THE USE OF FOCUSED AEROSOL DEPOSITION IN THE COLLECTION AND ANALYSIS OF NANOPARTICLES FROM ULTRAPURE WATER SYSTEMS USED IN SEMICONDUCTOR AND PHARMACEUTICAL INDUSTRY

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KANOMAX FMT
A Kanomax Company

INTRODUCTION

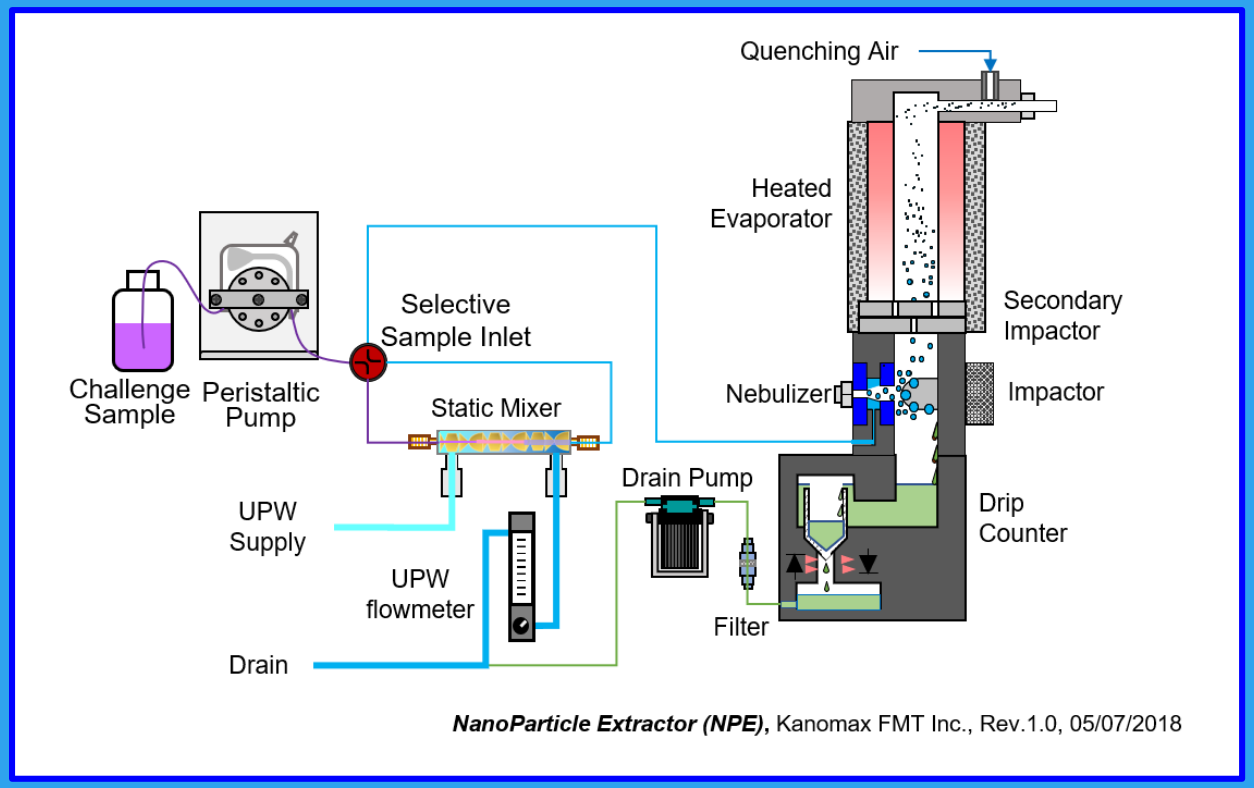
- PARTICLES AS SMALL AS 10 NM AND LESS HAVE THE POTENTIAL TO CAUSE "KILLER DEFECTS" IN THE LATEST AND NEXT GENERATION OF SEMICONDUCTOR DEVICES.
- DETECTING, COLLECTING AND IDENTIFYING THESE "KILLER" PARTICLES IN HIGH-PURITY LIQUIDS IS EXTREMELY CHALLENGING AND TIME CONSUMING.
- DEVICE GEOMETRIES AND FEATURE SIZES WILL CONTINUE TO PRESS THESE SIZES TOWARD 5 NM IN THE COMING YEARS.
- TRADITIONAL FILTER-BASED CAPTURE TECHNIQUES HAVE BOTH PORE-SIZE AND FLOWRATE LIMITATIONS, AND MAY TAKE WEEKS FOR ONE SAMPLE.
- THIS PRESENTATION WILL REVIEW FOCUSED AEROSOL DEPOSITION (FAD) AS A TOOL FOR CAPTURING LIQUID-BORNE NANOPARTICLES FOR OFF-LINE SIZING AND COMPOSITIONAL ANALYSIS BY ELECTRON MICROSCOPY (SEM AND TEM) AND ENERGY DISPERSIVE X-RAY (EDX)

PRESENTATION OUTLINE

- FOCUSED AEROSOL DEPOSITION (FAD) THEORY OF OPERATION
- FAD TECHNOLOGY DEVELOPMENTS AND CAPABILITIES
- TEST RESULTS AND POTENTIAL APPLICATIONS
- NEXT STEPS
- SUMMARY

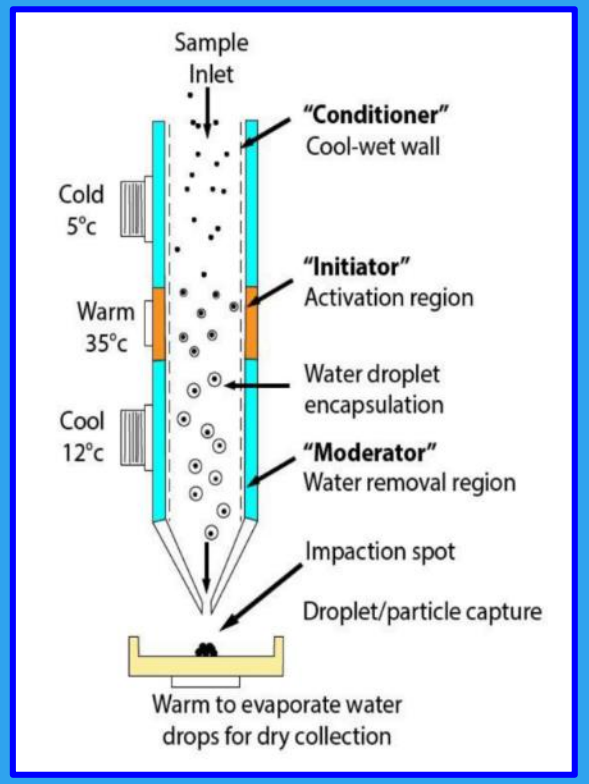
THEORY OF OPERATION – FAD[3]

Ultrafine Aerosolization[1]



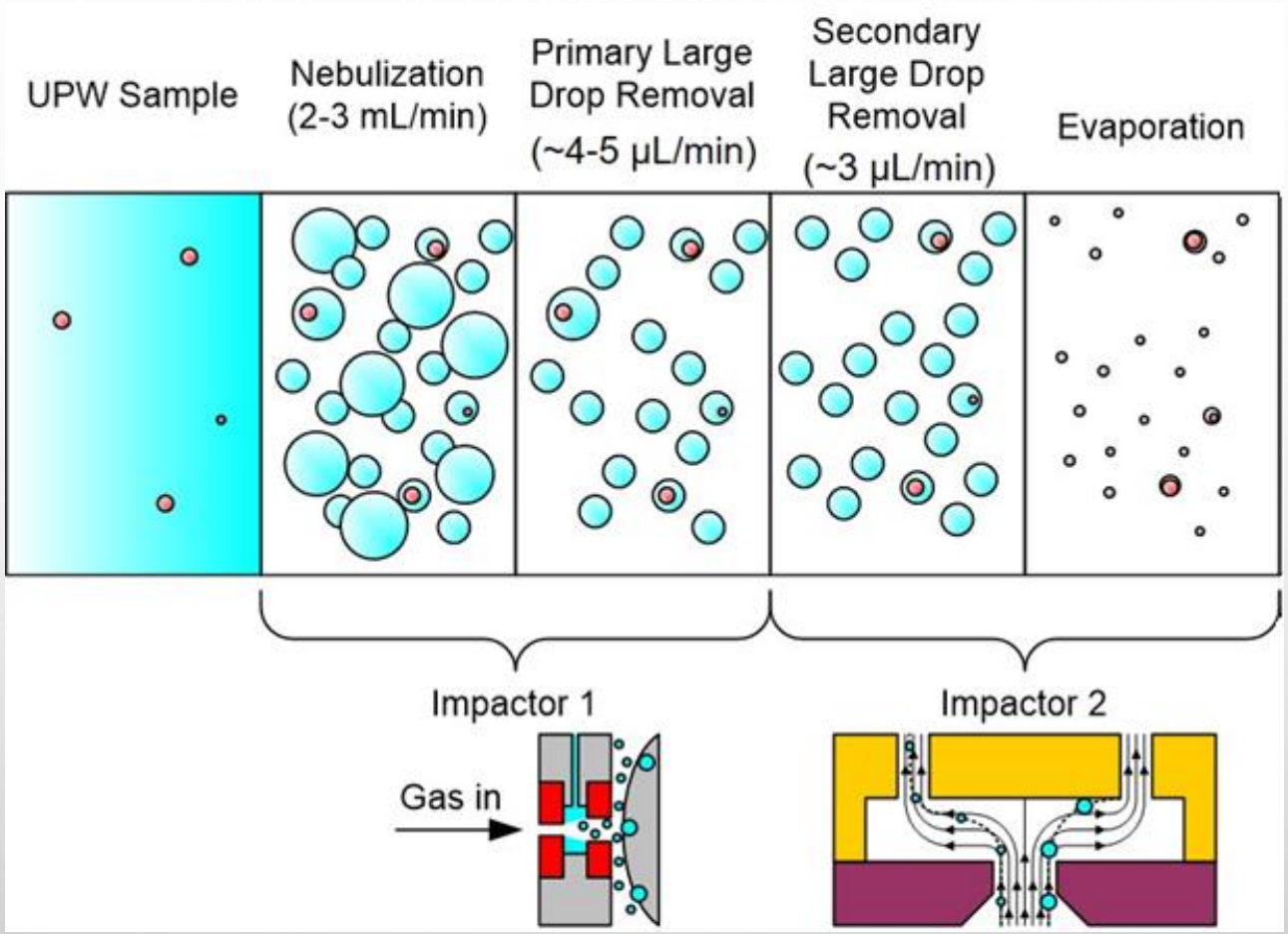
NanoParticle Extractor (NPE), Kanomax FMT Inc., Rev.1.0, 05/07/2018

Nanoparticle Collection[2]



[1] Kanomax FMT NanoParticle Extractor (Model 9410-00)
[2] Kanomax FMT NanoParticle Collector (Model 9410-01)
[3] Kanomax FMT NanoSpotLight™

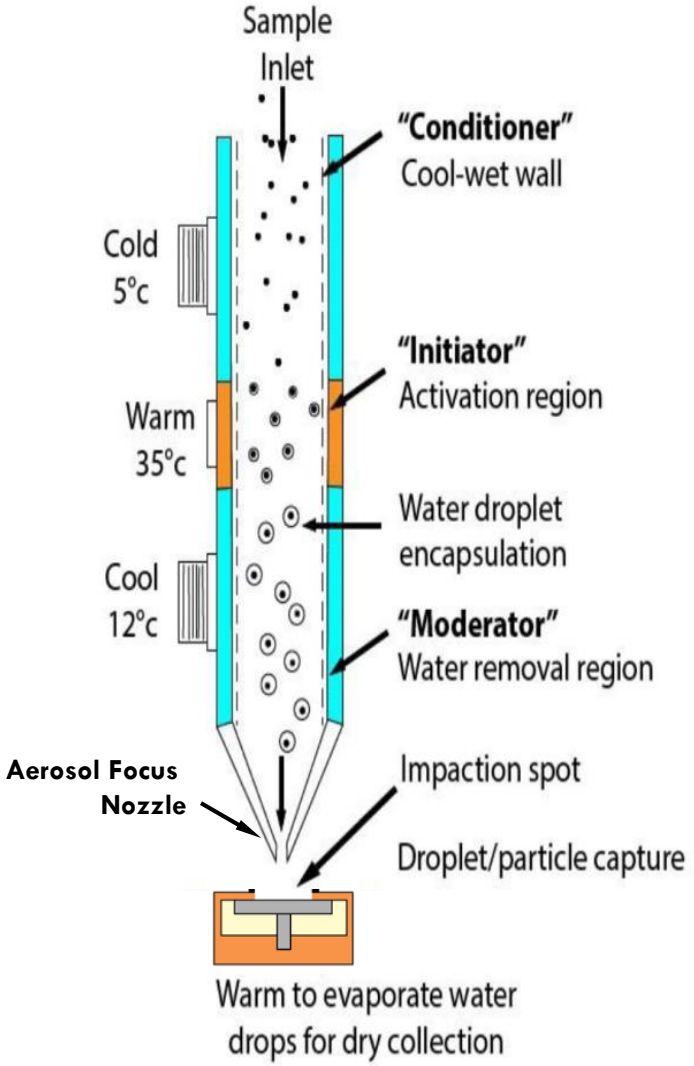
THEORY OF OPERATION – NANOPARTICLE EXTRACTOR

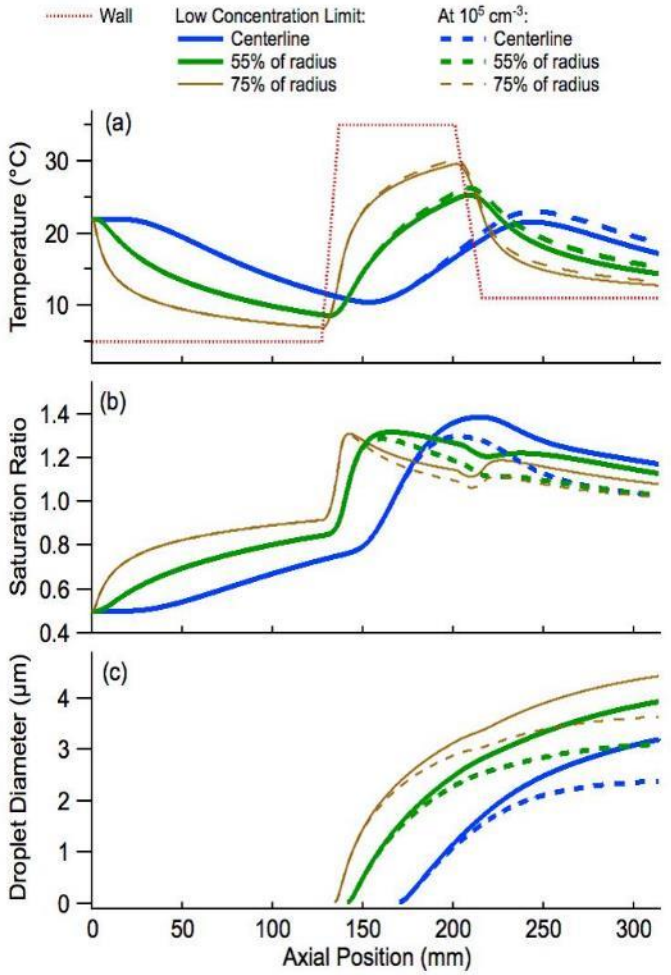


Large droplet removal limits the formation of large precipitated non-volatile residue (PNVR) particles.

Van Schooneveld, et al., Focused Aerosol Deposition, NanoTech 2019, Boston, MA

THEORY OF OPERATION – NANOPARTICLE COLLECTOR





Moderate sample flow temperatures never exceed 30 ˚C. Exit flow temperature <18 ˚C; dewpoint < 20 ˚C.

Supersaturation levels of 120-140% activate condensation growth on particles as small as 5 nm.

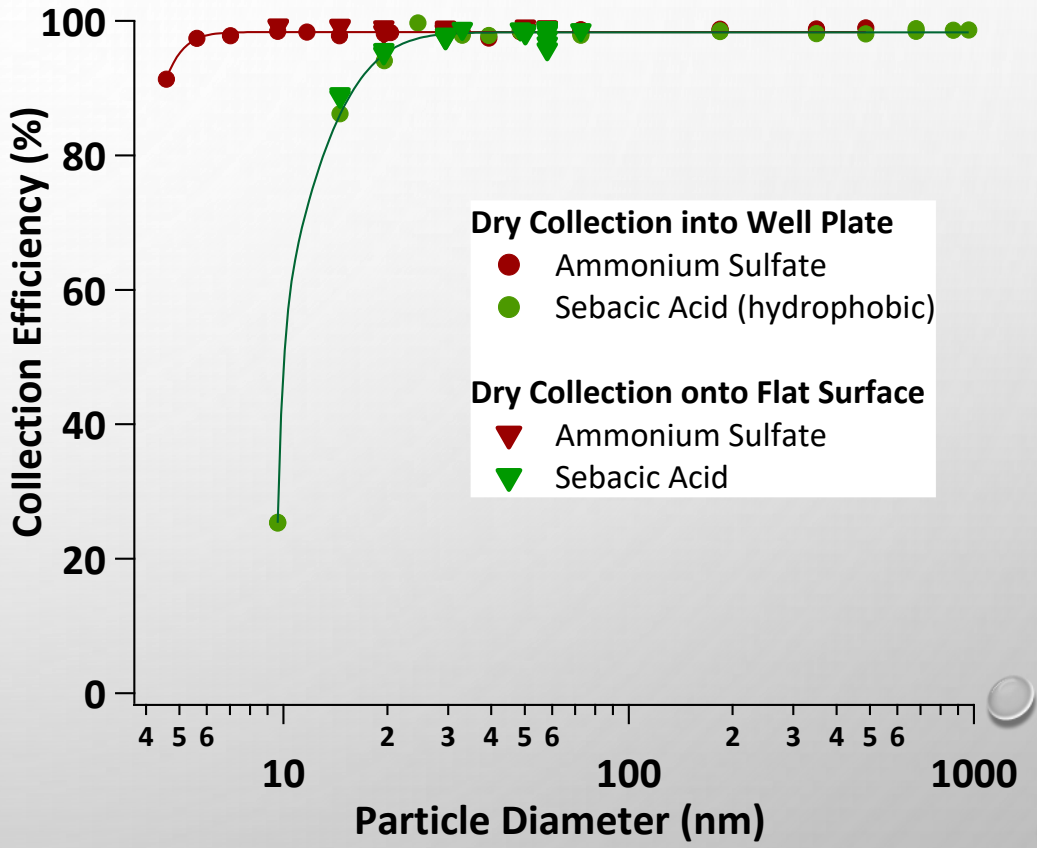
Droplets grown to nominal 3µm diameter are easily captured by bounce-free, soft inertial impaction.

Van Schooneveld, et al., Focused Aerosol Deposition, NanoTech 2019, Boston, MA

ACTIVATION EFFICIENCY AND SIZE IMPLICATIONS

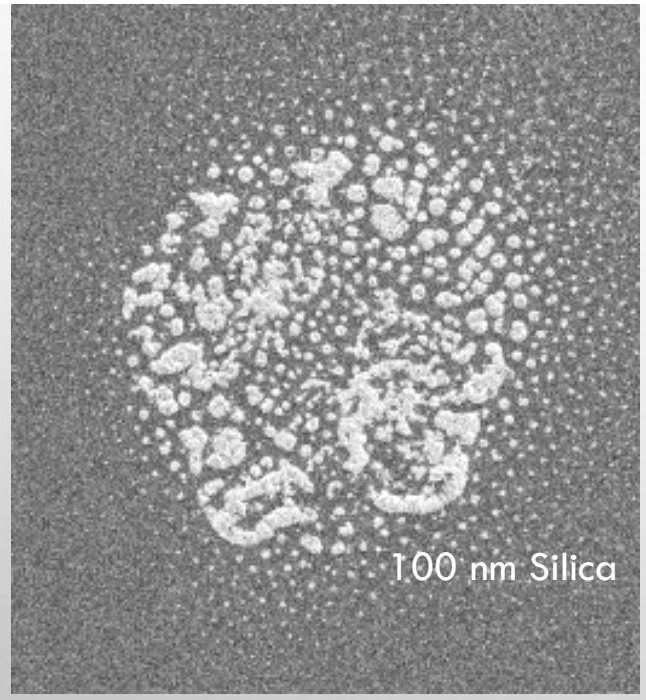
- **Material Effects:**
  - Hydrophilic vs. hydrophobic particles
- **Condensation Growth Tube:**
  - Temperature, flowrate, bore size, gas
- **Aerosol Concentration :**

Parameter	< 1E4/cc	> 1E4/cc
Minimun activation size	Smaller (5nm)	Larger
Droplet size	Larger (3μm)	Smaller
Collection efficiency	Higher (> 98%)	Lower
Media heating requirements	Lower (<40°C)	Higher



BENEFIT OF SPOT CONCENTRATION

Spot pattern at 50 X magnification



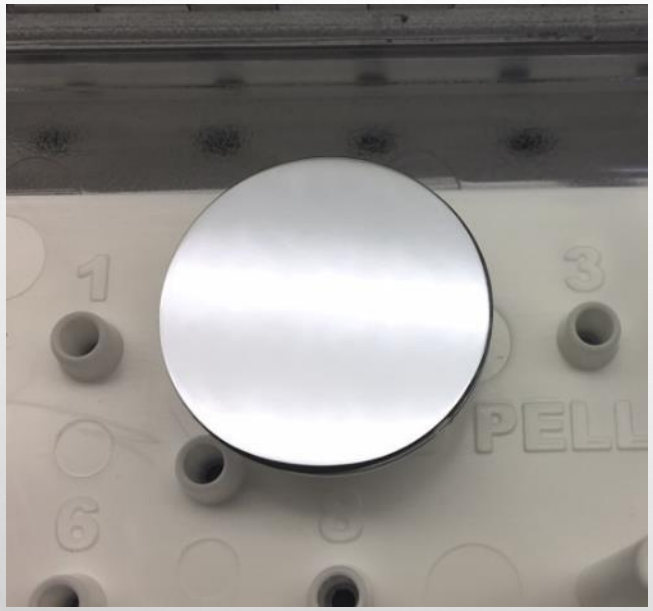
	Minimum Particle Size (nm)	Inspection Area (mm^2)	Typical flow rate (mL/min)	Depostion Rate (mL/mm2)	Relative Sampling Time (to FAD)
FAD	5	0.01	0.005	0.64	1
Al_2O_3 Filter	20	346	37.3	0.11	5.9
Track Etch Filter	50	415	10.0	0.02	26.5

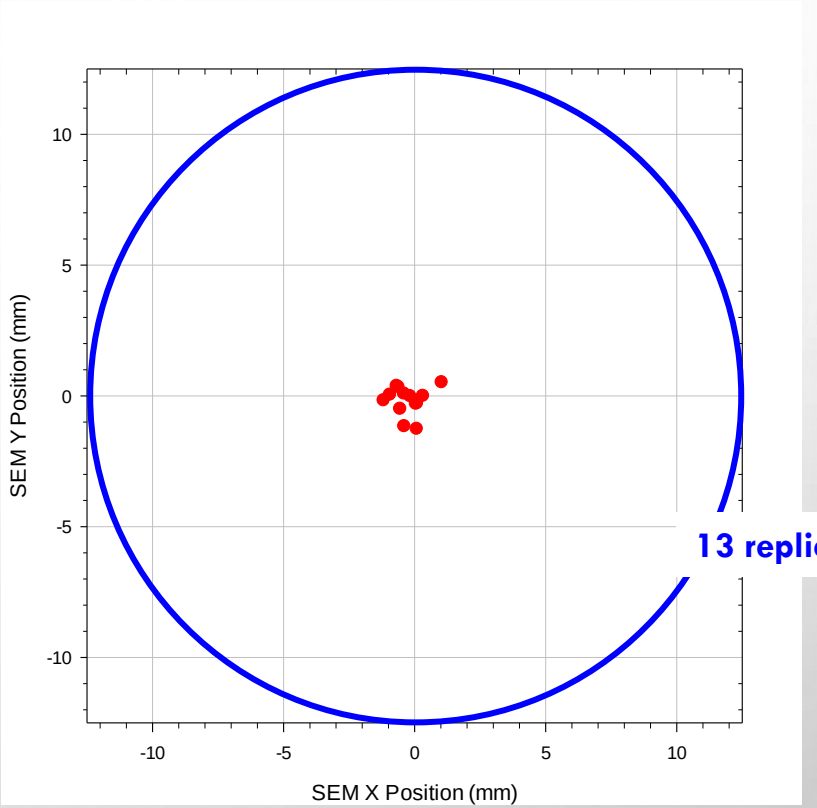
Assumes a 100 µm spot diameter with a 5 µL/min extraction rate.

Direct Deposition on SEM-Ready Stubs

Two Deposition Media:

- 25mm Silicon Prime Wafer
- 12.5mm x 12.5mm Germanium

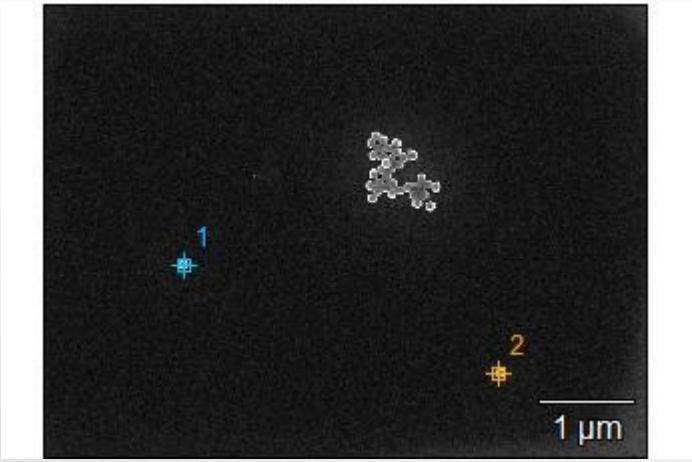


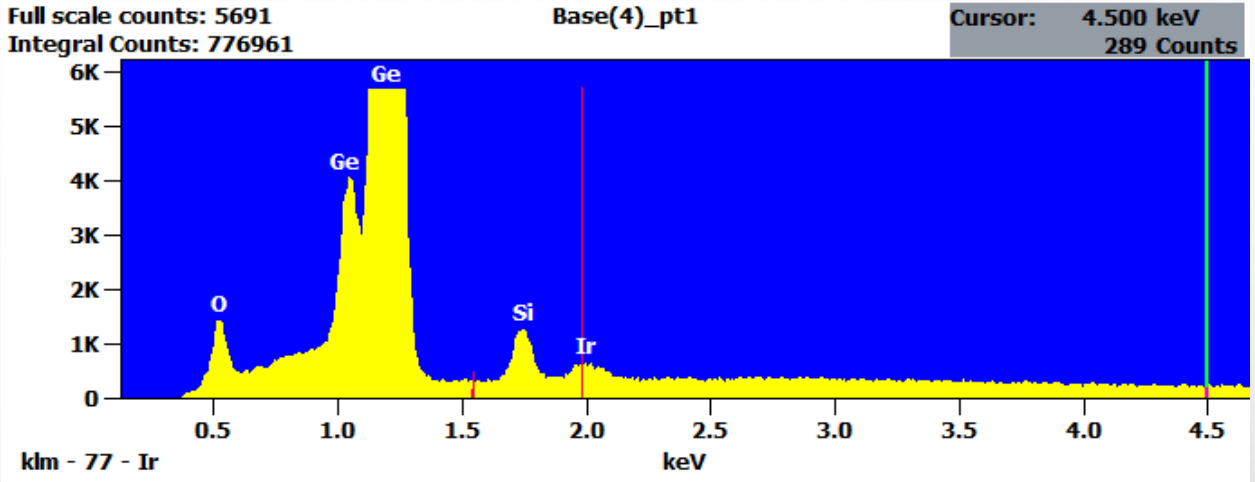


Depositing on SEM-ready stub with alignment pin provides the ability to rapidly locate spot and begin SEM/EDX analysis.

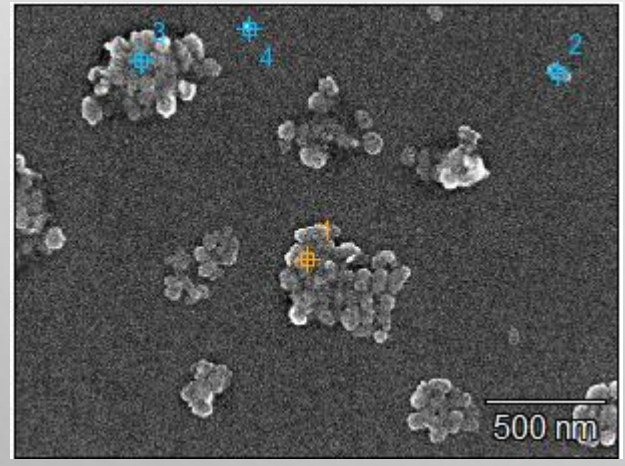
MEDIA CAPABILITIES

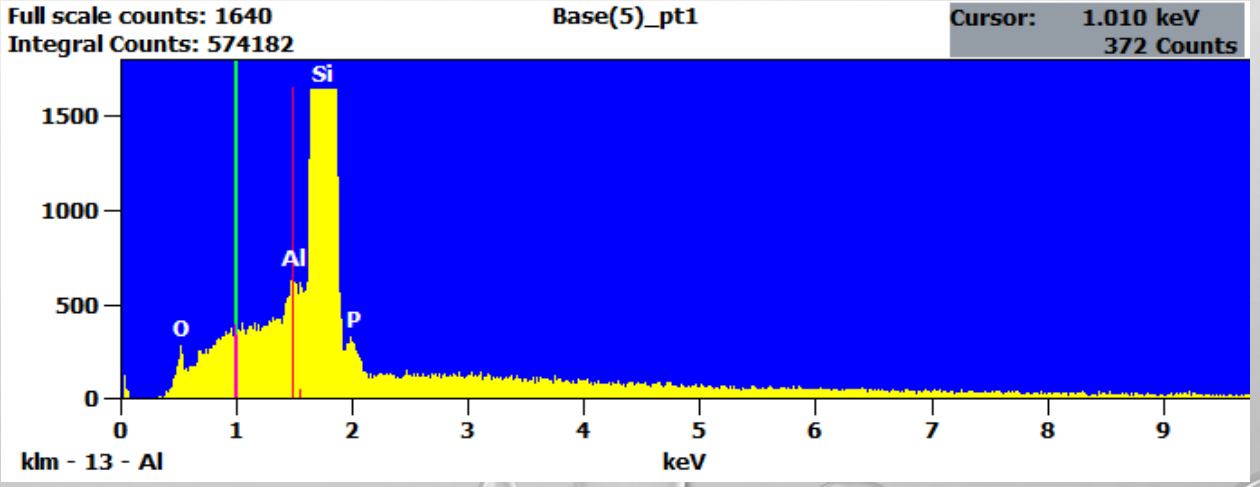
30 nm SiO_2 on Ge wafer





45 nm Al_2O_3 on Si wafer





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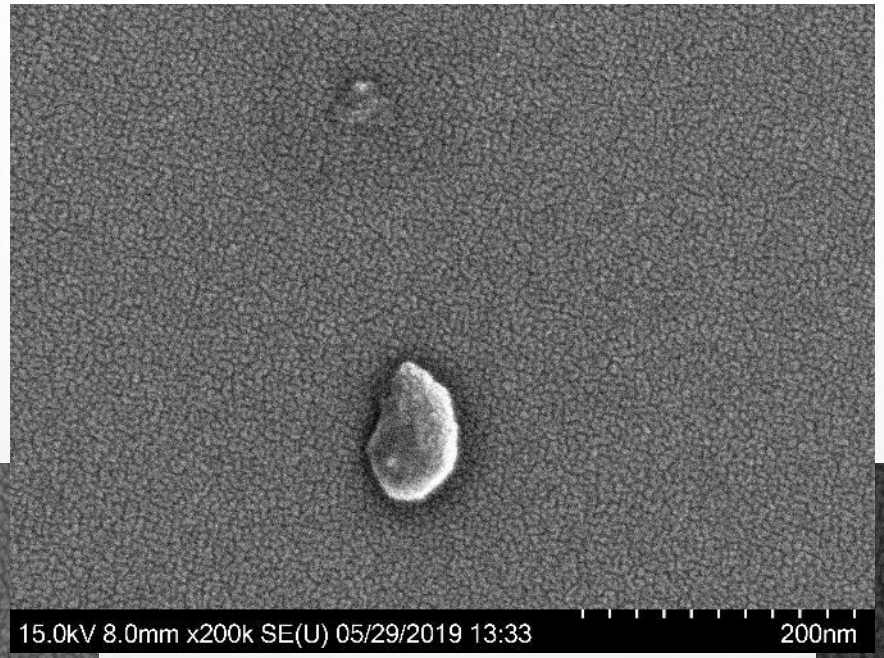
ULTRAPURE WATER APPLICATIONS

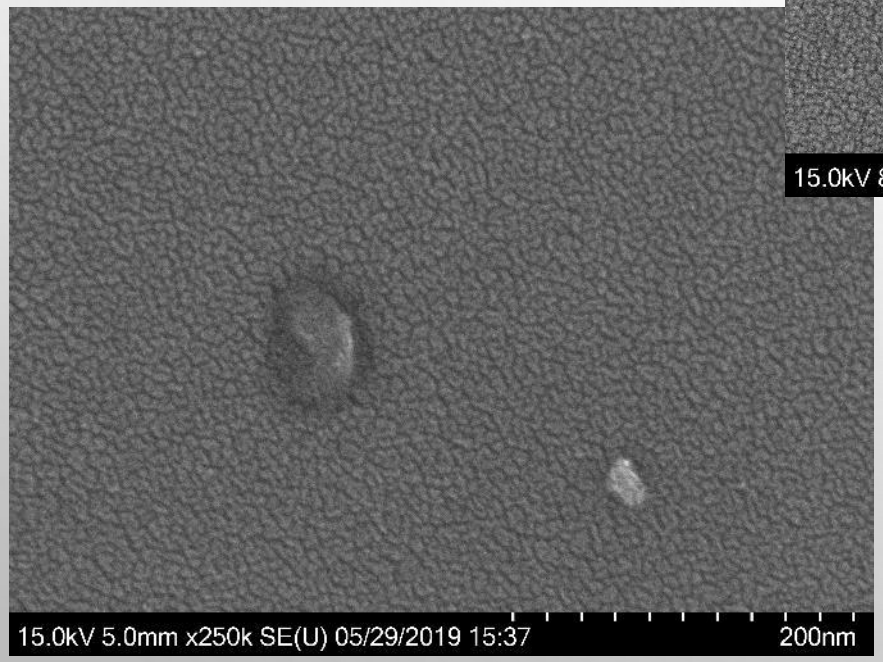
- UPW SYSTEM CONTAMINATION DETECTION AND IDENTIFICATION
- COMPONENT CONTAMINATION PROFILING
  - FILTER (MF AND UF) SHEDDING
  - IX RESIN RELEASE
  - MECHANICAL COMPONENTS (VALVES, REGULATOR, TUBING, ETC.)
  - MEMBRANE CONTACTORS
- RAPID BACTERIA COLLECTION AND CONCENTRATION

SEMICONDUCTOR UPW EXAMPLES*

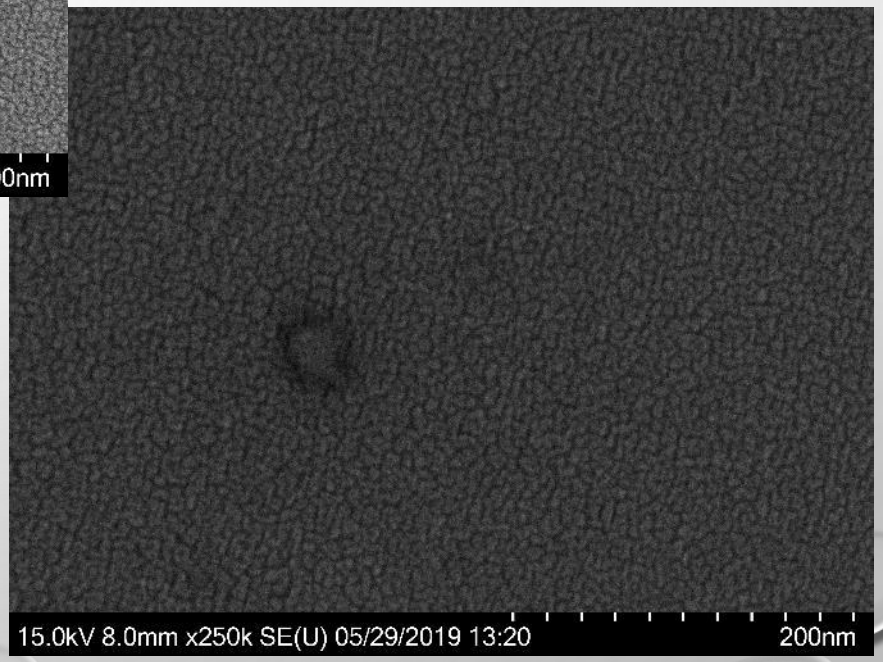
Source: 2019 IRDS Round Robin Testing
Participating Companies:
Global Foundries, IMFT, Intel, Micron, Samsung



Particles found downstream of the final distribution filters.



Predominately “soft” organic particles, some metal oxides



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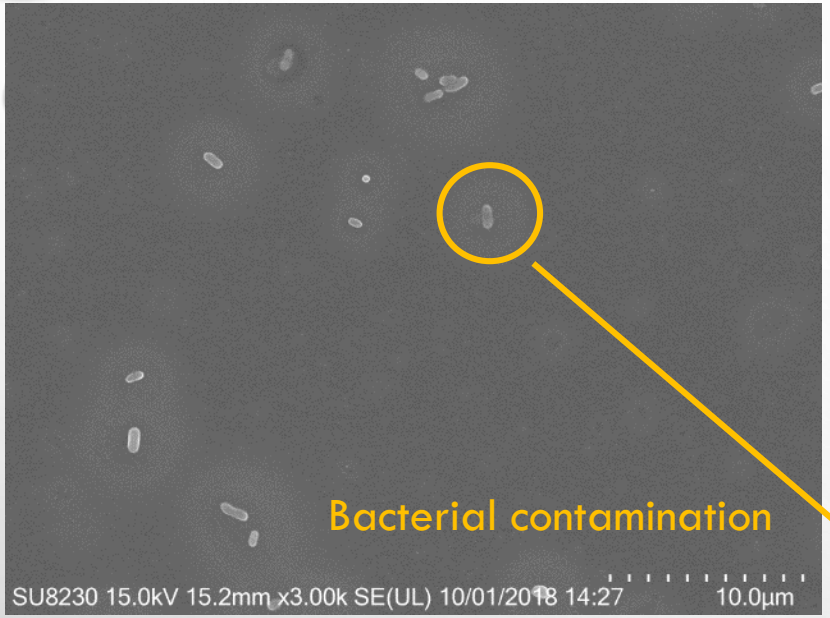
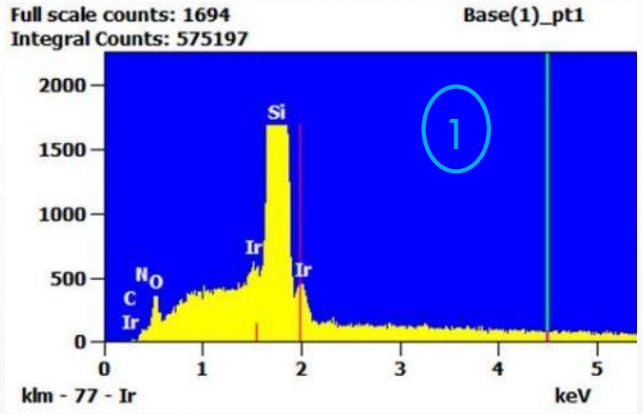
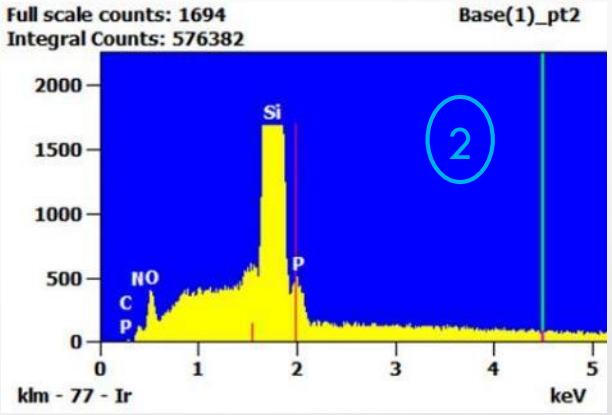
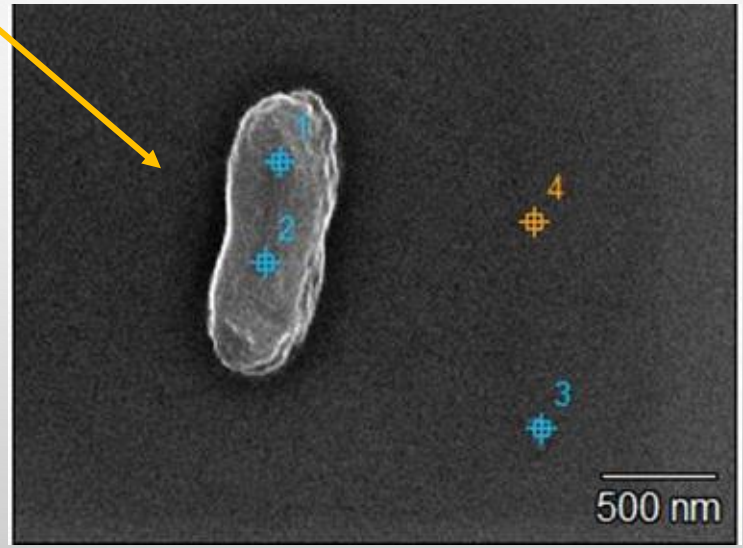
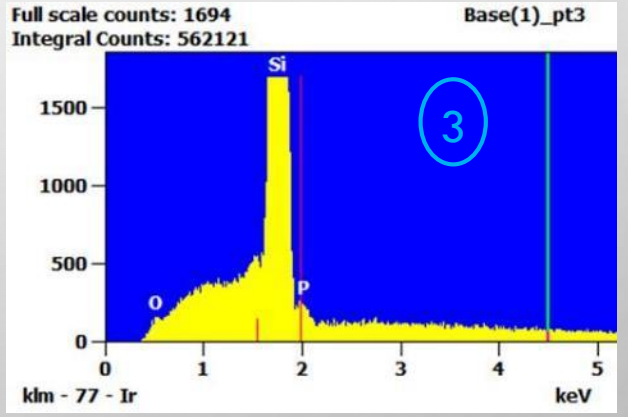
SEMICONDUCTOR UPW EXAMPLES*











Source: 2019 IRDS Round Robin Testing

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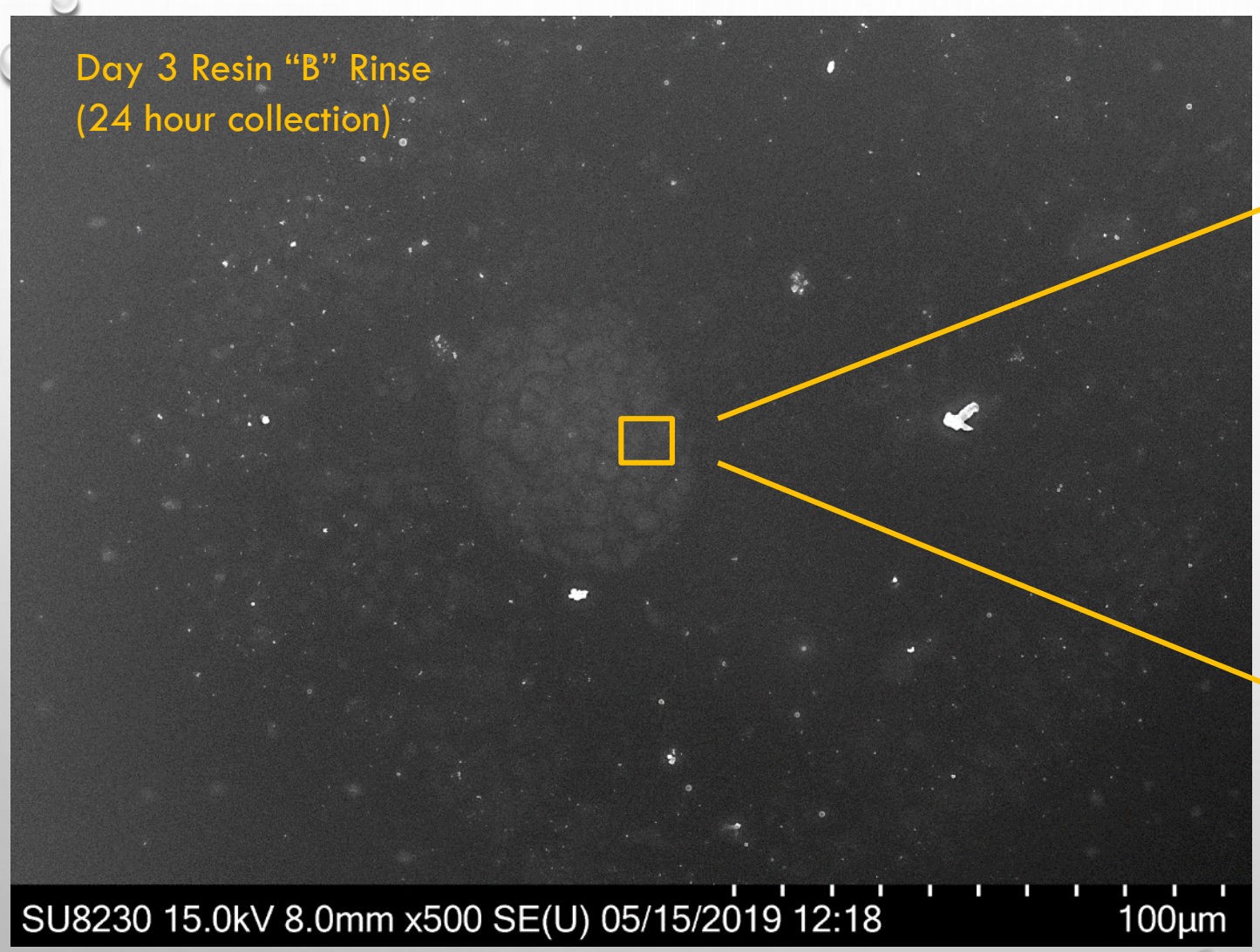
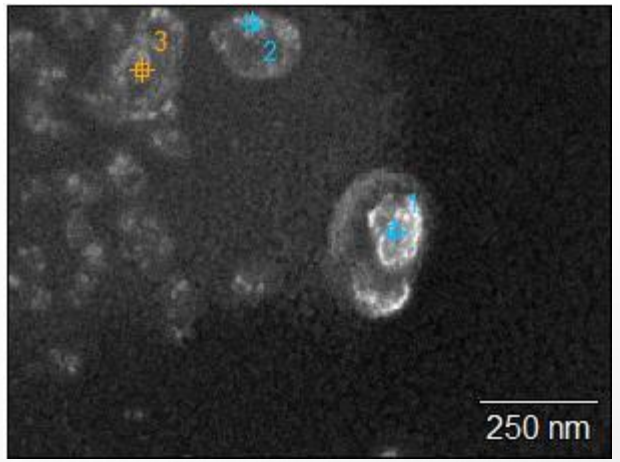
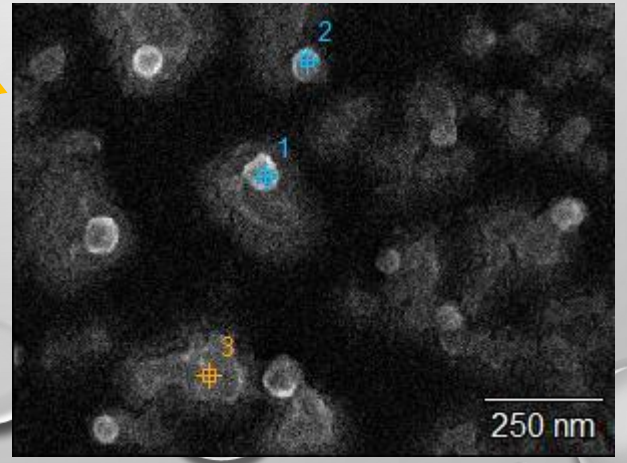
ION EXCHANGE RESIN RELEASE DURING RINSE

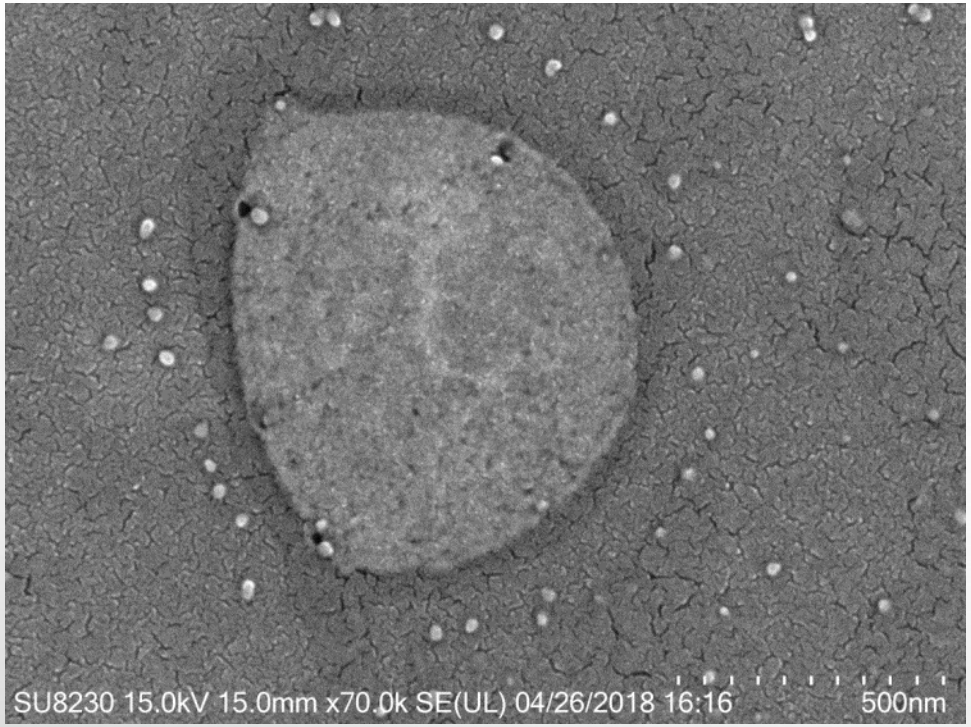




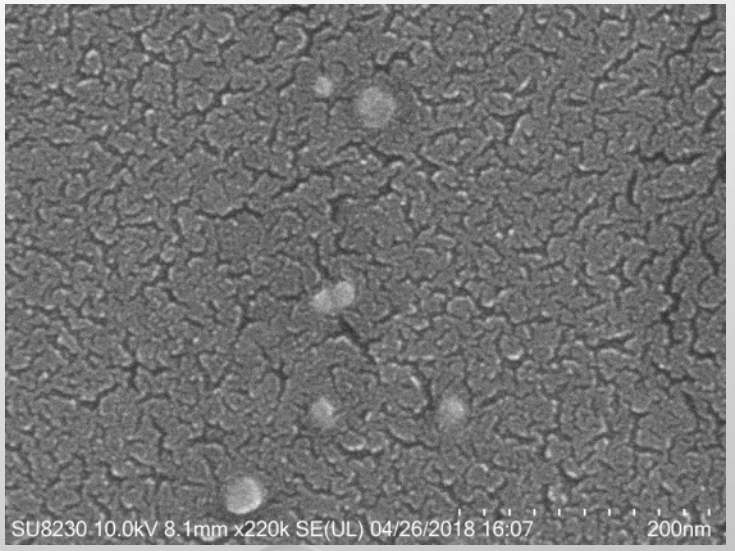
Location	Elements (less Si)
T1	O,Na,S,Ba
T2	O,Na,S
T3	O,Na,S
L1	O,Na,S
L2	O,Na,S
L3	O,Na,S



Component Contamination Profiling – IX Resin Effluent



Profiling individual contamination contributors will be beneficial in identifying or eliminating potential sources in the event of a contamination event.



- **Semiconductor grade virgin mixed IX resin.**
- **Triple rinsed in HDPE bottle in UPW.**
- **Agitated for 1 hour on rotary shaker table.**
- **Serial filtration with 100 and 20 nm Anodisk aluminum oxide filter.**
- **1000:1 online dilution for 1.6 hours.**

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DEVELOPMENT PRIORITIES

- CHEMICALLY COMPATIBLE NEBULIZER.
- INCREASED PARTICLE EXTRACTION AND DEPOSITION RATES.
- IMPROVED SPOT POSITION ACCURACY AND REPEATABILITY.
- DEVELOP QUANTIFICATION (COUNTING) METHODOLOGY.
- METHOD FOR TEM-READY DEPOSITION FOR SUB-10NM ANALYSIS.
- EVALUATE ADDITIONAL IDENTIFICATION TECHNIQUES (AFM-IR, MALDI, SERS, TOF-SIMS)

SUMMARY

- FOCUSED AEROSOL DEPOSITION IS A POWERFUL NEW TOOL PROVIDING RAPID COLLECTION OF SUB-50NM PARTICLE CONTAMINANTS FROM UPW.
  - TIGHTLY FOCUSED AND CENTERED PARTICLE SAMPLE ON READY-TO-ANALYZE SEM SUBSTRATE.
  - NEARLY 30 FOLD INCREASE IN PARTICLE COLLECTION EFFICIENCY COMPARED TO TRADITIONAL METHODS.
  - RAPID SPOT LOCATION AND RESTRICTED PROXIMITY FOR HIGH EFFICIENCY SEM/EDX ANALYSIS.

THANK YOU FOR YOUR ATTENTION!