

EHS Challenges and Potential Solutions Related to Manufacturing of Nano-Electronics

Farhang Shadman

Nano-EHS WG Meeting

December 14, 2004

NSF/SRC Engineering Research Center for Environmentally Benign Semiconductor Manufacturing

Shadman

Nano-Safety: Roles and Responsibilities

- As Practitioners:

- Create and maintain a safe working environment
- Use the best technology to reduce exposure to all harmful nano-materials.

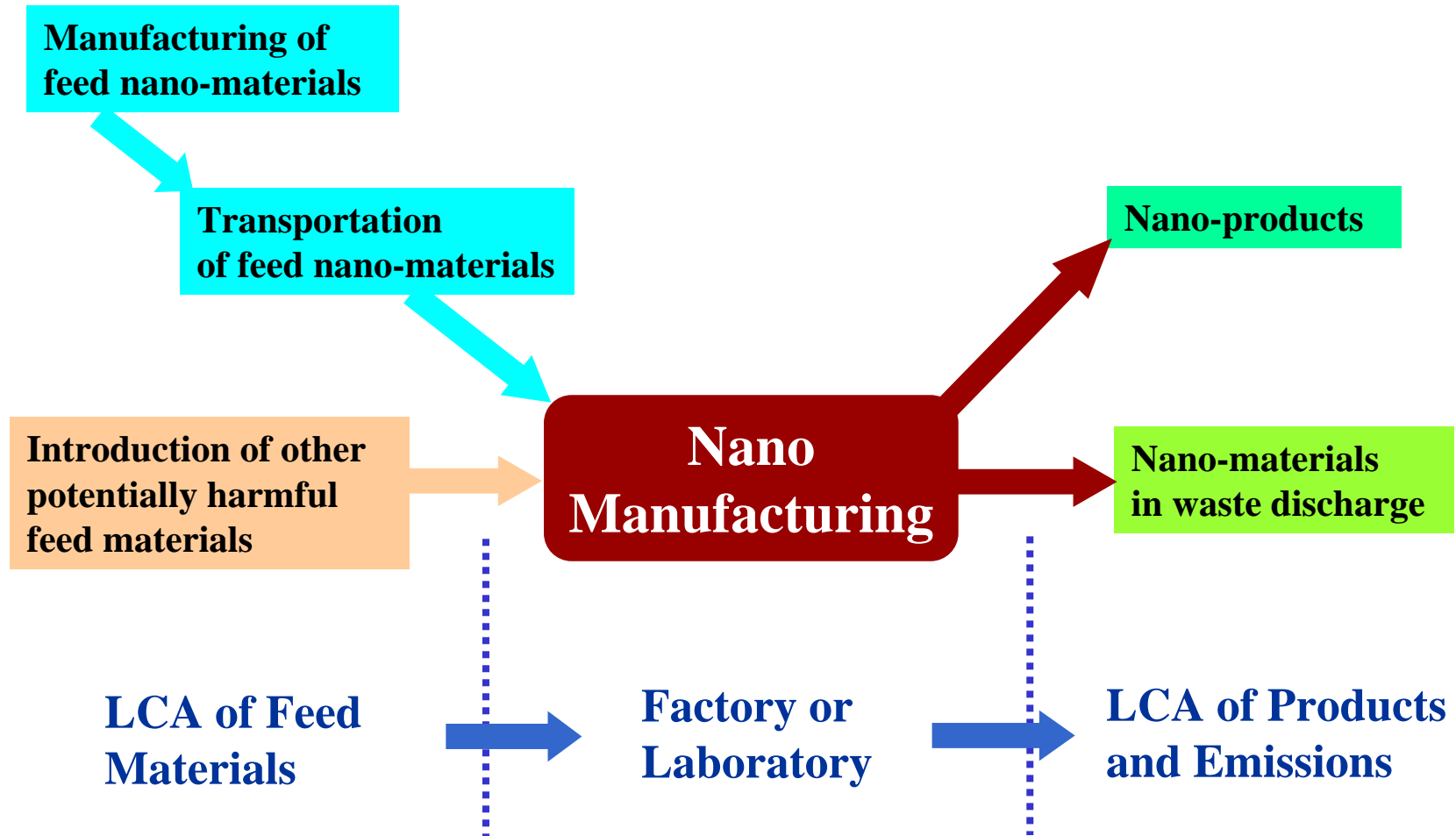
- As Educators:

- Educate students to separate the facts of science from the fictions related to the ESH impact of nano-technology
- Promote and teach the concept of *Design for Environment*

- As Researchers:

- Develop new technologies to reduce the ESH impact of nano-particles (both main products and the waste by-products)
- Go beyond the health effects of nano particles and consider the global ESH issues related to nano-manufacturing (*fabrication of nano-structures*)

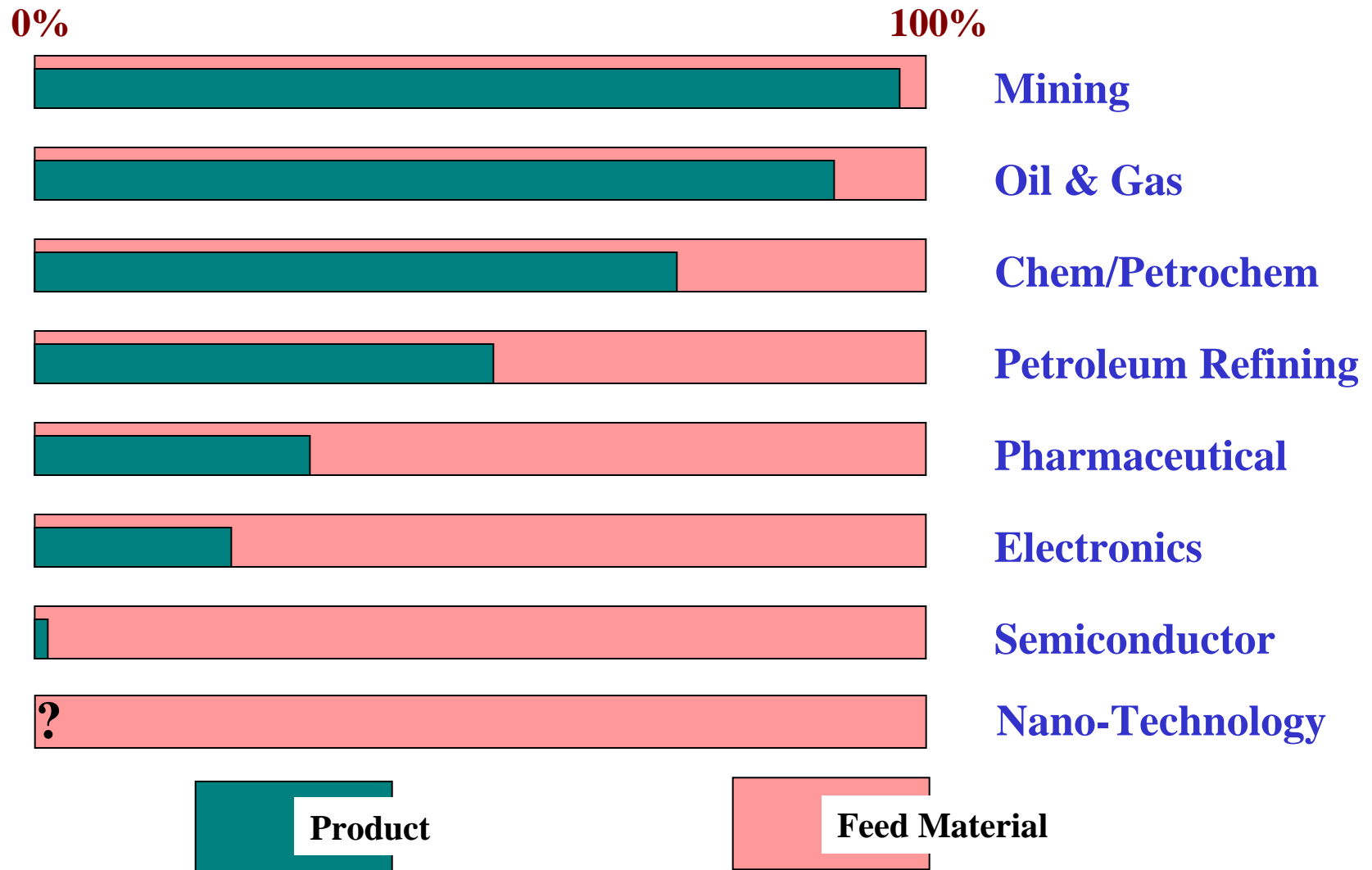
A Broad Scope of ESH in Nano-Manufacturing



ESH in Nano-Manufacturing: **Impact on Safety and Health**

- **Impact Types:**
 - **Direct (exposure)**
 - **Indirect (application necessitates the use of hazardous compounds, tools, or techniques);**
example: etching and cleaning
- **Mechanisms:**
 - **Entrainment, dispersion in the work environment, transport, deposition, exposure, and biological effects**

ESH in Nano-Manufacturing: Impact on Environment



ESH in Nano-Manufacturing: **Synergistic Interactions**

- **Nano-particles & organic contaminants**
adsorption, concentration, facilitated transport
- **Nano-particles & toxic metals**
adsorption, concentration, facilitated transport
- **Nano-particles & Acids and bases**
surface hydroxylation/activation
- **Adsorbed organics & adsorbed metals**
complexation, retention of contaminants
- **Nano-pores & trace level toxic volatiles**
Kelvin effect, pore condensation

EHS Aspects of Nano-Manufacturing

Fabrication of Semiconductor and Future Nano-Electronics

EHS Aspects of Nano-Manufacturing

Nano-Particles in Chemical Mechanical Planarization (CMP)

The fastest growing segment of S/C manufacturing

Chemical Mechanical Planarization

- **Removal rate: ranging from 100–400 atomic layers per second**
- **Key components: polymeric pads, slurry (nano-sized abrasive particles in mixtures of etchants, oxidizers, corrosion inhibitors, surfactants, pH buffer, and surface termination agents)**
- **Conventional particles: *fumed* or *colloidal* silica:**
 - **Colloidal: more control on size and morphology**
 - **Fumed: higher removal rate**

New Trends in CMP

- **In addition to silica, nano-particles of titania, zirconia, alumina, and ceria are introduced for the sub-65 nm technology node**
- **Engineered particles with layered structure for low shear and high removal rate**
- **Application beyond dielectrics, tungsten, and copper: organic and inorganic ultra-low-dielectric constant materials, diffusion barrier metals (e.g. Ta) and noble metals (e.g. Pt)**

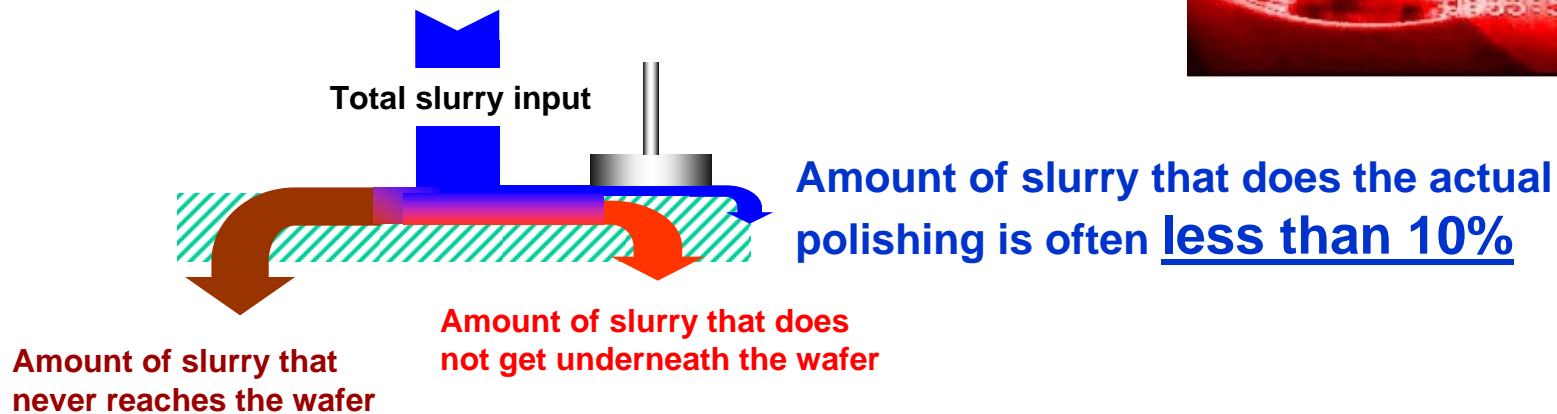
Low-Slurry Low-Waste Planarization

Philipossian (UA), Boning (MIT), Dornfeld (UC Berkeley)

Slurry: Large COO and waste

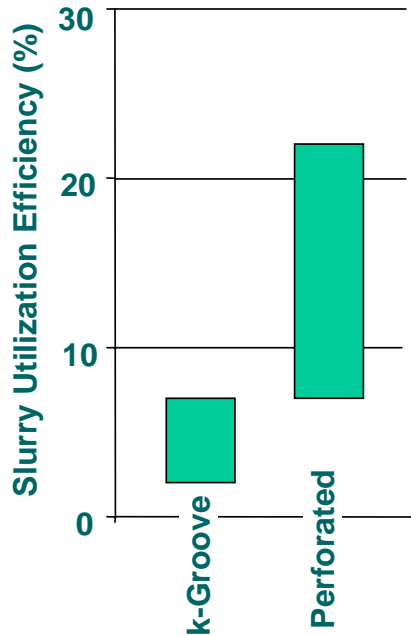
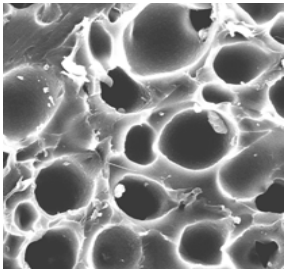
Example: for 8000 WSPW, 200-mm factory:

- 6,000,000 liters of slurry per year
- \$20,000,000 slurry per year
- 300 metric tons of solid waste per year

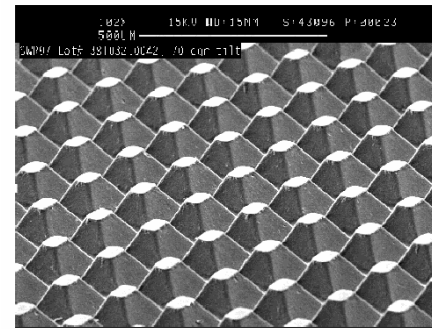
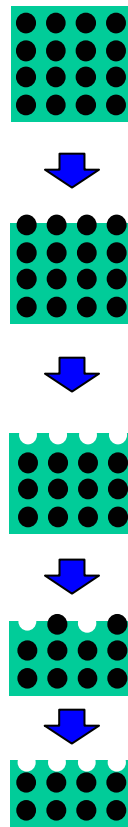


Technologies to Reduce CMP Waste

Novel Pad Design



Slurry & Porosity On-Demand



Fixed-Abrasive (Slurry Free) Planarization

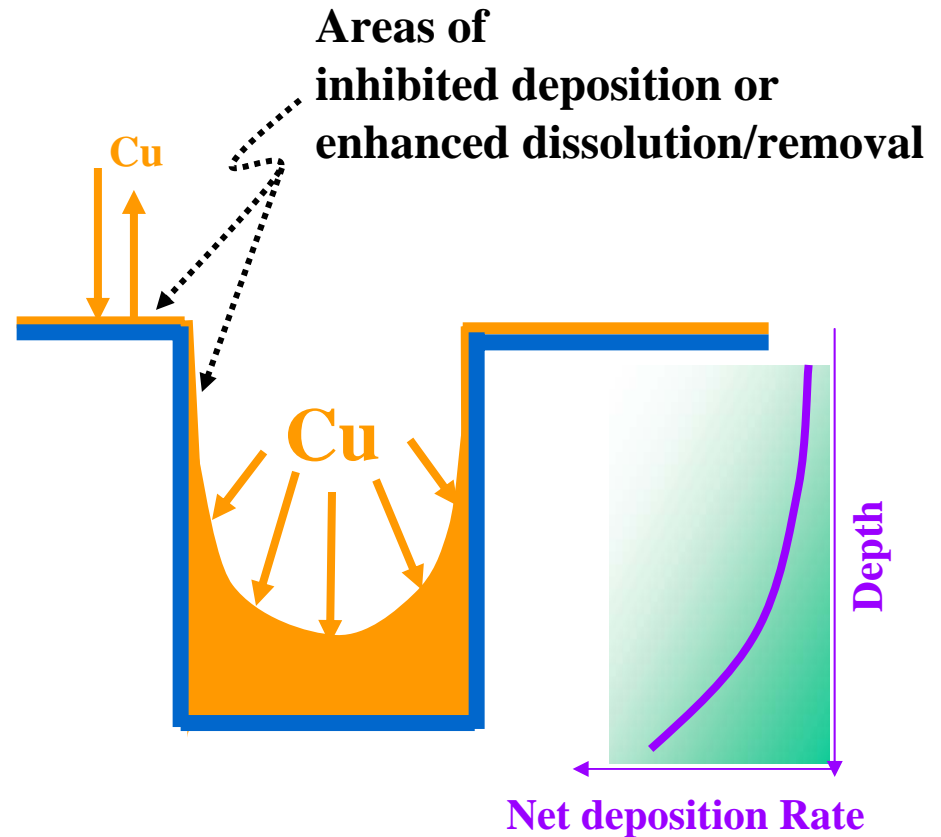
Abrasive-Free Planarization

Source: Philipossian (U Arizona), Boning (MIT)

Reducing CMP and Associated Waste By Selective Deposition of Metal and Dielectrics

Site-Selective Deposition:

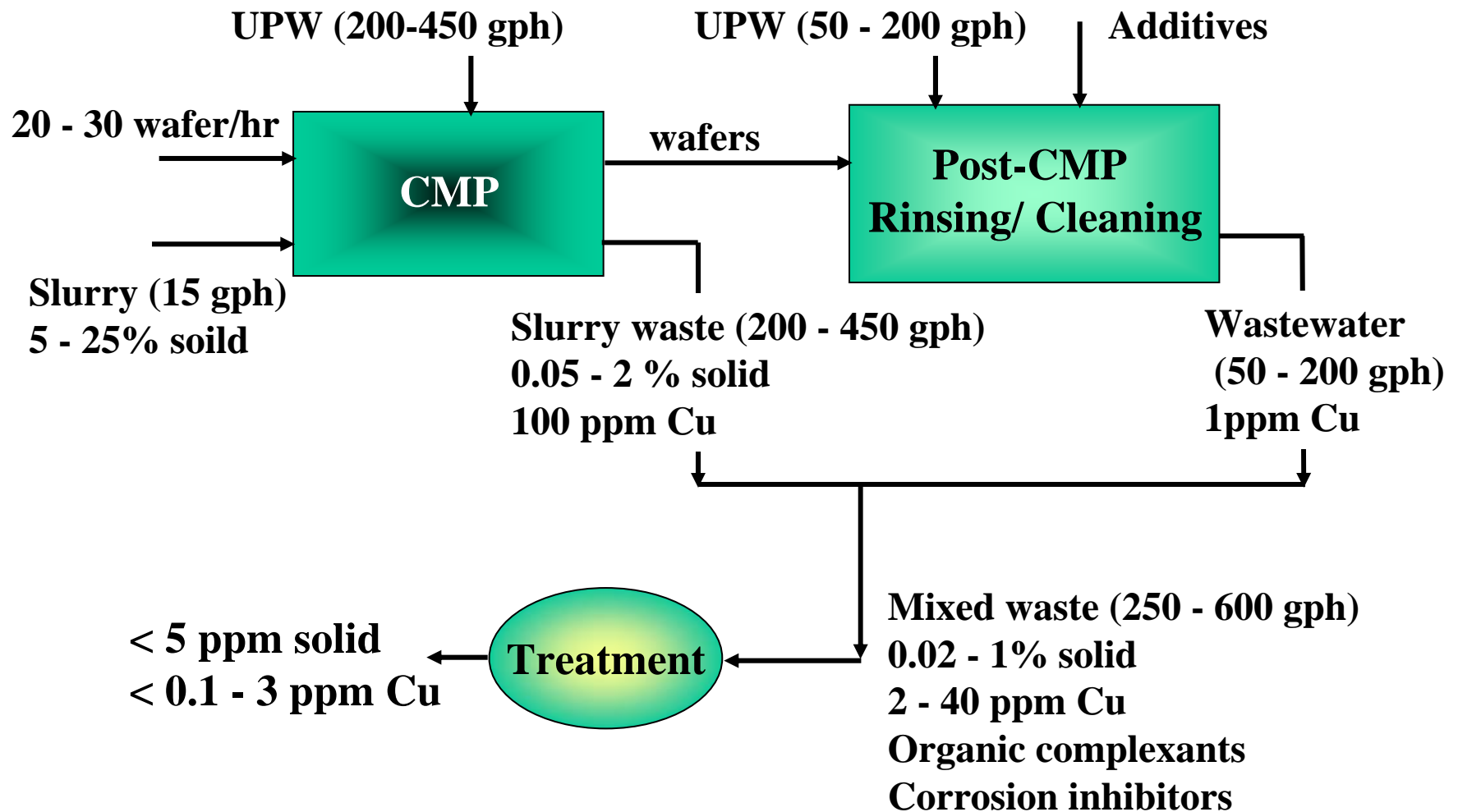
- Diffusion-limited inhibitors for local rate modification
- Cyclic deposition and dissolution
- Simultaneous deposition and planarization



EHS Aspects of Nano-Manufacturing

CMP Waste Treatment

ESH Aspects of CMP and Post-CMP Cleaning

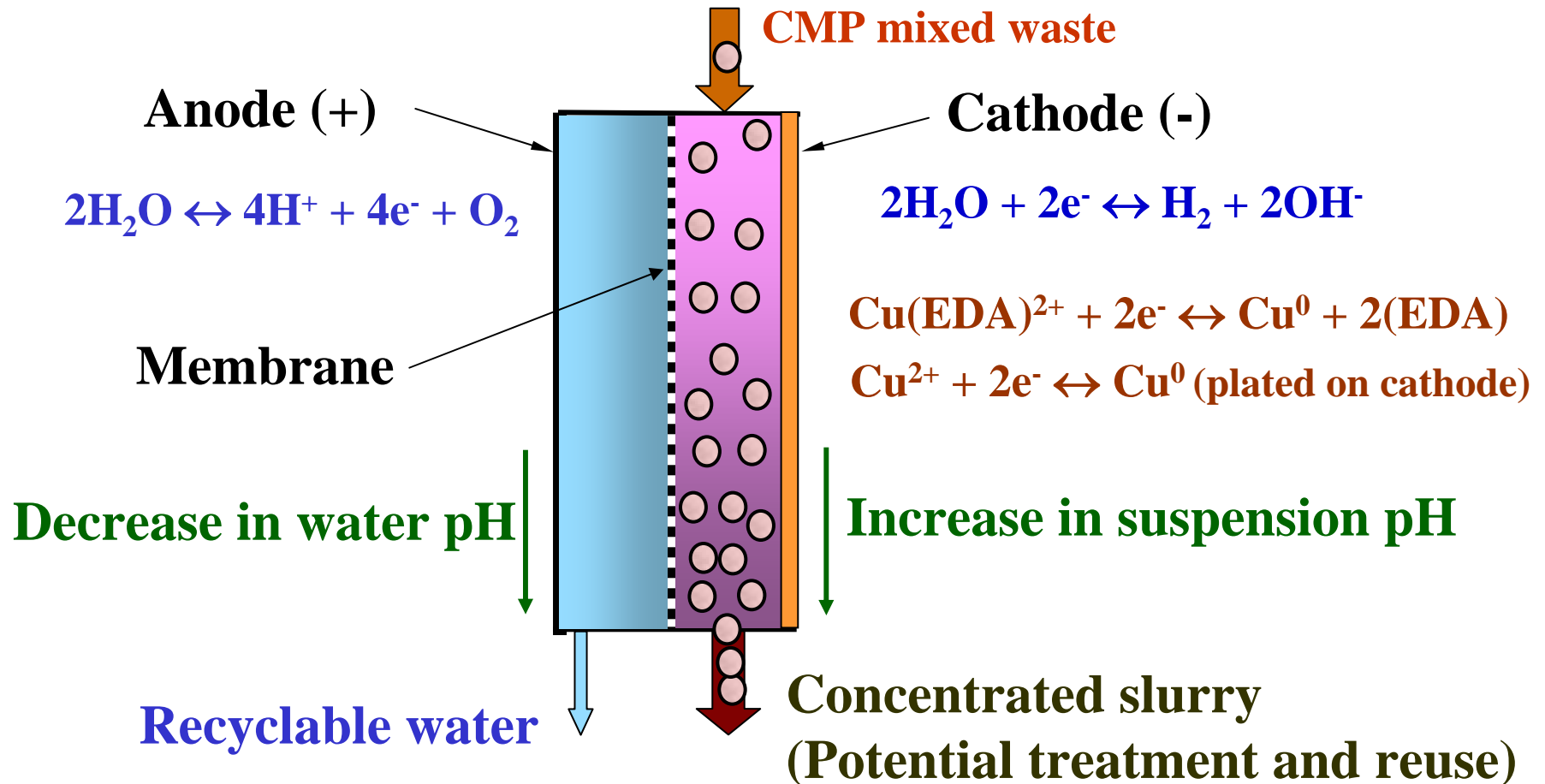


Treatment and Disposal of CMP Nano-Particles

- Nano-particles cannot be effectively removed by agglomeration, settling, and filtration; they also clog membranes.
- Nano-particles are potential environmental hazards; they also act as carriers for other hazardous compounds adsorbed on their large active area (providing greater life time, higher activity, and facilitated transport)
- Nano-particles clog the pores of active sorbents used for treatment of other wastes. This includes deactivation of activated carbon and ion exchange resin as well poisoning of porous catalysts.

Removal of Nano-Particles from CMP Waste

Raghavan, Baygents (U of Arizona)



EHS Aspects of Nano-Manufacturing

Generation and Deposition of Nano-Droplets (Liquid Aerosols)

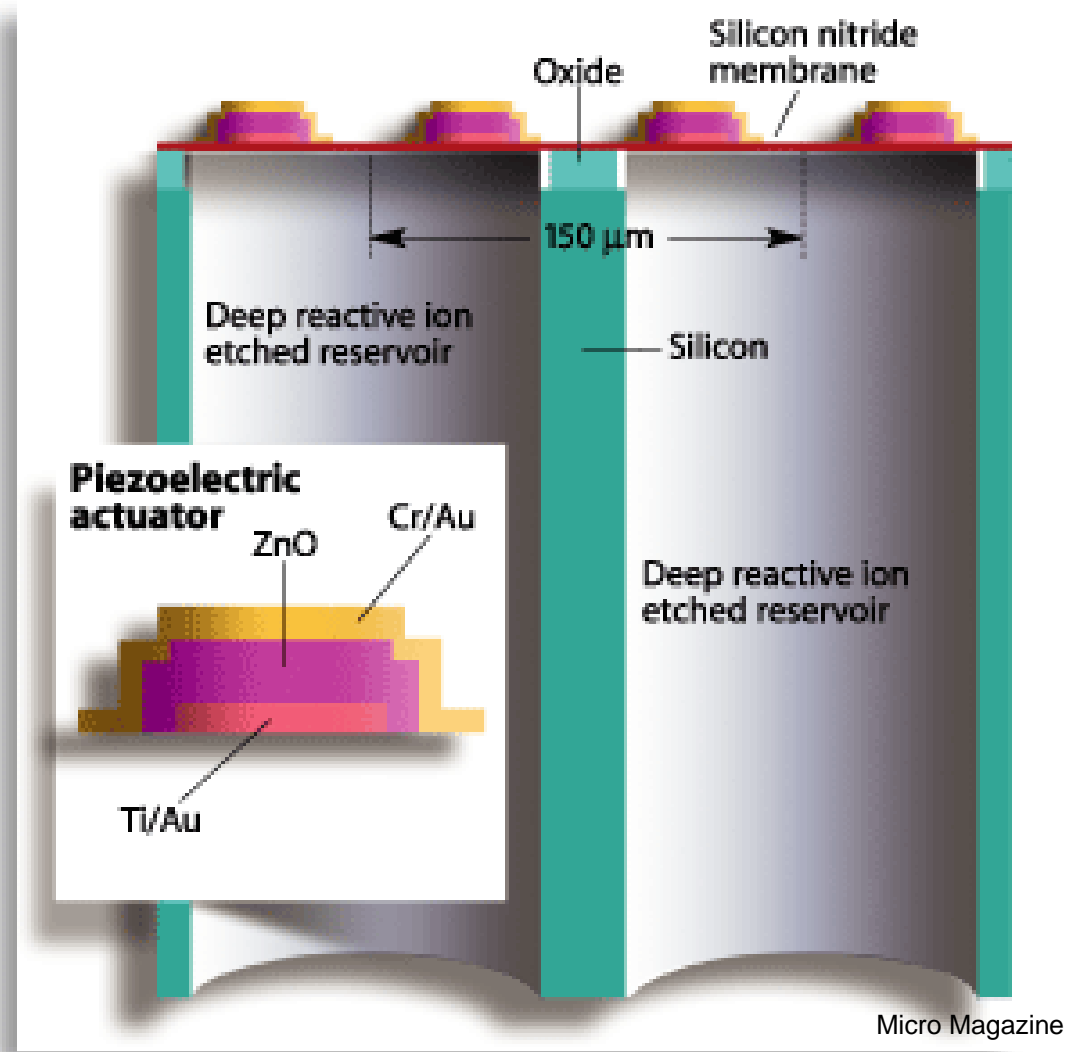
- **Inhalation hazard**
- **Formed in:**
 - **Sprays for wafer and tool cleaning**
 - **Nucleation and condensation of fumes**
 - **Spray deposition**

Generation and Deposition of Ultra-Fine Droplets

Khuri-Yakub (Stanford)

MINIATURE SPIGOTS:

- Micromachined ejector
- Multiple drivers inserted into silicon for dispensing liquids onto the wafer surface.
- An array will contain 10,000 actuators.



EHS Aspects of Nano-Manufacturing

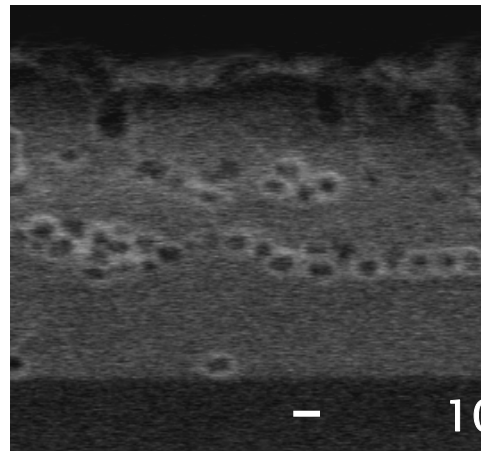
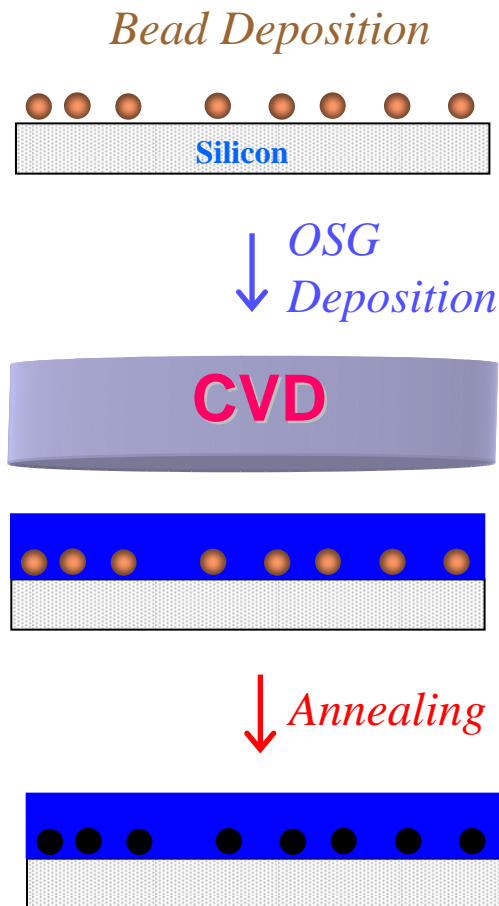
Manufacturing of Nano-Porous Low-k Dielectrics

Creating Nano-porosity in Low-k Dielectrics

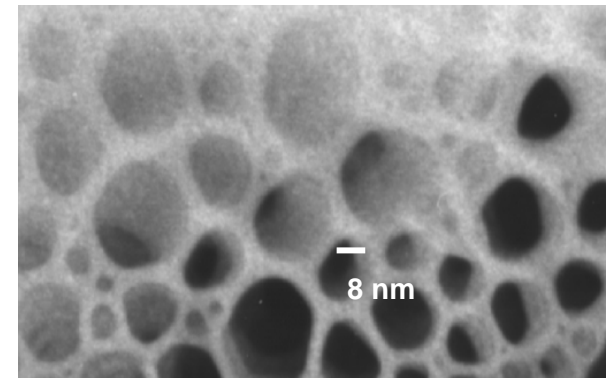
Gleason (MIT)

- Porogen: Polystyrene Nano-Particles

- Controlled Pore Size & Distribution
- Distributed Over Large Area
- Bead Diameters: 15 - 100 nm
- No Covalent Bonding



Alternating Bead/OSG Deposition:
Controls Degree of Porosity



Dielectric Constant = 1.4
Refractive Index = 1.067

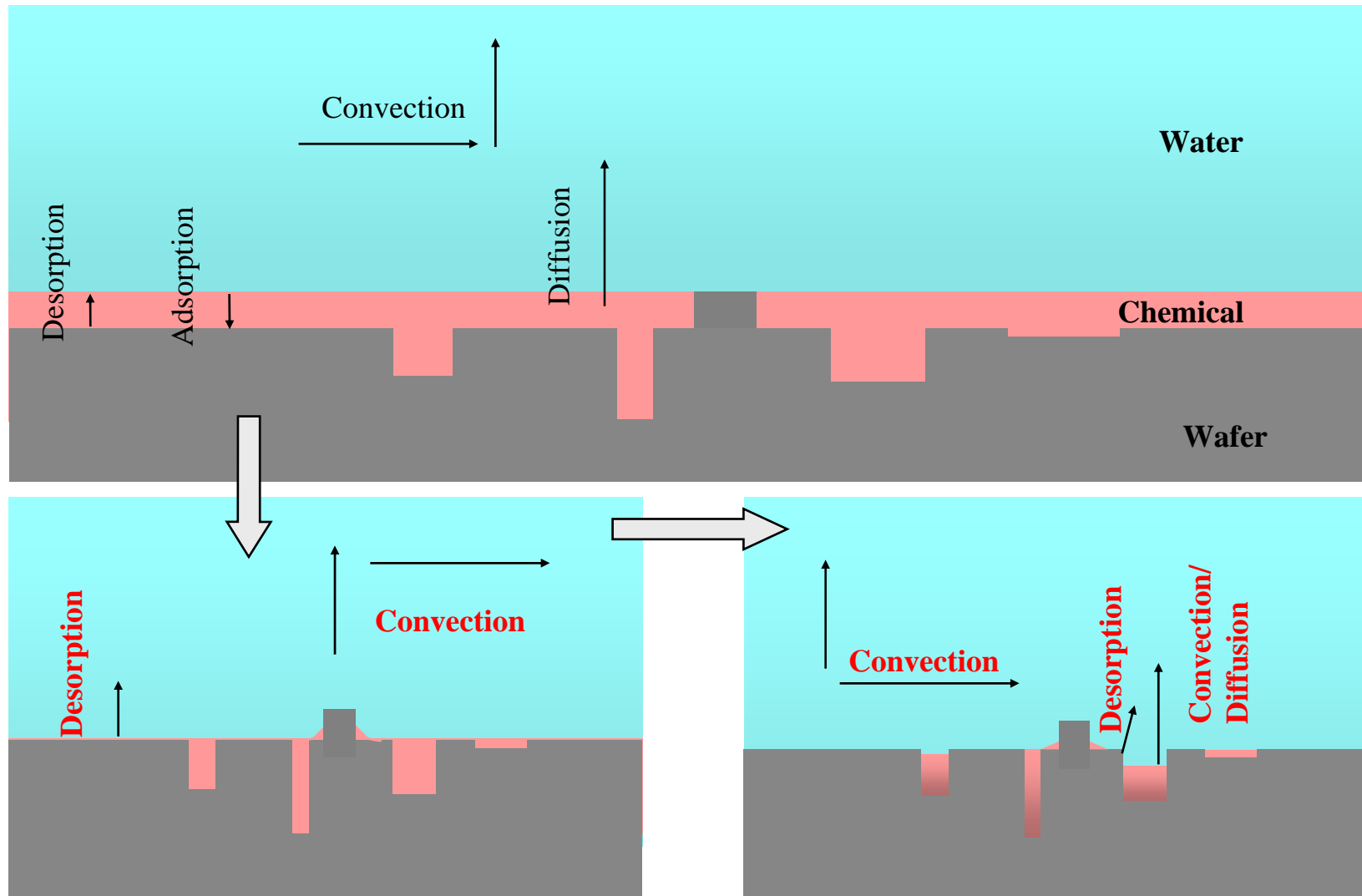
EHS Aspects of Nano-Manufacturing

Cleaning of Nano-Structures

Cleaning of Nano-Structures

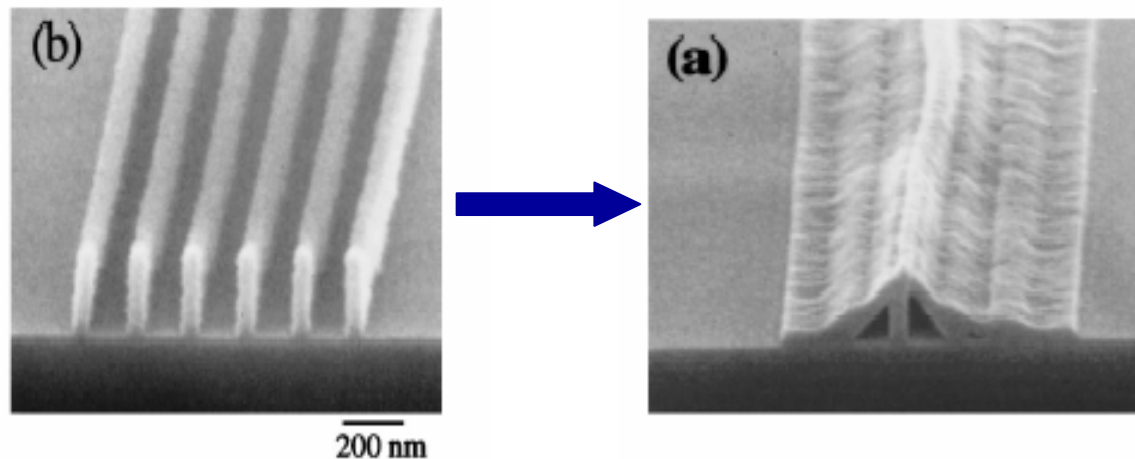
- **Typical surface to volume ratios in excess of 500 m²/gram of material.**
- **Excess active sites because of the reactivity of the substrate, the dangling bonds on the surface, and the presence of high-energy defects on the surface**
- **High adsorption rate, energetics, and capacity (usually as chemisorption) of contaminants on the surface.**
- **Slow removal of contaminants from the nano-structures**
- **Slow penetration of cleaning agents into nano-structures, particularly those with hydrophobic surfaces.**

Mechanisms of Cleaning and Drying of Nano-Structures



Drying of Nano-Structures

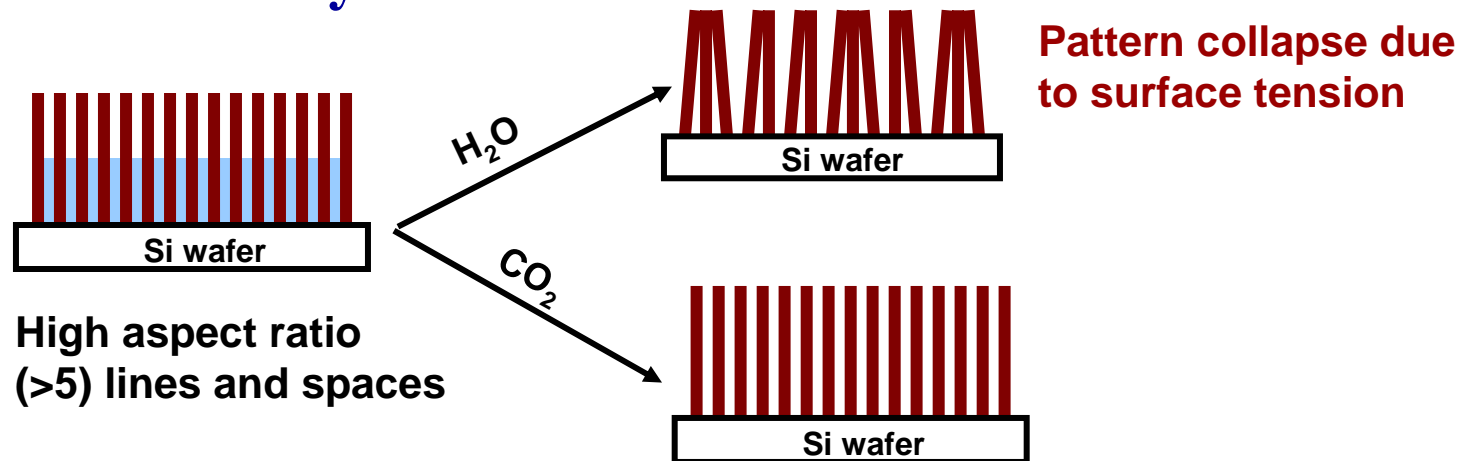
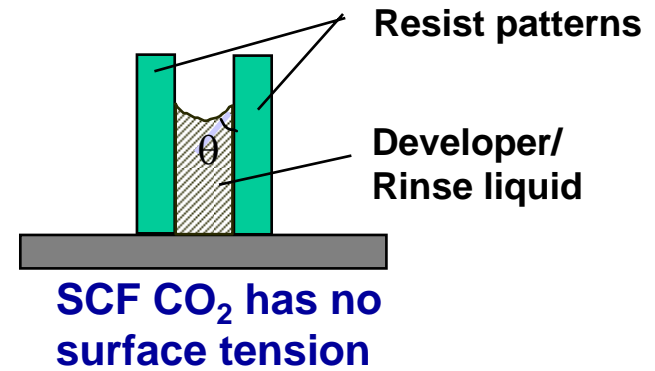
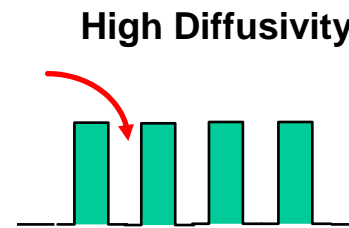
- Slow drying by evaporation and desorption because of the high surface to volume, high transport resistance in and out of the pores, and strong chemisorption
- Pattern collapse due to surface tension
- Adhesion (sticking) of nano-particles, nano-fibers, and other fine structures.



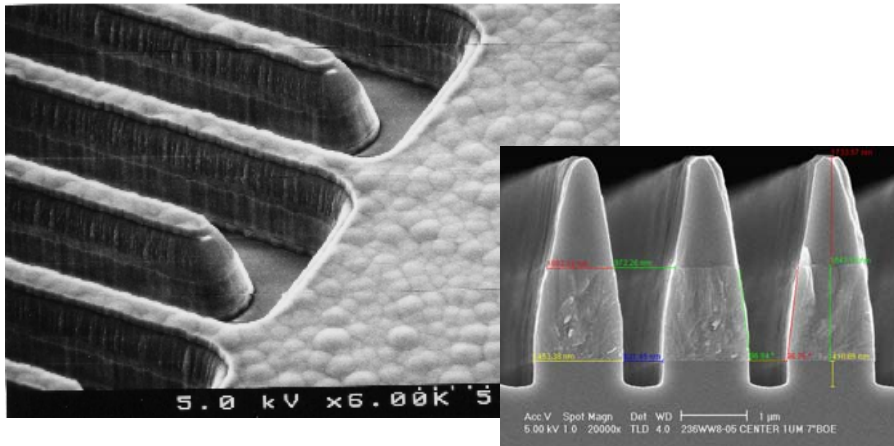
Super-Critical Carbon Dioxide: An Environmentally Benign Fluid

Performance Gain:

- High diffusivity
- No surface tension
- High selectivity
- Good solubility to F and Si-containing polymers
- Tunable selectivity

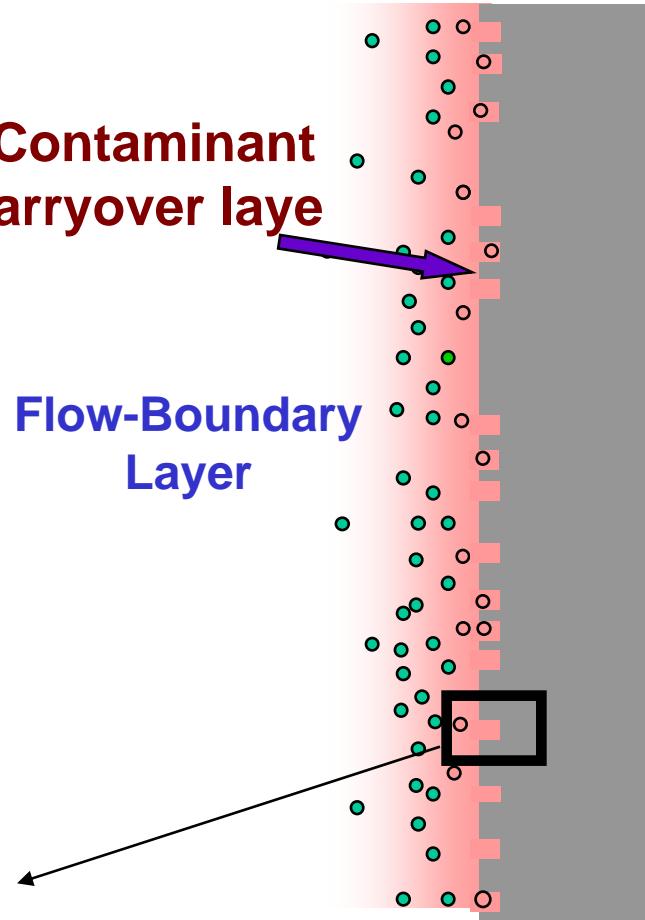


Novel Technology for Monitoring the Cleaning Process in Nano-Structures



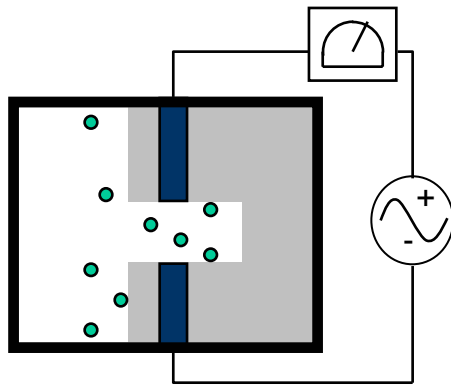
Contaminant carryover layer

Flow-Boundary Layer

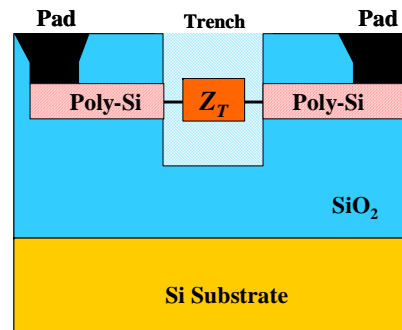


Side view of wafer after immersion in rinse tank

ERC Patented



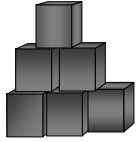
Feature-scale Measurement



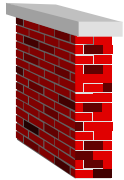
EHS Aspects of Nano-Manufacturing

Tools for Environmental Impact Assessment

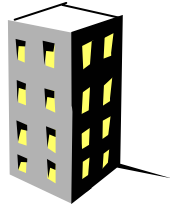
ESH Impact Hierarchy



Fundamental level

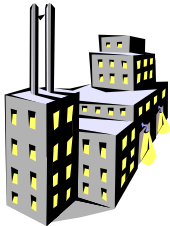


Process or tool level



Sub-fab or process group level

CMP; UPW Prep & Use Surface Prep



Fab or site level

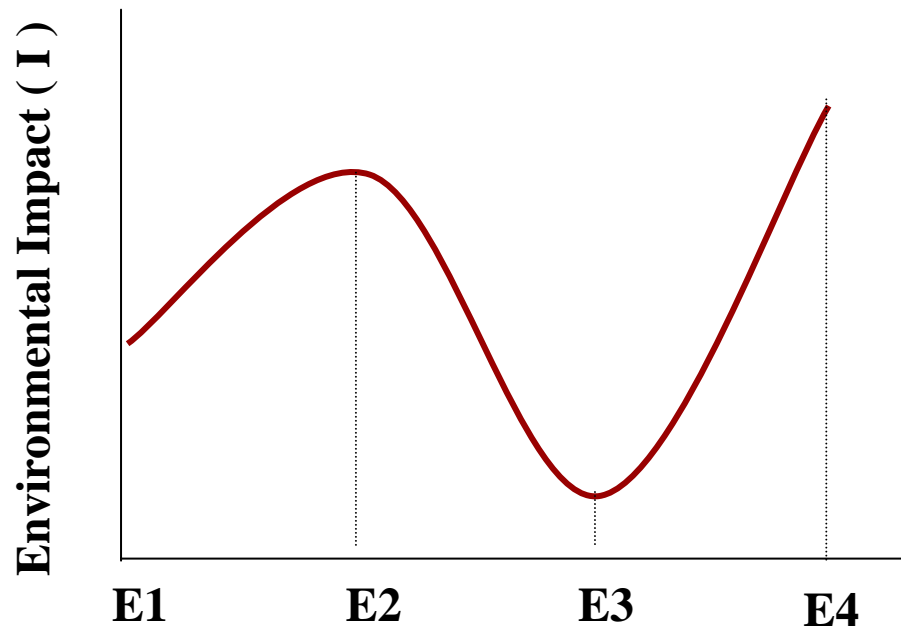
Factory Model



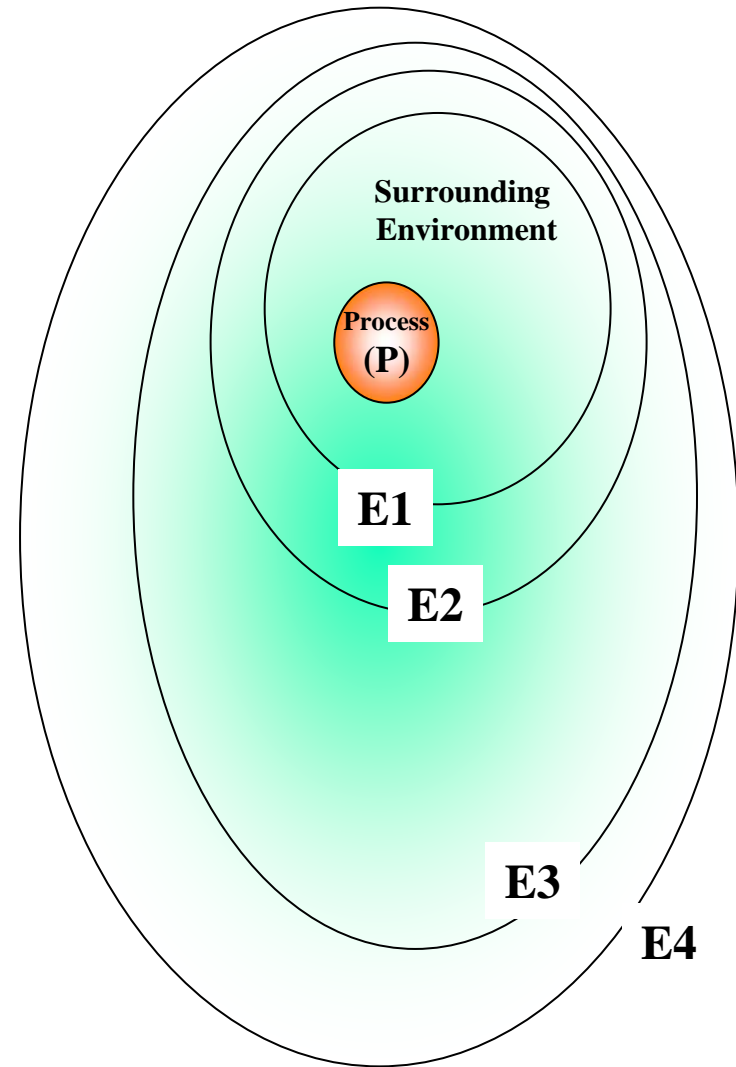
Global level { **Industry wide**
Large area

Life Cycle

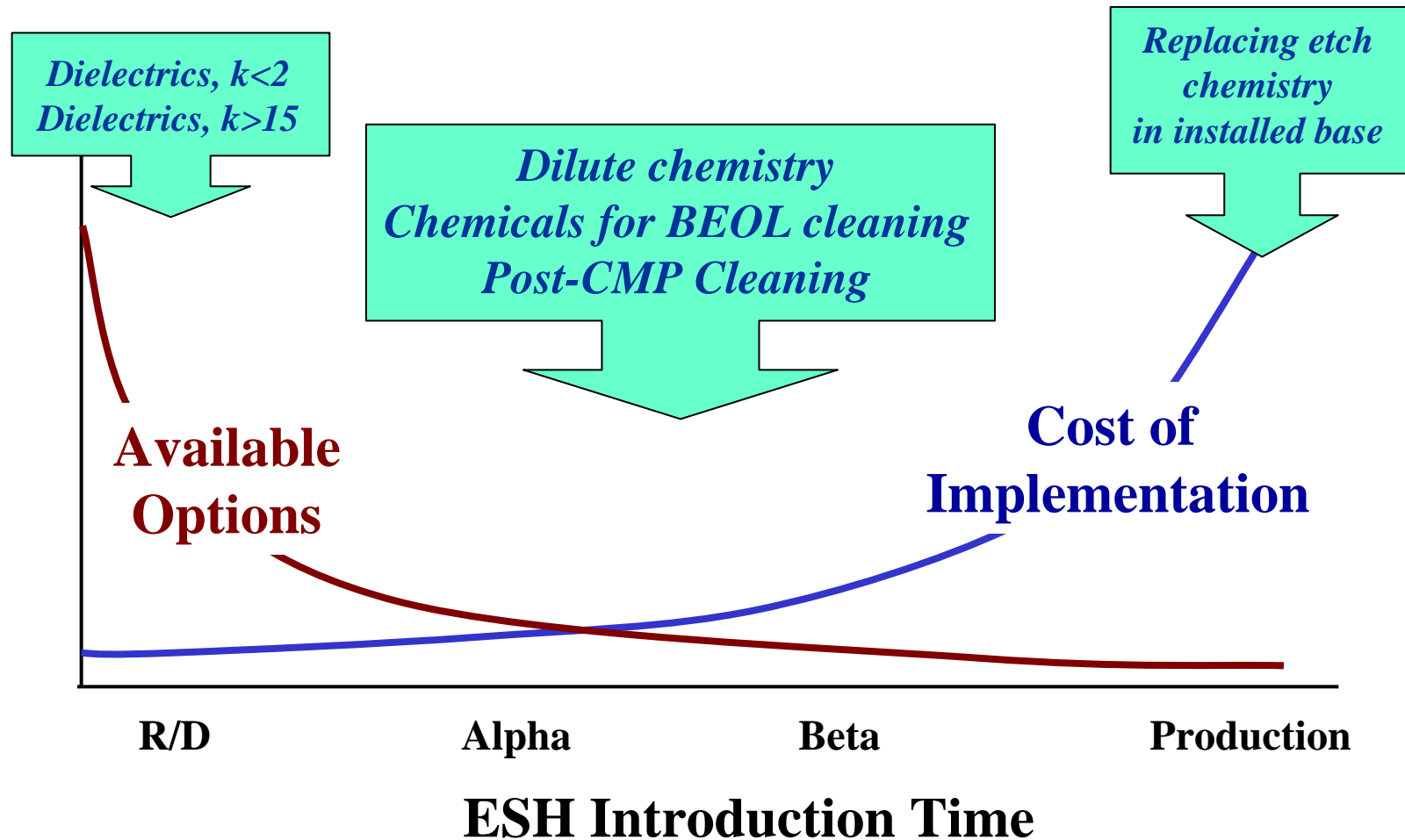
Complexity of Environmental Impact Assessment



$$I = \text{Function (P, E)}$$



Significance of Timely Consideration of ESH as a Design Parameter



ESH Research Needs **in Nano-Manufacturing**

- **Continued studying the health effects of all forms of nano-particles**
- **Identification of the key chemical and physical properties of nanoparticles (high area, high number concentration, large number of active sites, transport properties, stability, etc.)**
- **Robust on-line, in situ, and real-time monitoring techniques**

ESH Research Needs **in Nano-Manufacturing**

- **Post CMP removal of nano-particles from wafer surface**
- **Technology for treatment of waste stream containing nano-sized abrasive particles, chemical reactants, and CMP by-products (both in adsorbed or dissolved forms)**
- **Special ESH impact assessment tools (all levels: tool, R/D or factory site, and global levels); focus on scientific ways of dealing with uncertainties and gaps in data.**