Environment, Safety, and Health: A Strategic Vision and Emerging Research Needs

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Outline

- **An historical perspective:** Evolution of the ESH research vision
- **Looking forward:** A summary of strategic research priorities
- Discussion and closure

The ESH research vision: An historical perspective and epiphanies

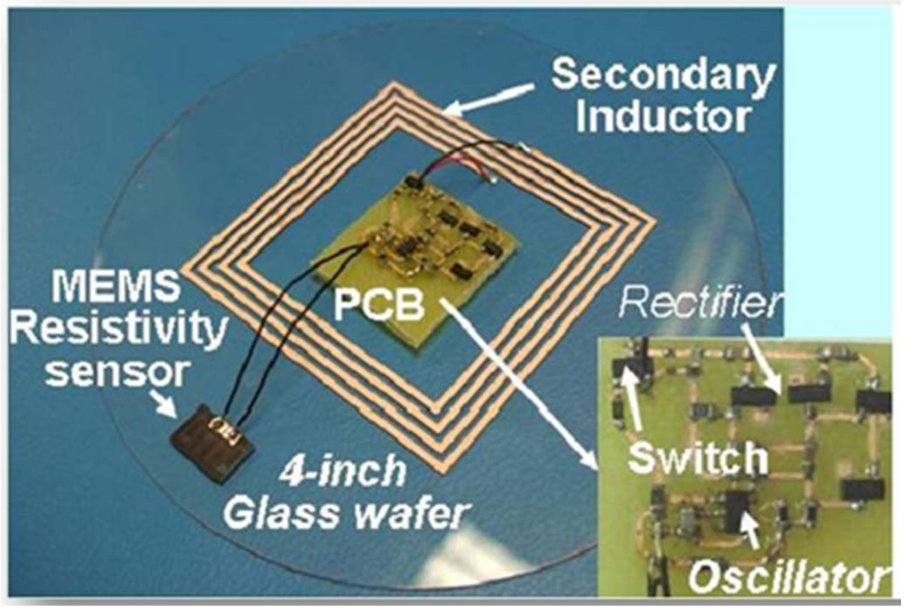
- Water recycling [F. Shadman]
- Water usage [R. Helms, B. Vermeire]
- PFC replacements [R. Reif]
- Dual performance-effluent optimization [G. Rubloff]
  - Real-Time Gas Sensors and Simulation for RTCVD Metrology and Control

Impact of ESH Technology on Nanomanufacturing

- **Challenge:** Industry faces orders of magnitude increases in energy, water, and chemical usage as manufacturing technology scales into the nanodomain.
- **Solution:** Development of new ESH-friendly nano-manufacturing techniques
- **Impact: Demonstrated that being a good environmental steward can be good for business** and not a burden

SRC's nanocatalytic recycling technology demonstrated that **recycled water costs less than purified external water**, without compromising performance.

Low Water and Low Energy Rinsing and Drying of Patterned Wafers



Objectives:

1) Understand the fundamental mechanism and dynamics of rinsing and drying nano-structures
2) Develop new methods to minimize the use of water, drying fluids, and energy
3) Develop an integrated rinse/POU purification/local recycle for selected process groups such as CMP.

Impact: Demonstrated staged rinsing with **>40% water savings**.

Received Semiconductor International Editor's Choice 2009 Best Product Award

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ESH as One of the Key Criteria for Semiconductor Process Development

[Excerpted from a 1999 AVS Presentation]

A. Bowling, T. Wooldridge,
J. DeGenova, T. Yeakley,
T. Gilliland, A. Cheng, and L. Moyer
TEXAS INSTRUMENTS Inc.

Why was SC Industry Not More Proactive on ESH?

- There was a worry that in order to optimize for ESH, you would have to sacrifice process performance and thus yield. Thus, you first optimize performance and yield, and then add the required ESH methods, which you can afford from optimized yield.

- Belief that ESH approaches always add extra cost, so you just add this in manuf.

What Have We Learned?

- Cost goals led us to focus on recycling and reuse of resources - this improved costs, but also optimized and improved processes! - which in some cases also improved yield!$$

- ESH optimization has required that we understand processes better, which has led to better understanding of how to optimize processes.

Conclusion [Epiphanies]

- There are process optimization and yield improvement benefits to using ESH goals as a key part of SC process development.$$$

- ESH pursuit as a science has had many side benefits - most of all in the reduction of resources used and thus improvements in cost.

Concurrent ESH Research Drivers

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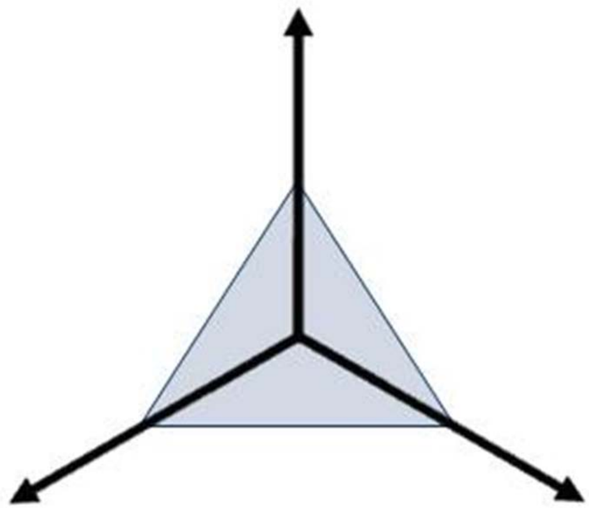
[Increase Performance, Functionality, and Reliability]



Reduce Cost

Reduce ESH Impact

Nanoengineered Materials Thrust

[[1] ETAB Priority; [2] ITRS Challenge]

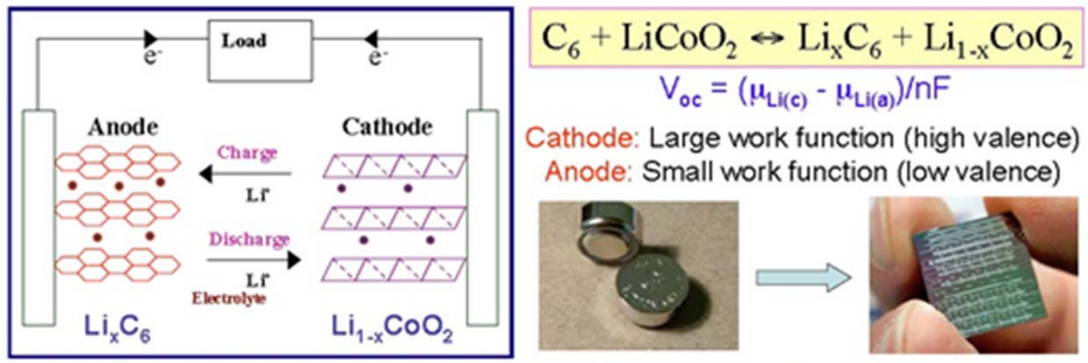
NEM Thrust Research Priorities	2012	2013	2014	2015	2016
Functional Diversification on CMOS[1,2]	grow			sustain	
ITRS-Identified Emerging Research Materials &ERD[CMOS and A/MS] [1,2]	sustain		grow		
Predictive Material Property Modeling, [including 3D][1,2]	start	grow			
New CMOS and Analog/Mixed Signal Materials/Processes[1,2]	start	grow			
Deterministic Fabrication[2]	sustain			decline*	

Progress Towards Fabricating an Embedded Li-ion Battery

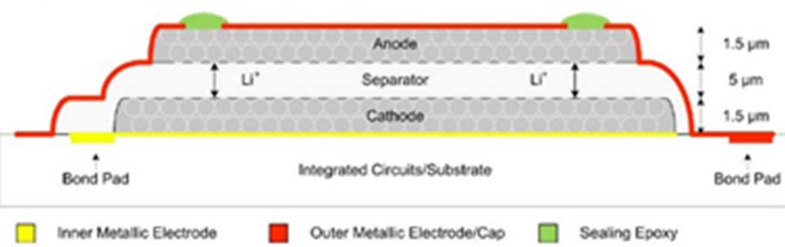
Objective: For portable electronics and lithium ion battery development, demonstrate the potential of inkjet-printing (IJP) technology to **deliver high performance lithium ion battery materials directly to 3D electrodes** that are created using conventional microfabrication techniques. IJP technology allows additive deposition of nanostructured materials with picoliter precision.

Approach: Use **inkjet printing** technology to fabricate embedded Li ion batteries.

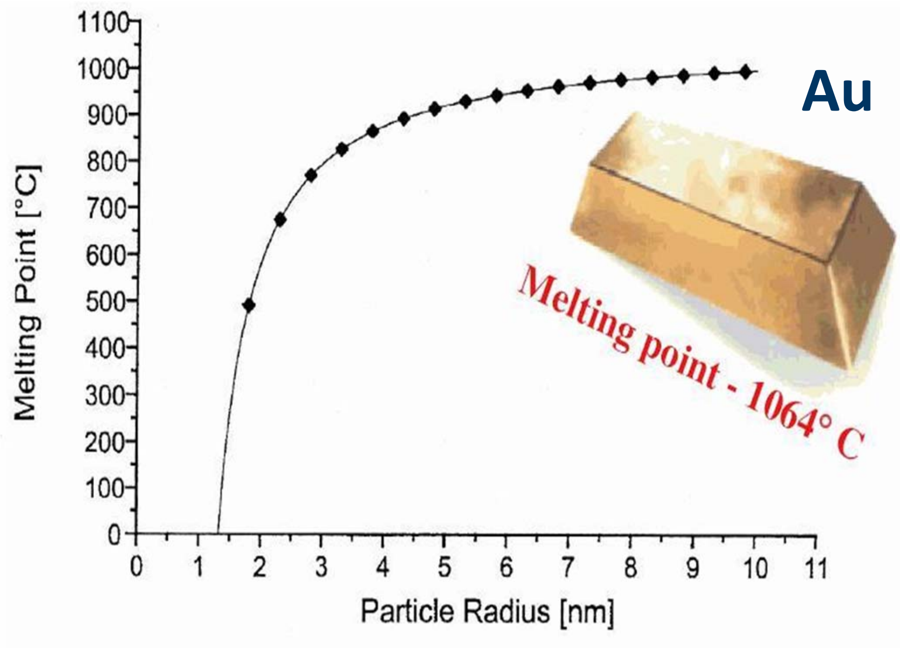
Accomplishments: **Demonstrated the feasibility of using inkjet printing to fabricate lithium ion batteries**, targeted for embedded high energy capacity applications

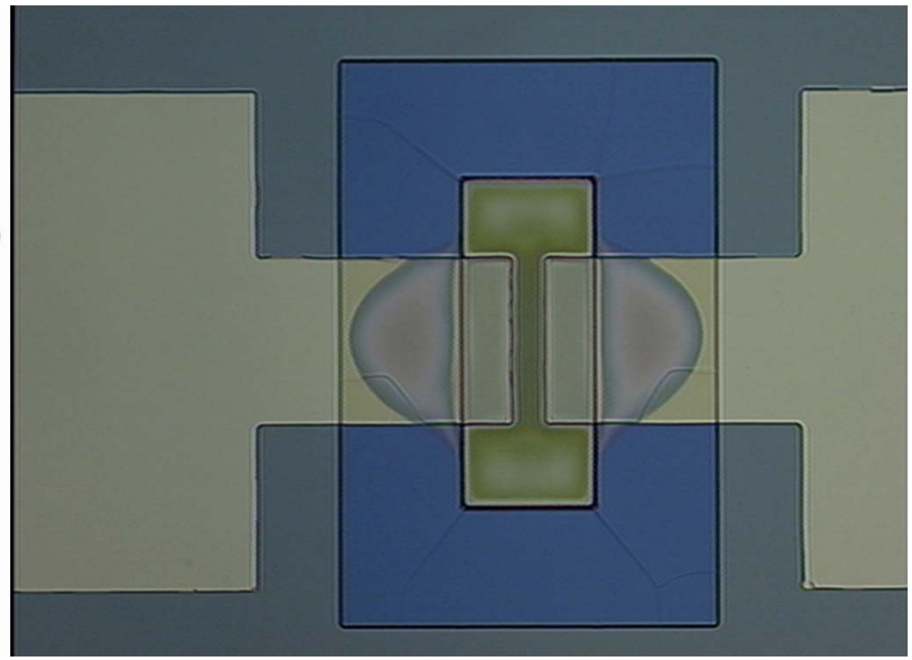


Embedded High Energy Capacity Inkjet Printed Lithium Ion Battery Concept



Low Energy Processes: Metal Nano-particles as Lead Solder Replacements





Nano-inkjet patterning of organically coated Cu nanoparticles enables **low temperature [130 C] sintering**, enhanced conductivity, i.e. better than lead.

SRC research is exploring the ESH impact of metal nanoparticles.

Looking Forward: Strategic Research Priorities

Environment, Safety, and Health Thrust

[[1] ETAB Priority; [2] ITRS Challenge]

ESH Thrust Research Priorities [Near term growth through leverage]	2012	2013	2014	2015	2016
ESH Impact of New and Nanomaterials					
New Materials and Associated Processes[2] - Includes packaging materials and processes	grow	sustain			
ESH for Nanotechnology[2]	grow	sustain			
New Technologies for Detection, Hazard Assessment, and Toxicity Screening[1,2] - Includes dose definition, hierarchical assessment, and data mining	grow	sustain			
ESH/Process Improvement					
Reduction in "Net" Water Use[1,2]	sustain				
Energy: Utilization, Management, and Sources[1,2]	start	grow			
Chemical Utilization and Waste Reduction[2]	sustain				
Hazardous Chemicals Use Reduction[2] -Includes sustainable chemical substitution	sustain				
Reduction of Hazardous Emissions, e.g. PFCs[2]	grow [phase II]			sustain	
Design for ESH/Life-Cycle Analysis[2]	start		grow		

2009 ITRS ERM Guidance: ESH Section [p35]

Over the past decade, **the introduction of new materials has enabled the semiconductor industry to continue increasing the density of transistors and increasing their performance through "equivalent scaling"**. Examples of this include the introduction of Cu and low κ interconnects to increase interconnect speed and the introduction of high κ gate dielectric with new gate electrodes to extend transistor performance while reducing power consumption. The introduction of these new materials into the integrated circuit also required the use of multiple new materials in the manufacturing process. The semiconductor industry faces many significant challenges to continue delivering higher density, higher functionality technologies in the future and very few material options could provide solutions.

2009 ITRS ERM: ESH Section [p35]

Since the difficulty of introducing a new material into a technology is high, the **new material would need to provide a significant performance advantage** over evolutionary approaches. However, in some cases all of the options have known or unknown toxicological behavior. In cases where the need for a solution is compelling and toxicological behavior is unknown, the **need for research to characterize potential acute toxicity and chronic effects** will be highlighted. As the materials become more viable as technology options, our industry needs to better understand technical and ESH properties and behavior so **mitigation and management strategies** can be developed. As critical ERM get closer to potential insertion, the ESH TWG will assess the viability of strategies for managing potential issues for these materials.

ITRS Emerging Research Materials: Potential Insertion Matrix, as of 2009

Application Opportunities	Ge and III-V	Conducting Nanotubes	Nanowires	Graphene	Oxide Nanoparticles	Metal Nanoparticles	Novel Macromolecules	Self-Assembled Materials	Complex Metal Oxides	Spin Materials
Process Materials										
Lithography					Resist nD			~ 2019		
Device: Memory										* MRAM
Device: Logic										
Interconnect										
Packaging								< 2 yrs.		

Earliest Potential Insertion Horizon	Current Application	3-5 yrs.	5-10 yrs.	10-15 yrs.	15+ yrs.	Not on Roadmap

Summary of Concurrent Nanofabrication Metrics

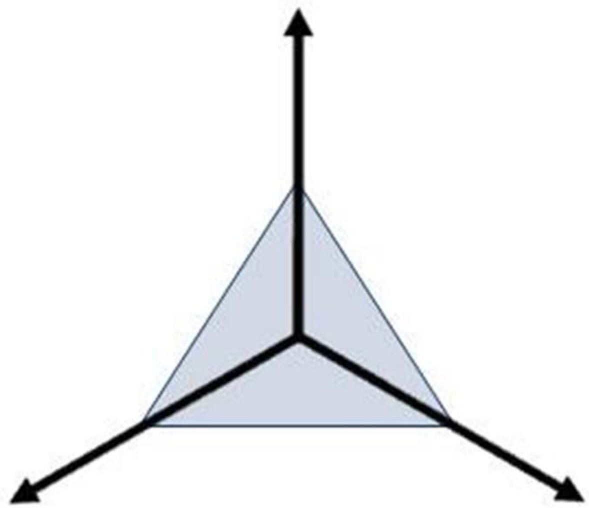
- **Centered, low variability fabrication technologies:** Demonstrate that the percent of manufacturing variability need not increase with functional density, i.e. with respect to **dimension, overlay, placement, composition, architecture**, etc.;

- **New cost curves for nanoelectronics fabrication:** Develop novel materials, process, and equipment options that:
  - Enable **extensible nanoelectronics fabrication**, defect detection, and yield management into the sub-10 nm domain and
  - Leverage the existing fabrication infrastructure;

- **Enhanced functionality:** Design, identify, and enable the **integration of** customized materials with **electronically useful functionality** for high value application opportunities;

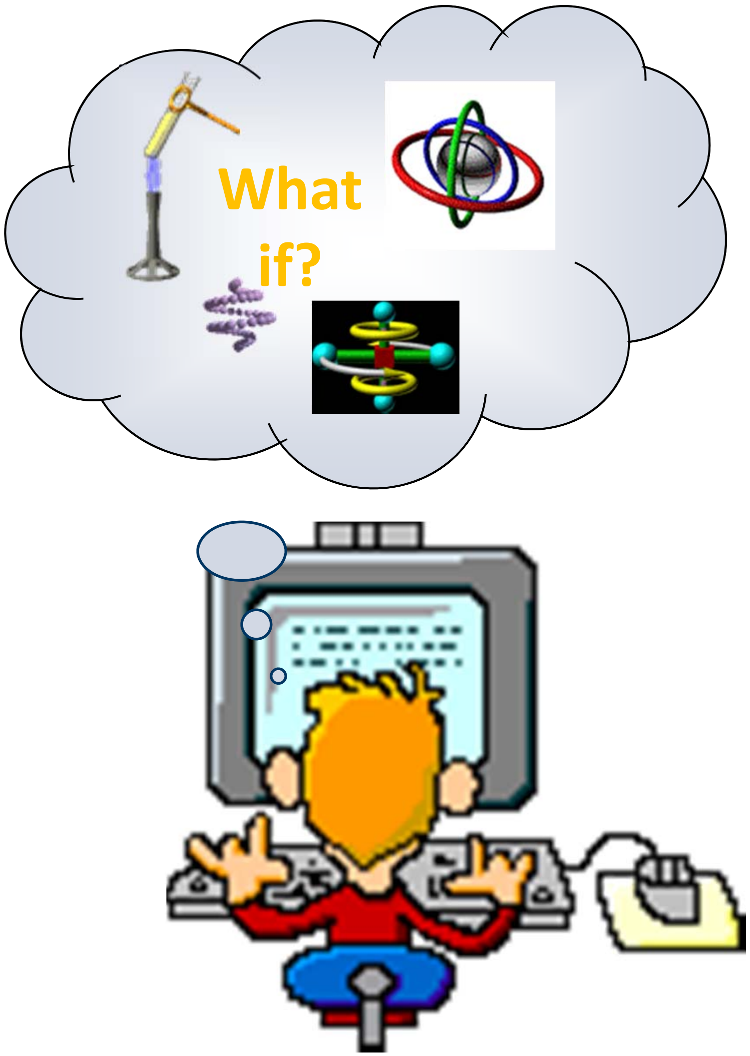
- **Sustainable, high performance fabrication:** Extend sustainable, **benign, high performance nanomanufacturing technologies** into the sub-10 nm domain.

Concurrent ESH Research Drivers

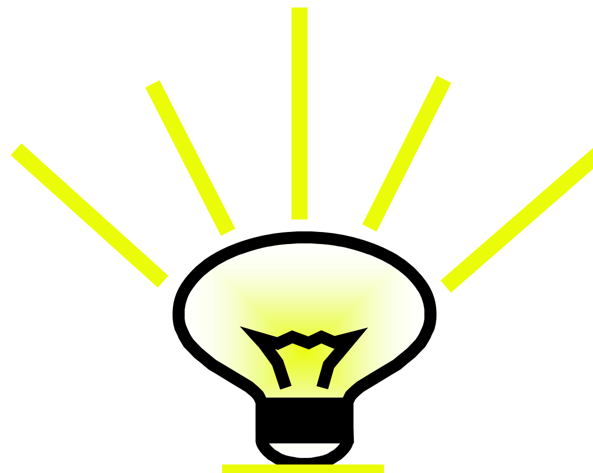


Discussion and closure

- Needs Document:
- ESH Framework:



Thank You



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