

NSF/SRC Engineering Research Center

Environmental Implications
and Impact of Semiconductor
Manufacturing

Farhang Shadman

A University-Industry Collaborative Program

Founding Universities (1996)

- U Arizona
- U California – Berkeley
- MIT
- Stanford

Other University members

- Arizona State U (1998 -)
- Columbia (2006 - 2009)
- Cornell (1998 -)
- Georgia Inst. of Tech. (2009 -)
- U Maryland (1999-2003)
- U Massachusetts (2006 - 2009)
- U North Carolina (2009 -)
- Purdue (2003 - 2008)
- U Texas - Dallas (2009 -)
- Tufts (2005 - 2008)
- U Washington (2008-)
- U Wisconsin (2009-)
- UCLA (2011 -)
- North Carolina A&T (2012 -)
- Johns Hopkins (2012 -)
- Colorado School of Mines (2012 -)

Presentation Overview

Nano-manufacturing is not simply an extrapolation or scale-down version of the larger-scale manufacturing:

- a) It has unique ESH and sustainability challenges.**
- b) It also presents opportunities for application of new tools and techniques.**

Introduction of New Materials

[1980s]

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1 H 1.0079																	18 Ar 39.948																		
3 Li 6.941	4 Be 9.0122															19 K 39.098	20 Ca 40.078	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr		
11 Na 22.990	12 Mg 24.305															37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.710	51 Sb 121.757	52 Te 127.6	53 I 126.905	54 Xe 131.29		
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.887	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.710	51 Sb 121.757	52 Te 127.6	53 I 126.905	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57-71 *	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)	87 Fr (223)	88 Ra (226)	89-103 Ac															

11 Elements

[1990s]

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K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Fr	Ra	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Ac		
39.098	40.078	44.956	47.887	50.942	51.996	54.938	55.845	58.933	58.693	63.546	65.38	69.723	72.64	74.922	78.96	79.904	83.80	85.468	87.62	88.906	91.224	92.906	95.94	(98)	101.07	102.91	106.4	107.87	112.41	114.82	118.710	121.757	127.6	126.905	131.29	(223)	(226)		178.49	180.95	183.84	186.21	190.23	192.22	195.08	196.967	200.59	204.38	207.2	208.980	(209)	(210)	(222)			

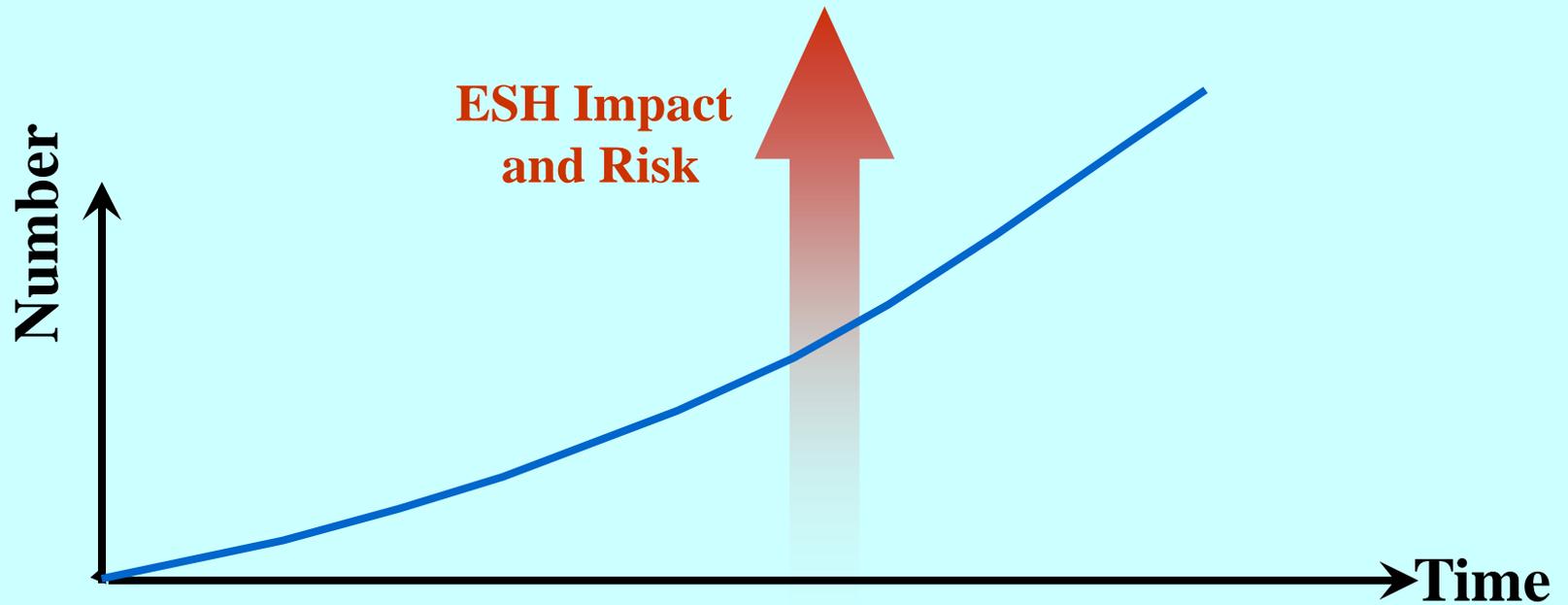
15 Elements

[2000s]

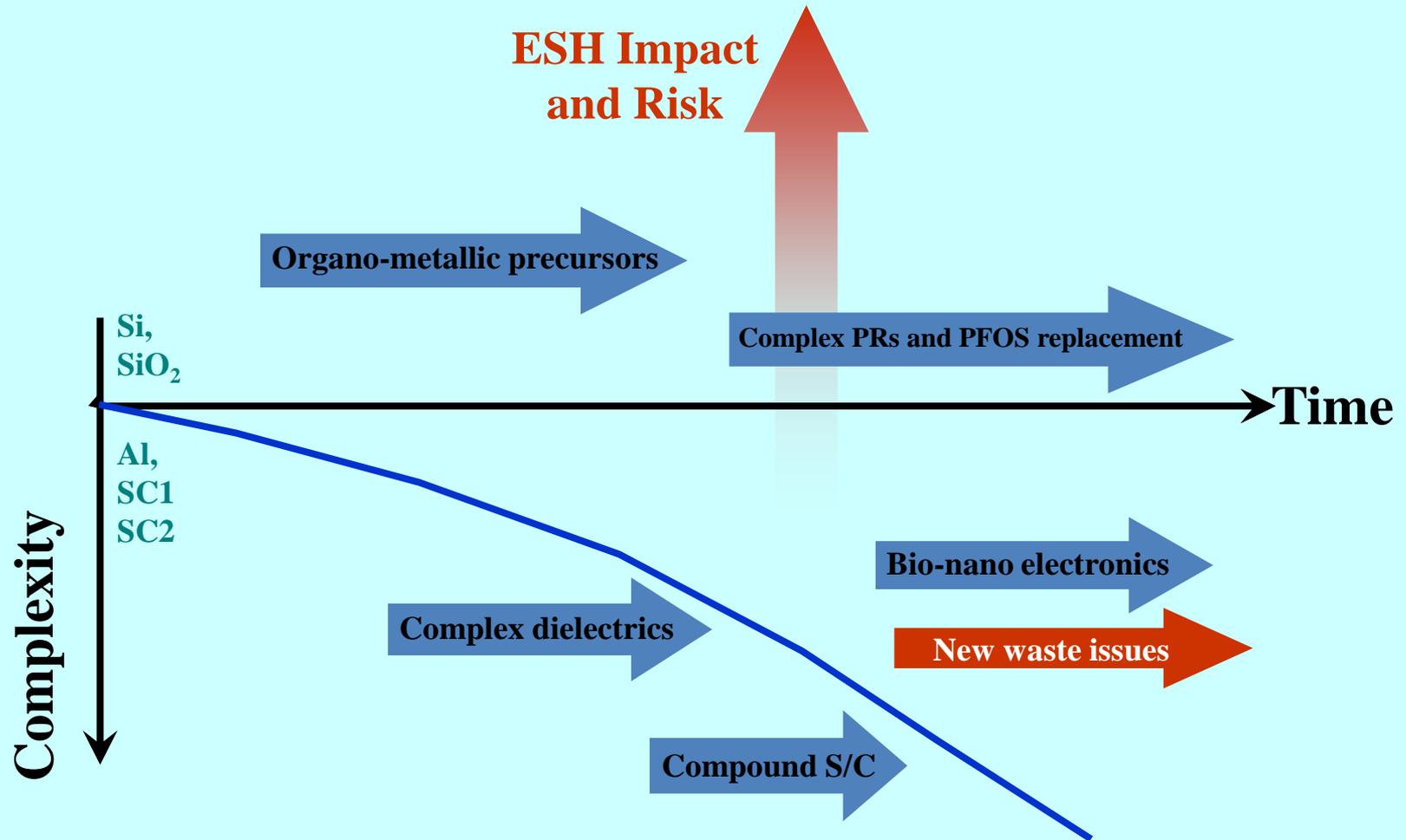
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>60 Elements

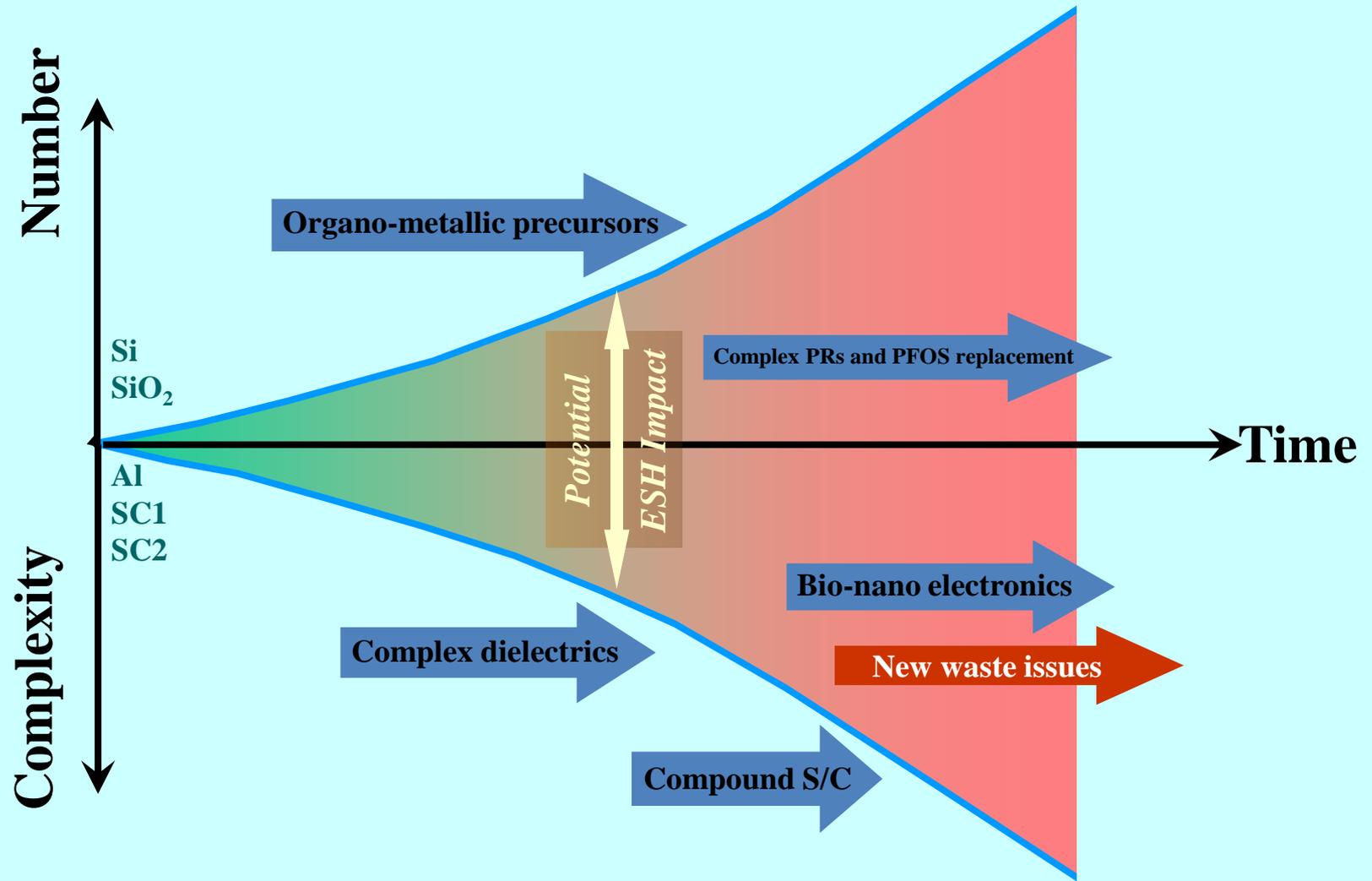
Introduction of New Materials



Introduction of New Materials



Introduction of New Materials



Unique Properties of Nano-Particles

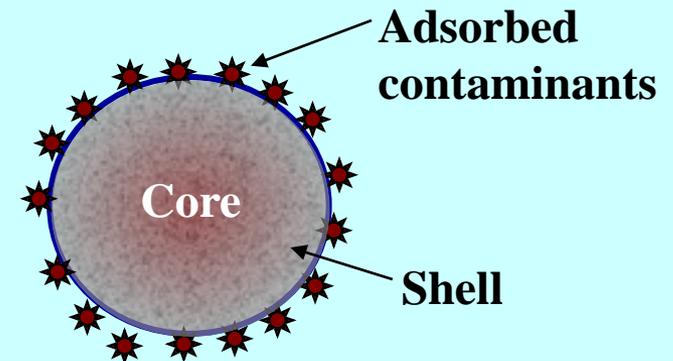
Treatment problem:

- Nano-particles cannot be effectively removed by conventional separation methods such as agglomeration, settling, and filtration.

Synergistic ESH impact of nano-particles:

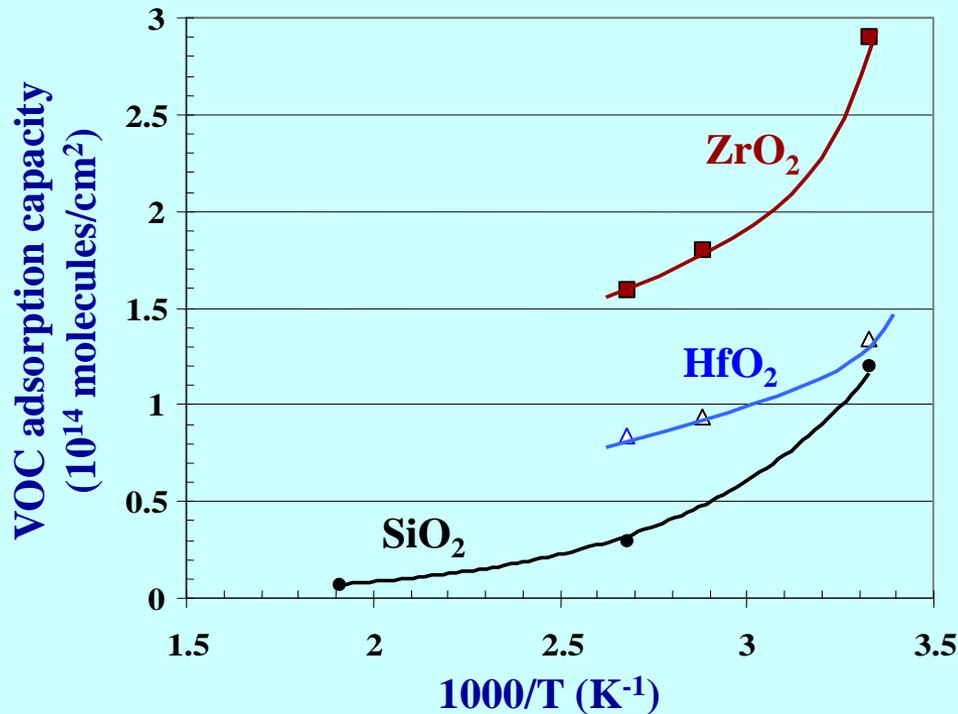
- *Active surface*
- *Selective adsorption*
- *Pore condensation (Kelvin Effect)*

Consequence {
◦ *Concentration*
◦ *Facilitated transport*
◦ *Enhanced life-time*



Unique Properties of Nano-Particles

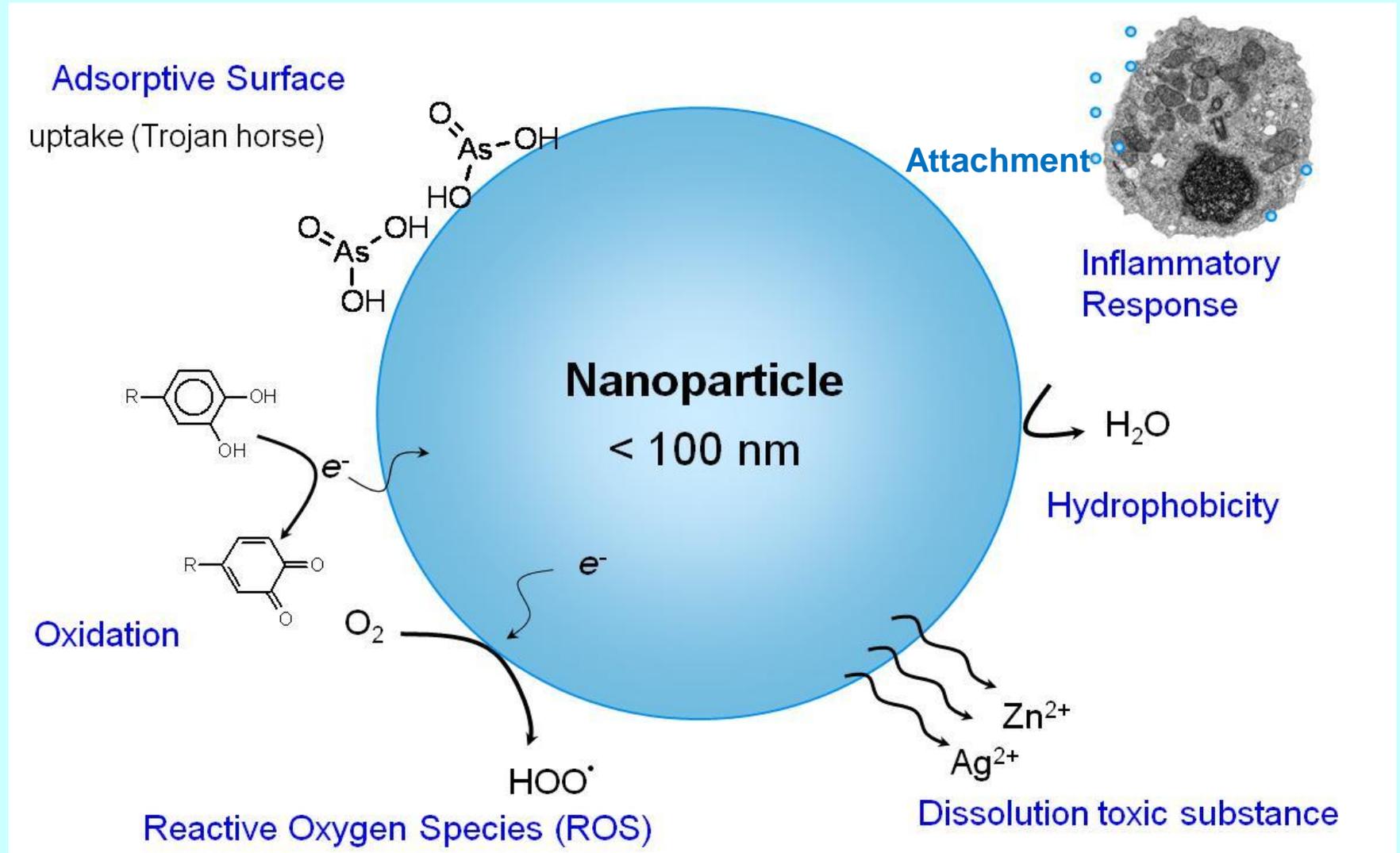
a) Nano-particles in the gas phase
15ppb VOC; 40 nm particles



b) Nano-particles in the wastewater

- 10 ppb of Cu⁺⁺ in CMP wastewater results in 3×10^6 ppb of adsorbed copper on 90 nm CeO₂ nano-particles
- 10 ppb of PFOS in wastewater results in 2.8×10^4 ppb of contaminated 10 nm carbon nano-particles

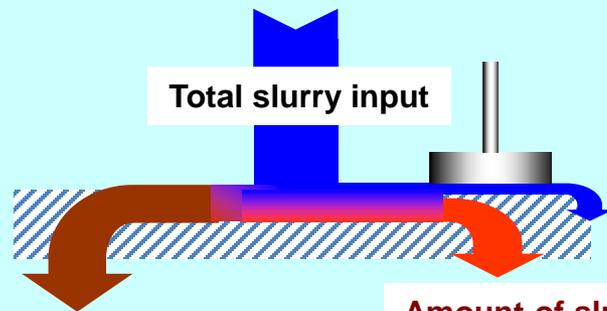
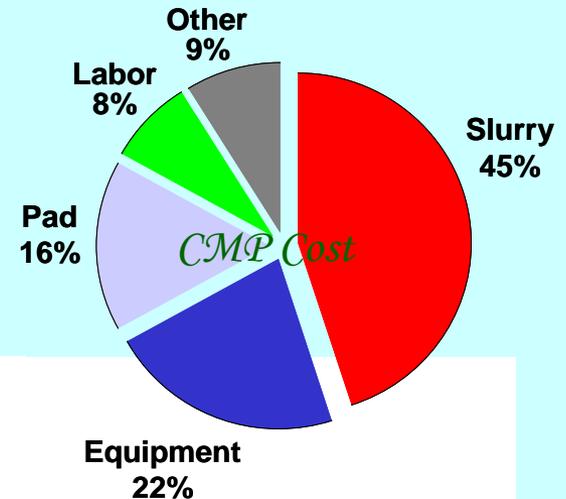
Toxicity of Nano-Particles



Nano-Particles in CMP Process

Program Leader: Professor Ara Philipossian

- Major source of nano particle emission in S/C fabs.
- Costly and wasteful operation: For a typical 200-mm factory:
 - 6,000,000 liters of slurry per year
 - 300 metric tons of solid waste per year



Amount of slurry that never reaches the wafer

Amount of slurry that reaches the wafer but does not get underneath

Amount of slurry that does the actual polishing is often less than 10%

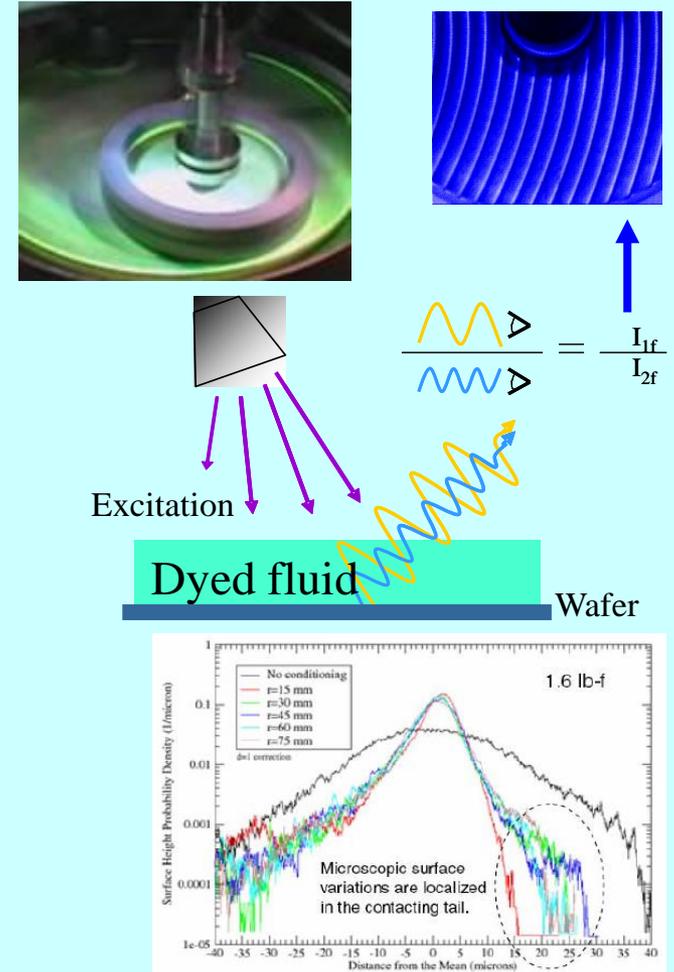


Integrated ESH-Friendly Planarization

Program Leader: Professor Ara Philipossian

Integrated Technology for CMP:

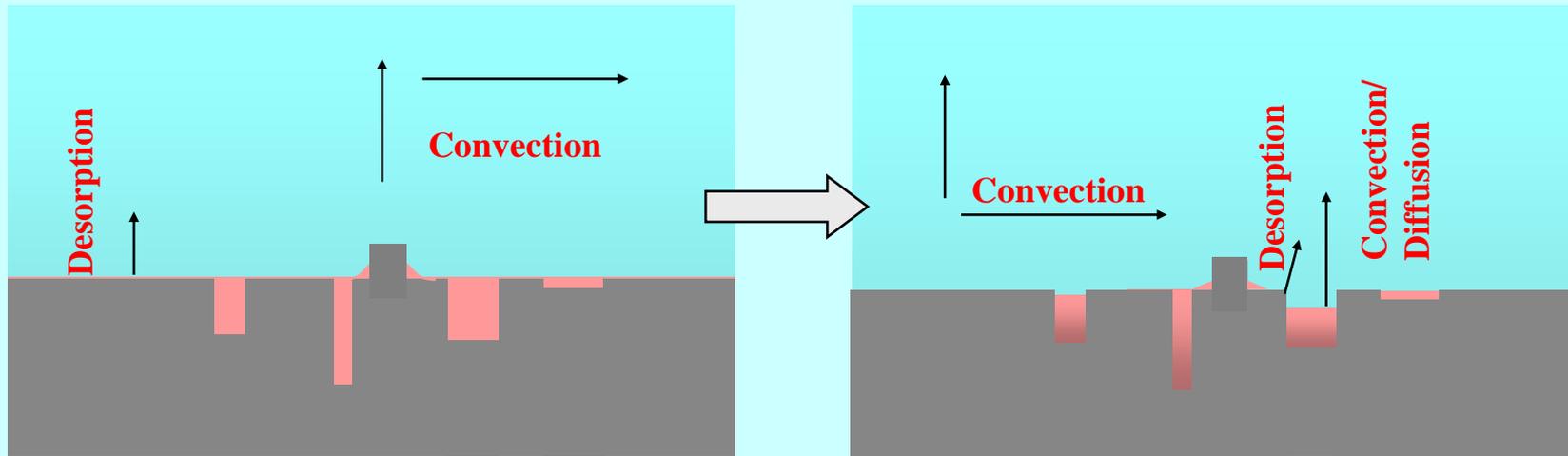
- Reduced slurry usage by 20-40%
- Reduced Cu in waste stream) by 25%
- Increased pad life by 20-50%
- Reduced diamond disc consumption by 20%
- Shortened CMP polish time by 20-50%
- Improved yield by 1-2%
- Developed ESH-friendly chemicals for ECMP



Impact of Nano-Scale Manufacturing on Resource Utilization

Water and Energy Use Reduction

Cleaning of Nano-Structures

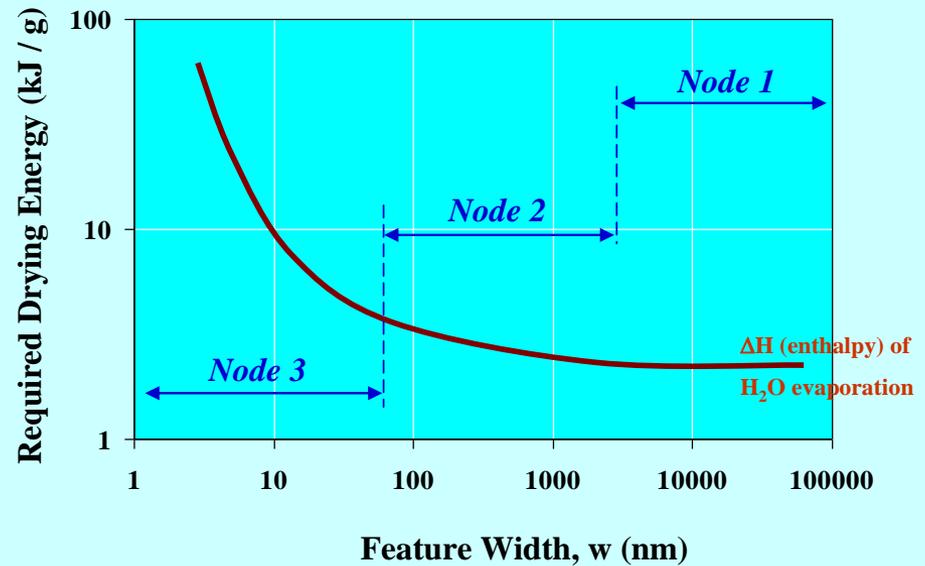
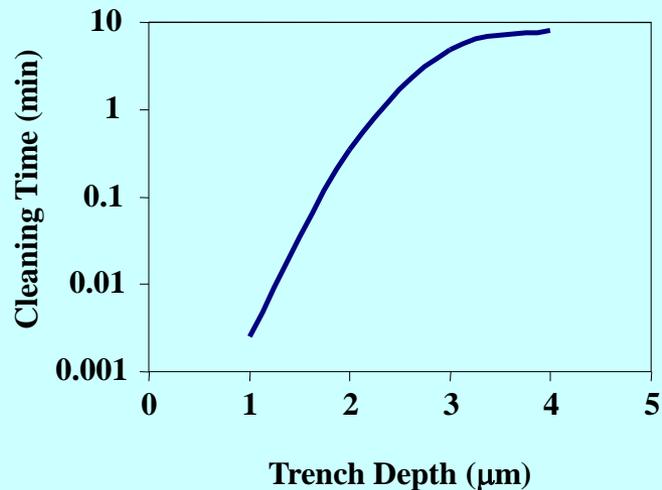
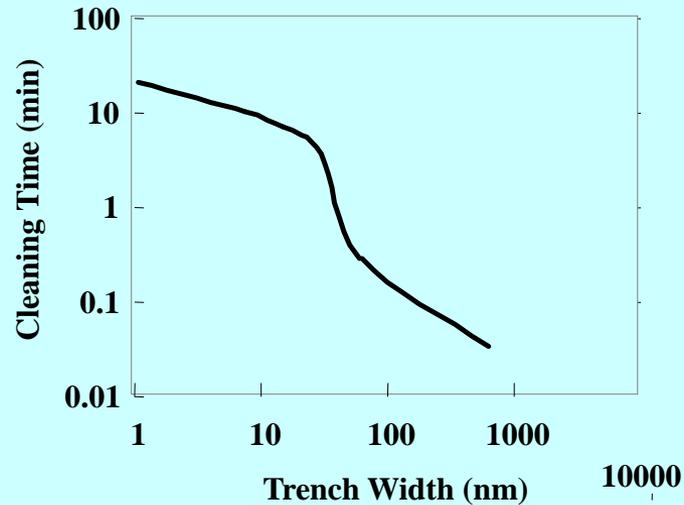


Mechanism	Time Scale	Flow Effect
Boundary Diffusion Convection Desorption	$d^2/D \sim 10 \text{ s}$ $d/u \sim 1-3 \text{ s}$ $1/k_d \sim 0 - 10^5 \text{ s}$	Indirect, mild Direct, strong No effect

Needs:

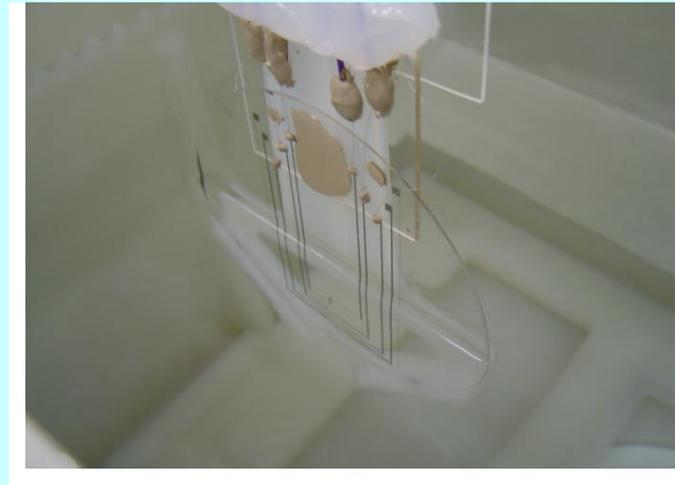
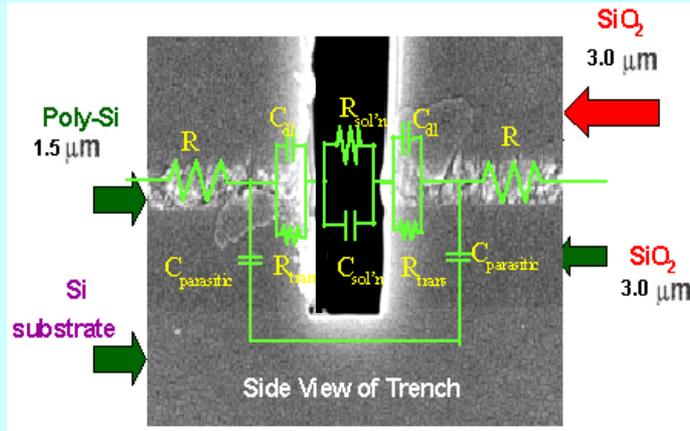
**Lowering water and energy usage
Better metrology and process control**

Increased Use of Resources in Nano-Manufacturing



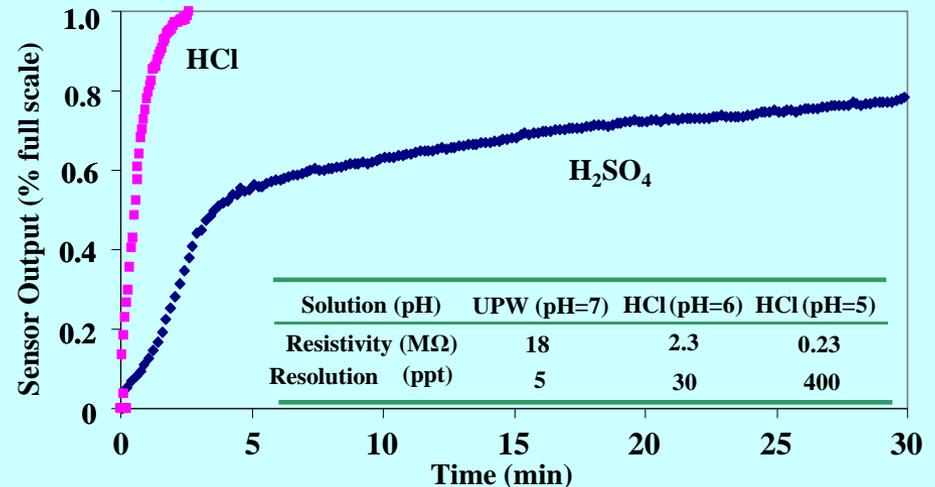
Trend: Large increase in *water, chemicals, and energy usage* as feature size decreases and wafer size increases.

A Novel Metrology Technology: Electro-Chemical Residue Sensor (ECRS)

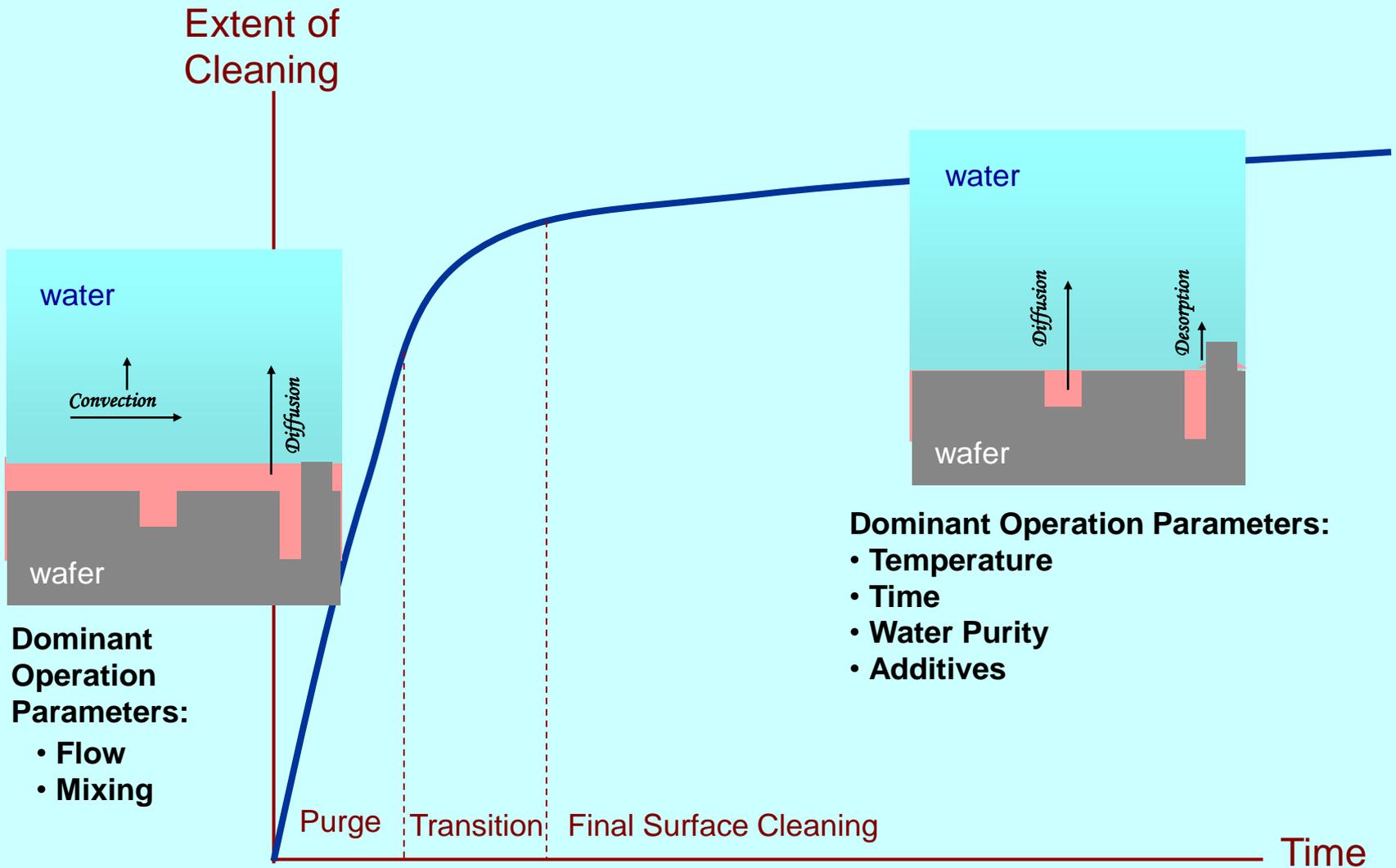


Unique Characteristics:

- In-situ
- Real time
- On-line
- High sensitivity for small feature sizes
- Very short response time
- Total integration



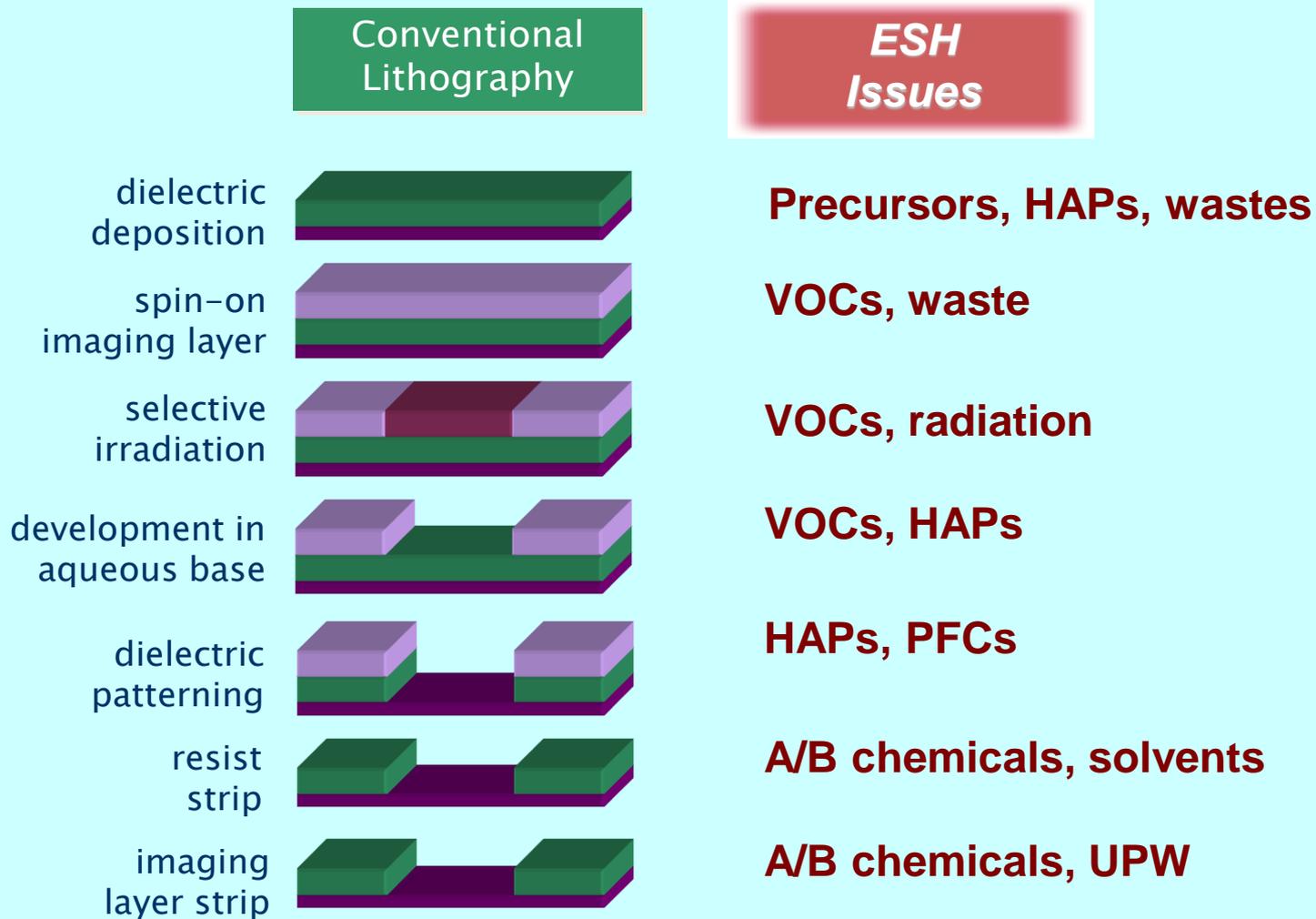
A Novel Staged Rinse Process



Major Paradigm Change: Application of New Manufacturing Concepts and Methods

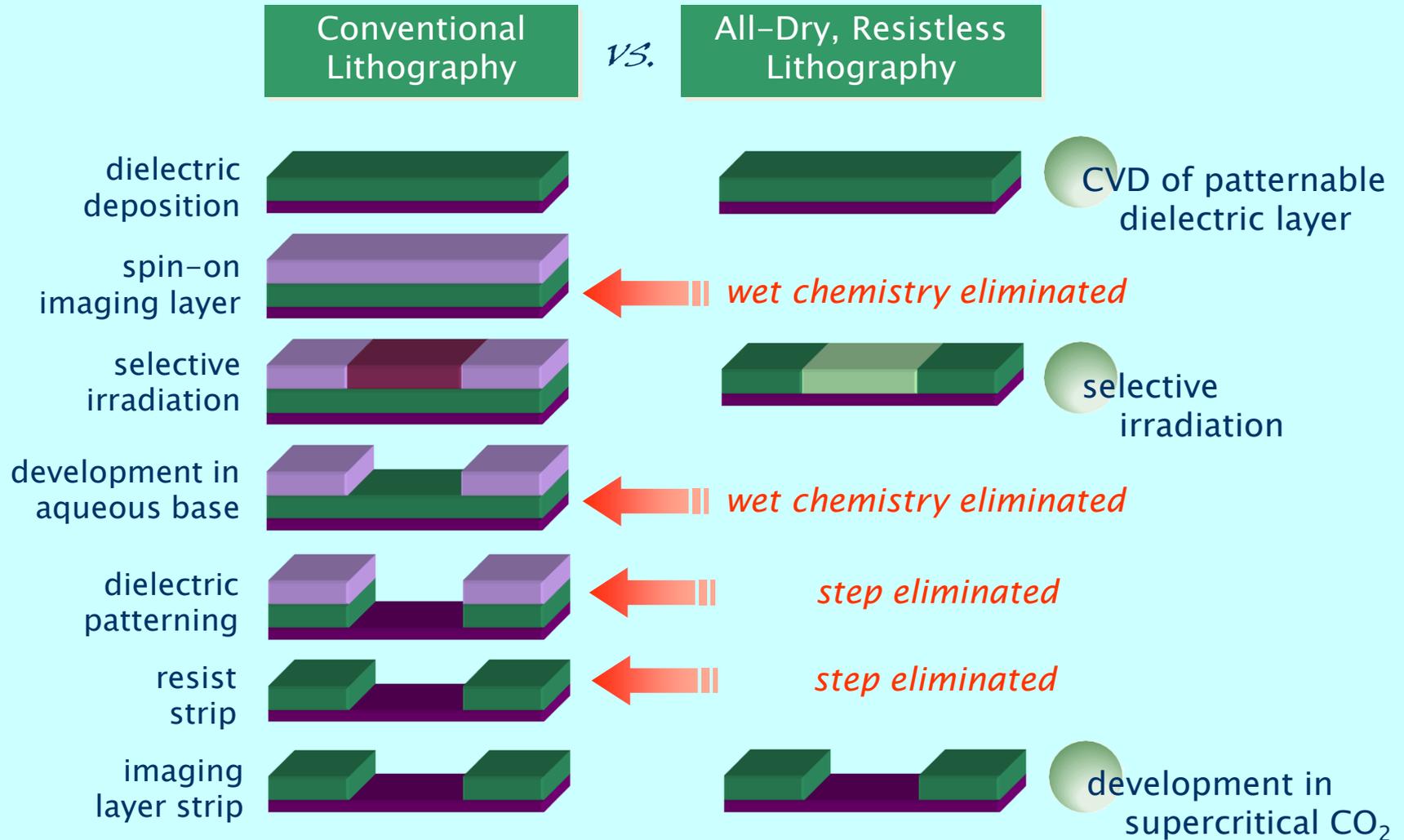
1. *Subtractive:* Carve the structural details in a solid block or solid deposited layers
2. *Additive:* Place the final materials only in places where they are needed.

An Example of Subtractive Processing Deposition and Patterning of Dielectrics



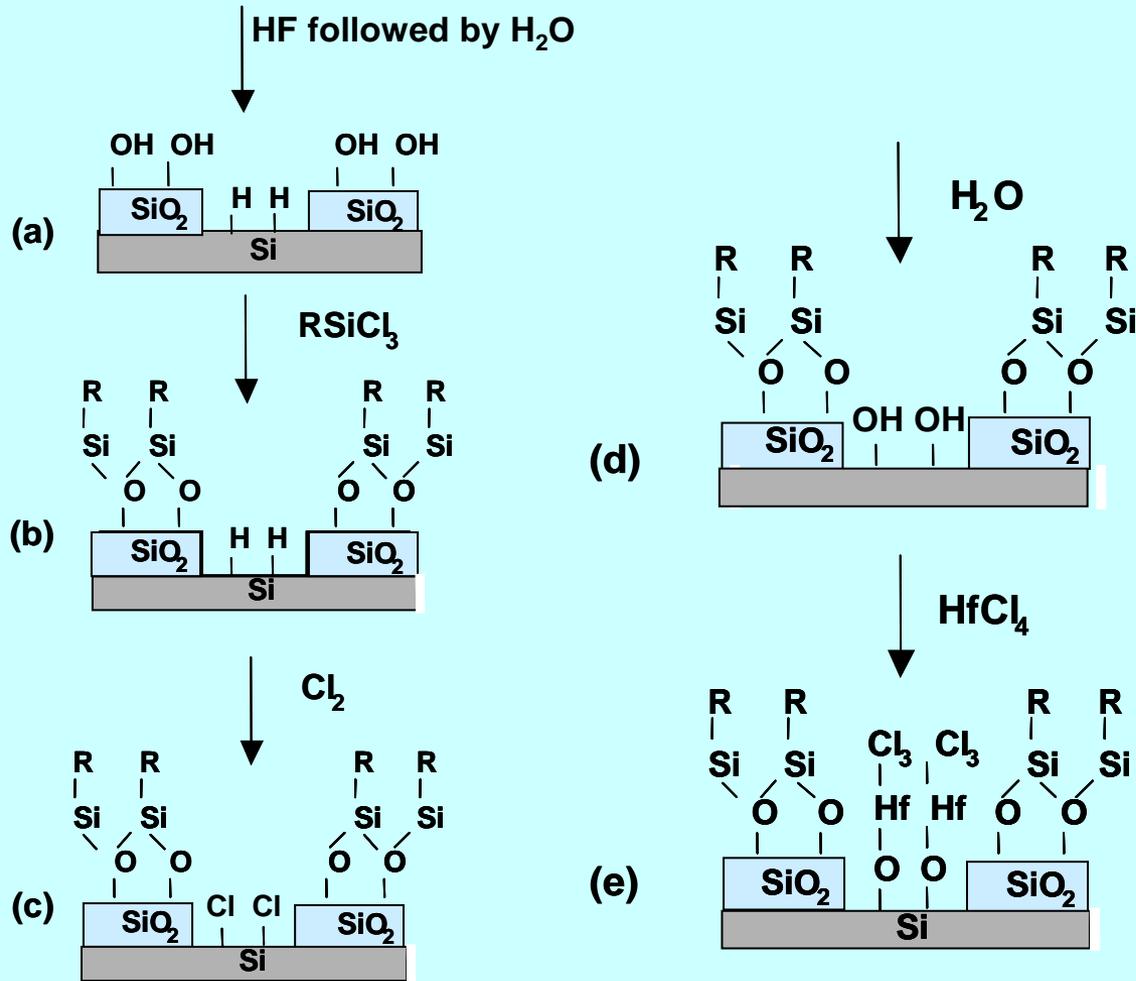
Deposition and Patterning of Dielectrics

Lead: Professors *Karen Gleason (MIT)*, *Chris Ober (Cornell)*



Reducing Environmental Impact by Additive Processing

Lead: Professor Anthony Muscat



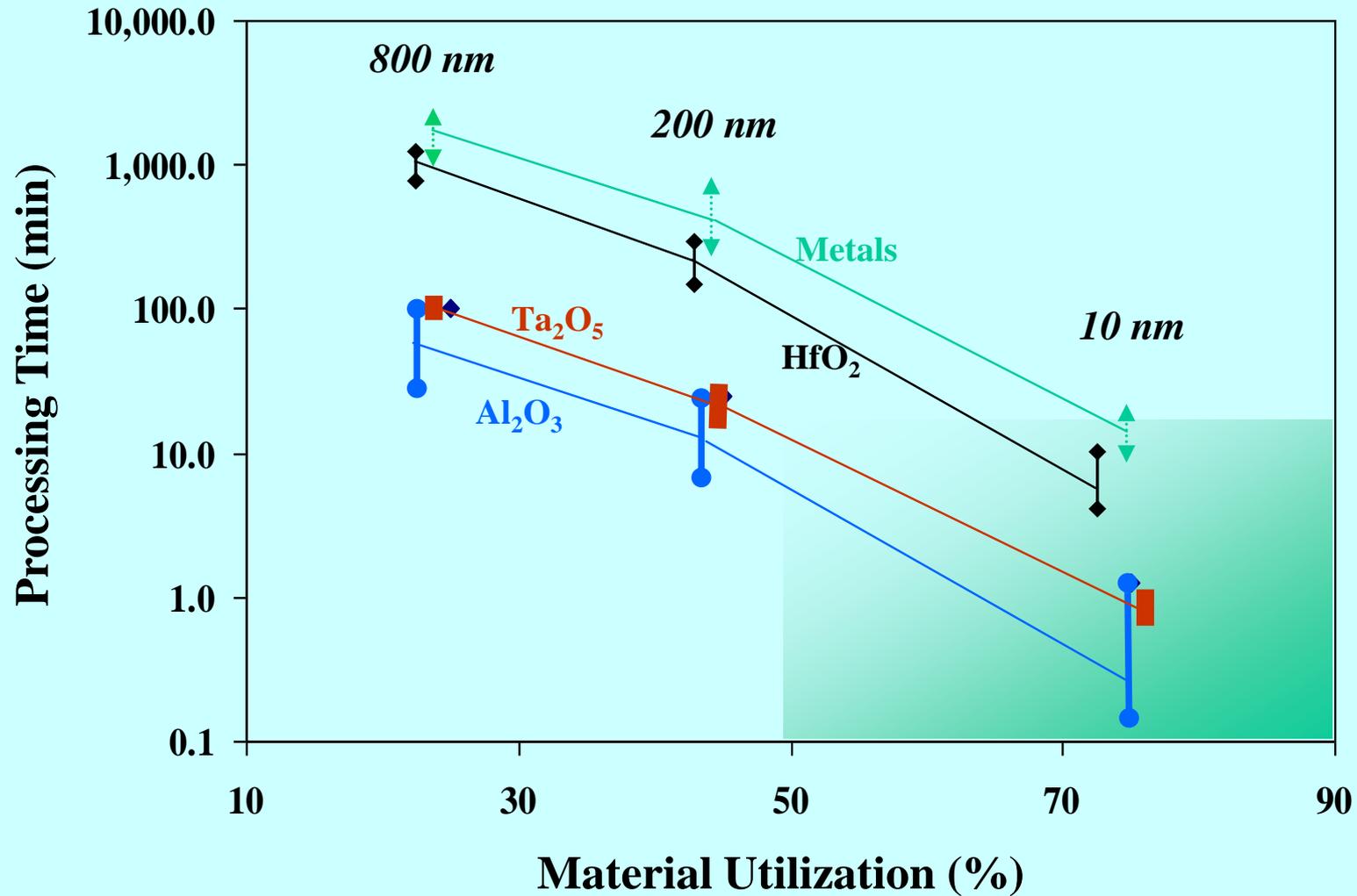
a) Clean and Pattern Si

b) Protect SiO_2

c) Activate Si

d, e) Maskless selective ALD of high- k dielectric

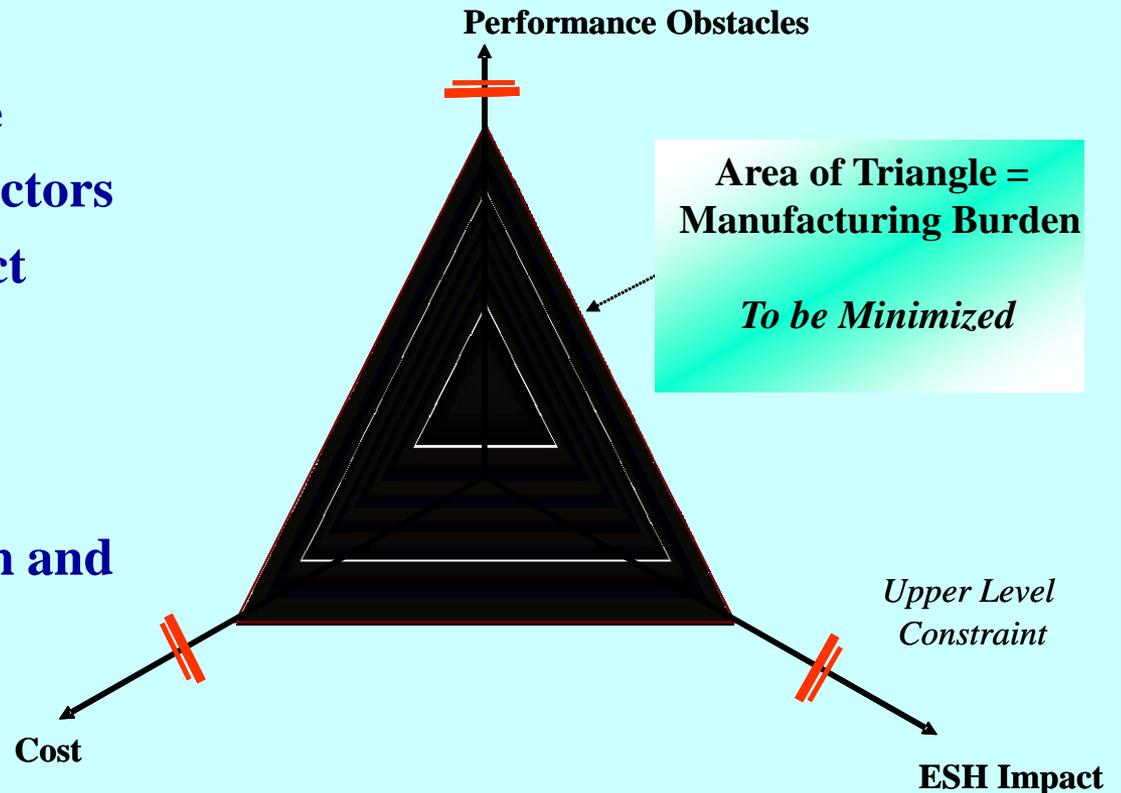
Feasibility of Additive Processing in Nano-Scale Selective Atomic Layer Deposition (ALD)



Quantifying Environmental Impact and Sustainability

Factors that determine the sustainability of a product, a process, or a manufacturing technology:

1. Product performance
2. Cost and economic factors
3. Environmental impact
 - Safety and Health
 - Social factors and compatibility
 - Resource utilization and availability



Summary

Nano-manufacturing is not simply an extrapolation or scale-down version of the larger-scale manufacturing:

- a) There are unique ESH and sustainability challenges**
- b) There are also opportunities for application of novel approaches and introduction of new tools/techniques.**