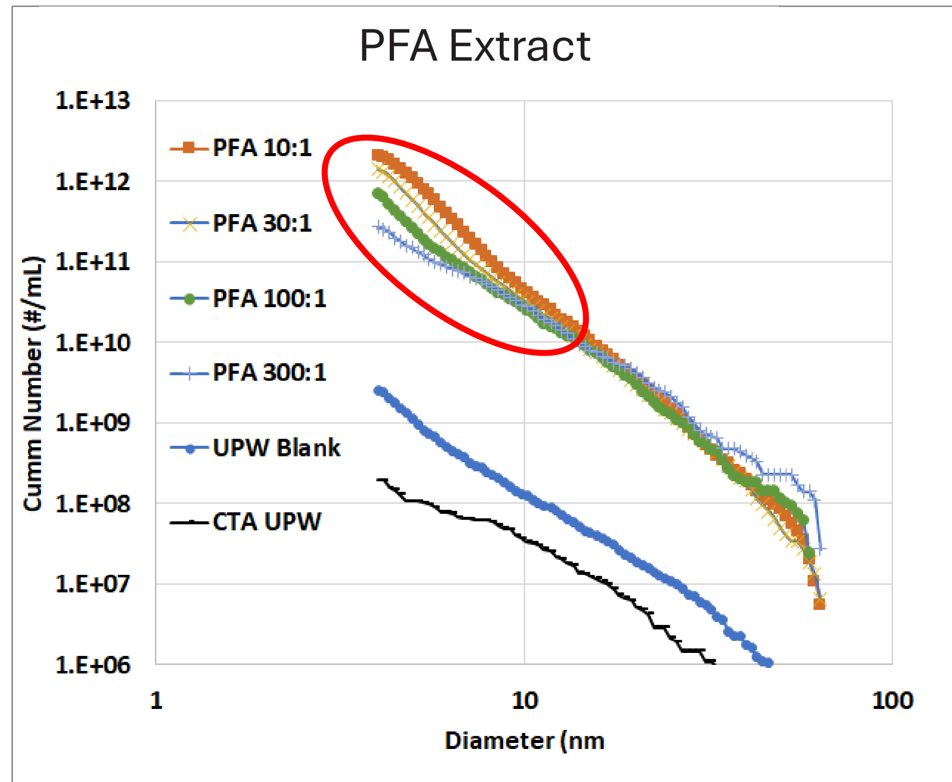
Particle precursor signal

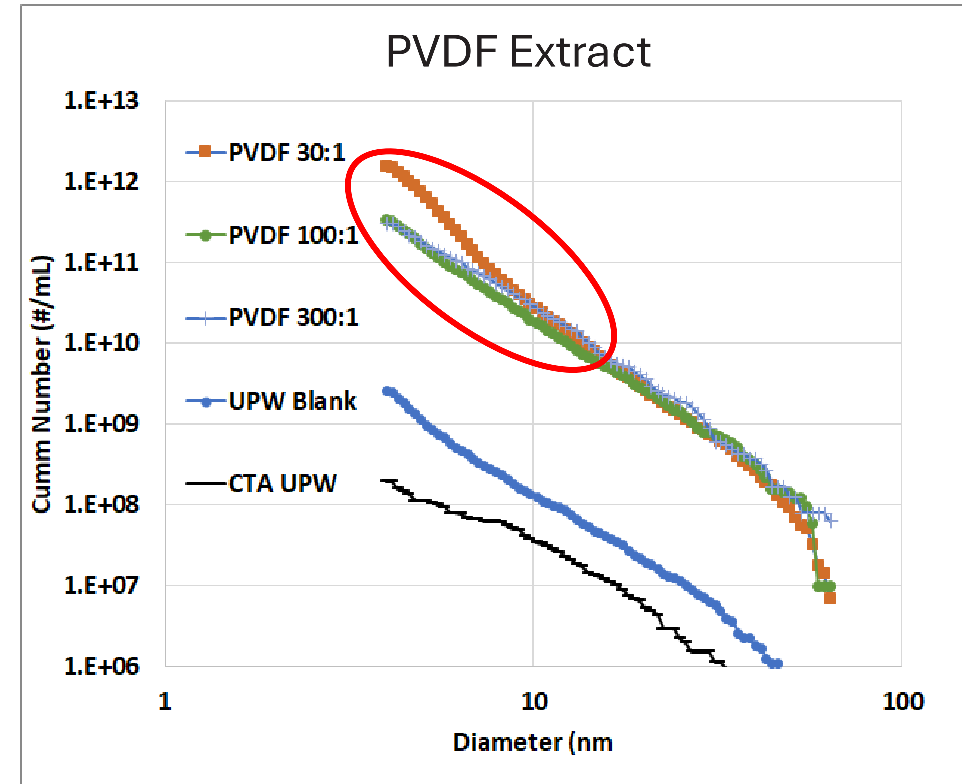
PP mass concentration is determined using SEMI F121's calibration methodology.

Native particle distribution (linear log-log)

Source: Van Schooneveld, et al, Ultrapure Micro 2022

How do we distinguish PPs and Native Particles?

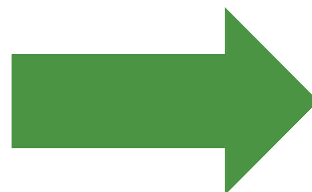


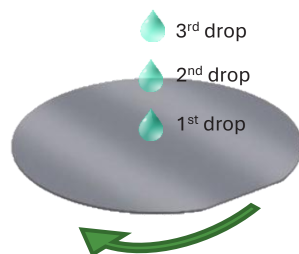


Native particles and particle precursors are evident in both 85ºC UPW PFA and PVDF extracts

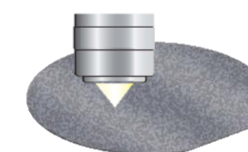
Source: Van Schooneveld, et al, Ultrapure Micro 2022

Sequential Spin Coating (SSC) and Surface Enhanced Particle Sizing (SEPS)





Sequential Spin Coating



PVD for signal enhancement

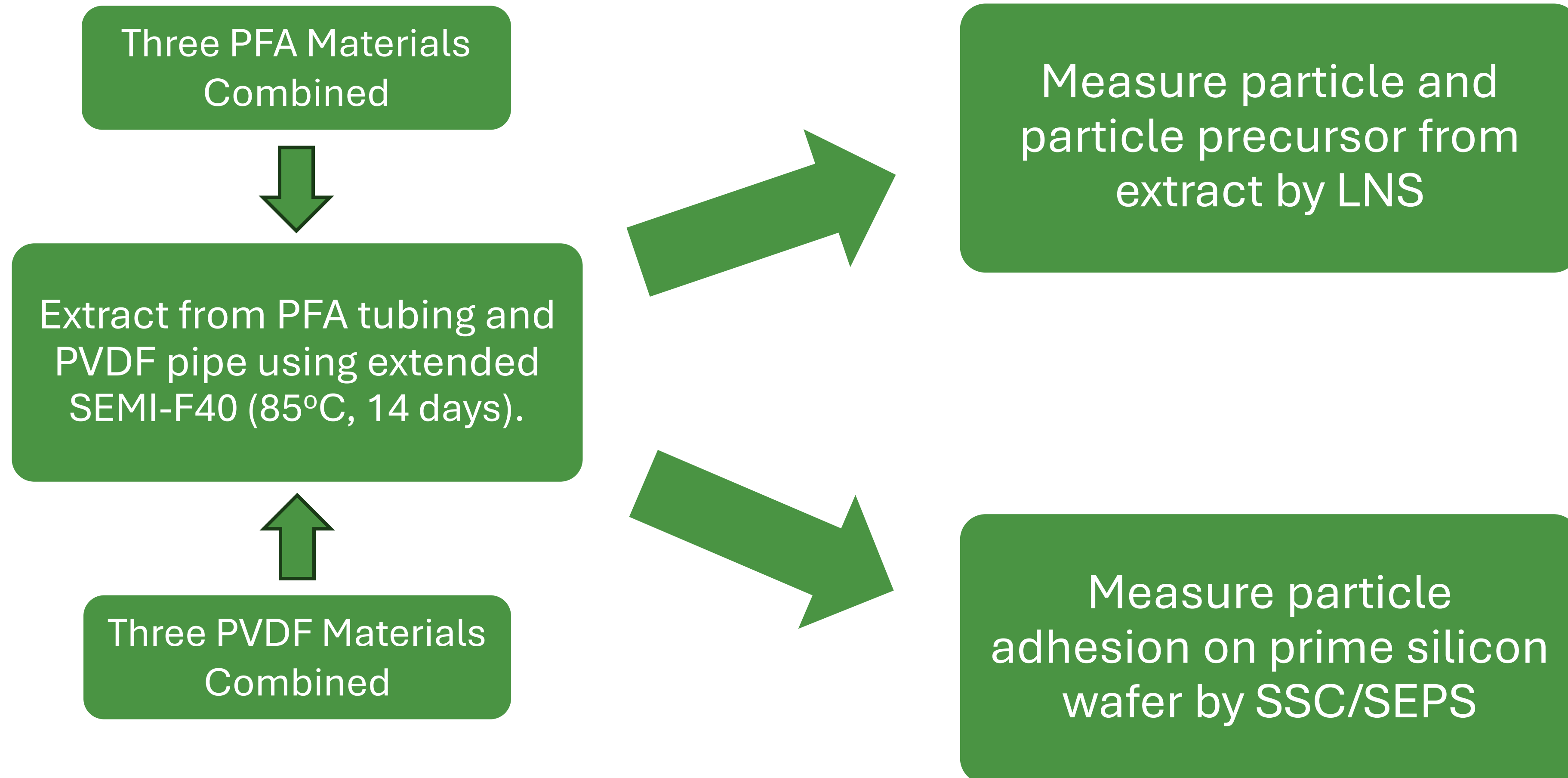
- Universal vacuum-based coating for any substrate/contamination
- Enhances both SEPS and SERS signals

SEPS & SERS analysis

- Complete analysis with surface enhanced particle sizing (SEPS) & surface enhanced Raman speciation (SERS)

Phase 2 Results – Hot UPW Extract from PFA tube and PVDF pipe

Test Overview



PFA to PVDF Particle and PP Comparison

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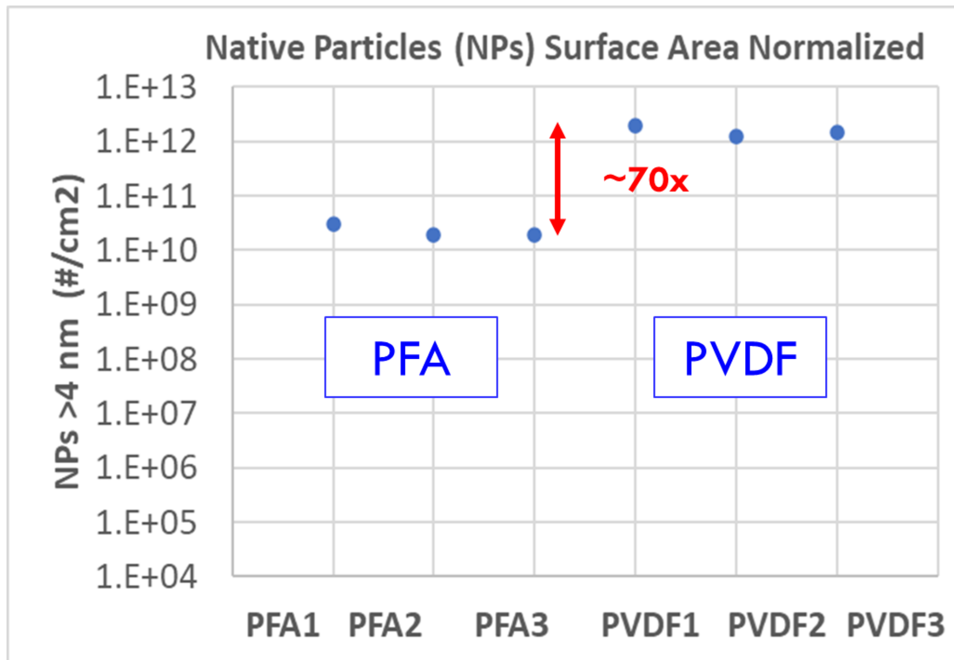

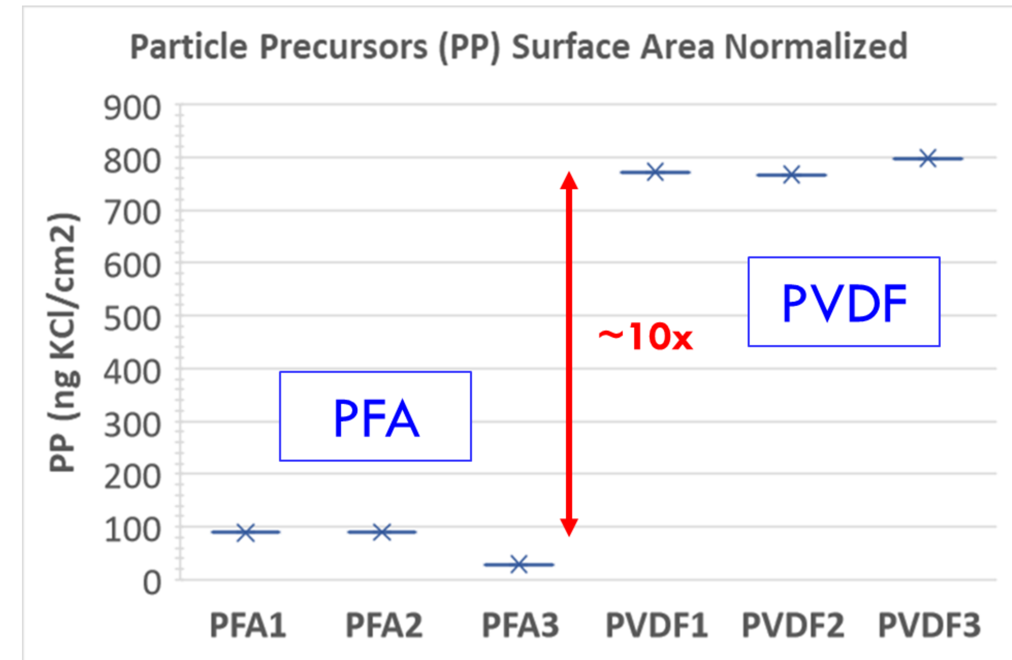

PVDF had 70 times higher concentration of native particles than PFA for the same surface area.

PVDF had 10 times higher concentration of particle precursor than PFA for the same surface area.

PFA to PVDF Particle and PP Comparison

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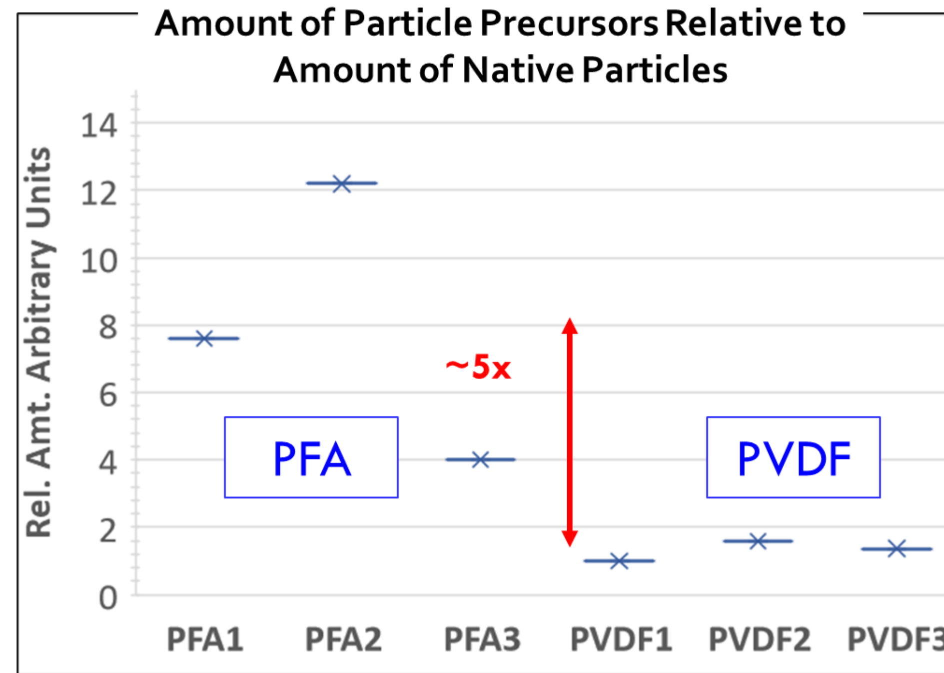

The ratio of particle precursors to native particles was five times higher for PFA than for PVDF.

On-wafer Adhesion Comparison

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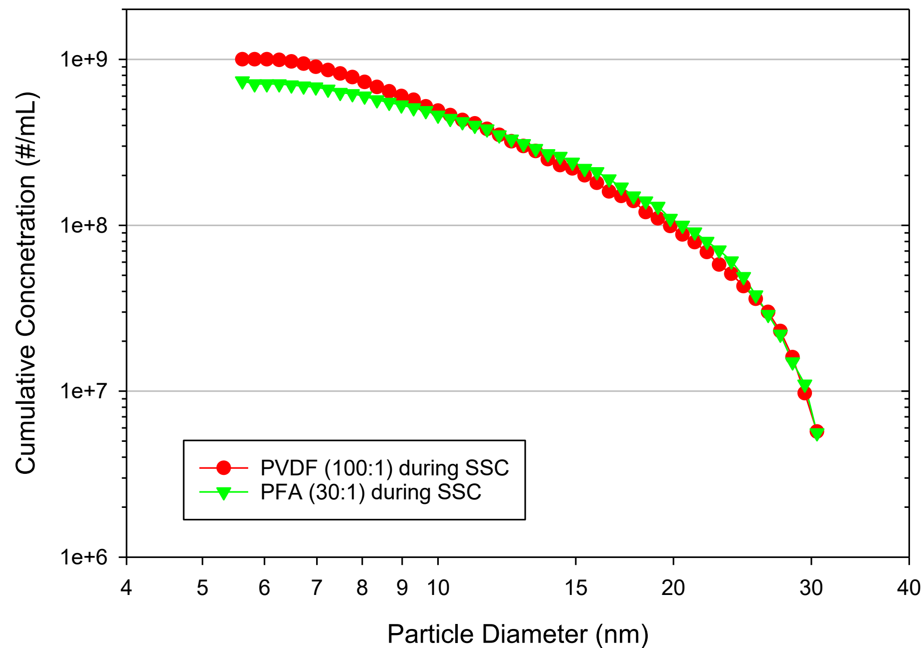

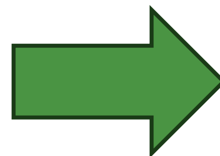

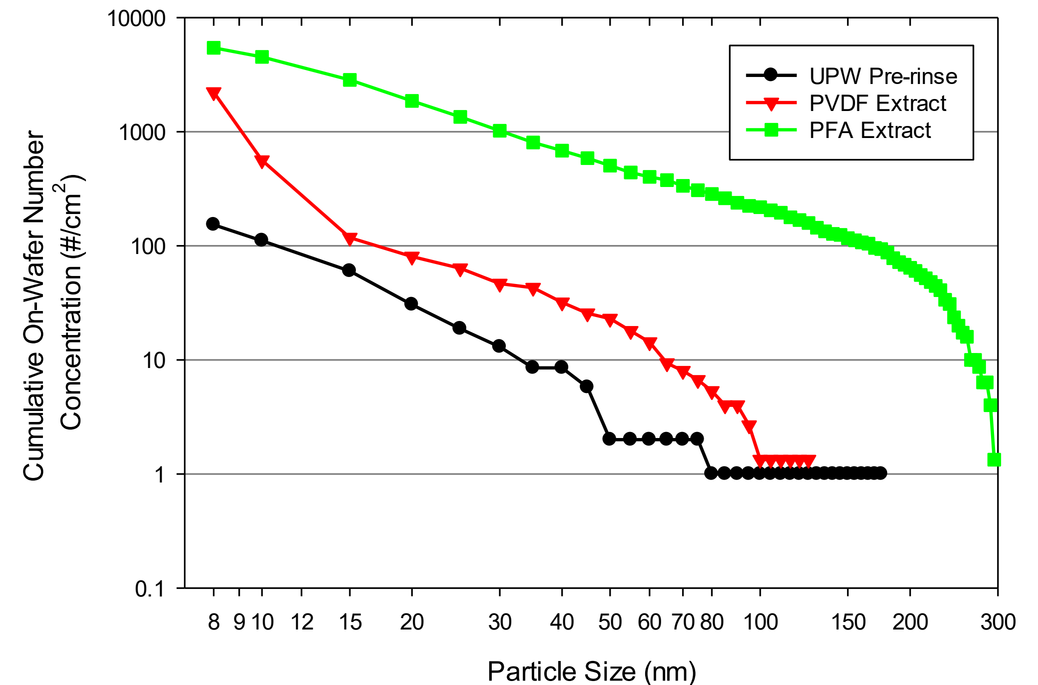

Approximately equal particle and particle precursor concentrations for PVDF and PFA were used in the spin coating process. The “stickiness” of PFA was significantly higher than PVDF.

On-wafer Adhesion Comparison

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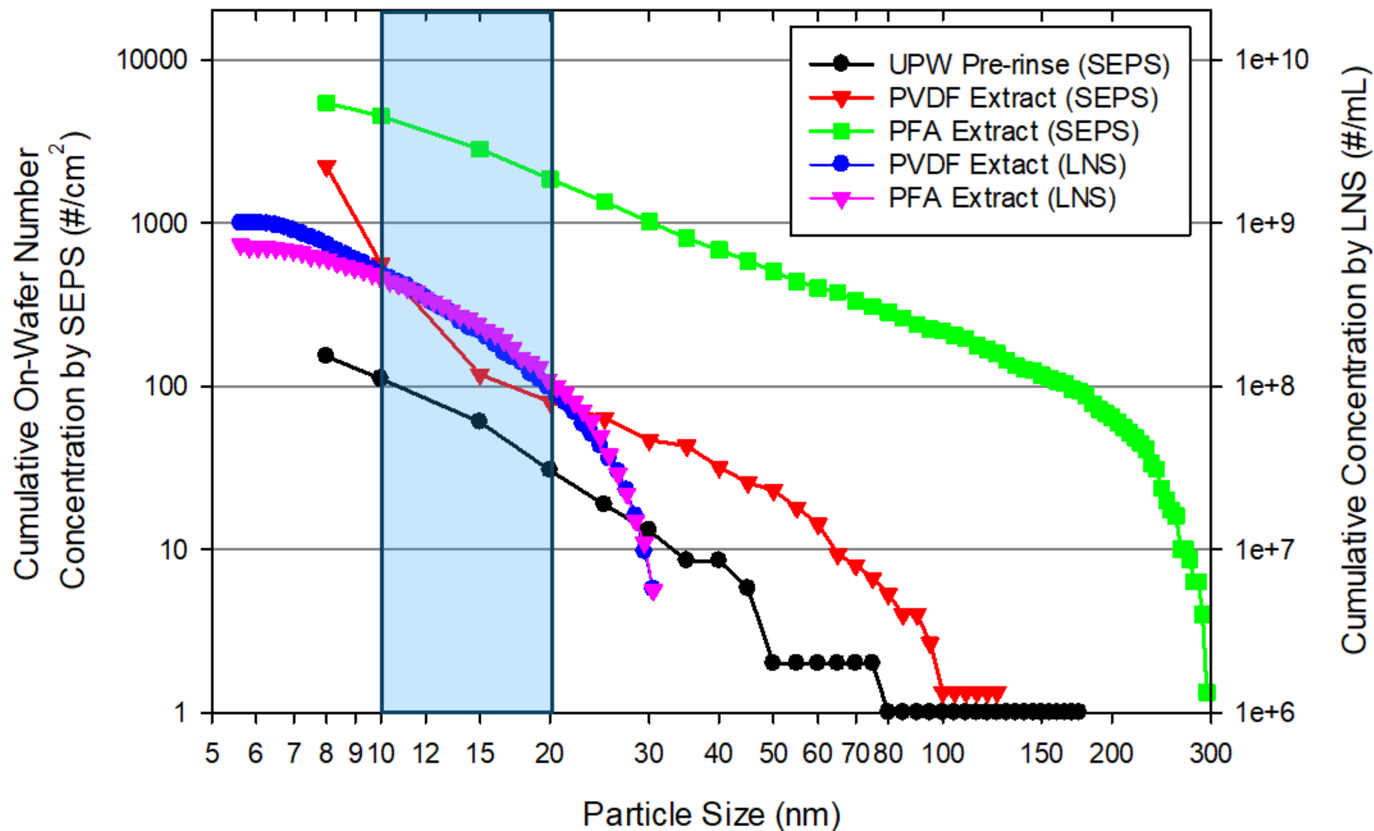

Defectivity Coefficients per Coat (10 – 20 nm):*

- PFA – 7.4E-8 particles/wafer-cm^2 per #/mL
- PVDF – 1.2E-8 particles/wafer-cm^2 per #/mL

* *Not normalize for extraction surface area*

On-wafer Adhesion Comparison

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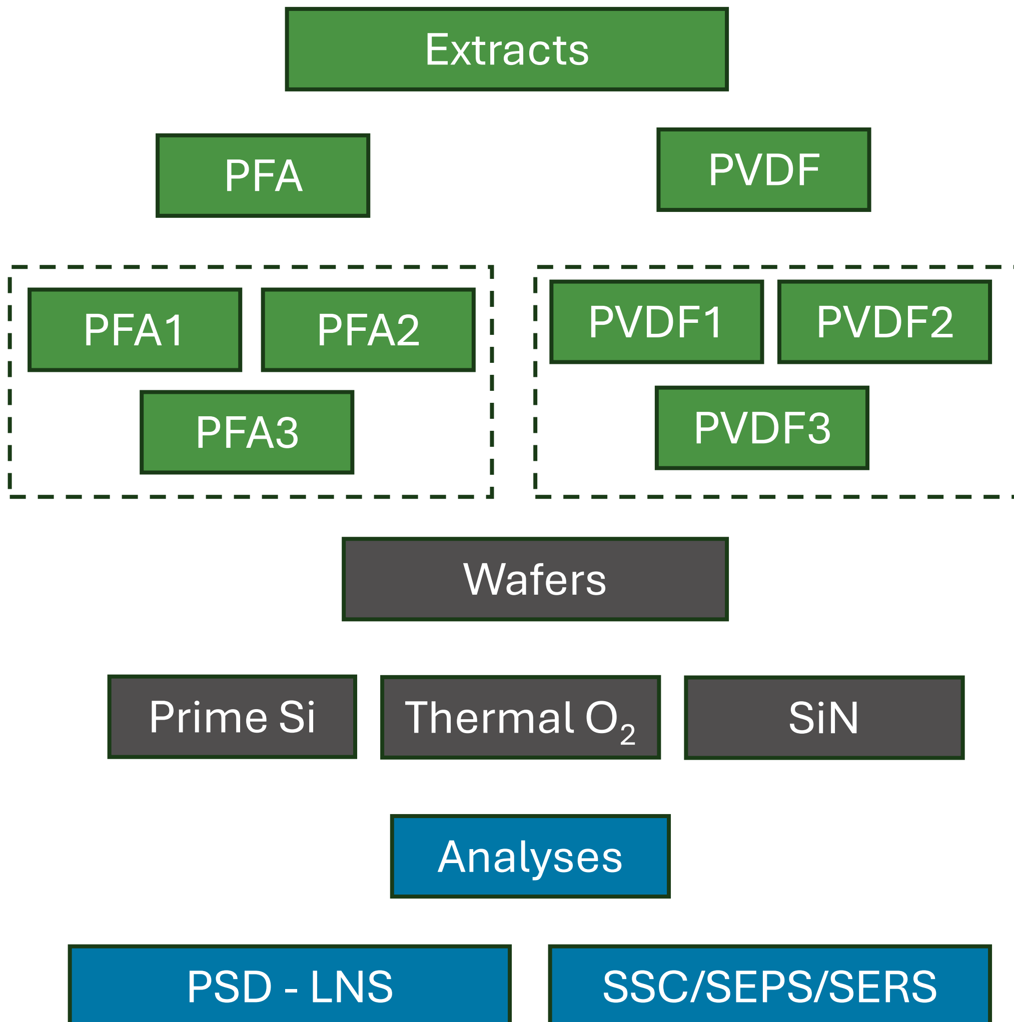
Particle Adhesion Risk (10-20 nm)				
Polymer	# particles/wafer-cm^2 per #/mL per coat (by LNS)	Relative Adhesion Ratio (Equal Particle Concentration)*	Native Particle Concentration - Surface Normalized (#/cm^2)	Relative Particle Adhesion Risk (Surface Normalized)*
PFA	7.40E-08	6.2	2.27E+10	1
PVDF	1.20E-08	1	1.58E+12	11.3

* *Higher number indicates higher relative risk of a particle adhering to the wafer surface.*

Phase 3 Test Plan



IRDS Critical Components IRDS – On-wafer Defectivity Test Method Development

Task 0 – Coating Protocol – Constant vs Ramp

- PFA 1 – Single Speed - 50 coats (triplicate) - Prime Si, ThO_2, SiN
- PFA 1 – Ramp to dry - 50 coats (triplicate) - Prime Si, ThO_2, SiN
- Select two substrates

Task 1 – Method Development

- PFA 1 - 0/25/50/100 coats (duplicate) – Two substrates
- PVDF 1 - 0/25/50/100 coats (duplicate) – Two substrates

Task 2 – Method Validation

- PFA 1/2/3 – 0 & TBD coats (triplicate) – Two substrates
- PVDF 1/2/3 – 0 & TBD coats (triplicate) – Two substrates

Particle and Particle Precursor Size Distributions

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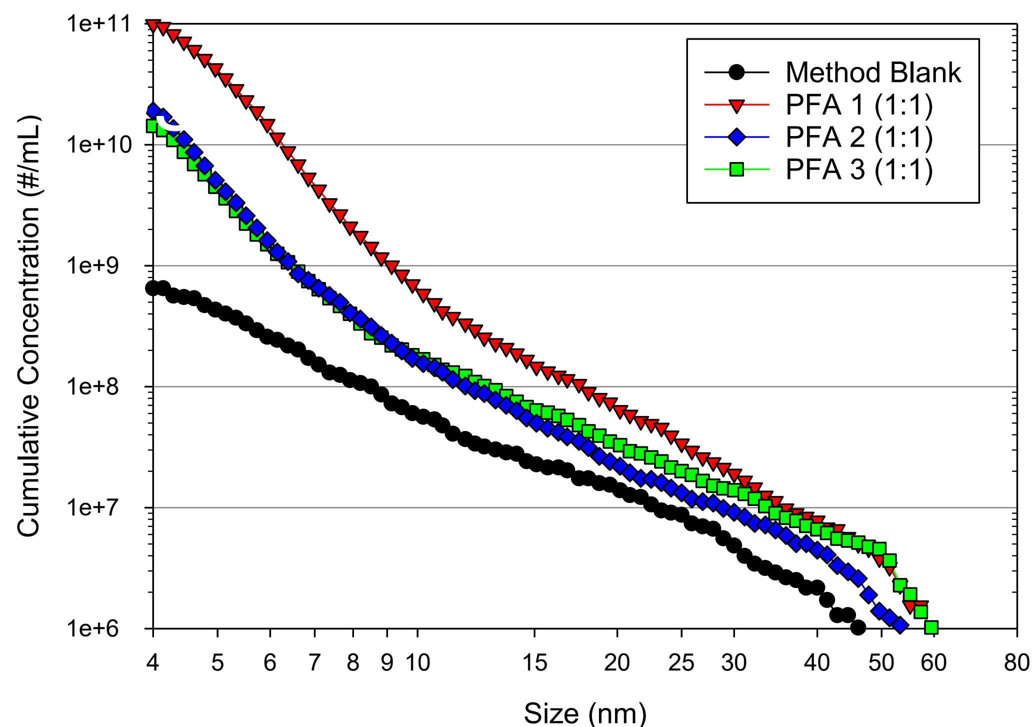
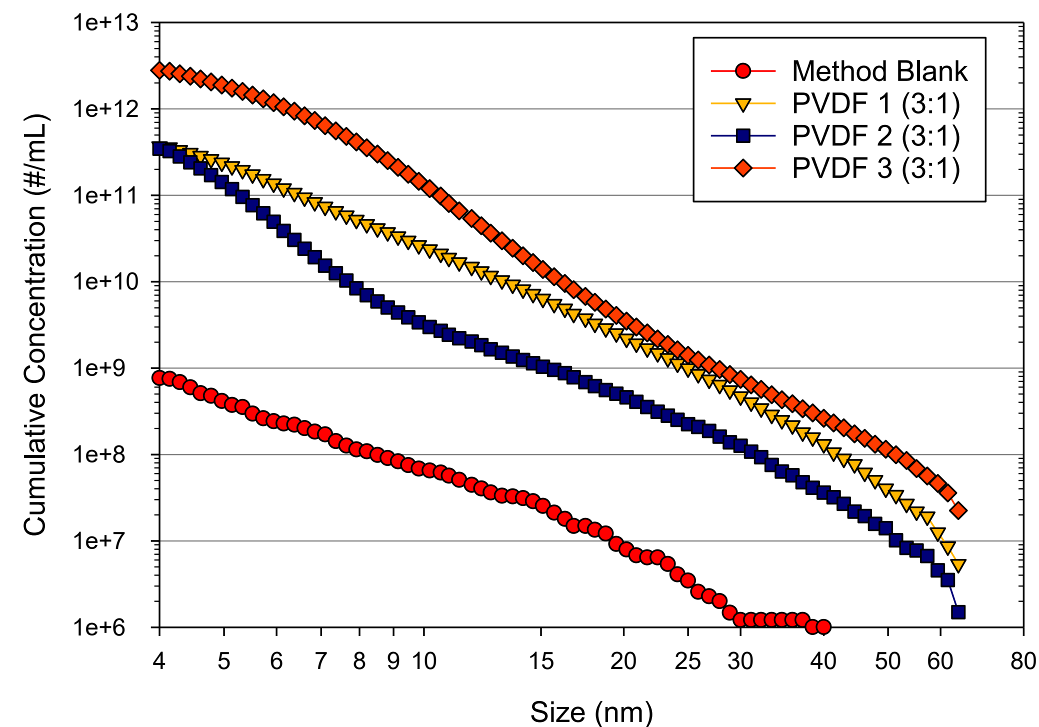
PFA PSDs*



PVDF PSDs*



* Not Surface Normalized

PDS variability of one order magnitude for PFA
PDS variability of up to 1.5 orders magnitude for PVDF

Influence of Extract Source and Wafer Type

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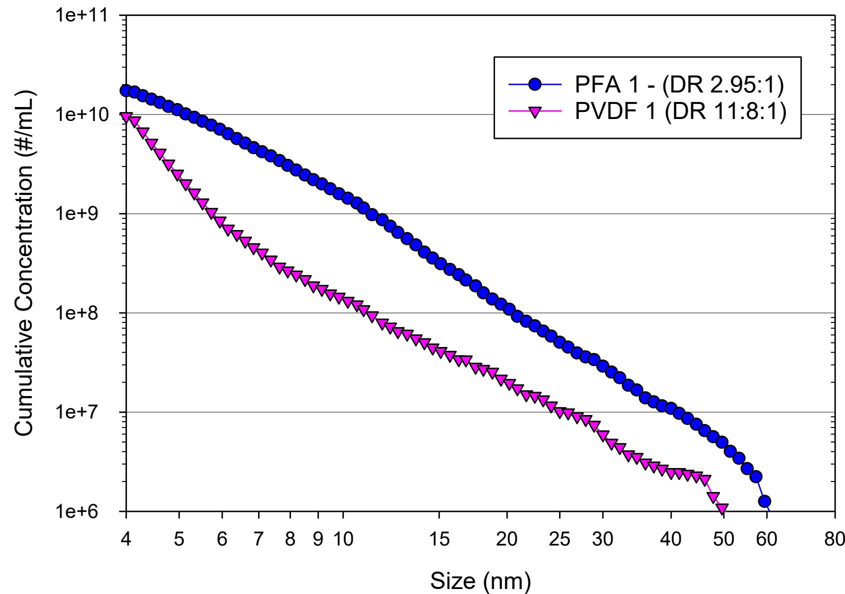
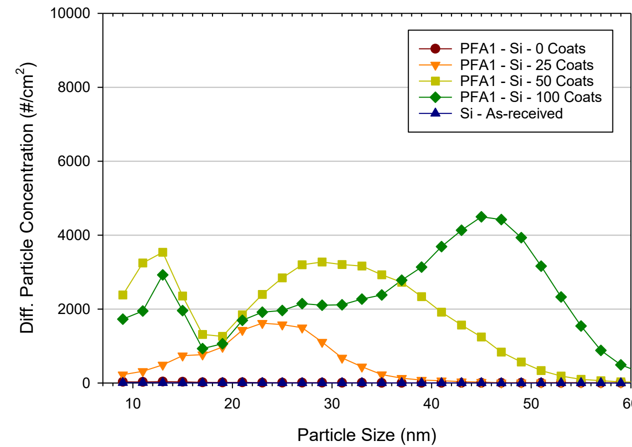
PSD of Coating Solution

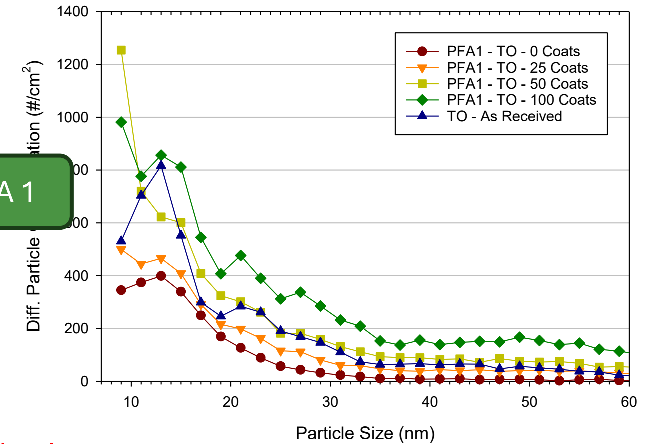


Prime Si

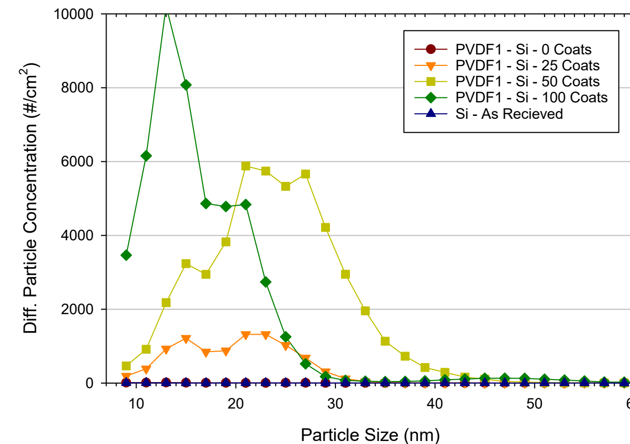
Thermal Oxide



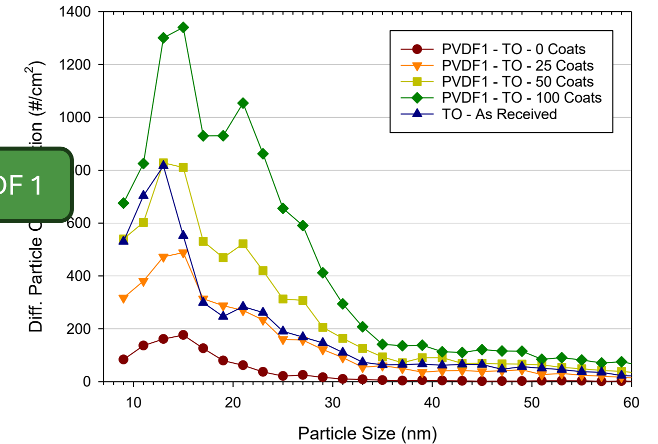
PFA 1



<<< Note scale change >>>



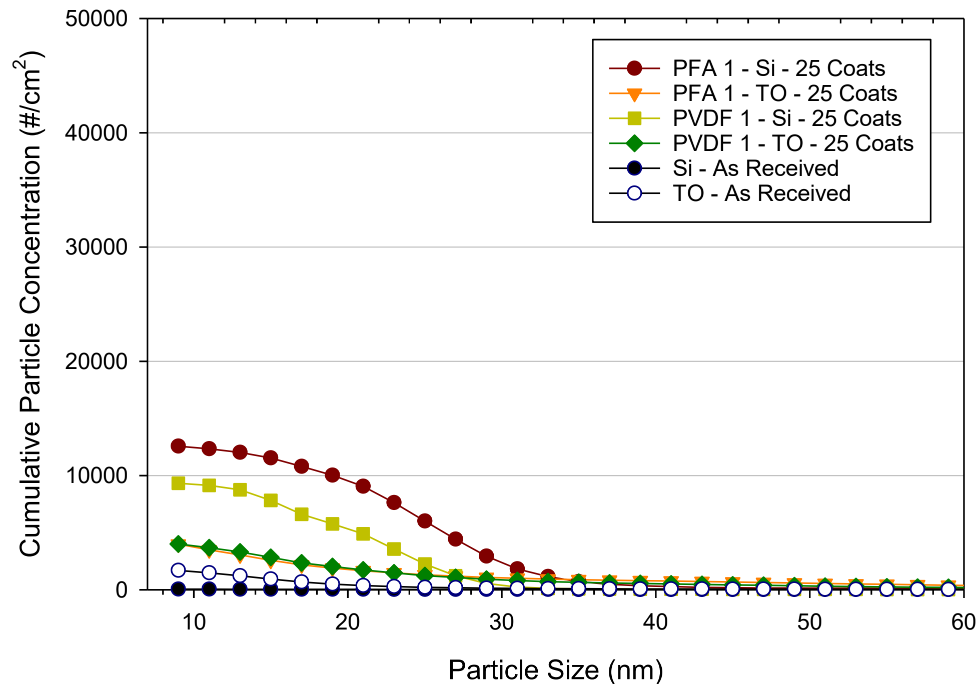
PVDF 1



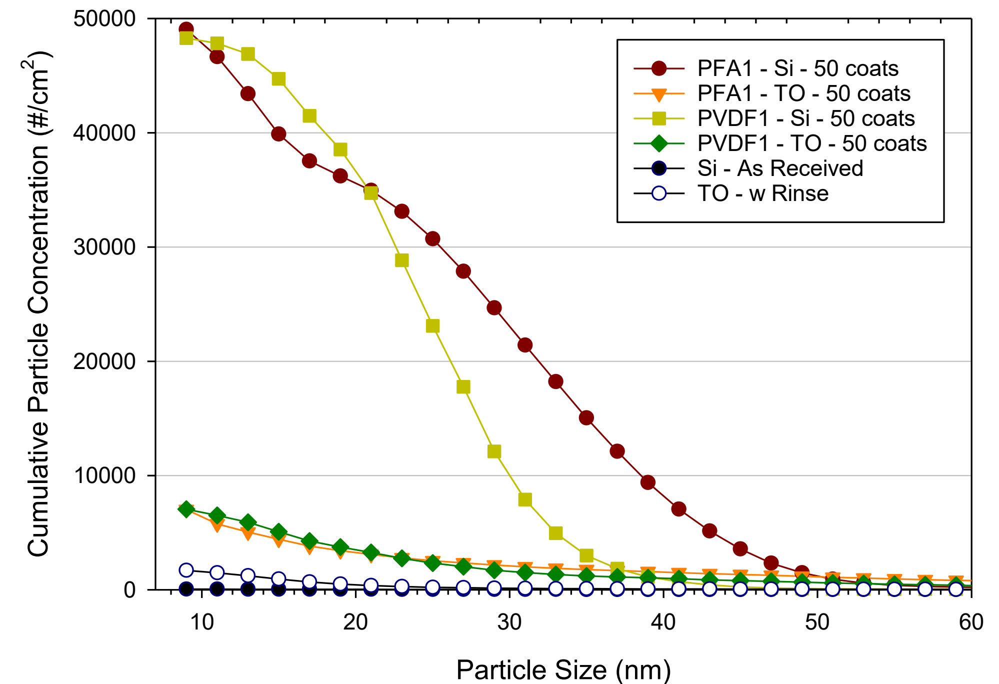
Depositions on prime Si exhibit particle agglomeration while thermal oxide exhibits increasing concentration. Likely due to differences in hydrophobicity of the two surfaces.

Influence of the Number of Coatings

25 Spin-Coats



50 Spin-Coats



Greater than 25 coats, the results become distorted for prime Si. Thermal oxide continues to increase linearly improving the sensitivity of the analysis.

Key Take-aways

Physical Property	Material	Trend	Material	Ratio
Native Particles (by LNS)	PVDF	>	PFA	70x[1]
Particle Precursor (by LNS)	PVDF	>	PFA	15x[1]
$\frac{\text{Particle Precursor}}{\text{Native Particles}}$	PFA	>	PVDF	5x[1]
Particle Adhesion Risk (~equal in-liquid particle concentration)	PFA	>	PVDF	6x[2]
Surface Normalized Particle Adhesion Risk	PVDF	>	PFA	11[1]

Notes: 1 – Extraction Surface Area Normalized
2 – No Extraction Surface Area Normalization

- Wafer surface chemistry appears to have a significant influence on the size and quantity of particles forming and adhering to the surface of the wafer.
- The remaining task will seek to optimize the test method and correlate particle and particle precursor concentrations to on-wafer PSDs.

A BIG thanks to the IRDS Critical Components financial sponsors!

- Arkema
- Asahi – America
- Chemours
- Daikin America
- Entegris
- George Fischer
- Pexco
- Saint Gobain
- Syensqo

Thank you for your attention!

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