The Future of Micro-Contamination Control in Chemical Delivery Systems for Advanced Lithography, Wet Etch & Clean Semiconductor Processes

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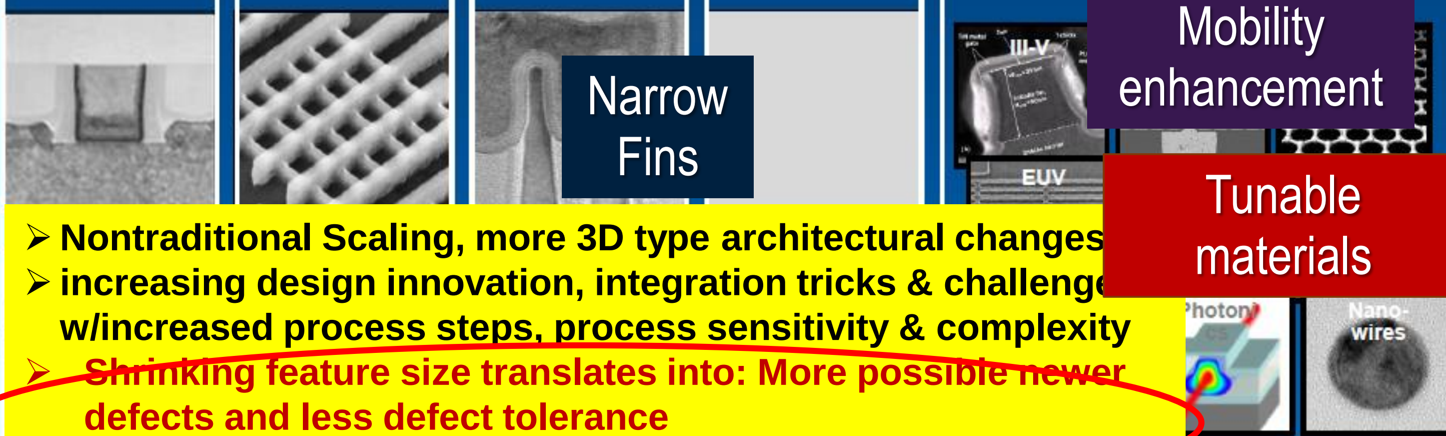
Overview

- Beyond 14nm: New Challenges with Supply line contamination and Nano-defectivity
- IDM Perspective of Problem Statement and End Goal
- Examples of Wafer Contamination Sources and Importance
- Addressing the Gaps:
  - Criticality of Metrology Requirement: Defect Identification/Characterization
  - Supply Chain Responsibility & Quality Control
- Need for Industry Collaboration:
  - Joint Responsibility
  - Expectation from POR Suppliers
- End remarks

Innovation Enabled Technology Pipeline

Precision Structure control

32 nm	22 nm	14 nm	10 nm	7 nm 5 nm
Manufacturing			Development	Research



Narrow Fins

Mobility enhancement

Tunable materials

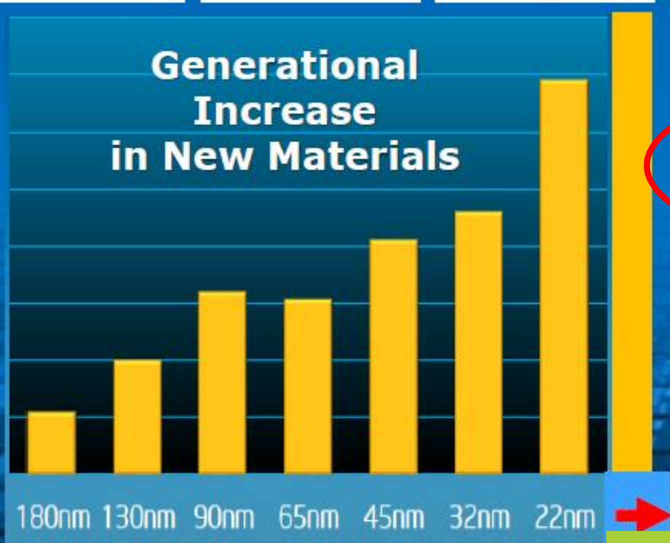
- **Nontraditional Scaling, more 3D type architectural changes**
- **increasing design innovation, integration tricks & challenge w/increased process steps, process sensitivity & complexity**
- **Shrinking feature size translates into: More possible newer defects and less defect tolerance**
- **Need To "Redefine" Defects**

The Future…

New Equipment & Materials

Higher Density & Integration

Lower Cost Per Transistor



- **Defectivity improvement is major key for HVM yield enhancement and keeping cost/transistor down**

100s of different materials of unprecedented purity and process maturity need

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Challenges in Defectivity Control beyond 14nm

- **Paradigm shift in thoughts about what we didn't care before, but we have to care to control now!**
- **What was "Process Variation" for previous Technology Nodes, can now be "Excursion"!**

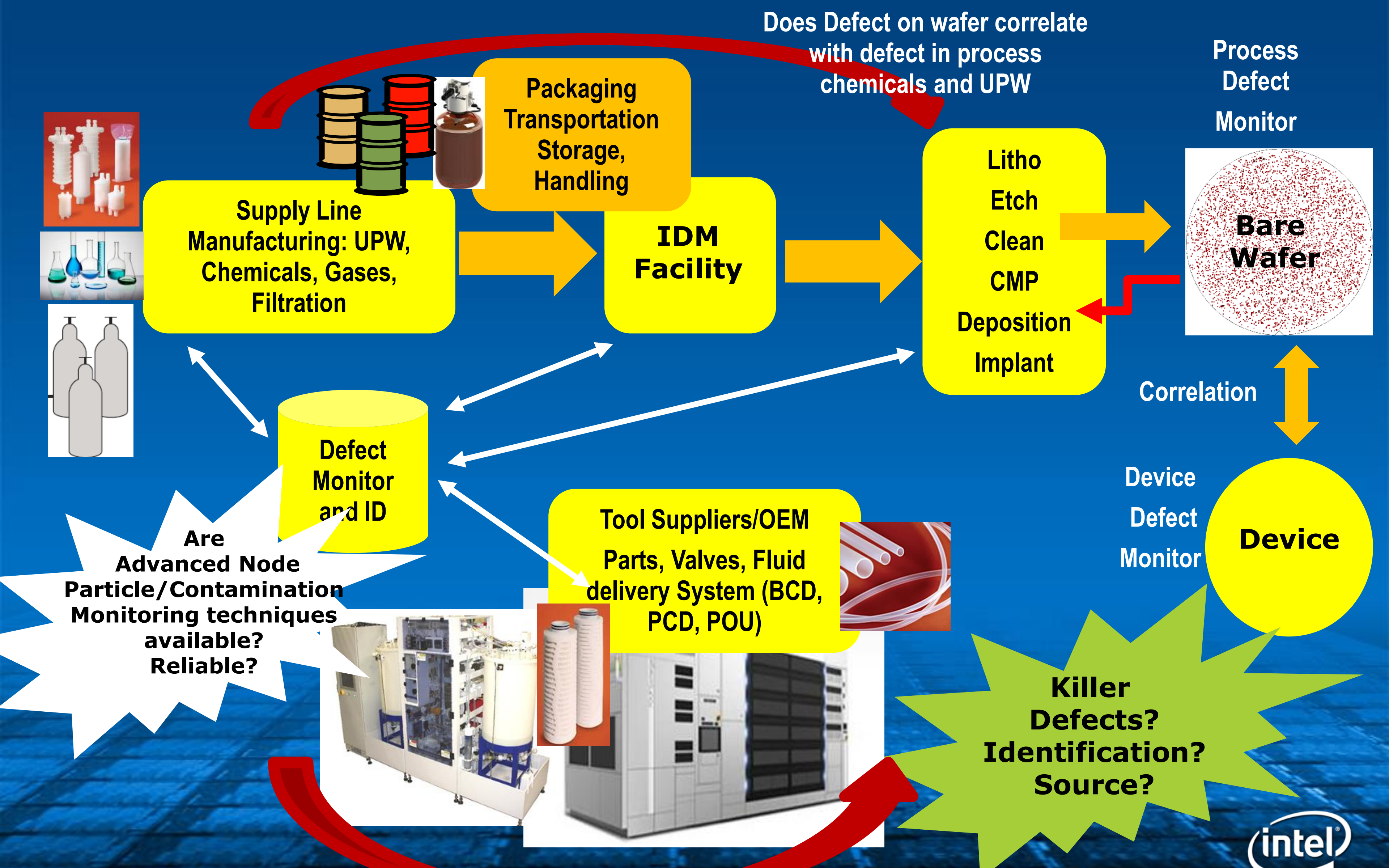
- **Integration of "Many" new, enabling materials creates challenges in purity and process maturity**
  - **Complex Chemistry: Compatibility Issues**
  - **New Defect Sources, increase Defect Sensitivity**

- **Metrology techniques of all types are challenged to provide sufficient sensitivity for early detection & prevention**
- **Supplier Infrastructure Development is lacking for better defect detection & characterization Metrology and Quality Control**
- **Need characterization and control established by a SEMI standard** so that IDM production can be protected by all sectors of the supply chain regardless of the source

HVM Requirements

- **Consistency/Predictability of and Less Start Up Time**:
  - Less Flushing for initial particles and metal ions extraction
  - Always Up and Running tools/Chemical Delivery Systems
  - **Need a very tight distribution of performance to bring up new tools**
- **Less Process Down Time**: Productivity Improvement
  - **Reduce excursion** of particles/metal ions
  - **Environmental Control** (No adders from components)
- **Meet "On wafer" Defectivity Baseline** (Process/Materials/Equipment)
  - Smaller particles
  - Metal ions
  - Organics/NVR
- **Consistency and Quality Control of "All" the products for HVM use**
  - **Across Supply Chain**

Global Control Needed for Defectivity



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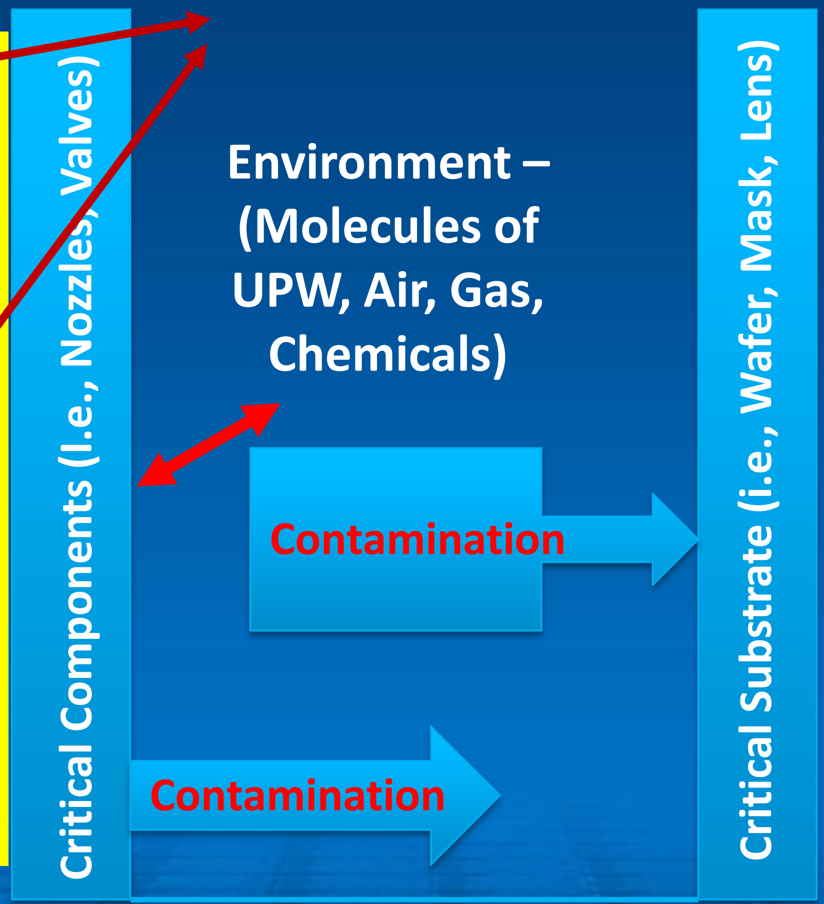
Contamination Interface Model

Started w/ SCIS charter, WECC -- still quite a bit of way to go!

- Many of the critical component systems do not have Spec, or Required Measurement standards.
- Many of the New Chemistries do not have spec.
- Interaction of Chemistry and Tools: Low concentration of particles/metals/NVR/Organics defects
- These Defects "Need to be Detected, Eliminated/Mitigated across supply chain"



- Collaboration

Total Wafer Environmental Contamination Characterization & Control are Essential for Yield Enhancement

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Which Wafer Defects Impact Yield?

- **Environmental and Process Contamination related**
  - **Particles**
  - **Metals**
  - **Organics**
  - **NVR**

Are we Monitoring these sources across supply line?

- **Defects in starting materials**
- **Printable defects during lithography process**
- **Process-induced patterning and device defects**

Example of Metrology Challenges: Chems

Material	Major Challenge	Gap in Metrology for Control	Gap in Metrology for Characterization
Wet chems and formulated chems, Solvents, Litho chem	• **Residues (Trace Metals/organics/Particles)** • **Interaction w/critical components**	• **Main component assay is insufficient for custom blend chem** • **Filtration may not be sufficient?** • **LPC: HVM monitor needs <30nm bin size.**	• **Specific detectors to enhance detectability** • High resolution to help ID the unknown • ICPMS DL, MS techniques to provide better ID capability.
CMP	• MPS trending <<100nm, • Complex interactions between chemicals/consumables: Filter+Nano-particle interaction	• **Performance-based monitors may be required** • **Normal impurity profile variation of commonly used Industrial-grade additives no longer acceptable**	• **Improved analytical metrology** to characterize abrasive colloids (<=20nm sized particle, a minute mass fraction of the hetero-dispersed abrasive PSD) • **Traditional CofA parameters not sufficient to predict performance**

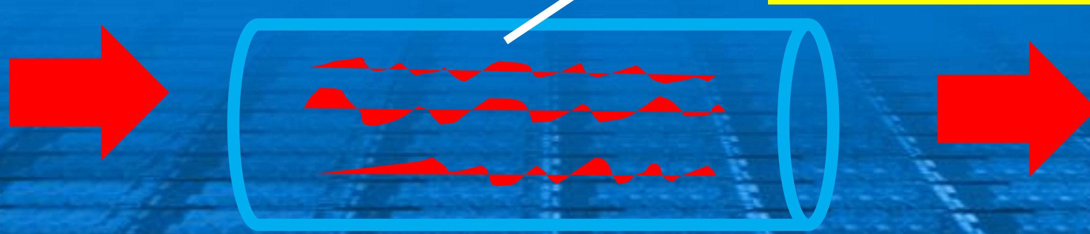
Defects caused by Chemical Handling and Delivery System (Chemical Pass)

- **As chemical travels within any dispense system, contamination is added (leaching and/or reaction with components)**
- PFA Tubing → May lead to "Metal Leaching"

Changing the Industry: New SEMI C90-1015 standard has been published: for limiting the amount of Fe in PFA materials (tube, valves, fittings, resin) used in the semiconductor industry for liquid chemical distribution.(Oct 2015)

Over time:
- **Metal Leaching**
- **Deposition of particles/organics (from hydrodynamic boundary layer)**
- **Dislodgement of particles**

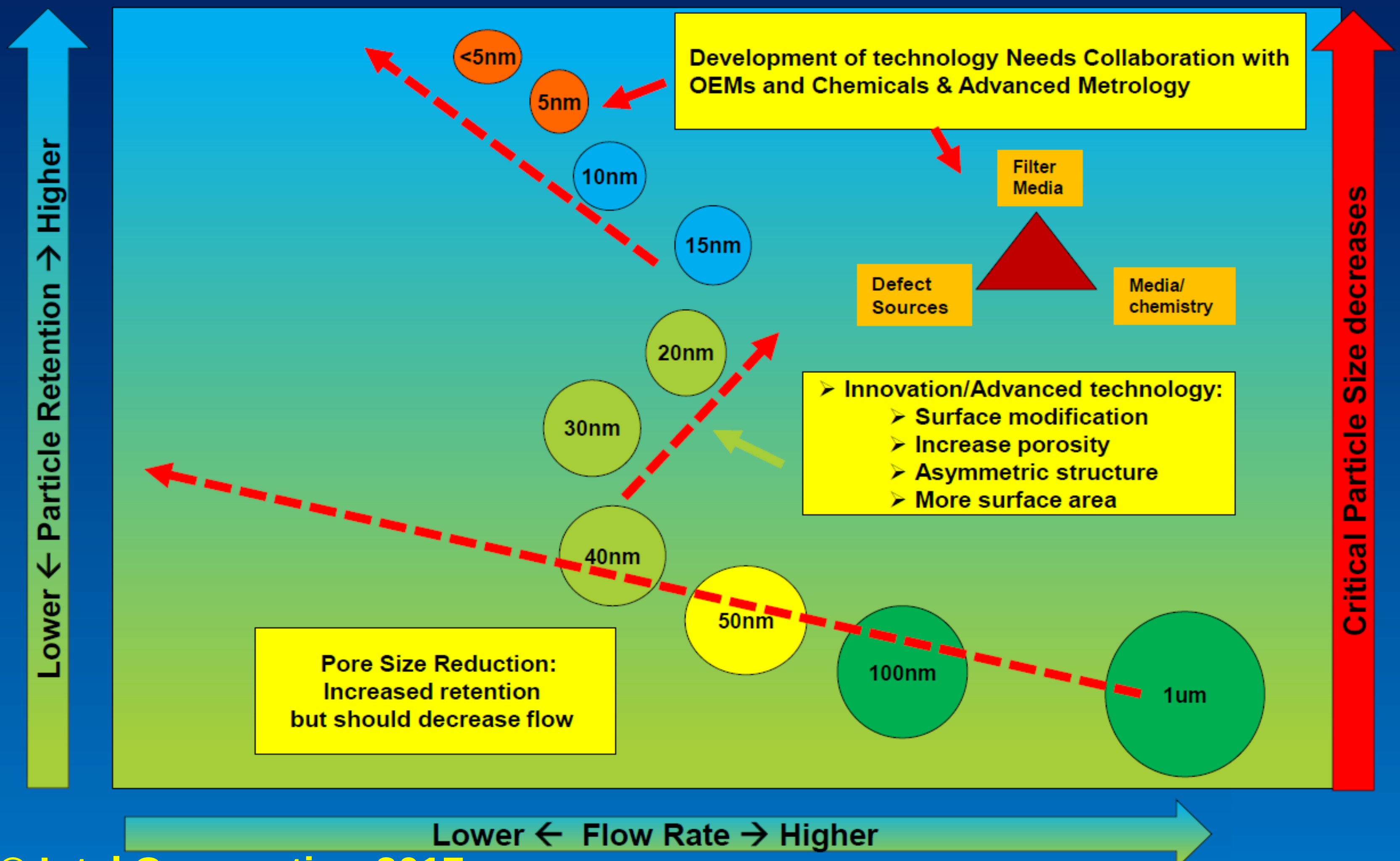
Chemical Entering (Post filtration)



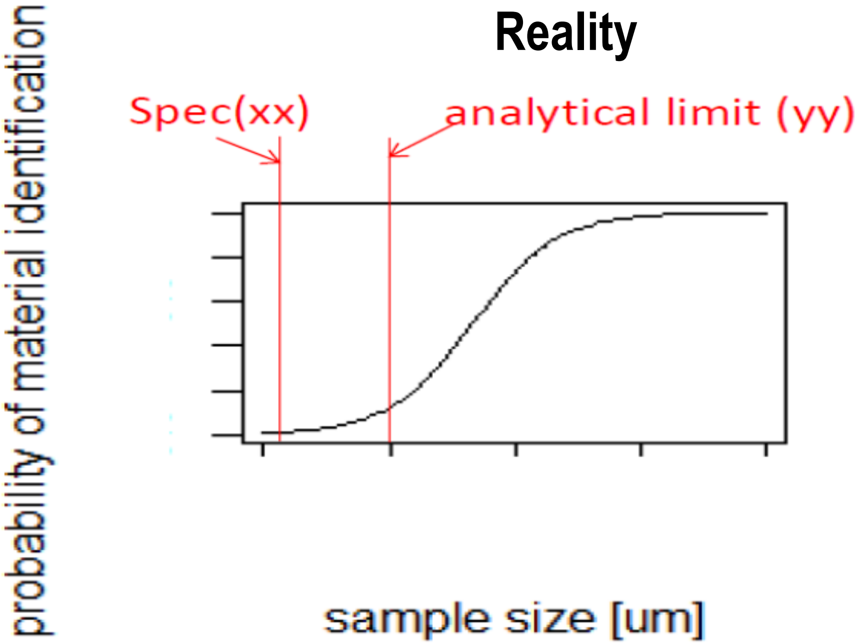
Chemical Exit (PM, Dispense rate, idle time etc. determine the residence time)

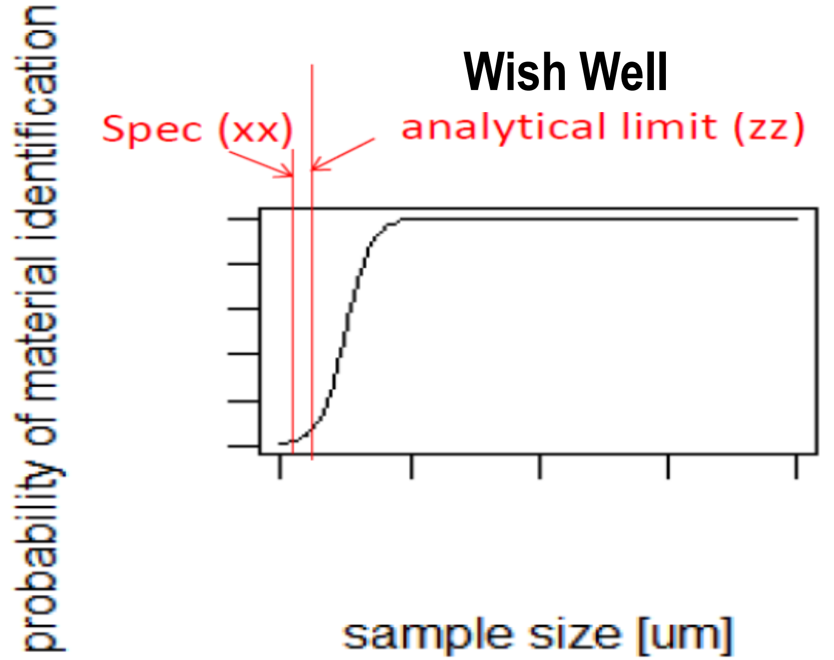
Filtration Technology Must Keep Up with Defect Scaling

- Customized Filtration is needed to meet “Paradigm Shift in Defect Tolerance”
- How to remove of <5nm Metals/Particles/Organics/NVR from Chemicals?



Analytical Metrology and Defect Analysis Gap





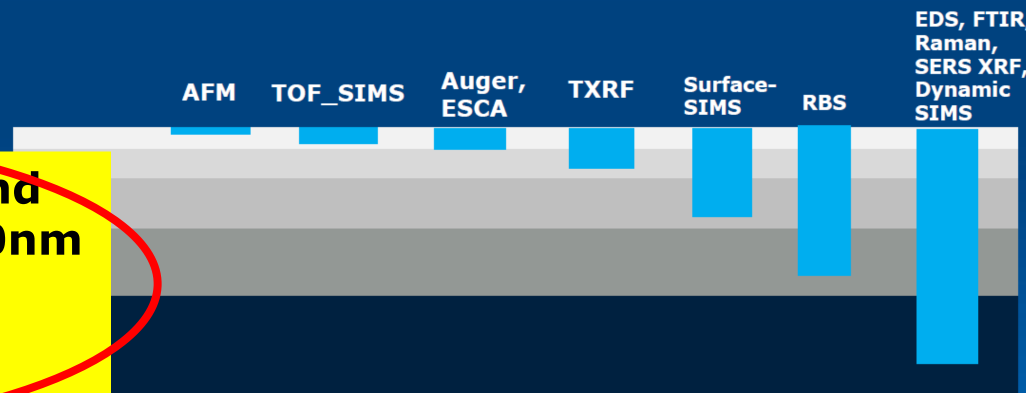
Final objective: Zero gap b/w spec and analytical limit (although spec will move down even more!)

Slide Ref: Y. Yonai, S. Morimoto, G. Yoshizawa, Y. Murata

SMC Defect Analysis and Characterization Gaps

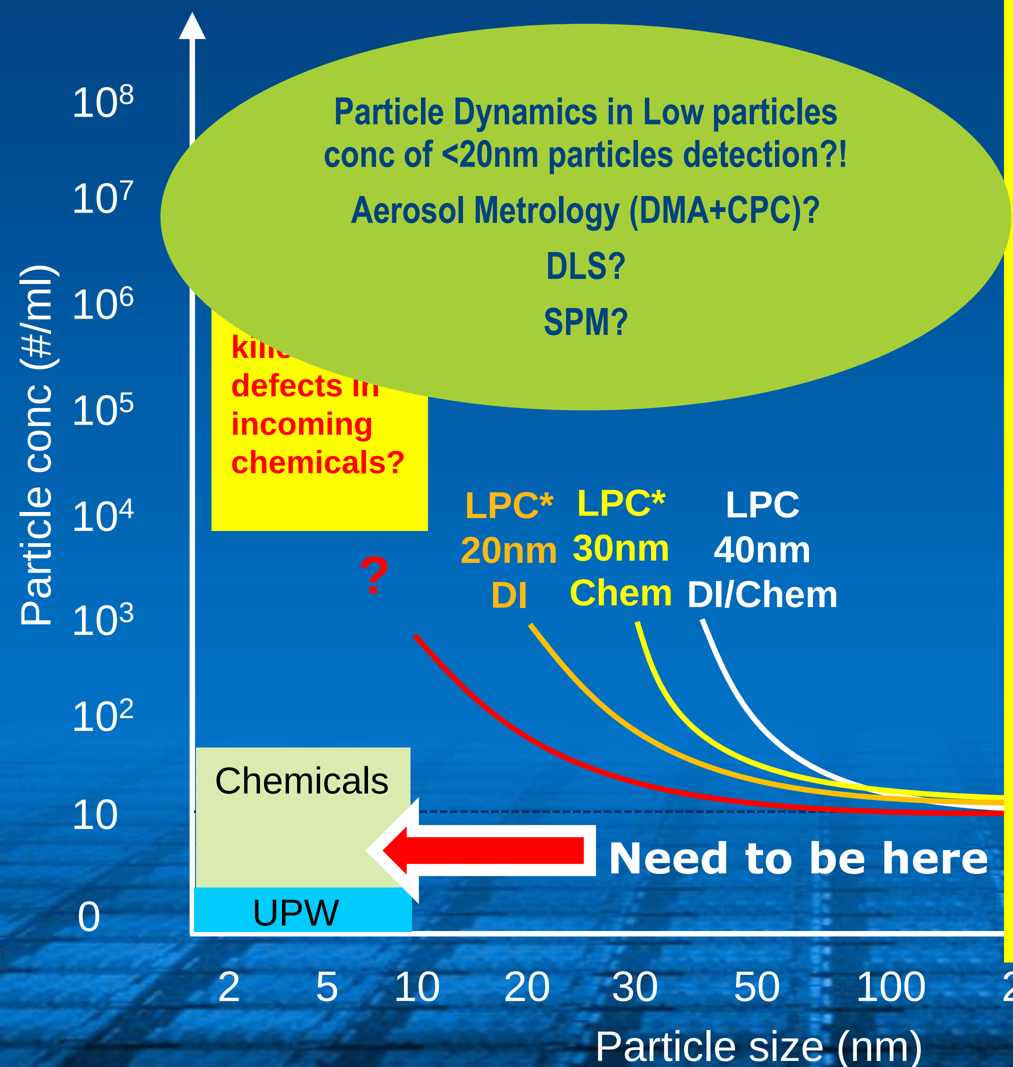
Need Hybrid Analysis Technology for Defect ID

Analytical Methods	Limitations	Gaps & Supply line concern
Physical Structure	SEM, e-SEM, TEM, AFM, XRD	• **Quantified Nano-mechanical measurement is becoming more and more critical for <10nm defects. tip/ defect artifacts for sub 10 nm defects? EDS on TEM samples for sub 10 nm defects. – Challenging**
Chemical/Elemental Composition (solids and Surfaces)	• Raman/SERS (Semi-Qualitative) • FTIR (Qualitative) • Auger, EDS (Elemental) • **SIMS, TOF_SIMS, XPS (Quantitative, Chemical ID)** • EELS, TXRF, XRF • **FCS (Novel)**	• **Limitations below 500nm, Near field AFM_Raman?** • **Limitations 10um-5um → AFM-FTIR** • **Great surface resolution** • **Difficult at 100nm-200nm** • **Low Z elements difficult** • **CMP particle characterization @ <20nm size, more sensitivity than DLS**
Chemical/elemental (Solids, Liquids, Gases)	GCMS, TD_GCMS, ICPMS, VPD-ICPMS, IC, LCMS Auto-filtration, CRDS, FTIR, FCS	• **Need better sensitivity and DL**



What Standardized Metrology and Analytical tools can be used <10nm Defect Identification!
Can I see it?
Do I know what it is?

Particle Metrology Gap: On Surface vs. In-Situ Liquid



- Alternative for Advanced e-beam or SPx across Supply chain particle detection?
- Reliable LPC for <20 nm particle detection (Chem/DIW/Solvent)?
- Detection efficiency/Sensitivity at low conc.
- Blended chemistry challenges (Micro-bubbles, micelles)
- Correlation between LPC counts and on-wafer defects for advanced nodes
- **Increased Sensitivity to Impurities is not identified on ITRS Roadmap due to Measurement Limits: Need for ULTRAPURE**
- Current liquid-based analytical LDLs are not comparable to gas-based instrumentation

How do we Control/Prevent the Contaminants?

1st Request: Three major control of the contaminants before ship the "Best" products to the factory:

- **The Materials**
- **The Equipment**
- **The Components**

2nd Request: We Cannot Evaluate Advanced Node Chemistry/Process Without Aggressive "Super-Filtration And Purification"

- **Need ultrapure materials, extreme retention, lowest possible interaction**
- Optimized at chemical manufacturing and at factory processing/tools

3rd Request: Help us closing the Metrology/Analysis/Standard Gaps

4th Request: Work Together: Collaboration

Picture Ref: Hera & Athena handshaking, late 5th century BC, Acropolis Museum, Athens

Semiconductor Ecosystem Must Work Together

- **Increasing interdependency with process complexity:**
- **Materials and Equipment Specs : Process Control And Traceability**
- **Need to re-write "Advanced Semi-Standards" for Measurement**

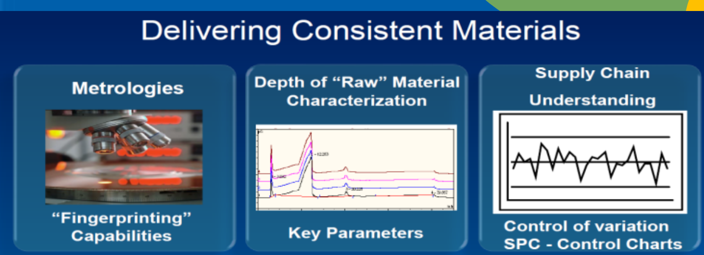
Device

Materials

Equipment

Collaboration for Defect Control to meet the target for

- **Technology Performance**
- **Process Yield**
- **Device Cost**

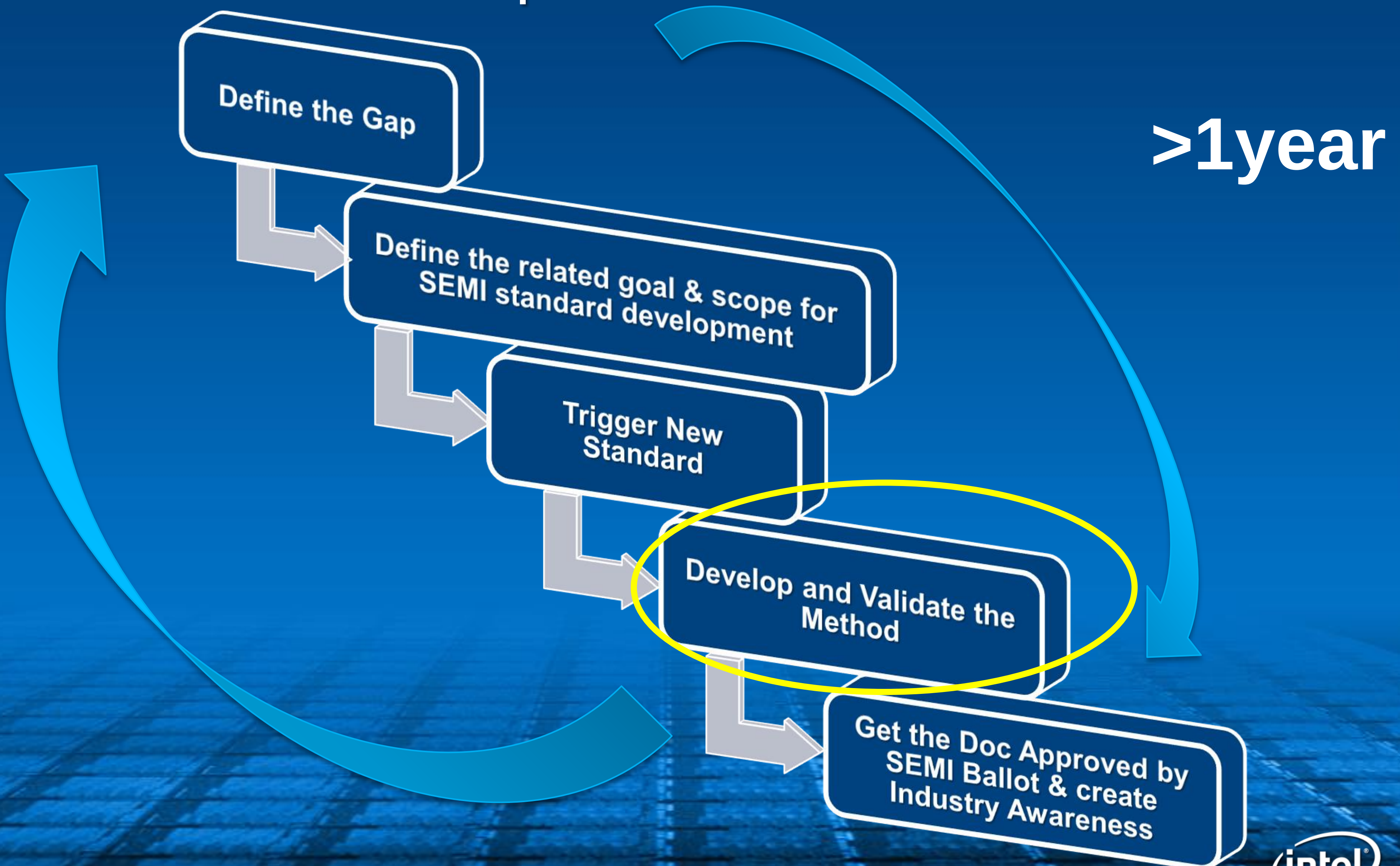


- **Process is as good as Control & Baseline**
- **What Matrix are we measuring?**
- **What Methodology we are applying?**

- **Need Complete Supply Line Visibility and High Level of Trust**
  - **Develop Joint Analytical capabilities for Defect Detection and ID**
- ***Success requires collaboration across all supply chain partners***

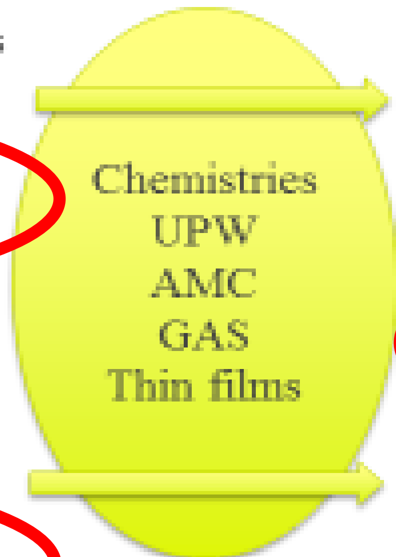
Industry Must Collaborate on ONE PLATFORM to redefine Materials & Equipment "Specs & Metrology Standards" for <=14nm Node

Collaborate on One Industry Platform and help each other?

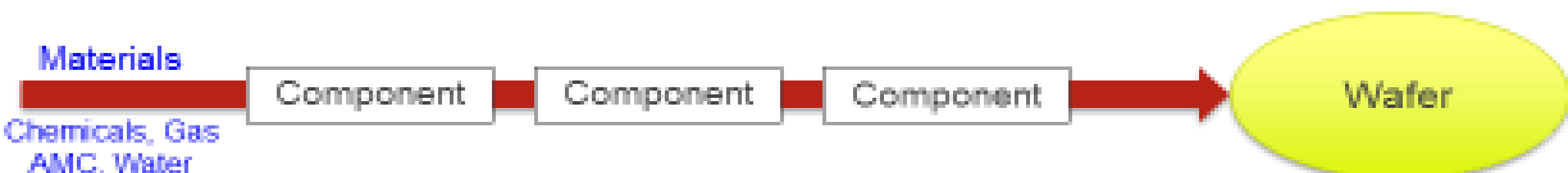


SEMI Special interest group and Overall Industry platform - Philosophies

- Forum for suppliers/OEMs/IDMs on supply chain challenges for HVM at advanced nodes
- Assumes all process critical components contribute to defects → establish control
- Establish baseline of contamination contributions of various components as well as their interactions with various chemistries or materials
- Define framework of means to measure



- Forum to develop technical solutions that will enable HVM at advanced nodes
- Assumes contamination on critical surfaces as highest priority → establish control there first
- Establish contamination requirement levels in chem/gases/water based on wafer contamination contribution limit for components and materials
- Define roadmap parameters, and the need for test methods, process controls (e.g., H_2O_2 in water)



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- **Major Challenges:**
  - **work within IP boundaries**
  - **Acquire adequate funding**

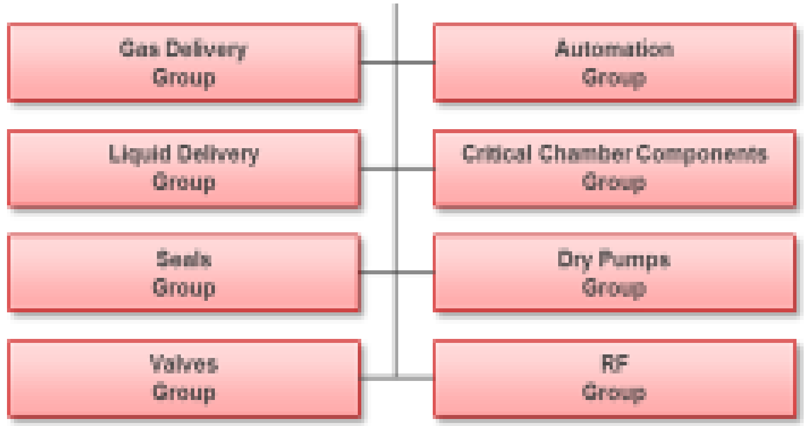
SEMI Component, Instrument and Subsystem (SCIS) Special Interest Group

- **Goal:**
- **To Create Standard System of comparable Metrics which will be used to rate, compare and classify process-critical OEM components in order to reduce defects generated in Semiconductor manufacturing**

- **Establish a general "framework" to guide Industry partners to**
  - **Define observable/measurable defects**
  - **Define comparable category attributes specific to each category component**
- **Define methods for identifying defects related to each category**
- **Guide industry to utilize the framework**

SCIS: Critical Component-OEM_End User Team

- **Components** such as seals, filters, mass flow controllers, valves, sensors, ion beam sources, etc.
- **Instruments** for in-line and off-line data measurement, collection, and monitoring
- **Sub-systems** that support process tools e.g. vacuum, robotics, power conversion, abatement, chillers, etc.



Slide Ref: Paul Trio, D. Rafferty, D. Vernikovsky

SCIS – SEMI – Other Industry Platforms Alignment
From Technology Gaps to SEMI Standards

SEMI SCIS Roles

- **Provide supply chain inputs** on critical components and related parameters that need measurement methods established
- **Define framework for component characterization**
- **Implement developed SEMI Standards** throughout supply chain, identify gaps and new requirements

- **Other Industry Platforms**
  - **Develop test methods** for measuring materials defect contribution as well as measuring performance of related components
  - **Obtain SCIS inputs on measurement methods** in development
  - **Conduct testing/experiments to validate** measurement methods

SEMI SCIS

Provide regular updates, reporting on progress and gaps to maintain alignment

SEMI Standards ⟷ **Other Industry platforms**

- **SEMI Standards Roles**
  - **Establish appropriate task force, develop/publish standards**

SCIS – SEMI TASK Force (TF)

- SEMI F57 was renamed in July 2016 to: High Purity Polymer Materials & Components TF

SEMI Standard TF	Final Goal	Contamination	Current Status
F57 – is the standard for contaminants in critical components as measured by F40	Revise Standard material to meet F63 standard - Include filtration	Ions (Fluoride first), metals, and TOC	- Testing is ongoing - Plans ready for Ballot late 2017
F104 – is the method for measuring particle contribution in critical components	Revise F104 to meet particle leaching requirements	Particles (static and dynamic testing) Considering TOC and NVR	SNARF will be submitted
F40 – is the method to measure extractable contaminants from critical components.	Rewrite adequate test methods for testing - Include filtration	Inorganic, Anions, TOC, NVR	Under discussion

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- **Definition of "Surface Contamination & High Surface Area components" – high purity polymers, high flow components**
- **Dynamic Rinse vs. Static Rinse contribution**
- **Definition of "Particles" (& Size to meet <=7nm Node requirement!) And Beyond Particles (TOC, NVR)**
- **F63: Gap in definition due to lack of metrology @ killer defects!**

SCIS Liquid Delivery Team Charter

Action	*Update and Next steps*
Complete OPC Technology considerations for particle contribution	Ongoing
Particle measurement for high performance polymer parts – Filters included	Revision of F57/104 for dynamic testing for all high performance polymer parts (update on F57) Update F104 for particle shedding of filters (reference to C79)
Ions, metals and TOC	Incorporation of Filters in F57 revision
Organic extractables	Team is discussing specific DOE

Alignment with SEMI F57, other SEMI Task Force and Other Industry Platforms

- Revision of F57 for Ions, metals and TOC (incorporation of Filters) filter performance for sub 15nm particle retention) *for leachable*
- Revision of F104 is being discussed – Static and dynamic particle shedding of *critical components* (Reference to C79 - Method to evaluate filters performance)
- Alignment with Chemical/UPW SEMI task forces

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Success Story of Collaboration to Change SEMI Standard: SEMI C90-1015

- Changing the Industry – One Step at a time.
- Led by Intel - New industry standard for measuring/limiting the amount of Iron contamination in PFA materials (tube, valves, fittings, resin) used in the semiconductor industry for liquid chemical distribution has been published by the SEMI organization (2015)
- Next, defining the frequency of the test and the reporting medium for the results so as to monitor and manage the supply chain
- Many suppliers were involved with this new standard development and have adopted transition

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SEMI C90-1015
TEST METHOD AND SPECIFICATION FOR TESTING PERFLUOROALKOXY (PFA) MATERIALS USED IN LIQUID CHEMICAL DISTRIBUTION SYSTEMS

This Standard was technically approved by the Liquid Chemicals Global Technical Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on August 31, 2015. Available at www.semiviews.org and www.semi.org in October 2015.

1 Purpose

1.1 This Document defines perfluoroalkoxy (PFA) resin and component preparation and pretreatment procedures for chemical test methods used to evaluate liquid chemical distribution system components and resin.

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END REFLECTION

- Leadership means **Corporate Responsibility**
- 14nm and Beyond: We have **paradigm shift in process scaling/defectivity challenges: Process Variation can end up as Excursion**
- **Interdisciplinary expertise need to work together**
  - **Tool suppliers, Material suppliers, Filter Suppliers, Component suppliers, Metrology suppliers and IDMs need to work together to achieve required defectivity baseline and create new STANDARDS**
- Next Generation Quality Systems combined with **Sub-Supplier Management** helps to **achieve "Ship to Control Across Supply Chain",** makes IDM "Quality Incident Free" and minimize costly learning during HVM ramp

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Thank YOU

- To My Co-Authors
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- To SPCC Committee for the opportunity to present

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