Detection of Engineered Nanomaterials: Semi-Conductor Facilities and Consumer Devices

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EHS Research Need

- Engineered nanomaterials (NMs) in air, water and soil pose potential environmental safety and health (ESH) issues for lab personnel and the environment.

- NMs present in liquid wastestreams (e.g., chemical mechanical polishing (CMP) solutions) may contain trace amounts of nanomaterials which could either be
  1. Discharged to the environment with the potential to bioaccumulate or generate toxicity, or
  2. Reduce the ability of recycling and reuse of ultra-pure water.

- Nano-enabled thermal packaging solutions of semiconductor products may also leach nanoparticles over their lifetime (e.g., carbon nanotubes in polymer/epoxy matrices).

Research Aim

To develop analytical methods for detecting and quantifying trace quantities nanomaterials relevant to the semiconductor industry in waste and recycled water, in lab air, and leached from packaged semiconductors.

Selected Nanomaterials

- As identified in the International Technology Roadmap for Semiconductors (ITRS):
  - CMP: silica, alumina, cerium oxide
  - Carbon nanotubes (MWCNT) in self-assembly or advanced packaging processes (alone and embedded in polymer matrices),
  - Silicon semiconducting nanowires
  - If companies are interested: hafnium oxides

Deliverable

SOPs will include procedures, but also source and preparation of standards, detection limits, and quality control procedures

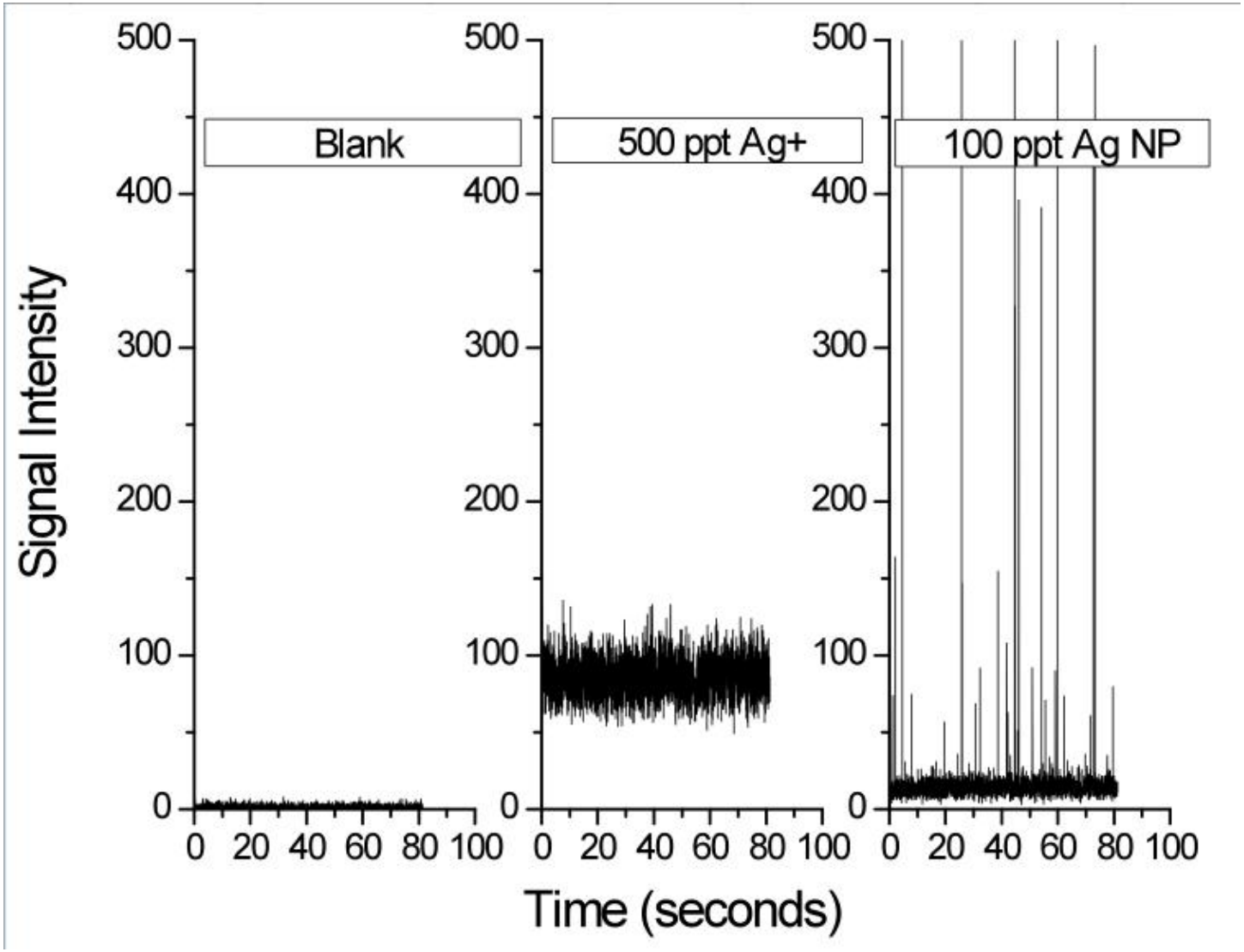
Analytical Approach

- Apply standard instrumentation:
  - SEM, TEM, XRD
  - Raman
  - DLS
  - Digestion + ICP; TOC
- Apply novel instrumentation developed on our NIH project for NMs in biological fluids:
  - Single Particle ICP-MS
  - FFF & HDSEC plus ICP-MS
  - Thermal optical transmittance/reflectance

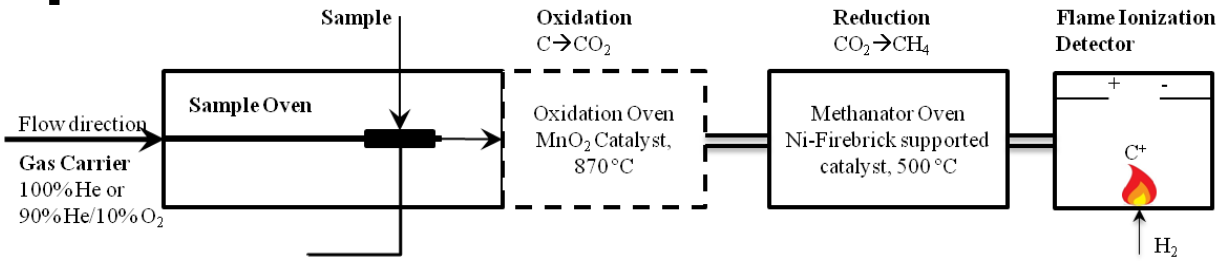
Single Particle ICP-MS

- For Metal-based NPs
- Uses instrumentation with modified data collection mode
- Sensitive to ppt levels
- Depending upon element can count NPs down to 5 nm
- Current focus has been spherical NMs, but works for nanowires

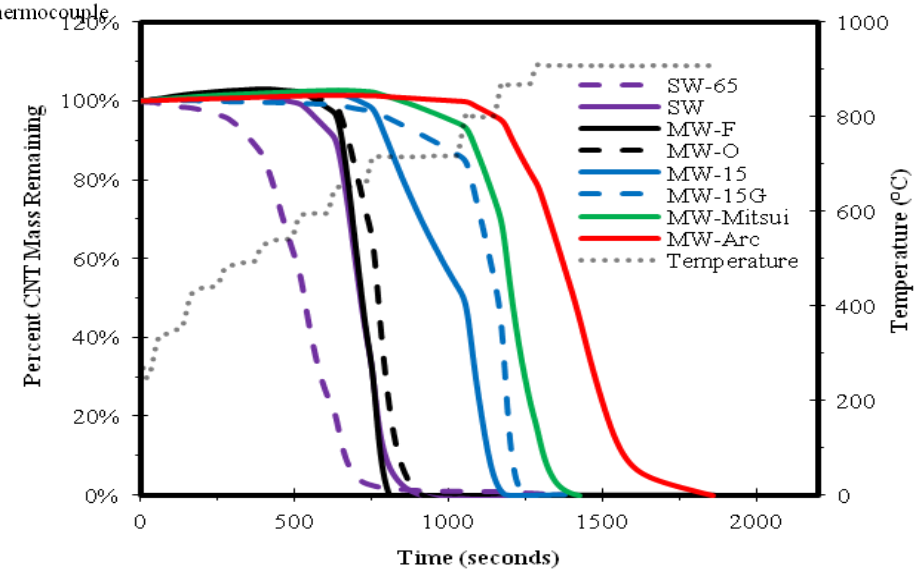
Example

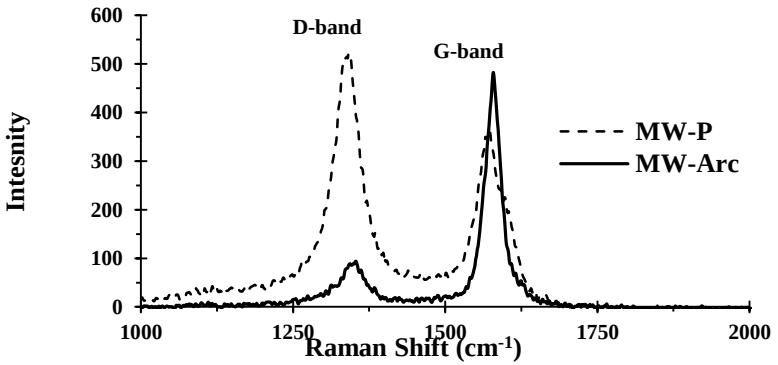

Blank
500 ppt Ag+
100 ppt Ag NP
Signal Intensity
Time (seconds)
0
100
200
300
400
500
0 20 40 60 80 100

Thermal Optical Transmittance



- For MW or SW CNTs
- Uses unique thermal properties of CNTs
- Current detection limit is < 5 ug CNT
- Validated with over 15 different CNTs
- Evolving method involves Raman to identify thermal property of CNTs





NM Analysis in different matrices

- Water
  1. ultrapure water
  2. simulated mixed liquid waste discharged to sewers
  3. filtered wastewater effluent
  4. CMP fluids
- Air samples
  1. NPs loaded onto air samples
  2. Develop new NP aerosol collection device
- Embedded NMs
  1. Tap water
  2. TCLP & WET testing (simulated landfill leachate)
  3. Abrasive & cutting “dust”

Outcomes

- Provide approaches and procedures for monitoring NMs in the workplace, wastestreams and product devices.
- Aids in meeting ESH goals and improves risk management by providing robust, reliable and quantitative measures of NM exposure.
  - C.1 provides analytical methods and SOPs using commercially available instruments for ESH monitoring of NMs in air and water.
  - C.2 aids in ESH workplace exposure monitoring and assessment of remedial actions to reduce exposures, and in monitoring NMs after they leave fabrication facilities.
  - C.3 aids in documenting nanomaterial fate over their life cycle.

- **Engagement**
- After leading a short technical live or virtual workshop, we hope to lead a round-robin comparison of analytical quantification of NMs amongst several SRC research groups and members.
- We want to interact on NM selection, sources and matrices

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