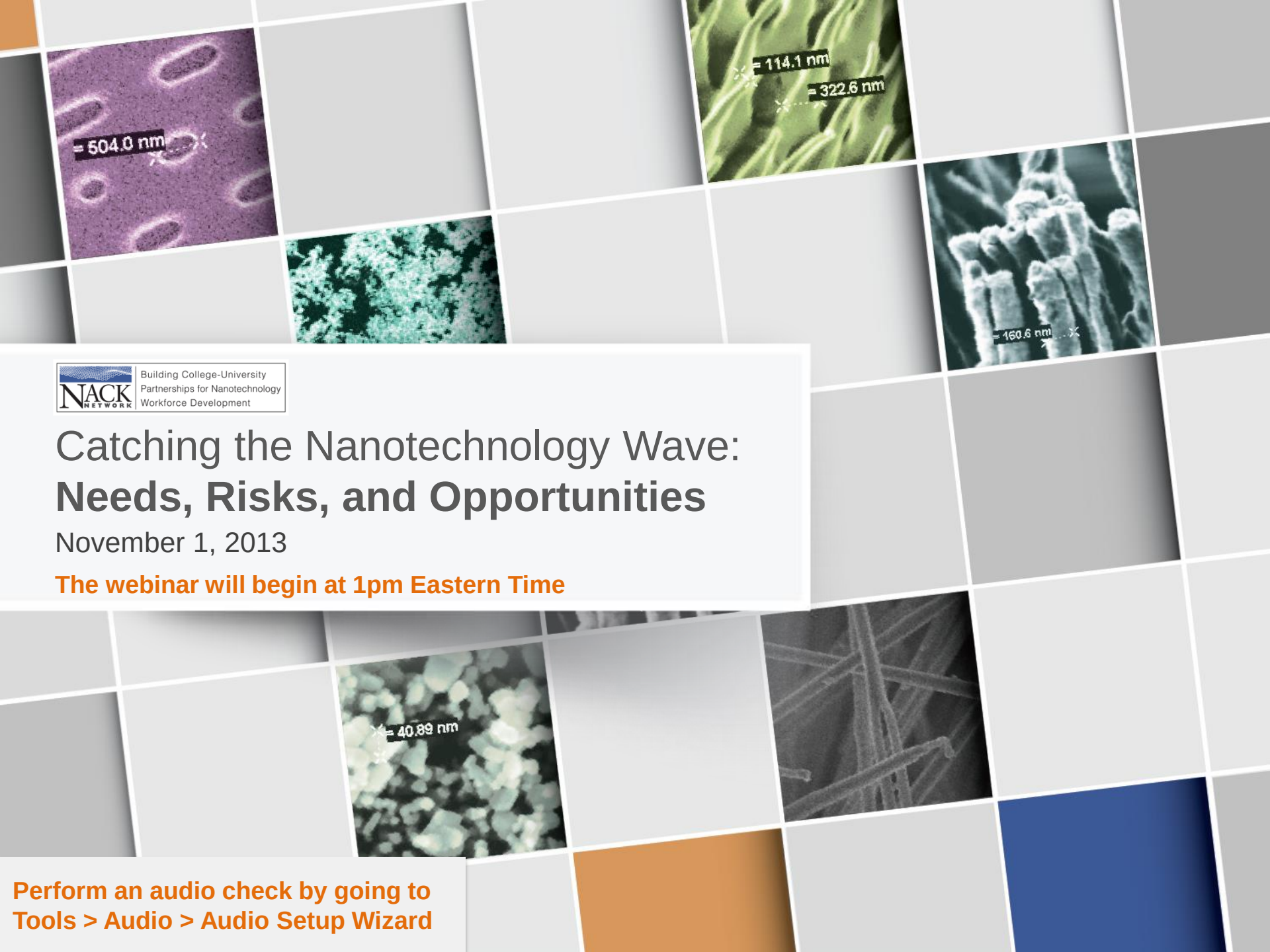

NACK NETWORK
Building College-University Partnerships for Nanotechnology Workforce Development

Catching the Nanotechnology Wave: **Needs, Risks, and Opportunities**

November 1, 2013

The webinar will begin at 1pm Eastern Time

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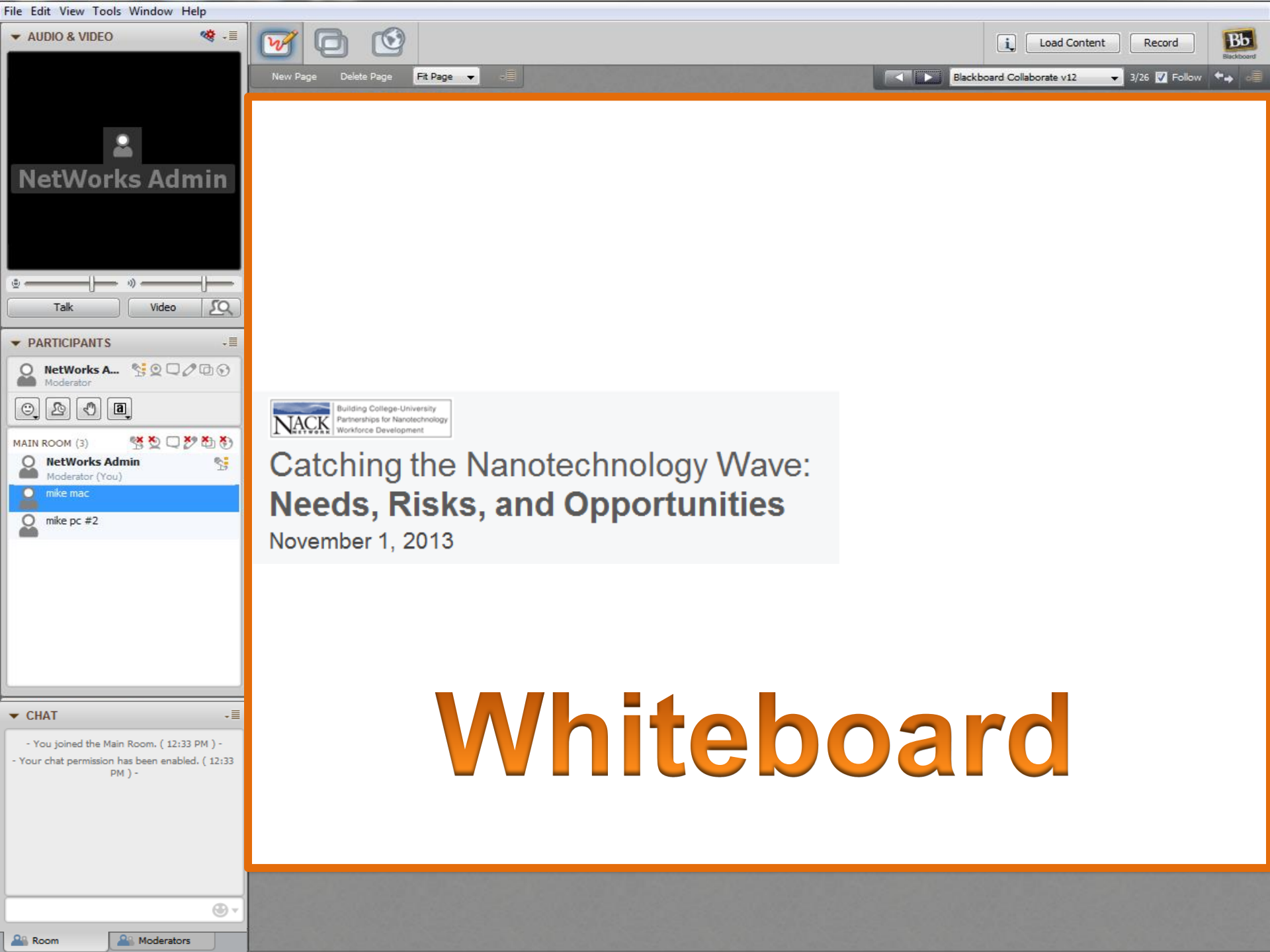
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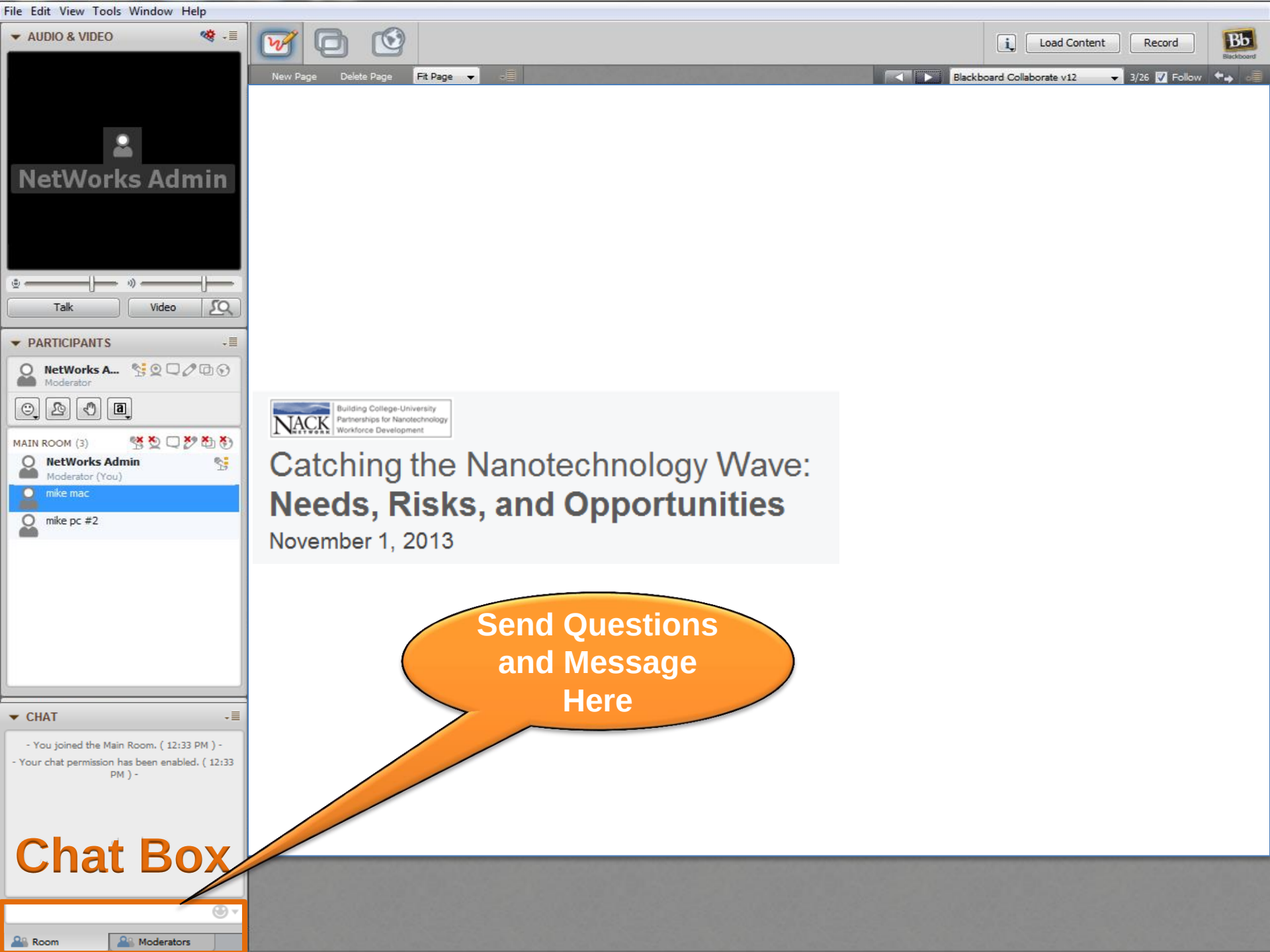
November 1, 2013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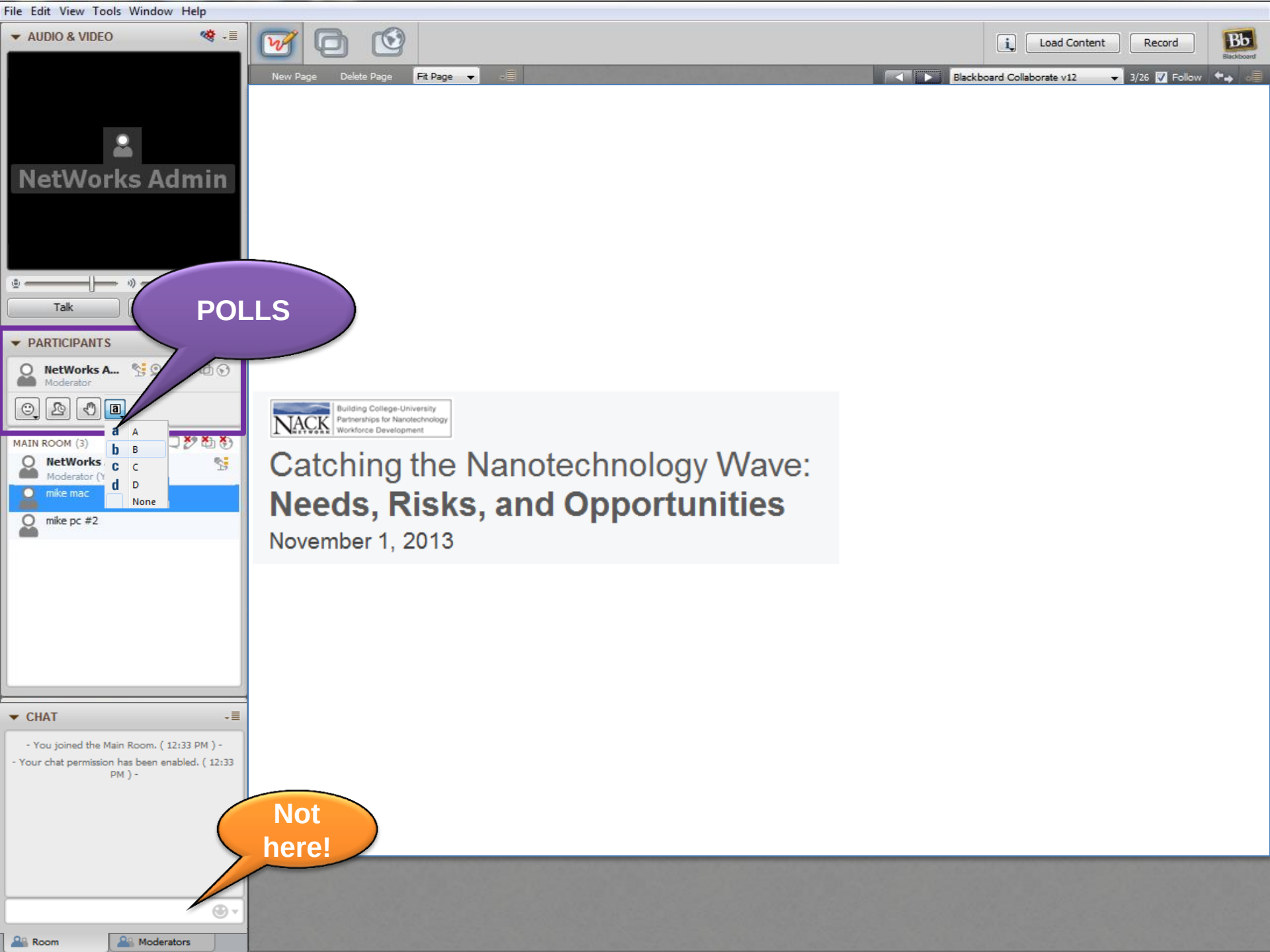
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Recording begins

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Catching the Nanotechnology Wave:

Needs, Risks, and Opportunities

Presented by MATEC NetWorks

November 1, 2013

Presenter

Daniel J. C. Herr

Professor and Nanoscience Department Chair and
Director - Nanomanufacturing Innovation Consortium,
The Joint School of Nanoscience and Nanoengineering

Co-Chair – Emerging Research Materials Working Group
International Technology Roadmap for Semiconductors

djherr@uncg.edu / 336-285-2862

Host: Michael Lesiecki

Audience Poll

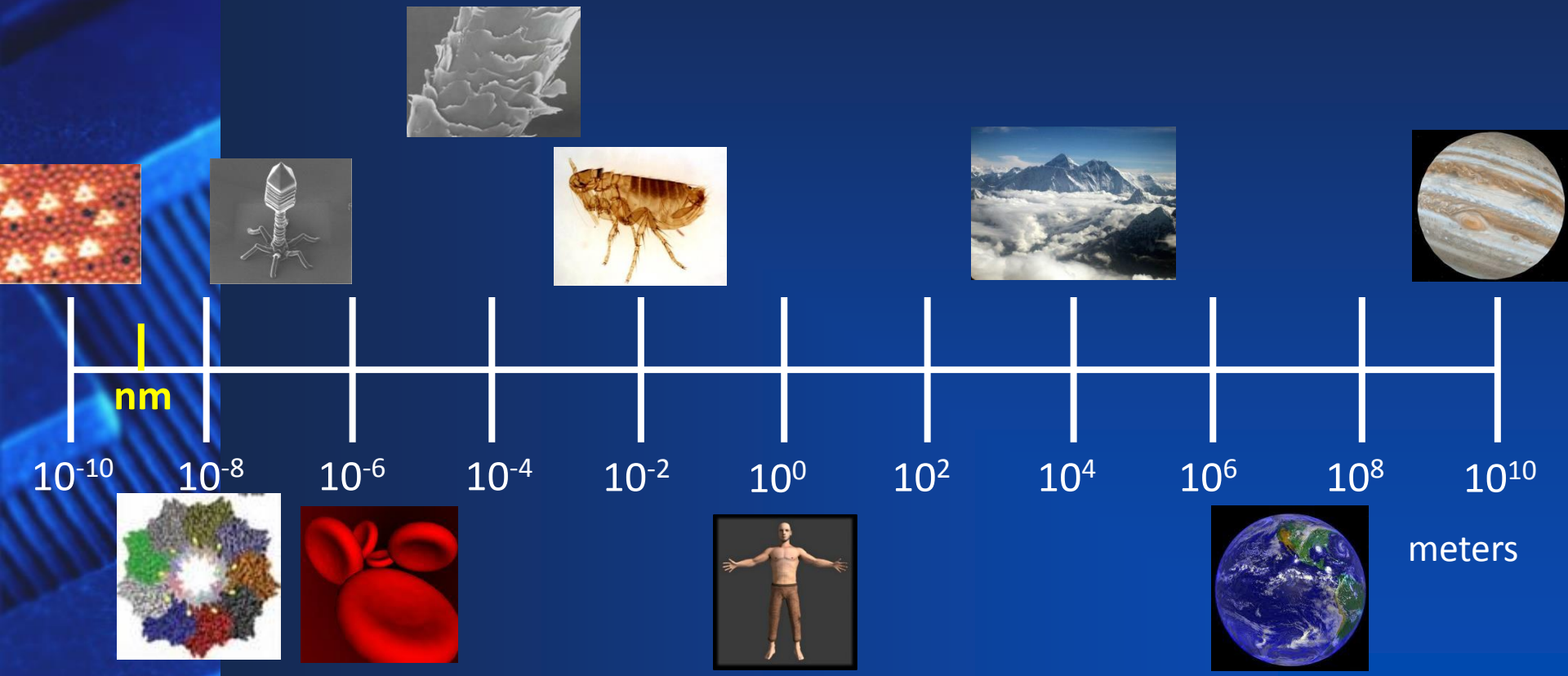
Who Are You?

A. K-12 Educator
B. Community College Educator
C. 4-year College/University Educator/Researcher
D. Industry scientist, engineer or technologist
E. Interested member of the community

Overview

- *What's the big deal about nanotechnology?*
- *Current device trends and challenges*
- *What can we learn from Nature?*
- *Emerging high-impact opportunities*
- *Inspiring the next generation of innovators*

What's the Big Deal About Nanotechnology: Orders of Magnitude in Length



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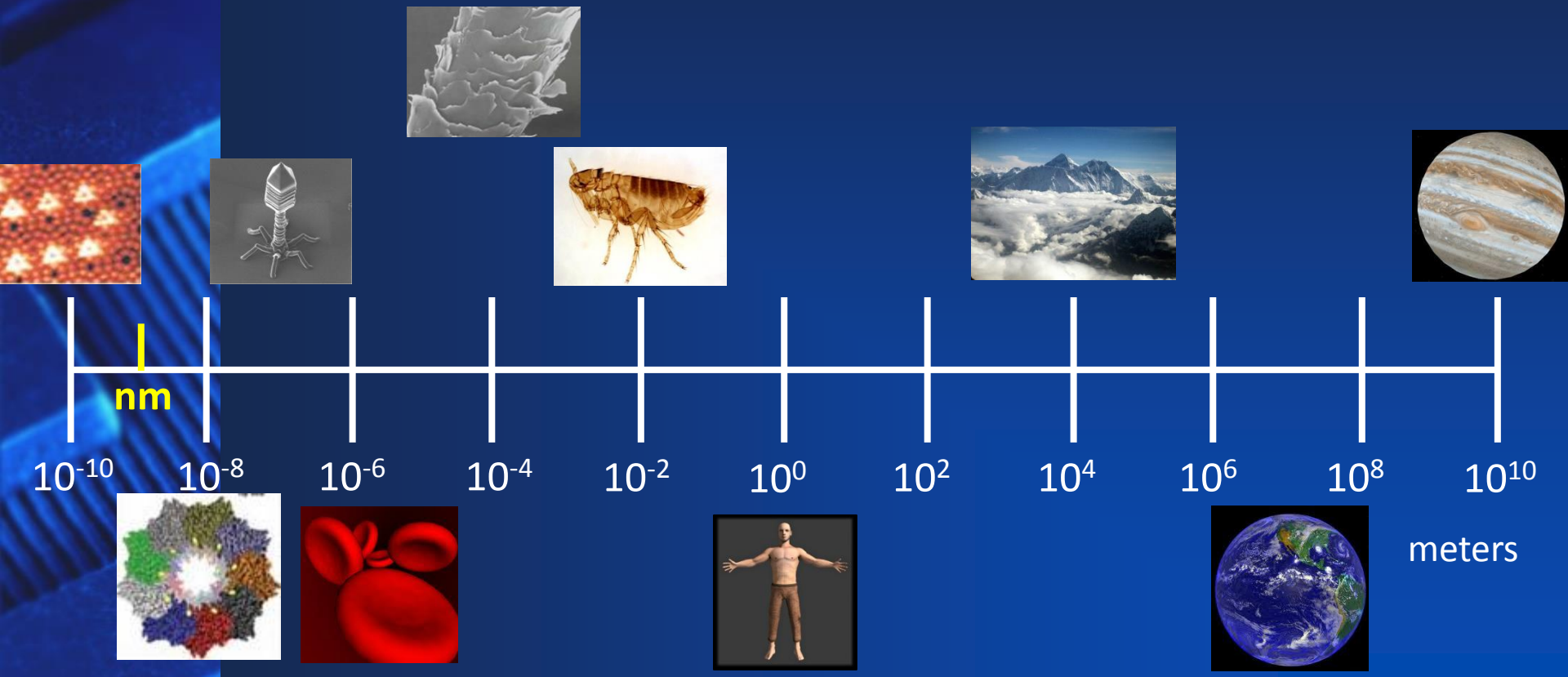

We are closer in size to Mount Everest than we are to a protein.

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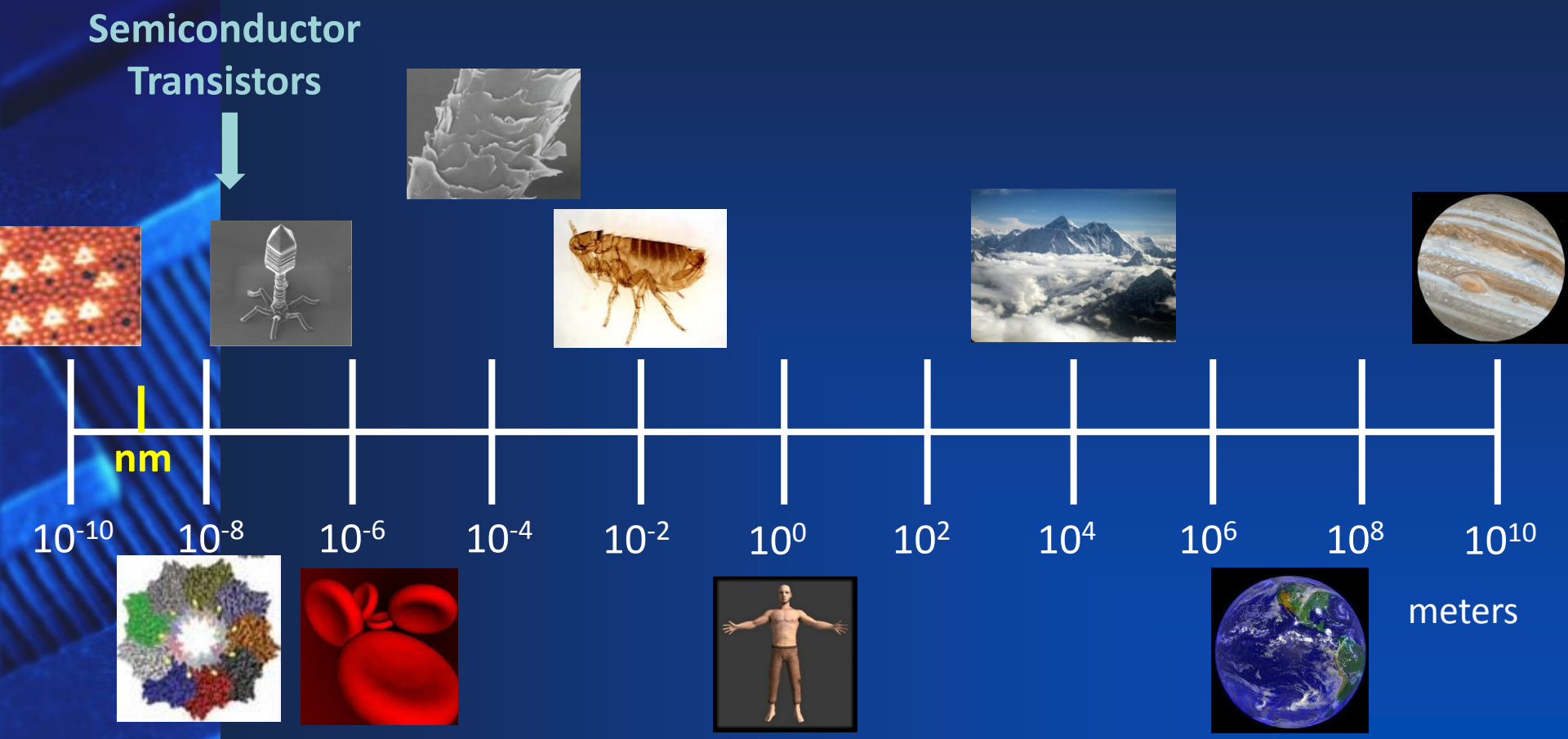

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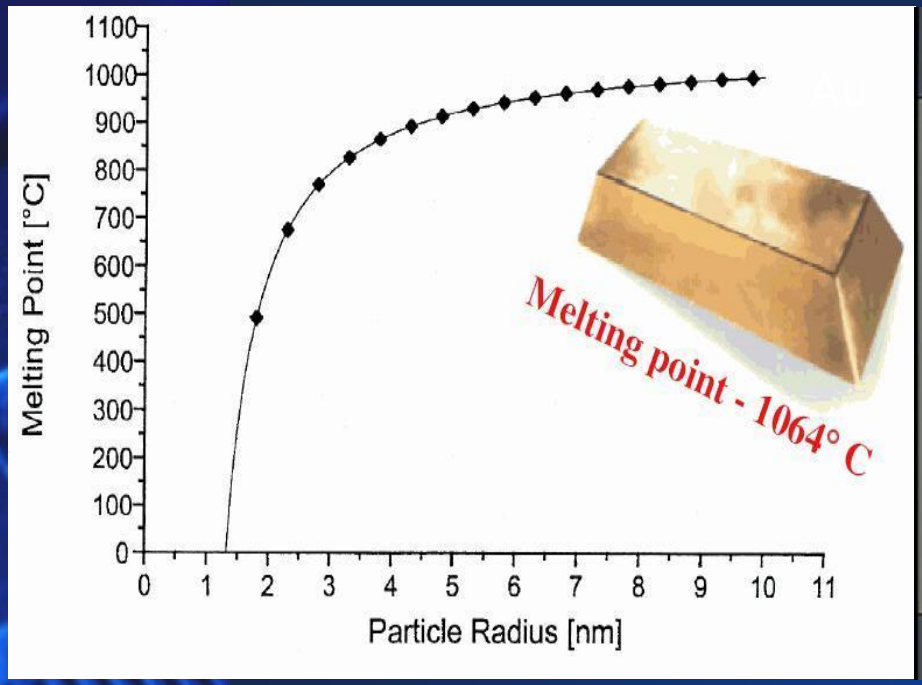
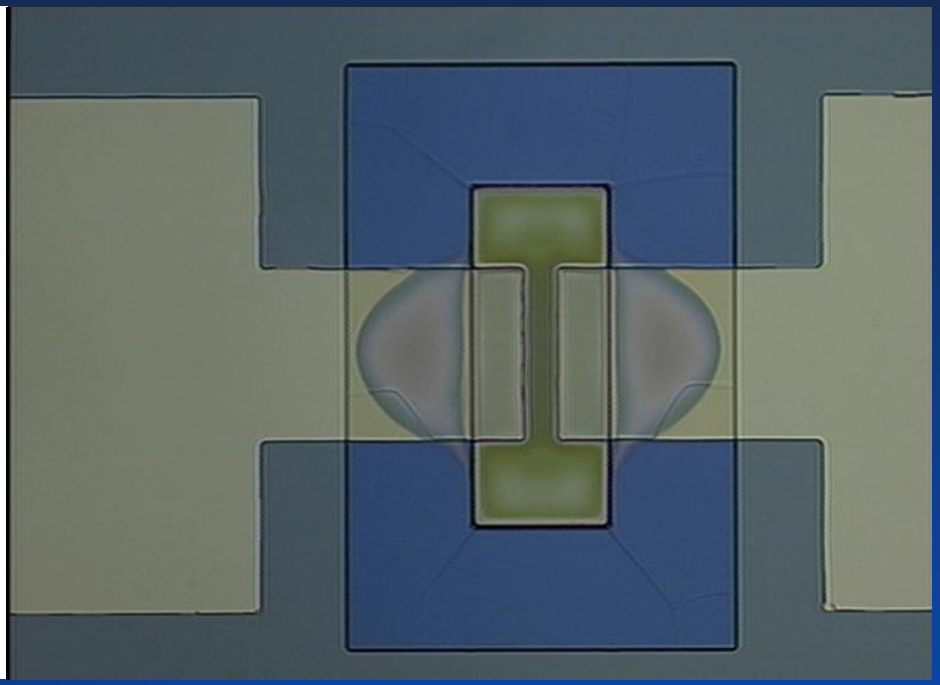
Benefit Unusual Properties Emerge at the Nanoscale:

Ex. Metal Nanoparticles as Pb Solder Replacements





K. J. Klabunde, "Nanoscale Materials in Chemistry", Wiley/Interscience publishers, New York (2001).
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Ex. Droplet on Demand patterning of organically coated **Cu** nanoparticles enables low temperature **[130 C]** sintering, enhanced conductivity, i.e. better than lead.

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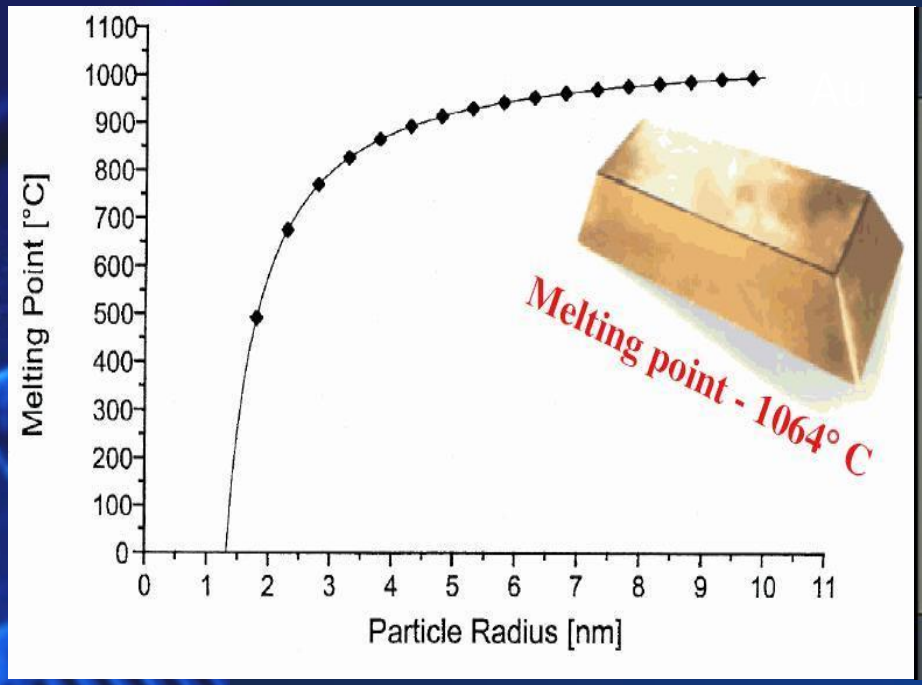

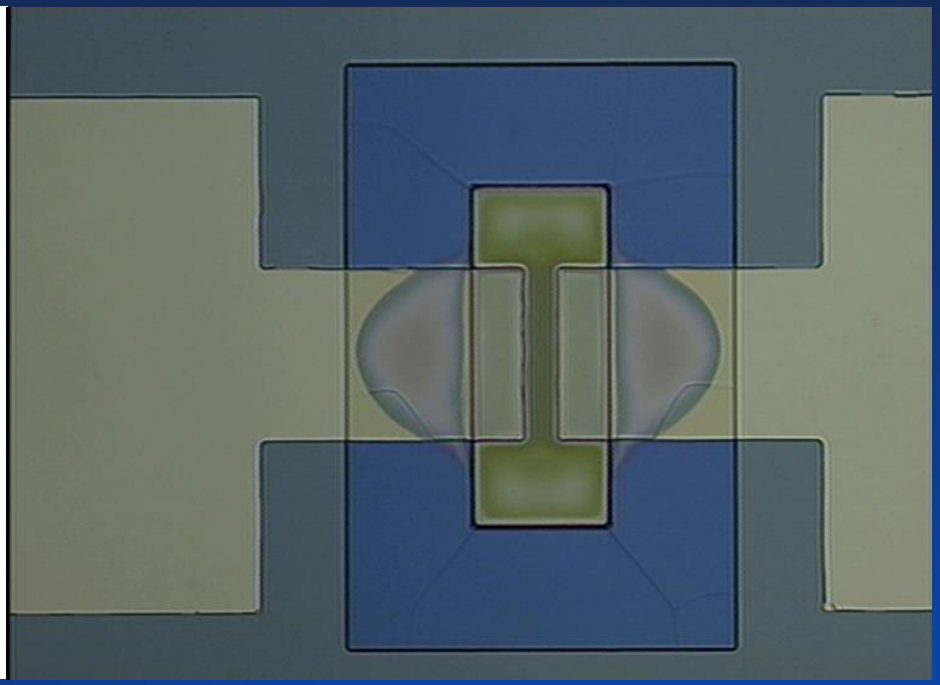

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What is the ESH impact of organically coated 3 nm Cu particles?

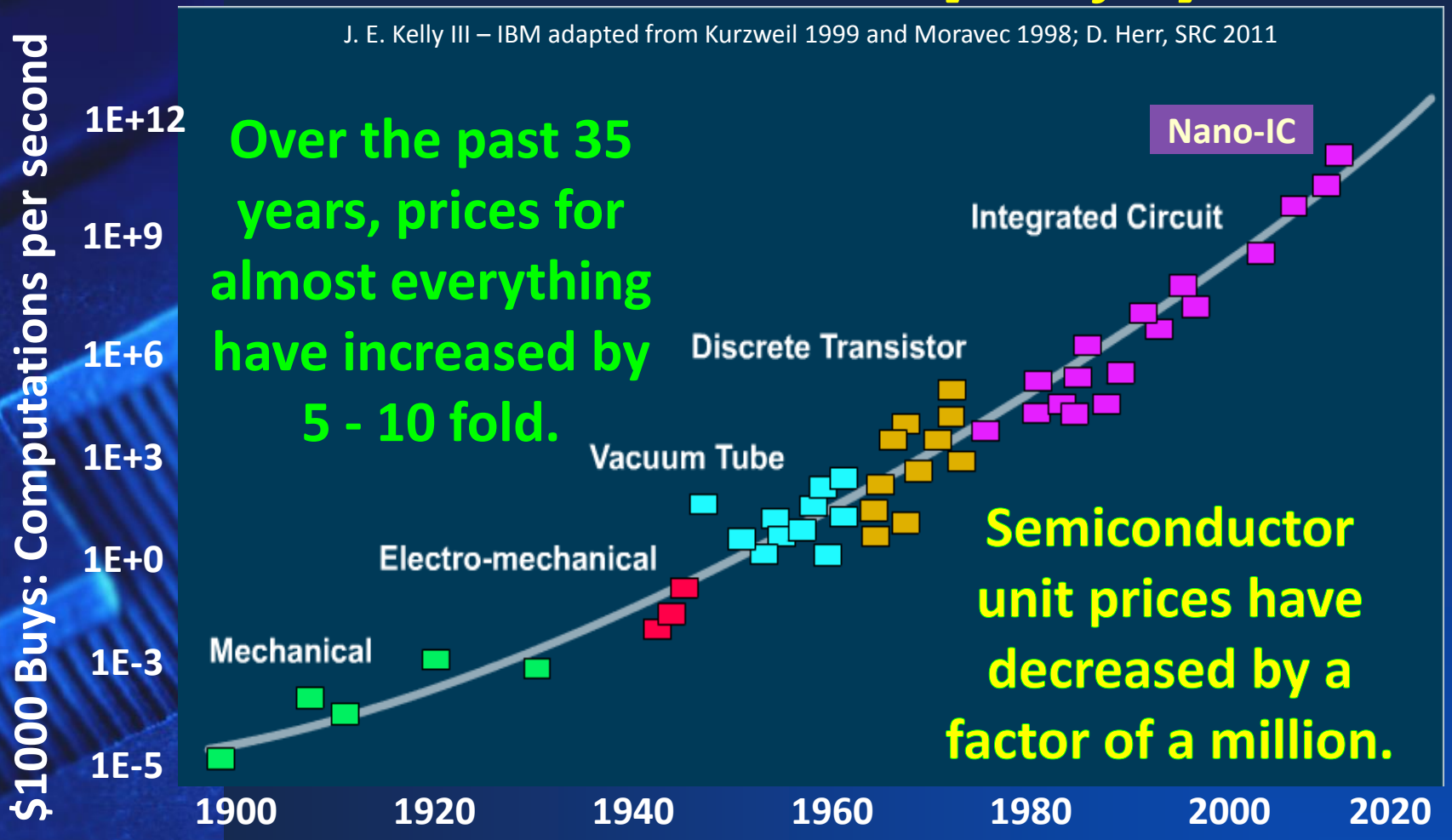
Scaling : The Benefits and the Costs -

Ex. Moore's 1st Law [Benefits]

Over the past 35 years, prices for almost everything have increased by 5 - 10 fold.

Scaling: The Benefits and the Costs -

Ex. Moore's 1st Law [Benefits]



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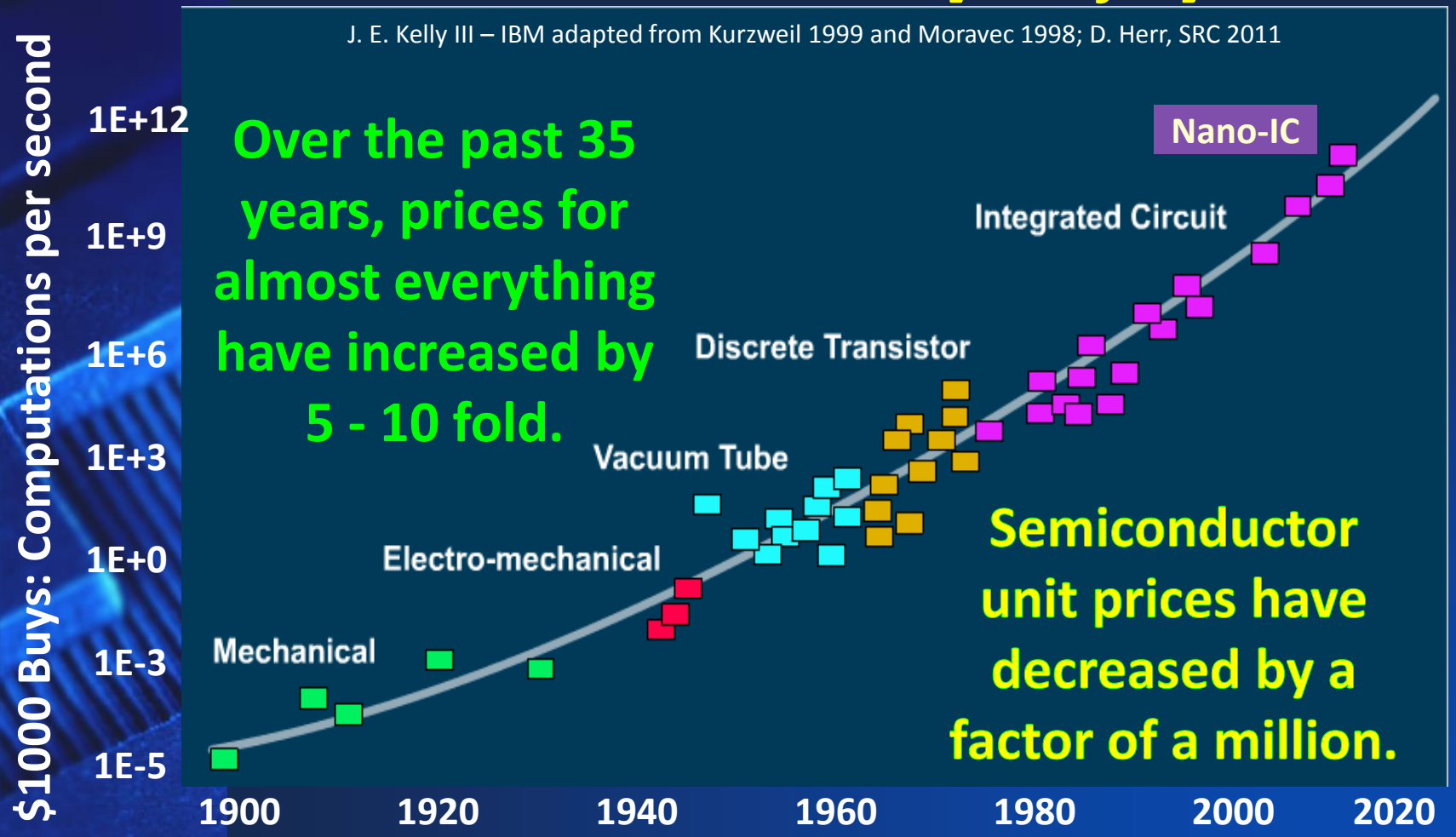
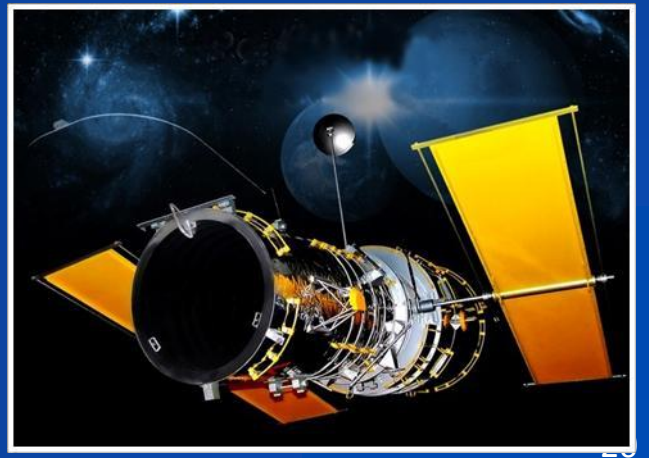


> 25,000 X cost reduction	126 IBM 3350's @ 635MB/Machine in 1976	iPOD (5G) 80GB in 2006	3TB Today **[80GB~$3.73]**
80 GB Storage	**~$9,000,000**	**$349**	**<$140**

The Impact of Scaled Nanotechnology

Scaling has allowed product and systems manufacturers to dramatically increase performance, while dropping costs in:

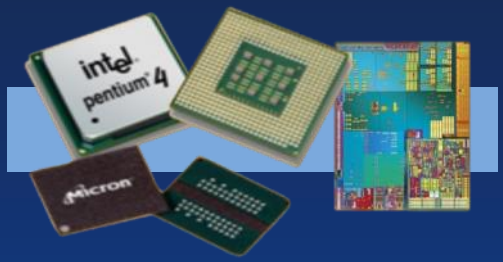
- Computers & information systems
- TVs, radios & audio systems
- Defense/Aerospace electronics



University research often fuels options, but rarely predicts, market success.

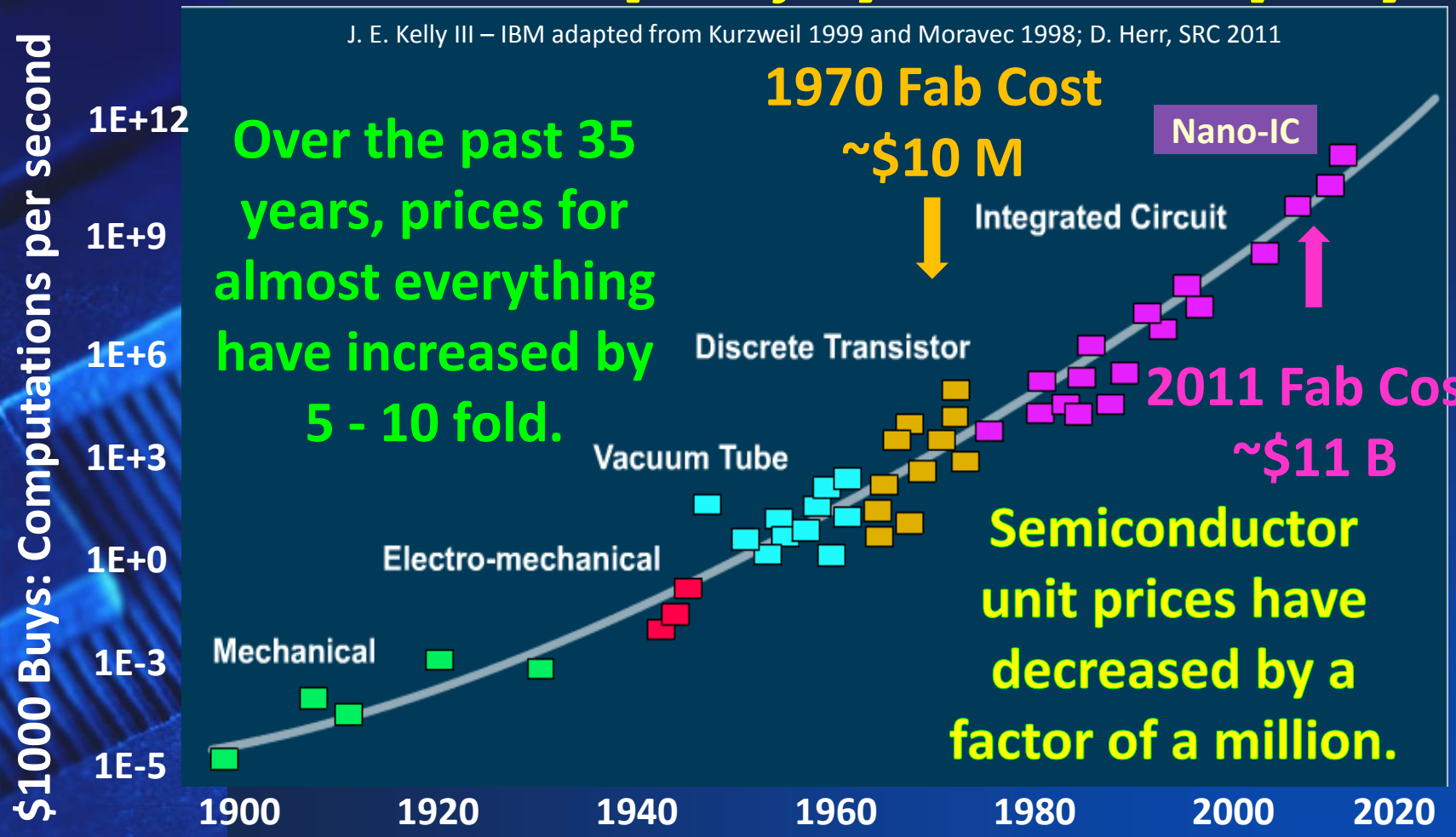
~ 20 Years Later

Precise Control of Atoms in Semiconductor Materials (Stanford)	→	Microchips with > 1 Billion Transistors
Single Crystals of SiC and GaN (NCSU)	→	Cell-phone Displays, Traffic Lights, LEDs
Laser Crystallization of Amorphous Silicon (Cornell, MIT, CalTech, Columbia)	→	Flat Panel Displays
Hot-electron Injection in Thin Films of Insulators (Berkeley)	→	Digital Cameras, Memory Sticks, iPod



Scaling : The Benefits and the Costs -

Ex. Moore's 1st [Benefits] and 2nd Laws [Cost]



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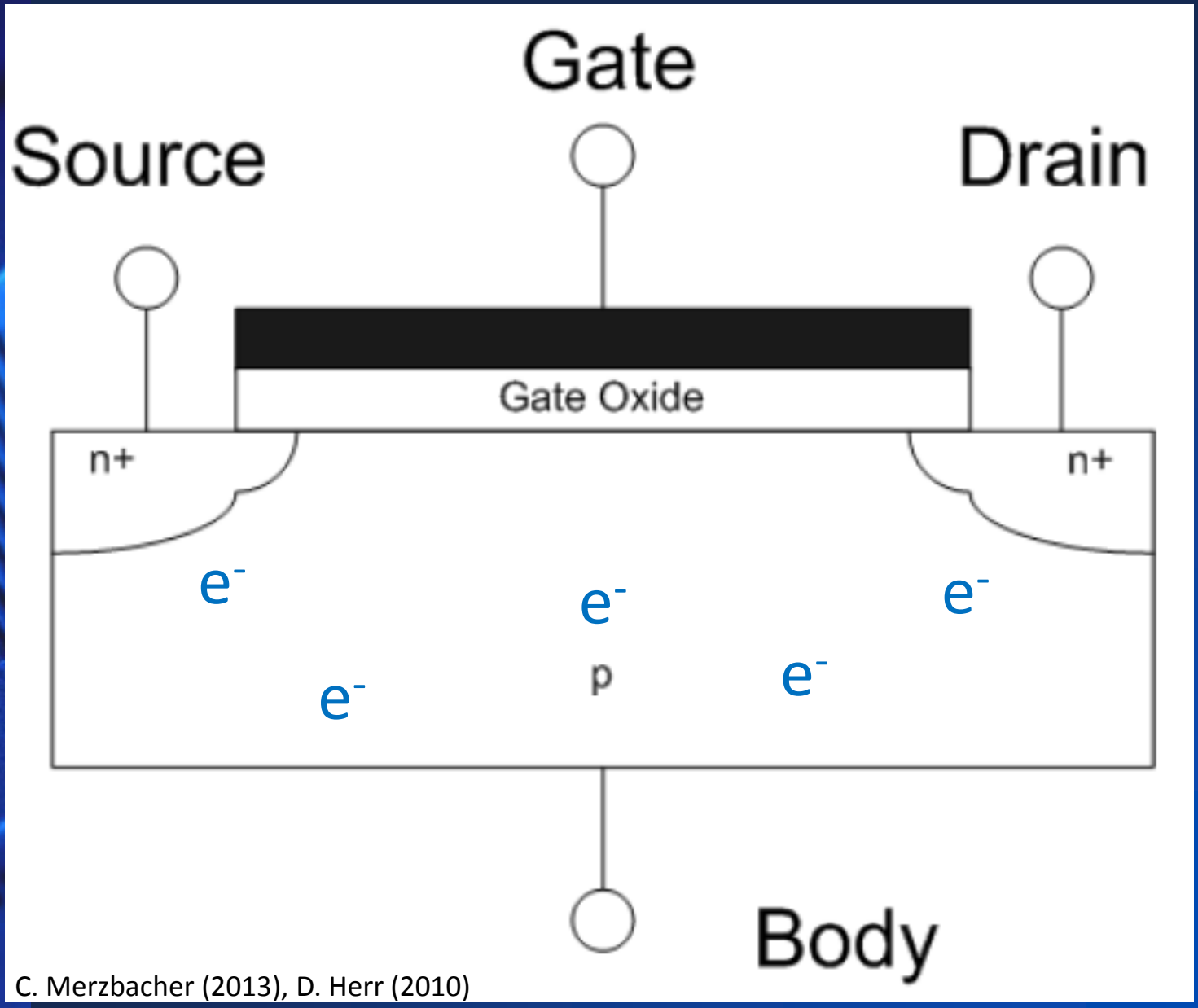
Basic Semiconductor Switch Mechanism



C. Merzbacher (2013), D. Herr (2010)

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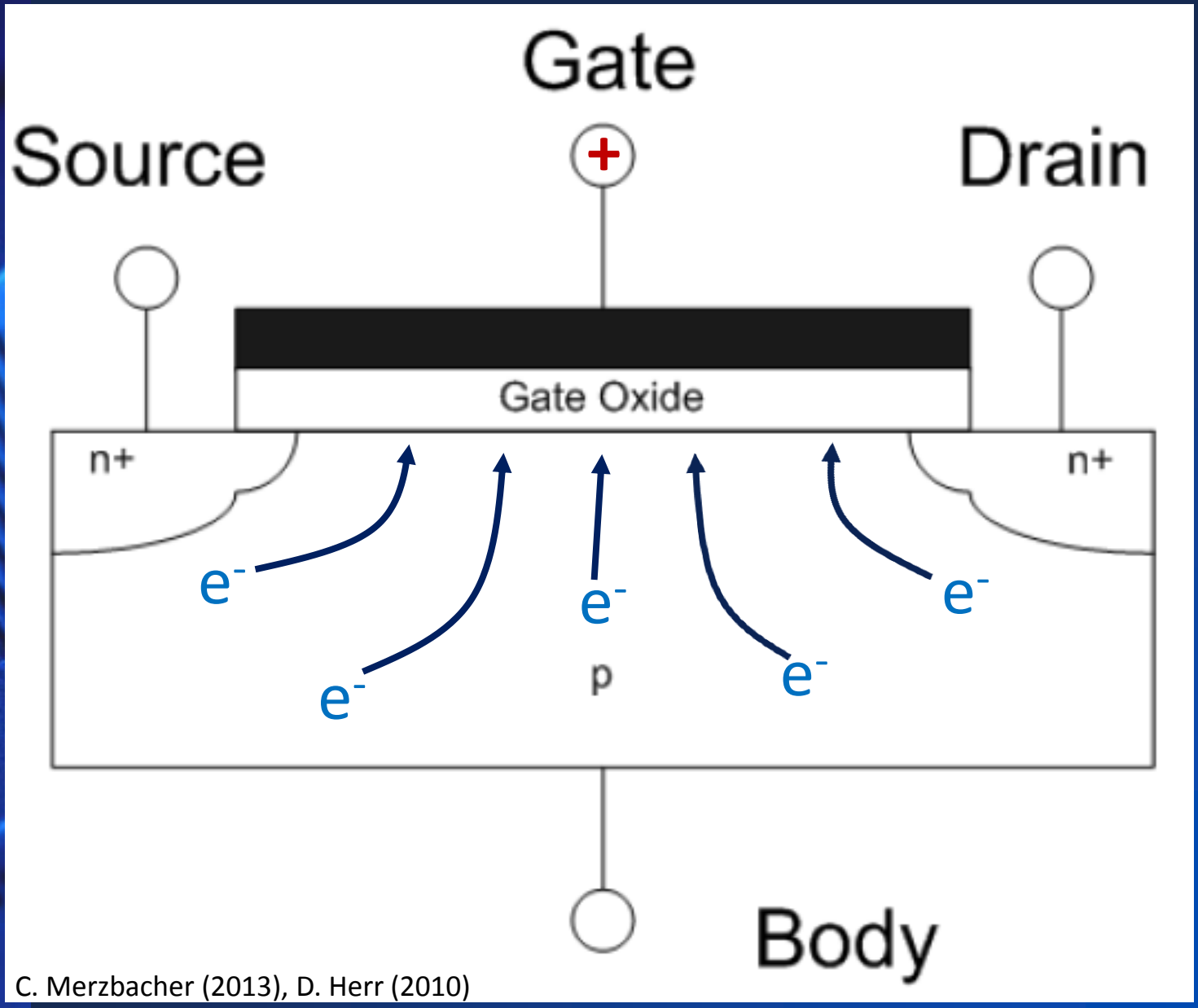

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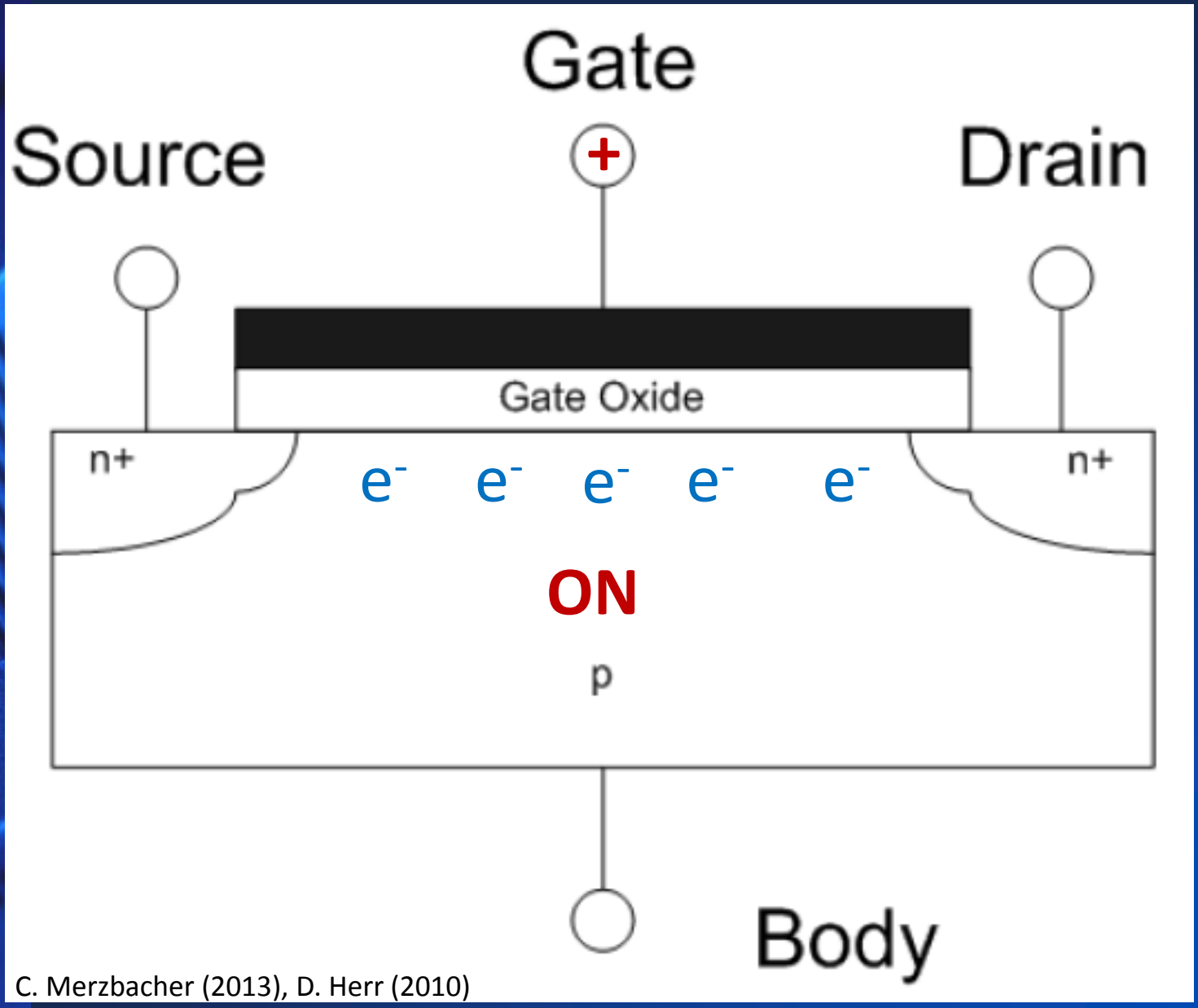

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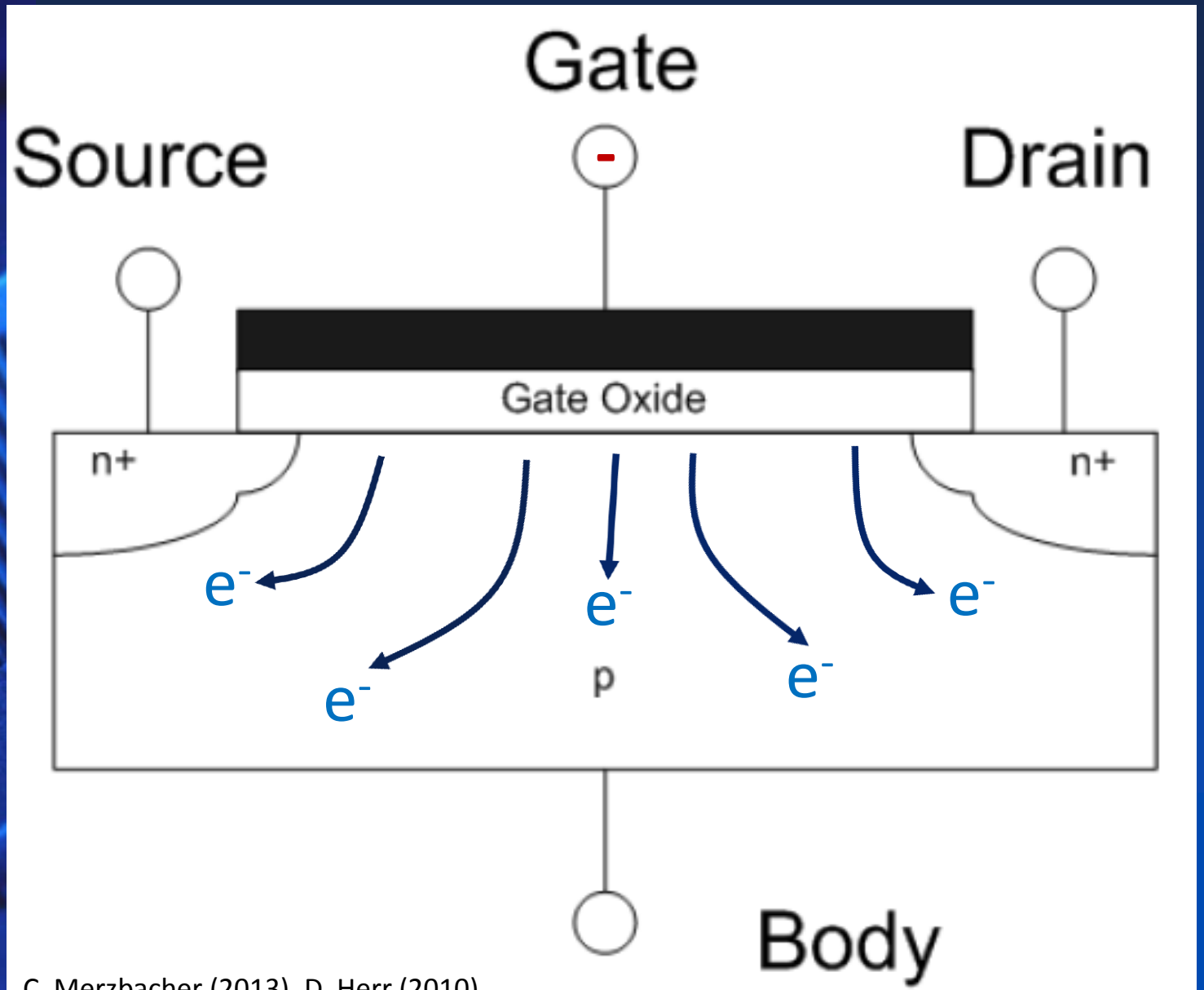

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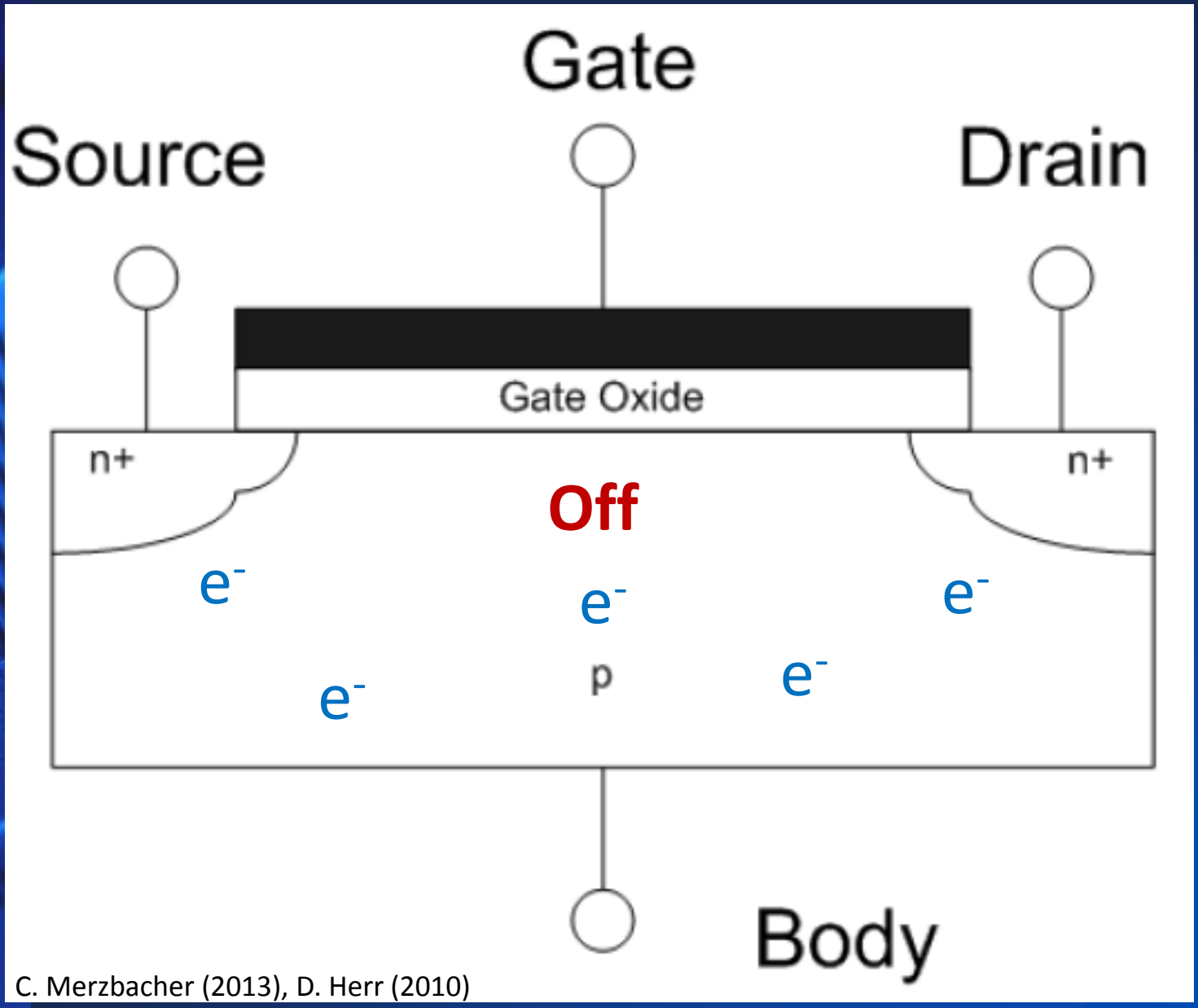

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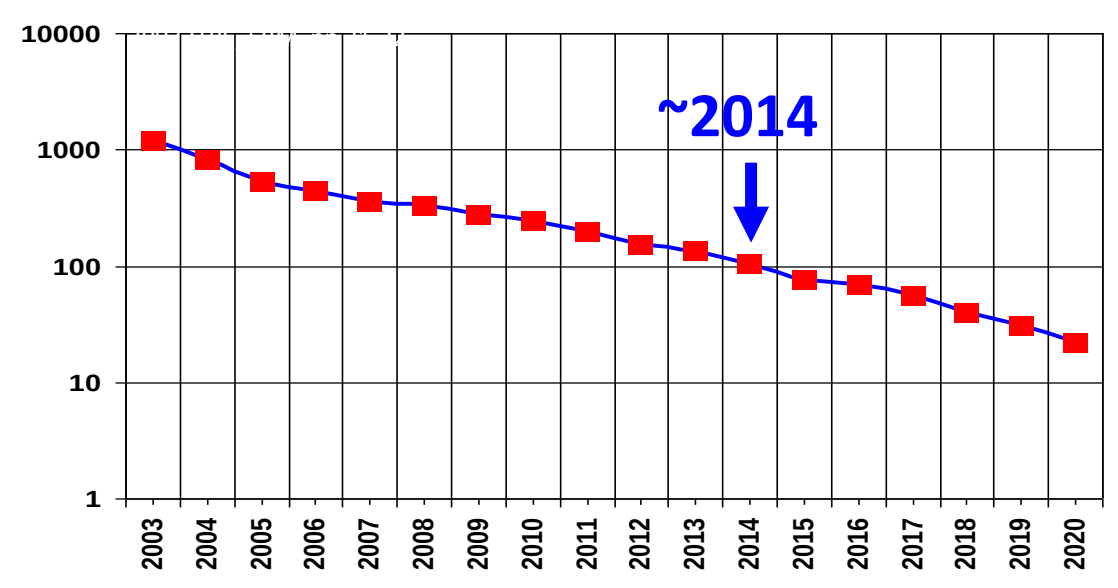
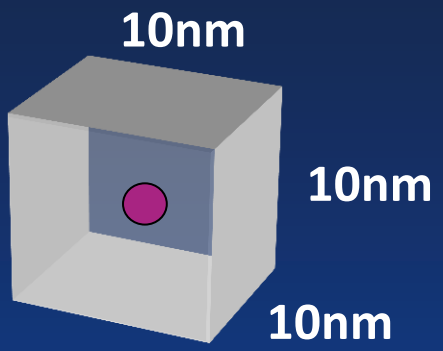
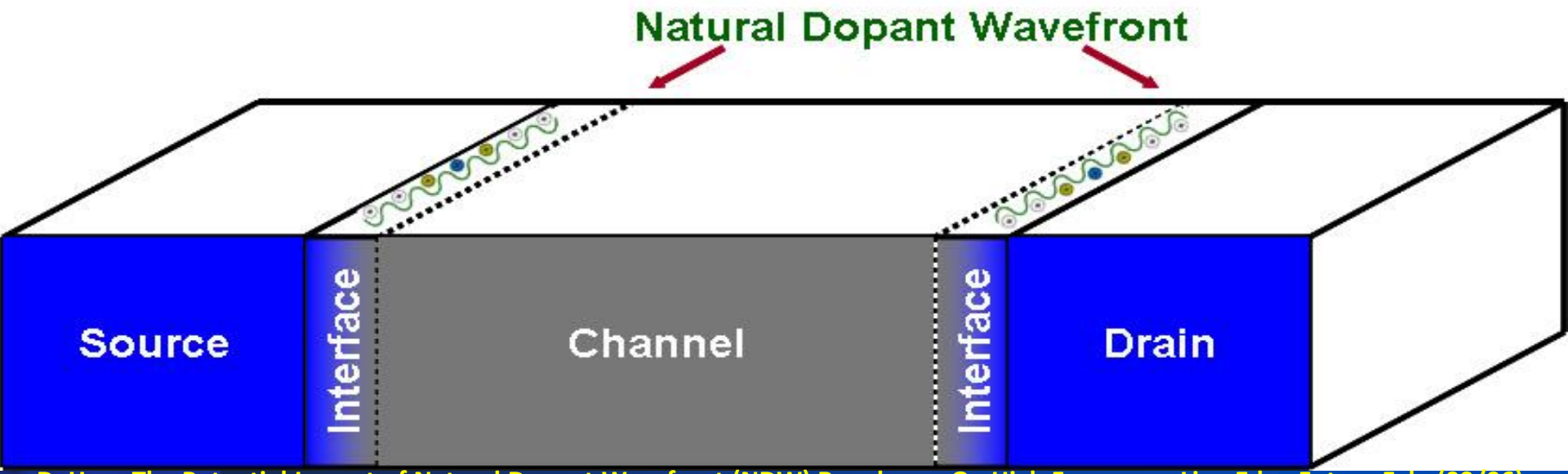
Fully Depleted Device Challenges:
Channel and interface variability



From D. Herr, with data from the 2005 ITRS, in 2007 ITRS, ERM, pp 21-22



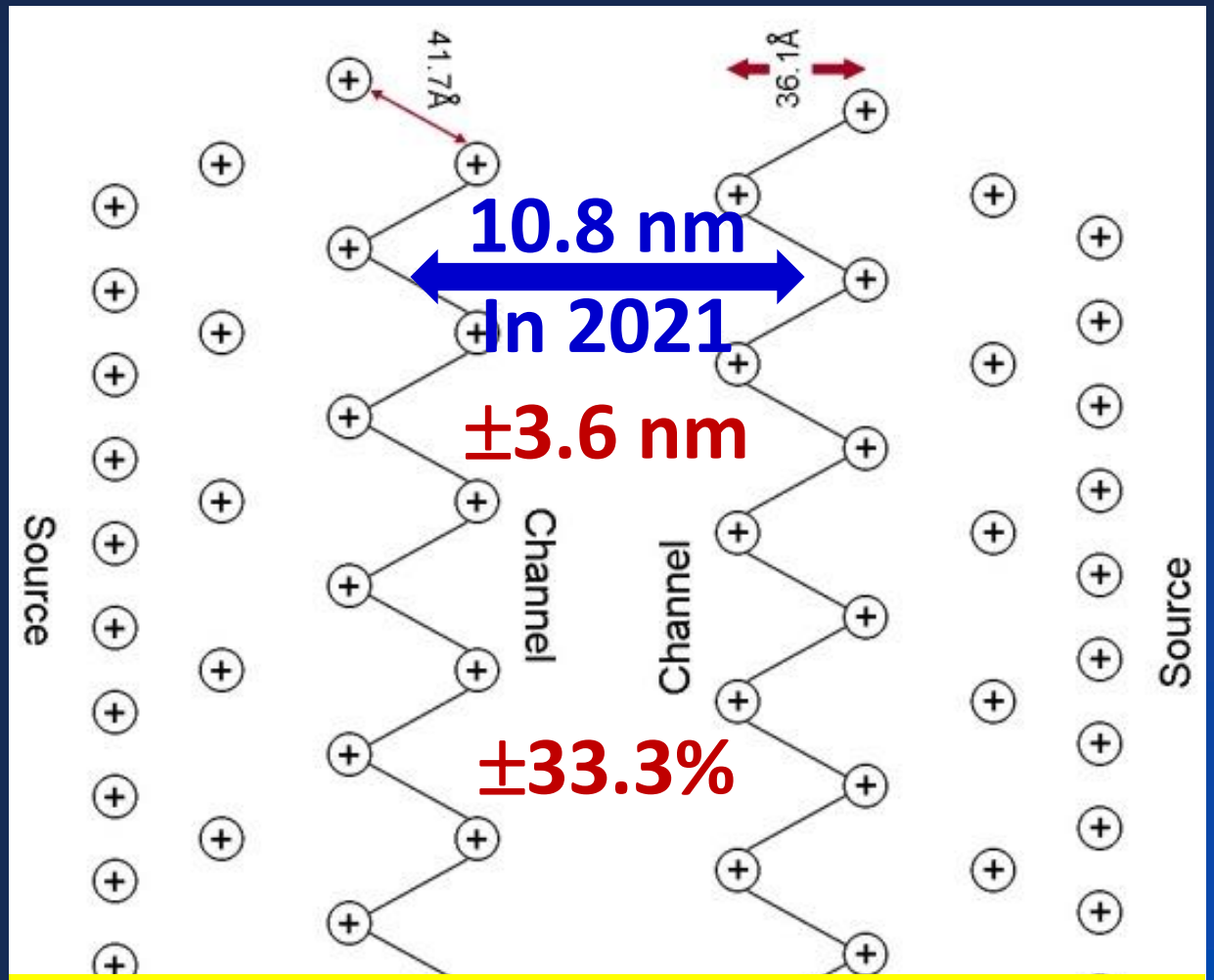
[Interface Dopant] ~ 1×10^{18} atoms/cm^3



D. Herr, The Potential Impact of Natural Dopant Wavefront (NDW) Roughness On High Frequency Line Edge Future Fab (09/06).

Top down fabrication wall:

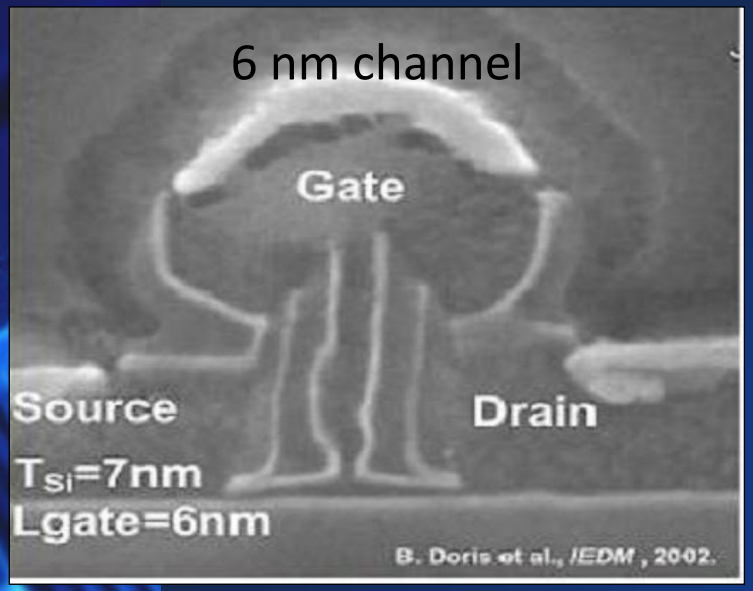
Ex. Channel interface variability



Fully Depleted Channel Length Variation ~ 66.6 % by 2021

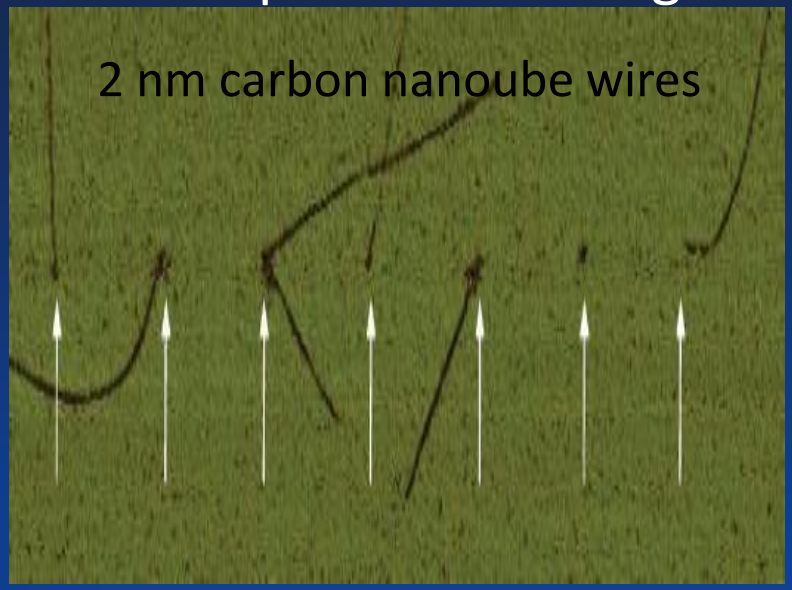
Ultimate Semiconductor Device Components?

CMOS switch



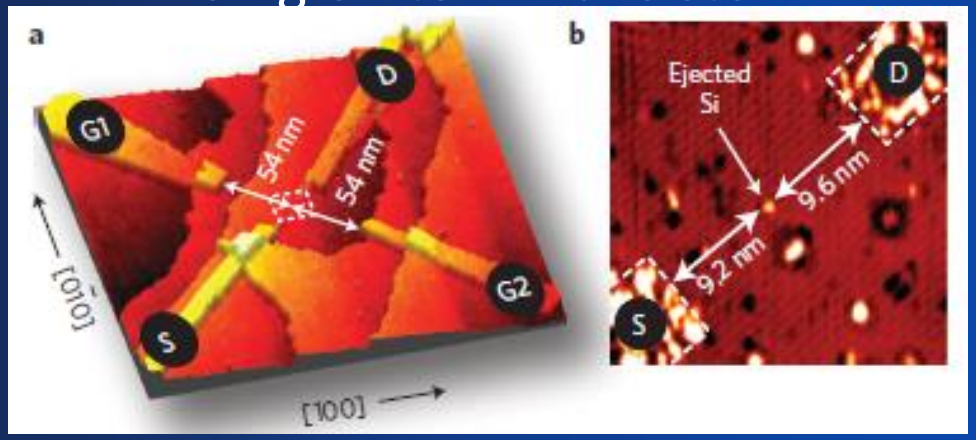
Doris et al. (2002)

Nanoscopic and atomic gold



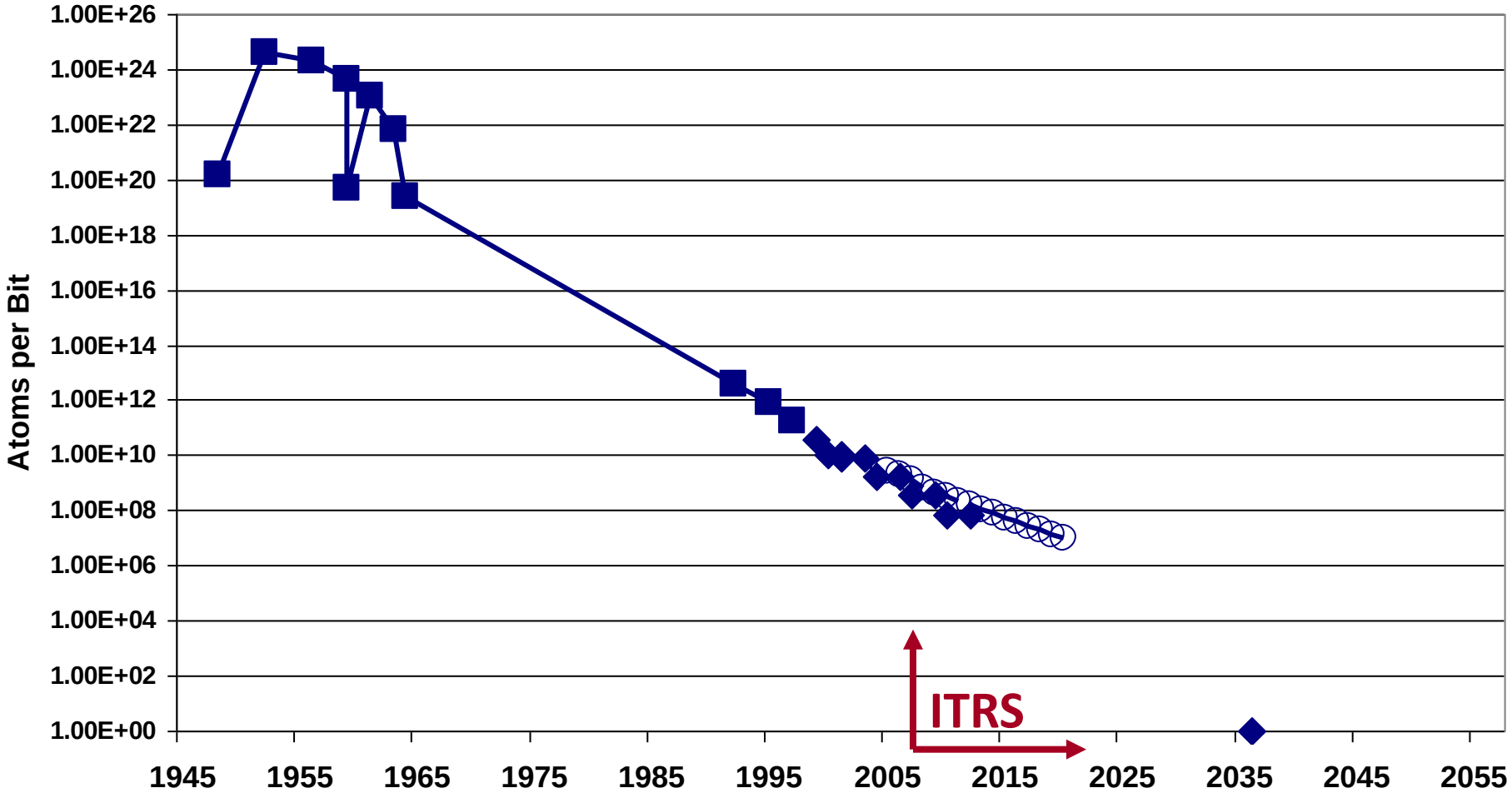
Dai et al.

Single Atom Transistor



M. Simmons et al. 2012

Towards Macromolecular Scale Devices:
The trend in atoms per bit and material complexity



ITRS ≡ International Technology Roadmap for Semiconductors

Revised 2006 from: D. Herr and V. Zhirnov, Computer, IEEE, pp. 34-43 (2001).

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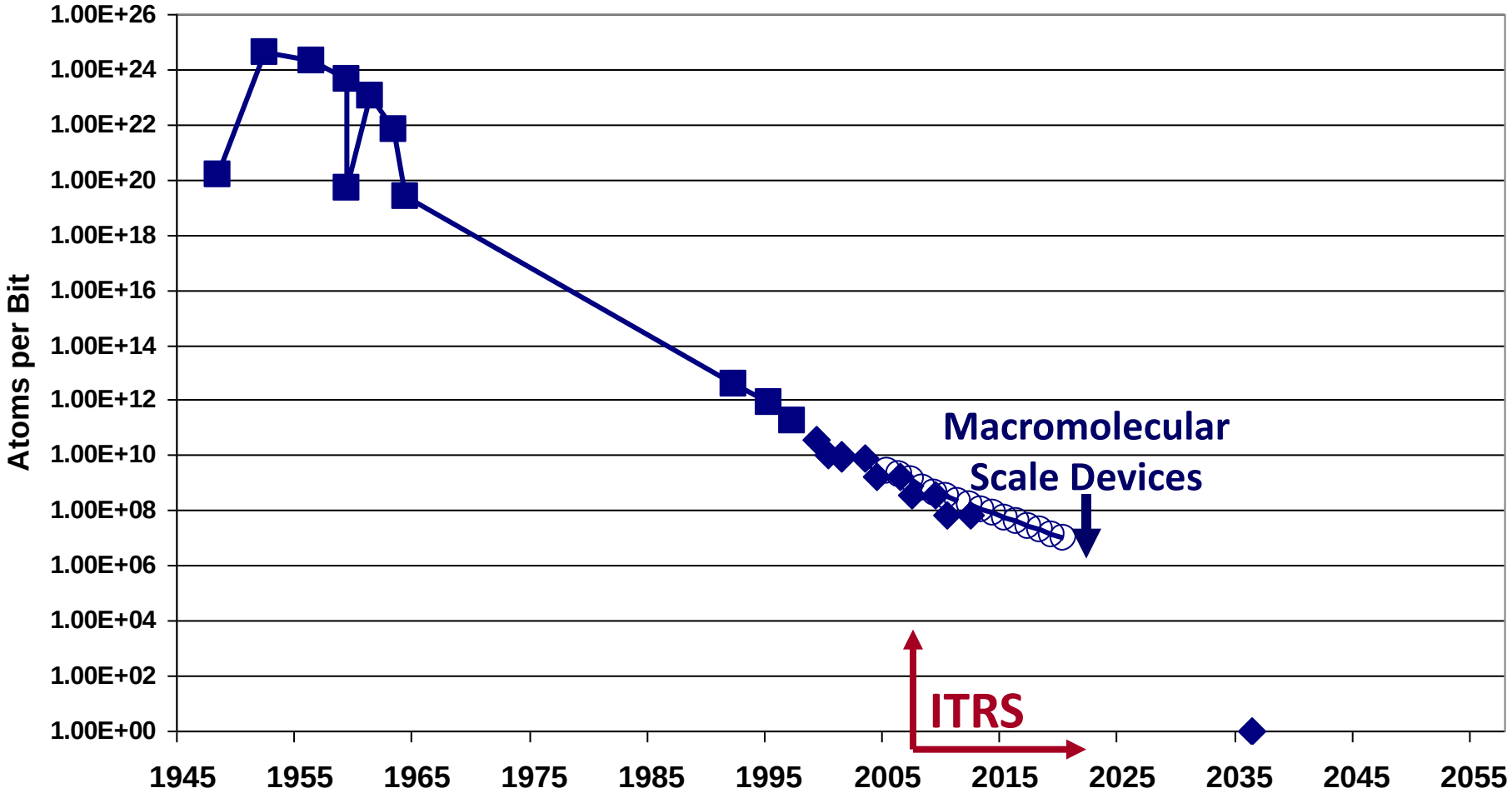

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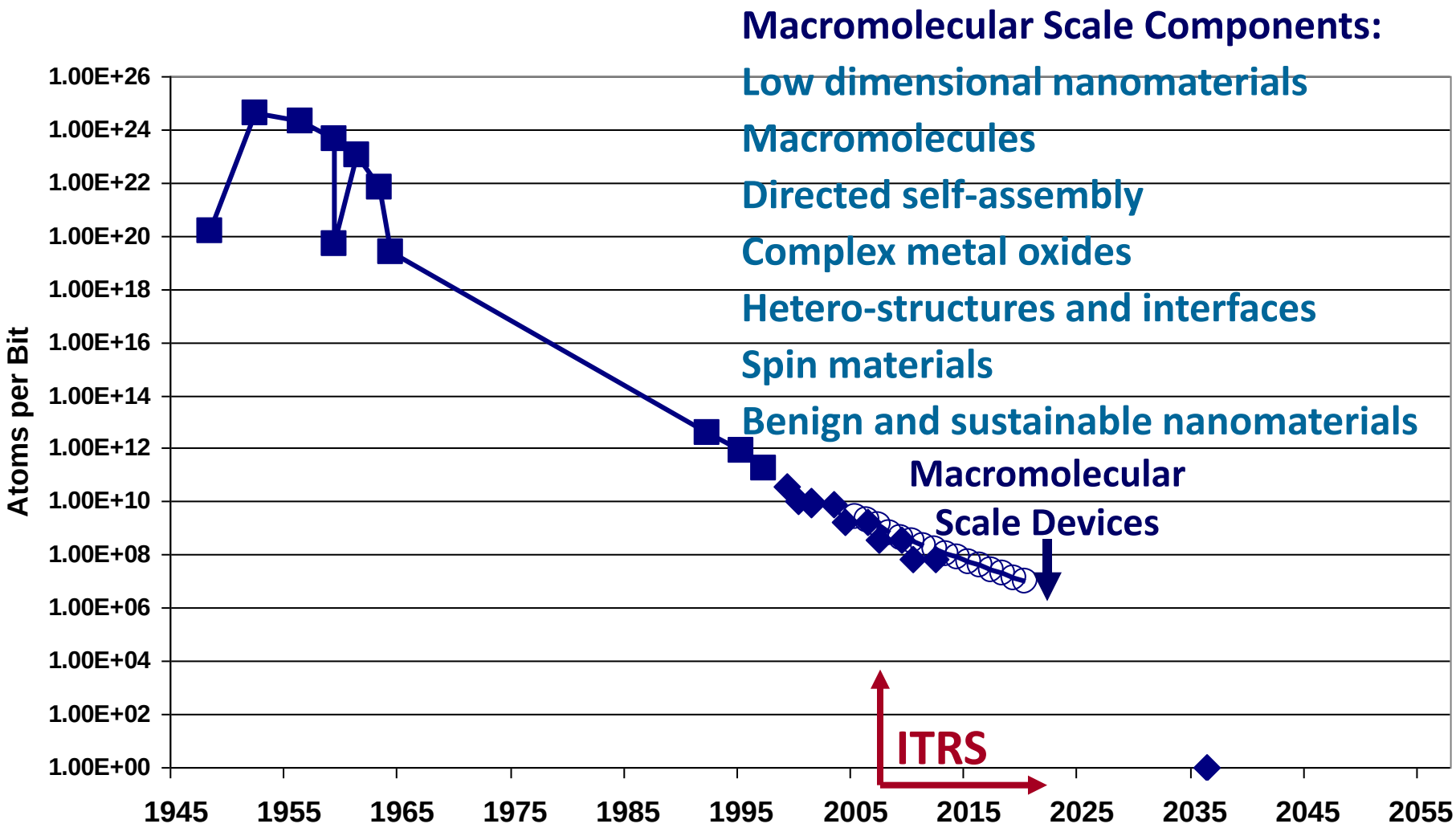

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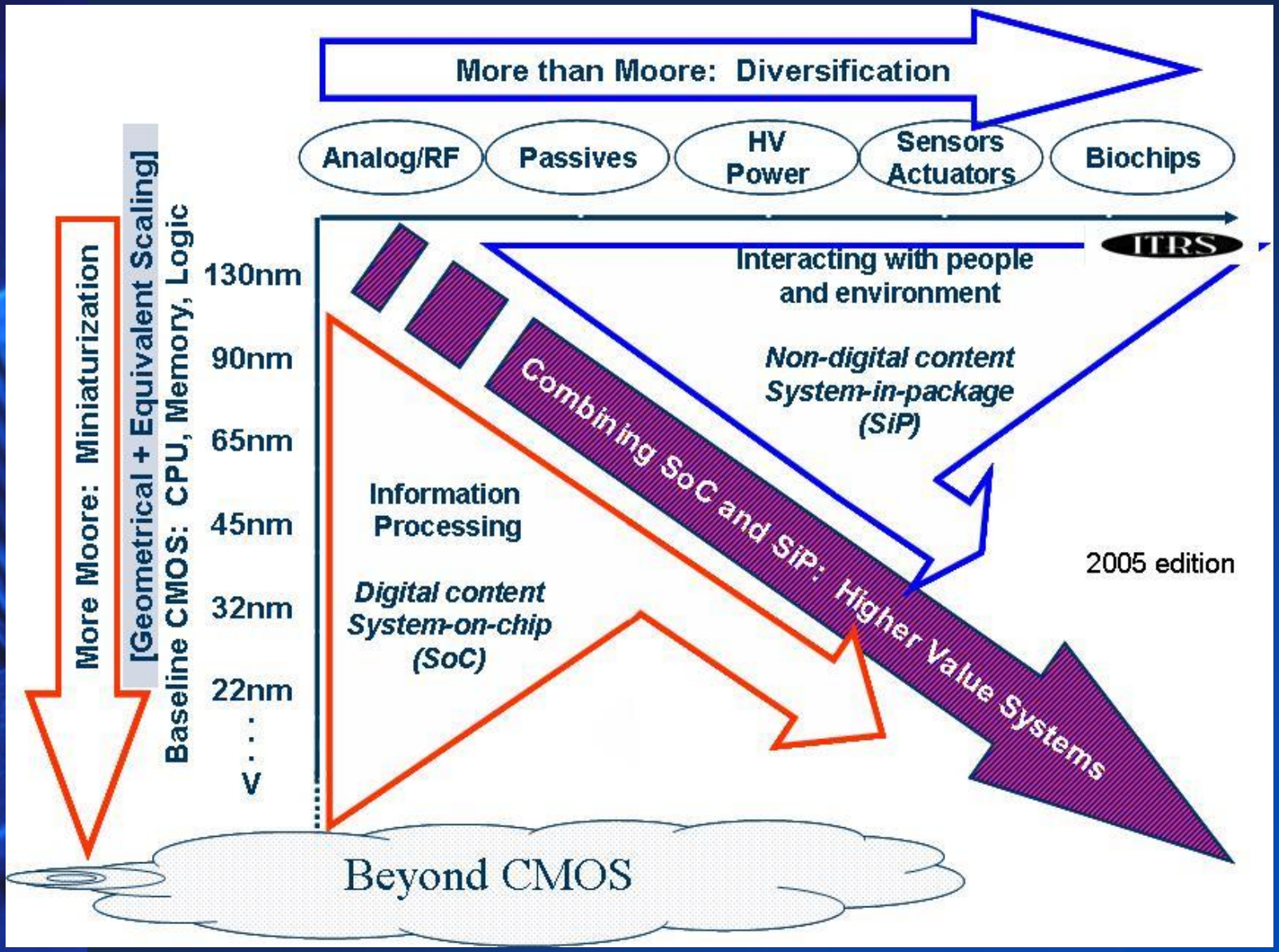
Beyond Scaling: Pursuing the race for added value for the end customer by combining on-chip ULSI and off-chip integration

Perhaps one technology cannot do it all alone.

There may be synergistic computational benefits from leveraging the collective action of several functional elements.

A key challenge is to develop nanoscale fabrication methods for enabling heterogeneous integration on CMOS**.**

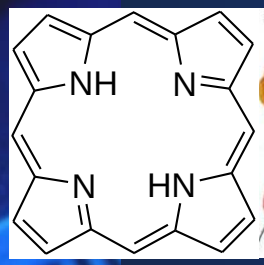
Beyond Scaling: Pursuing the race for added value for the end customer by combining on-chip ULSI and off-chip integration

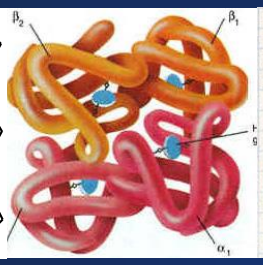


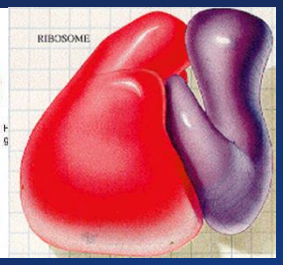
Invention and Innovation are Needed

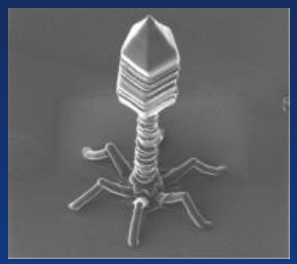
Beyond ~ 2020, a completely different approach to information processing will be needed.

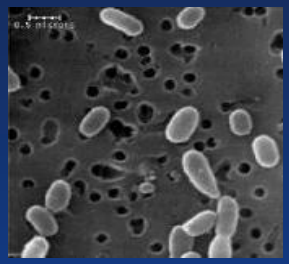
Residents of the Nanoworld Community

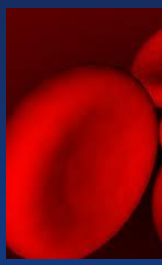












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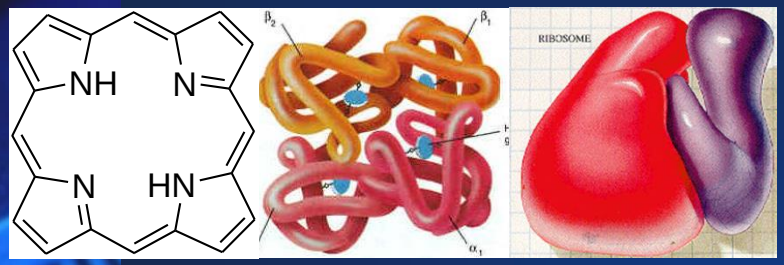
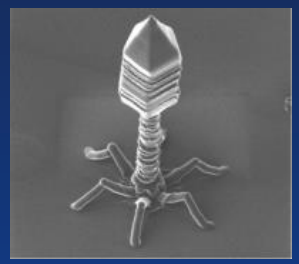
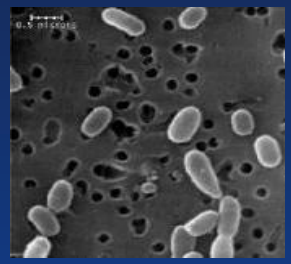
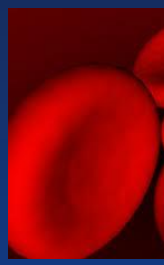
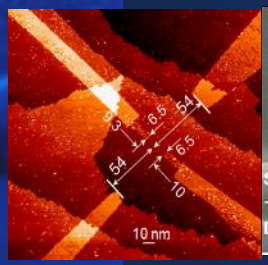
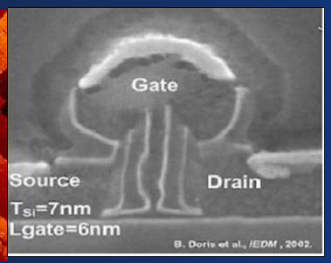


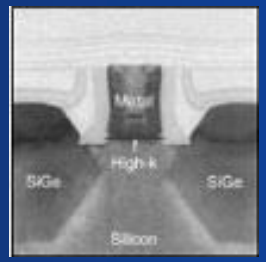


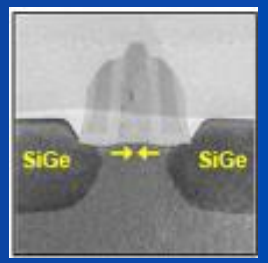




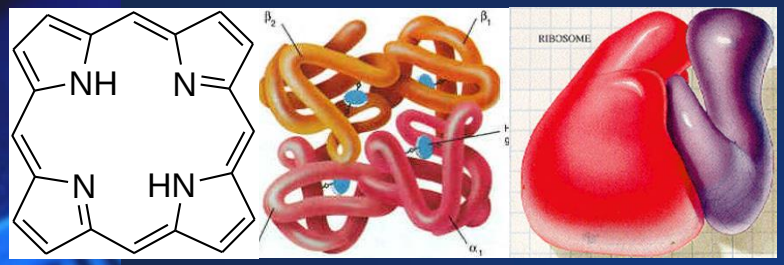


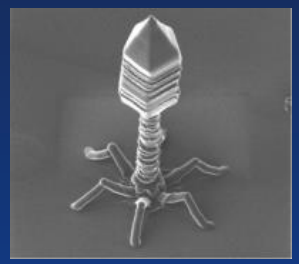


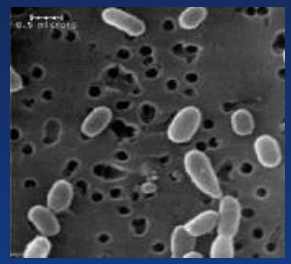


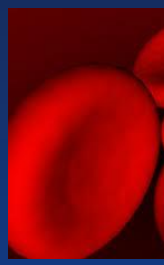


Residents of the Nanoworld Community

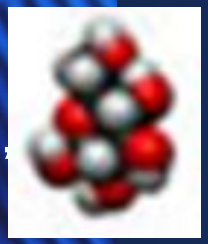


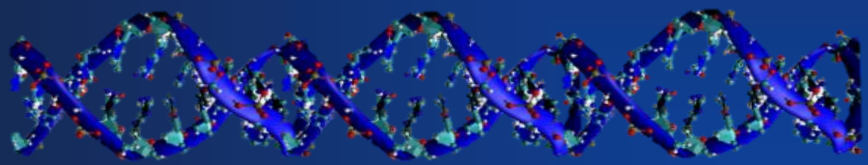


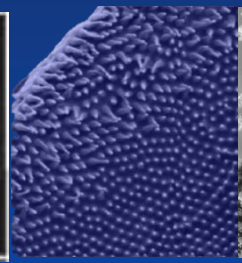


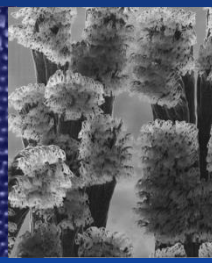


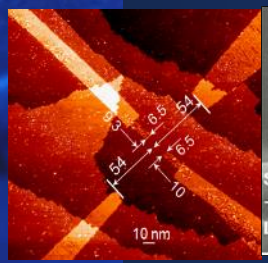
Atoms: C, O2, Au, Cu, Os

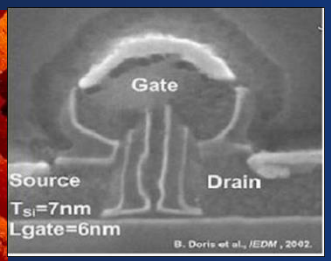


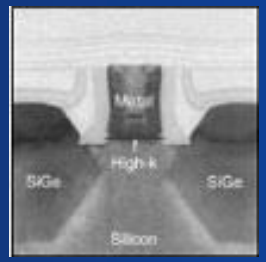


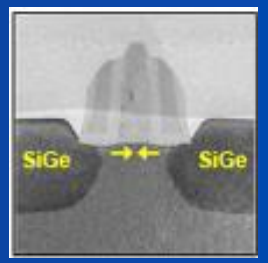












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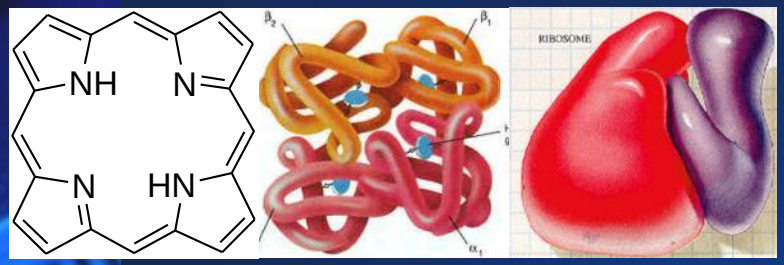

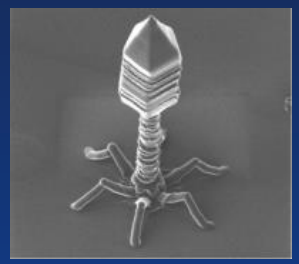

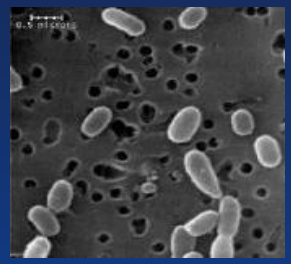

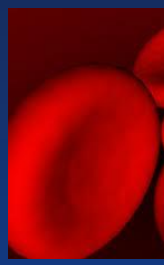

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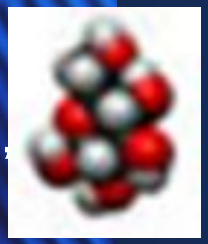
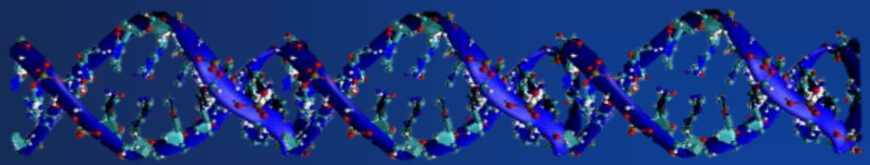
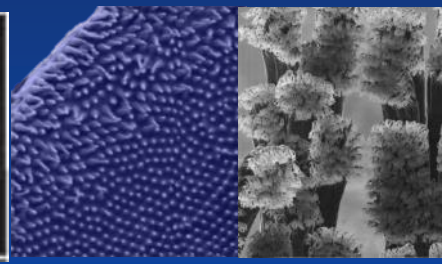
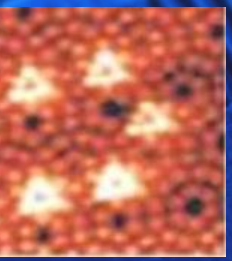
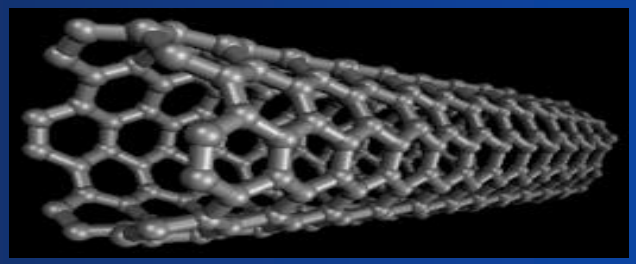
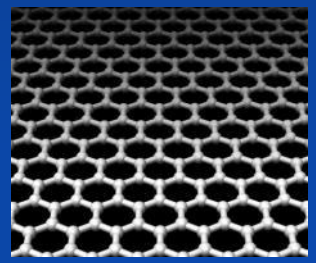


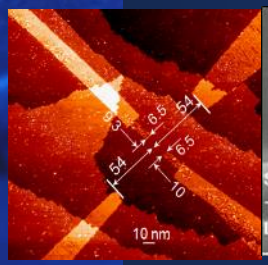


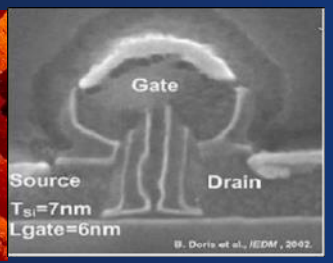


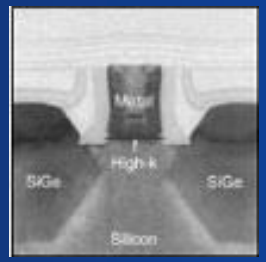


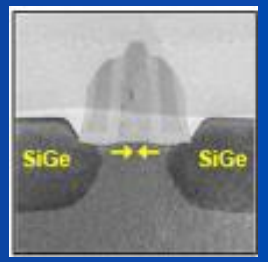












Invention and Innovation are Needed

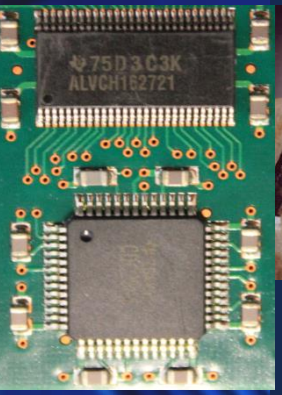
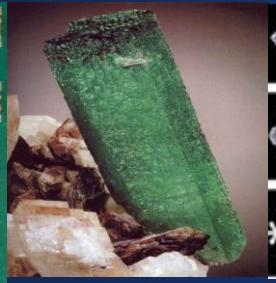
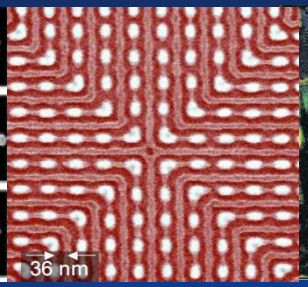
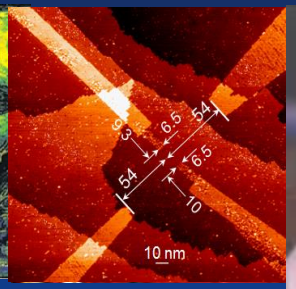
Beyond ~ 2020, a completely different approach to information processing will be needed.

We are likely to see a revolution in convergent technologies comparable to the monolithic integration of transistors more than fifty years ago.

Question Break

What can we learn from Nature?

We need new ways to make small stuff

Subtractive Patterning	Regular Self Assembly	Field Assisted Assembly	Directed Self Assembly	Serial Patterning	Deterministic Assembly	Programmed Self Assembly
						

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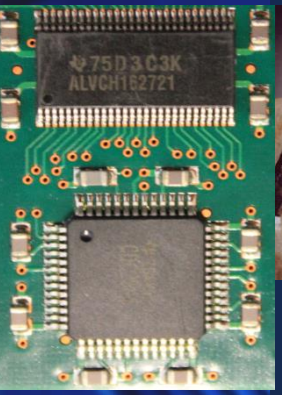			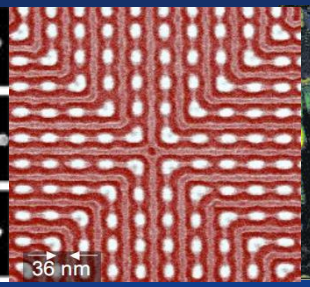		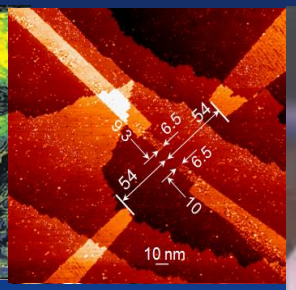	

Nature offers a hierarchy of fabrication options.

What can we learn from Nature?

We need new ways to make small stuff

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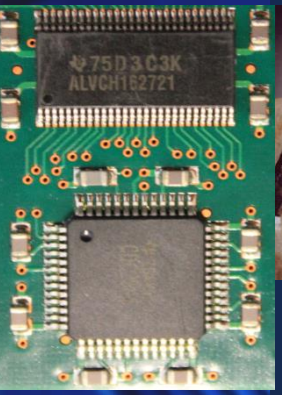			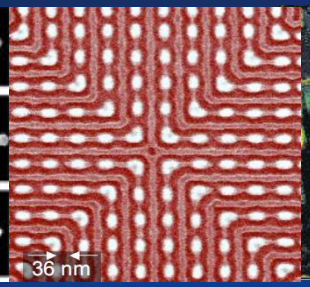		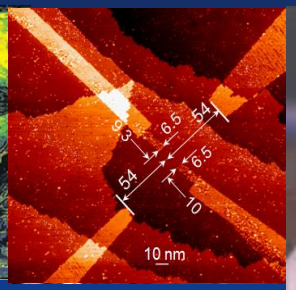	

Increasing material information content

Nature offers a hierarchy of fabrication options.

What can we learn from Nature?

We need new ways to make small stuff

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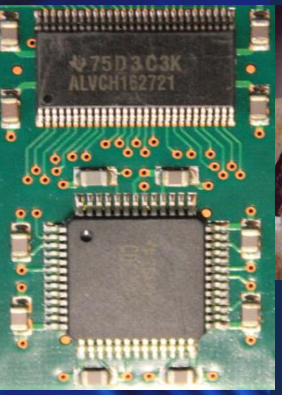
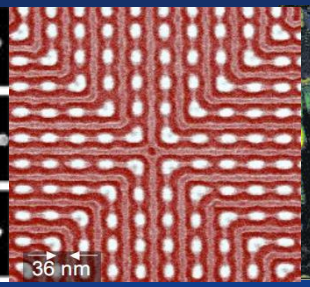
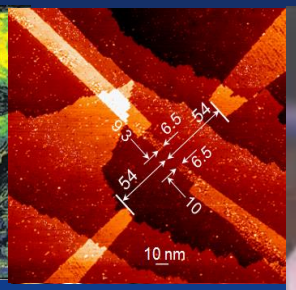






Semiconductor Manufacturing

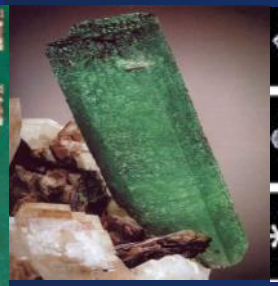
Increasing material information content

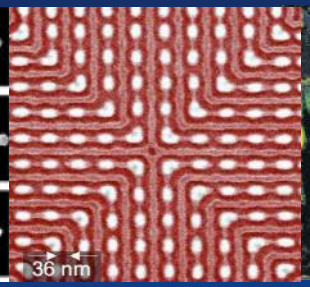
Nature offers a hierarchy of fabrication options.

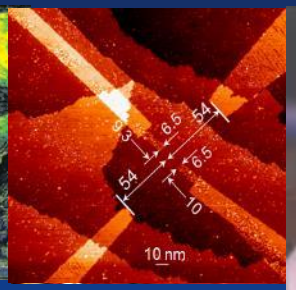
What can we learn from Nature?

We need new ways to make small stuff

Subtractive Patterning | Regular Self Assembly | Field Assisted Assembly | Directed Self Assembly | Serial Patterning | Deterministic Assembly | Programmed Self Assembly







Semiconductor Manufacturing

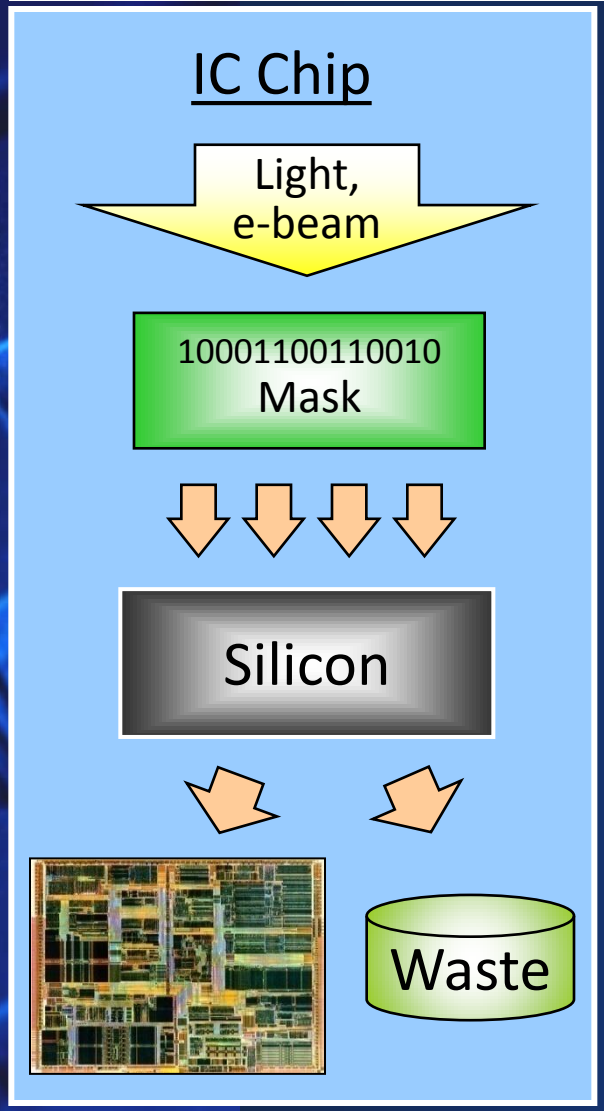
Increasing material information content

Living Systems

Nature offers a hierarchy of fabrication options.

Subtractive Versus Assisted/Additive Assembly

Complex Matter = Energy + Information + Material



ENERGY

INFORMATION

MATERIAL

Subtractive Versus Assisted/Additive Assembly

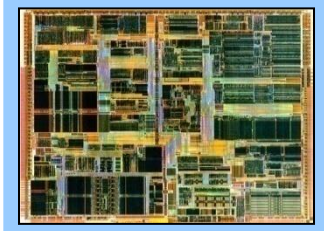
Complex Matter = Energy + Information + Material

IC Chip

Light, e-beam

10001100110010 Mask

Silicon



Waste

ENERGY

INFORMATION

MATERIAL

Living Organism

Food Oxygen

DNA

132442424241
423234132423
234122431142
351423232323
1423212

Amino Acids, Proteins

Waste

Subtractive Versus Assisted/Additive Assembly

Complex Matter = Energy + Information + Material

IC Chip

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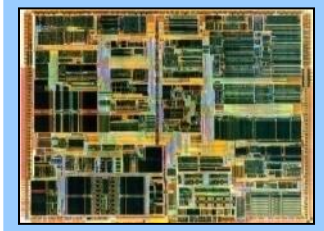
10001100110010 Mask

Silicon

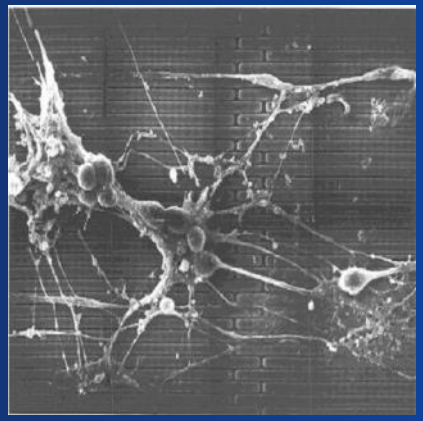


Waste

ENERGY

INFORMATION

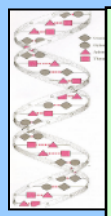
MATERIAL



Living Organism

Food Oxygen

DNA



132442424241
423234132423
234122431142
351423232323
1423212

Amino Acids, Proteins

Waste

Courtesy of Will Taylor, The JSNN

Courtesy of Alisa and Matt Herr

Top-down vs bottoms-up fabrication:

Ex. Comparing computer chips and babies

Complex Matter = Energy + Information + Material

	Fab output	Baby growth	Nature's advantage
Rate	**< 1.3E+9 bits/s**	**> 1.5E+17 amino acid/s**	**>1E+8**

D. Herr (2000/Revised 2010)

Top-down vs bottoms-up fabrication:

Ex. Comparing computer chips and babies

Complex Matter = Energy + Information + Material

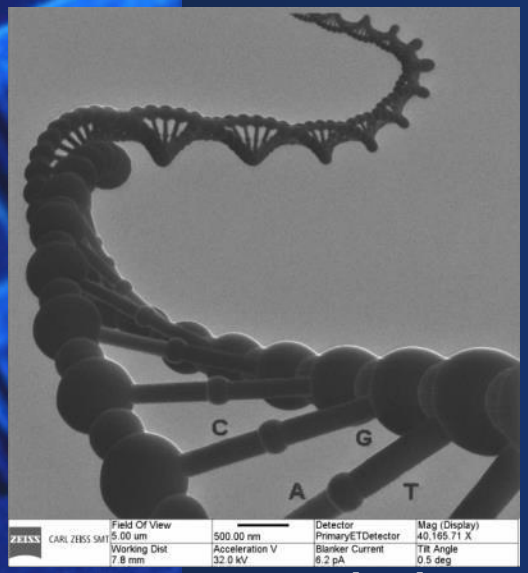
	Fab output	Baby growth	Nature's advantage
Rate	< 1.3E+9 bits/s	> 1.5E+17 amino acid/s	>1E+8
Energy	>>2.1E-8 J/bit	<6.6E-17 J/amino acid	>3E+8

D. Herr (2000/Revised 2010)

JSNN's Interdisciplinary Research Platforms

- Nanomaterials
- Nanobiology
- Nanobioelectronics
- Nanometrology
- Nanoenergy
- Computational Nanotechnology

Fruit Fly Eye,
D. LaJeunesse, JSNN

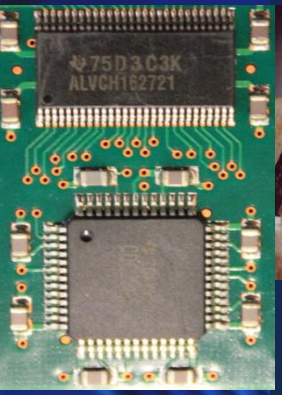


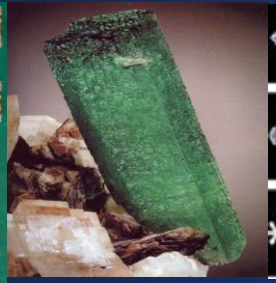
He Ion Etched
DNA Structure
J. Yang, Carl Zeiss

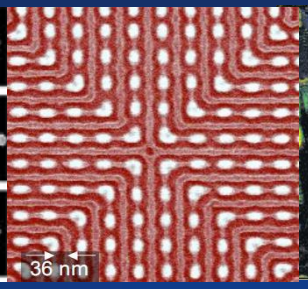
What can we learn from Nature?

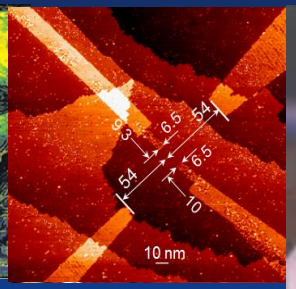
Ex. Alternative assembly methods

Subtractive Patterning	Regular Self Assembly	**Field Assisted Assembly**	Directed Self Assembly	Serial Patterning	Deterministic Assembly	Programmed Self Assembly



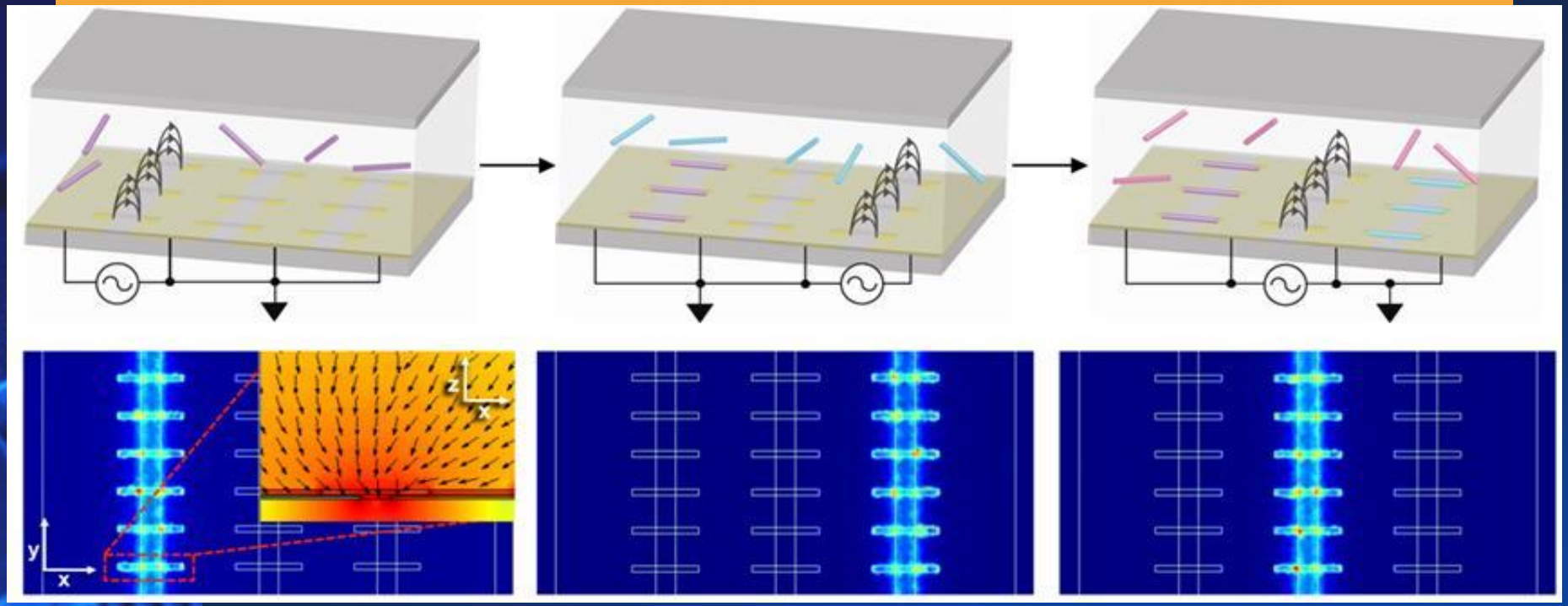






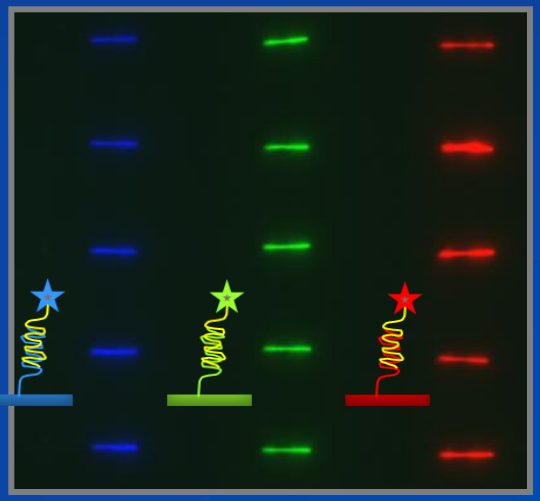
Semiconductor Manufacturing

Field and surface assisted assembly



Coupling sequential delivery with a field directed assembly directs different nanowire populations to different regions of the chip and then preferentially aligns individual nanowires within lithographically-defined microwells.

Morrow, Mayer, Keating *et al. Science*, 323, 352 (2009).



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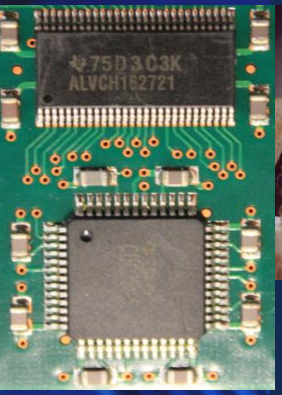
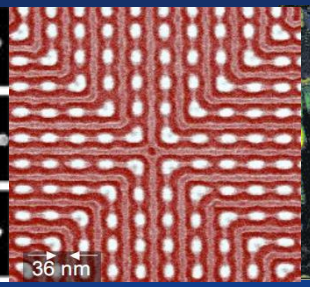
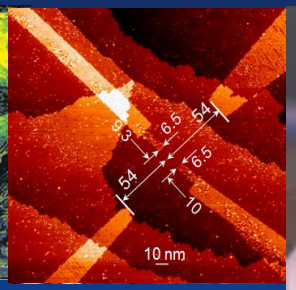




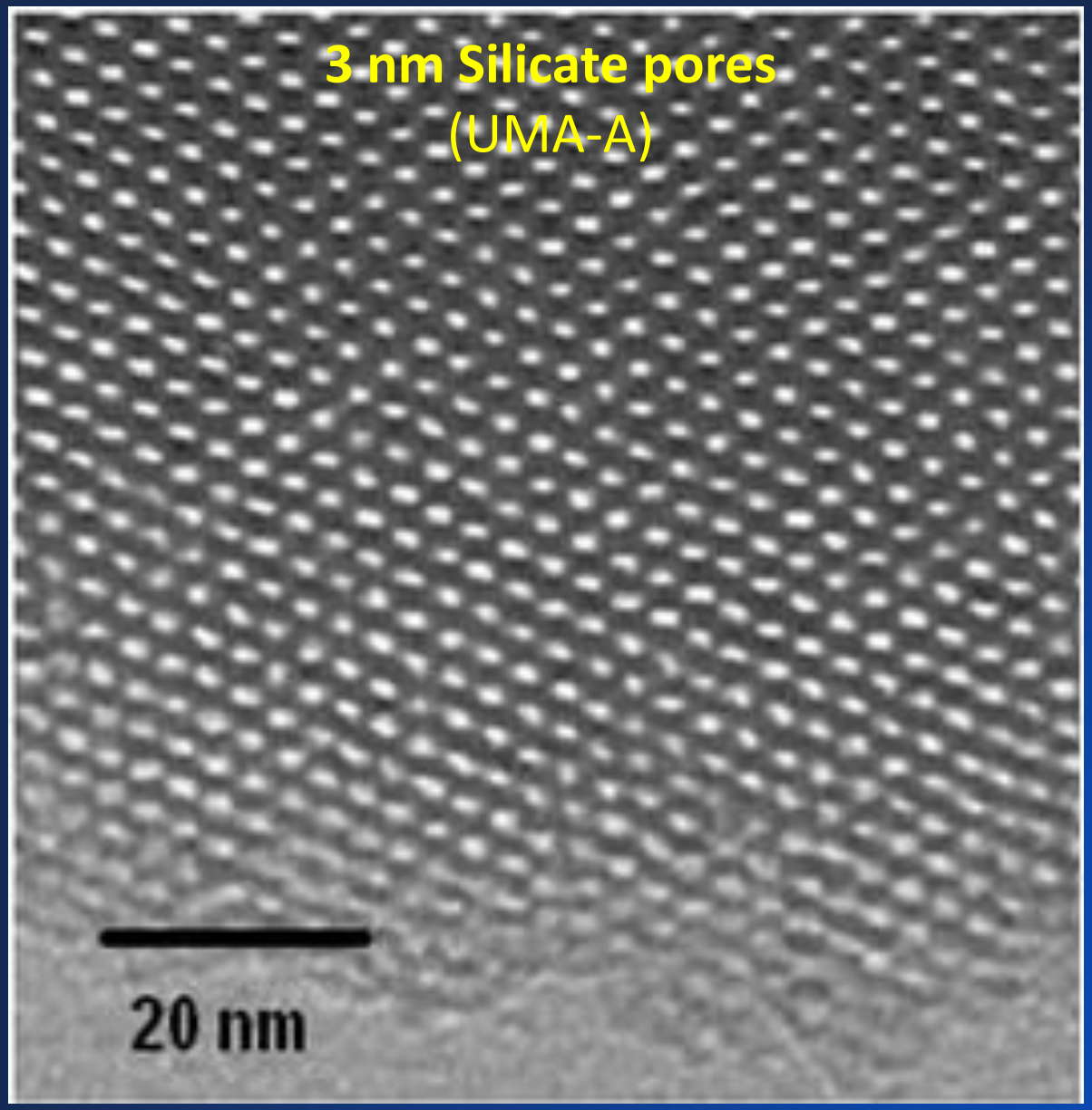


Semiconductor Manufacturing

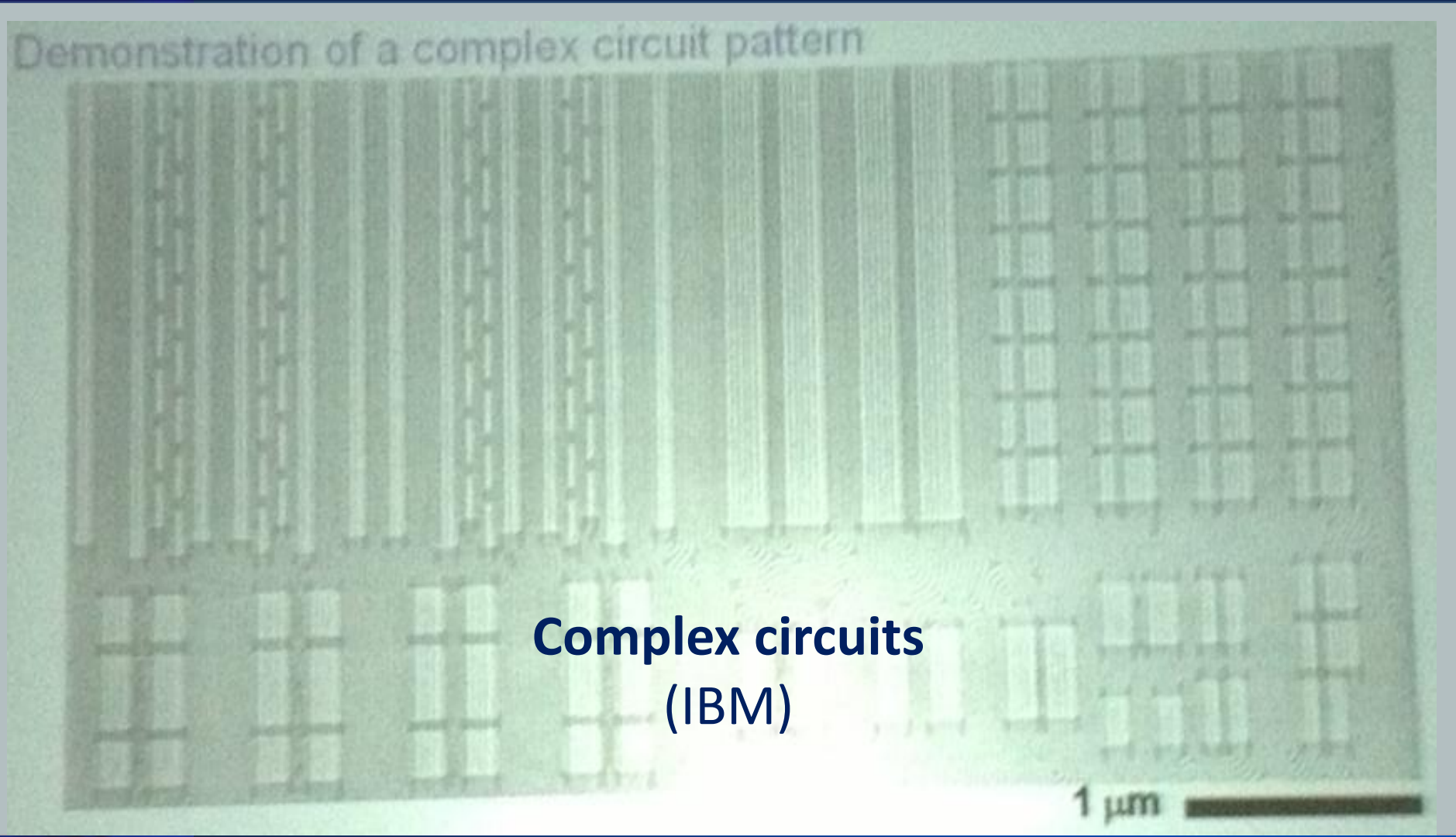
Biomimetic and Directed Self Assembly

D. Herr, D. LaJeunesse, and A. Hung

Directed Self Assembly
Resolution and complexity



Directed Self Assembly
Resolution and complexity



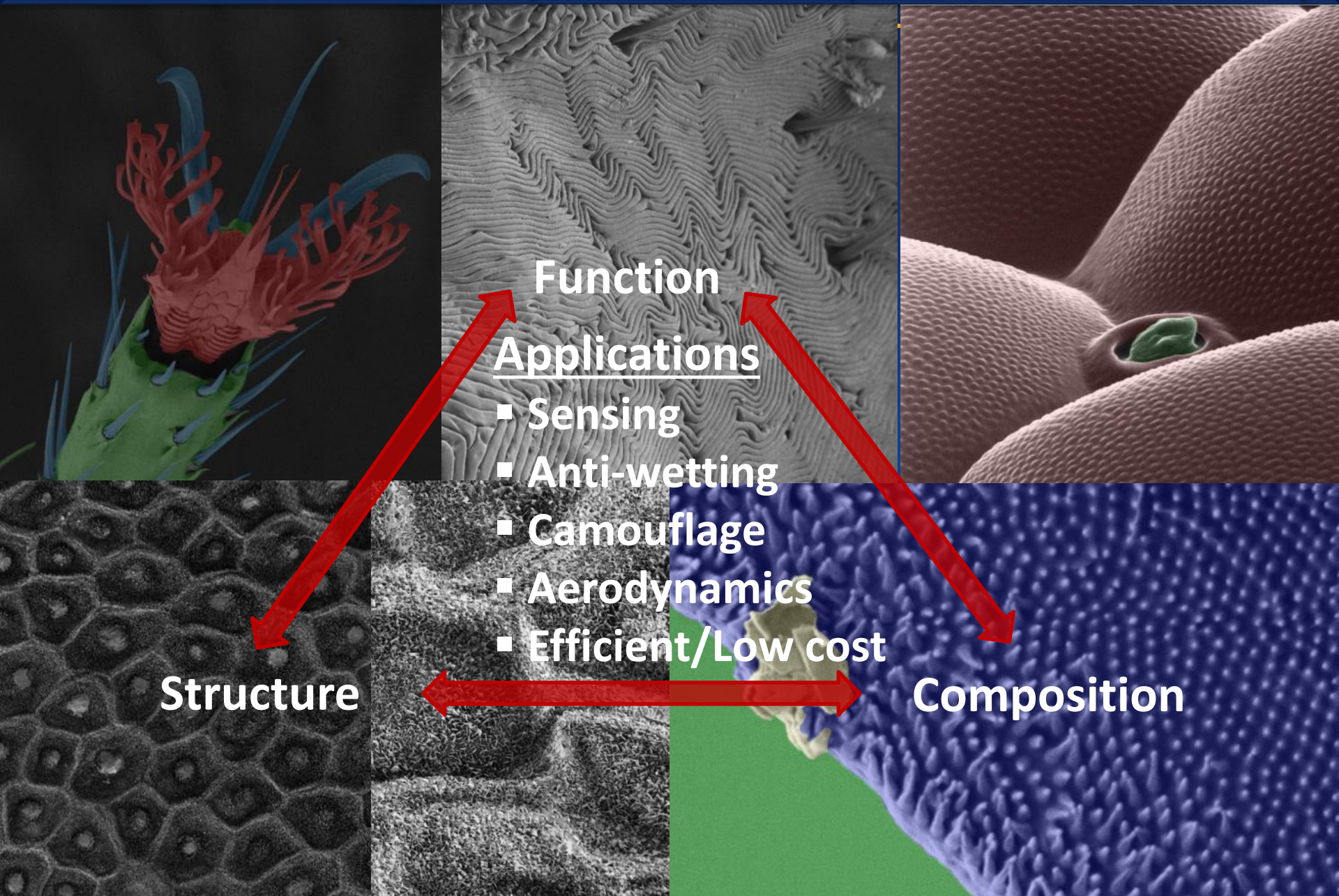
Complex circuits
(IBM)

Directed Self Assembly
Resolution and complexity

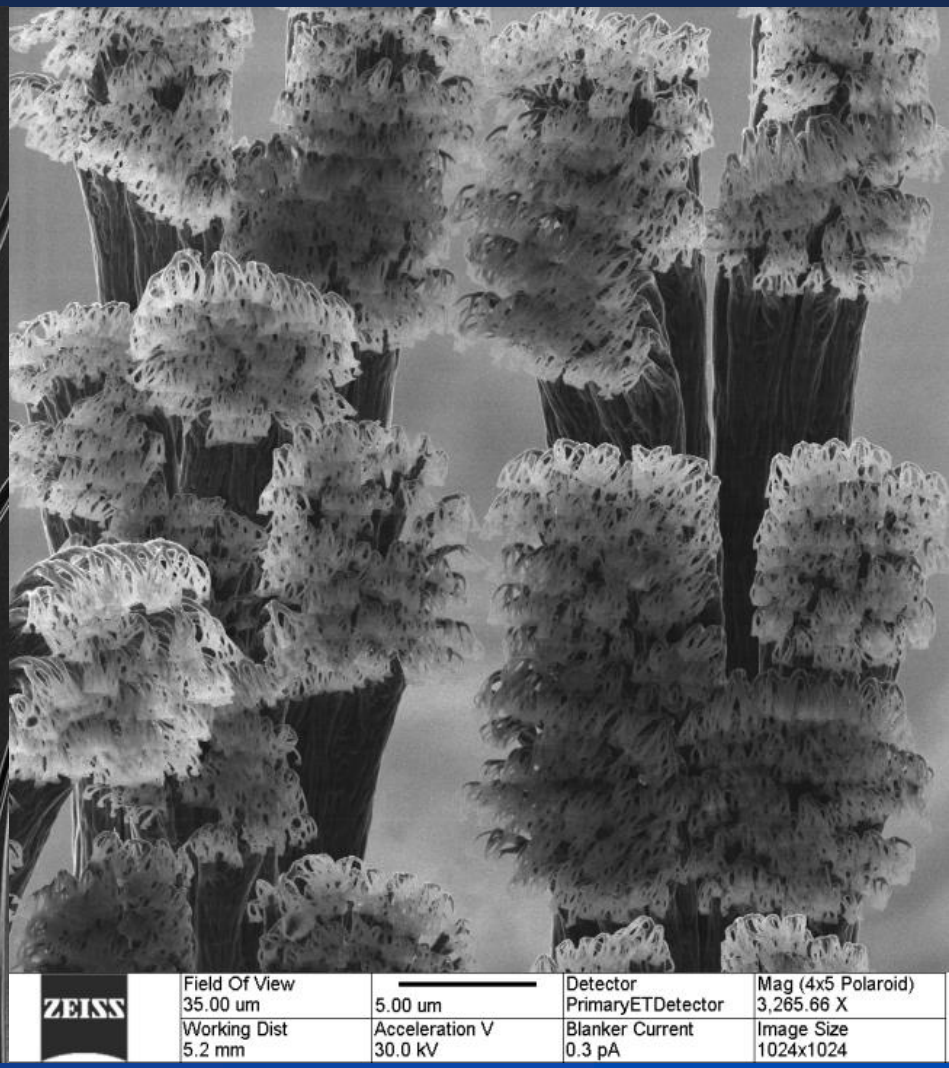
P. Rothemund, Caltech

Functional Nanomaterials

Biomimetic Nanomaterials/Nanostructures (D. LaJeunesse & D. Herr)



Nature Leverages Functional Nanostructures

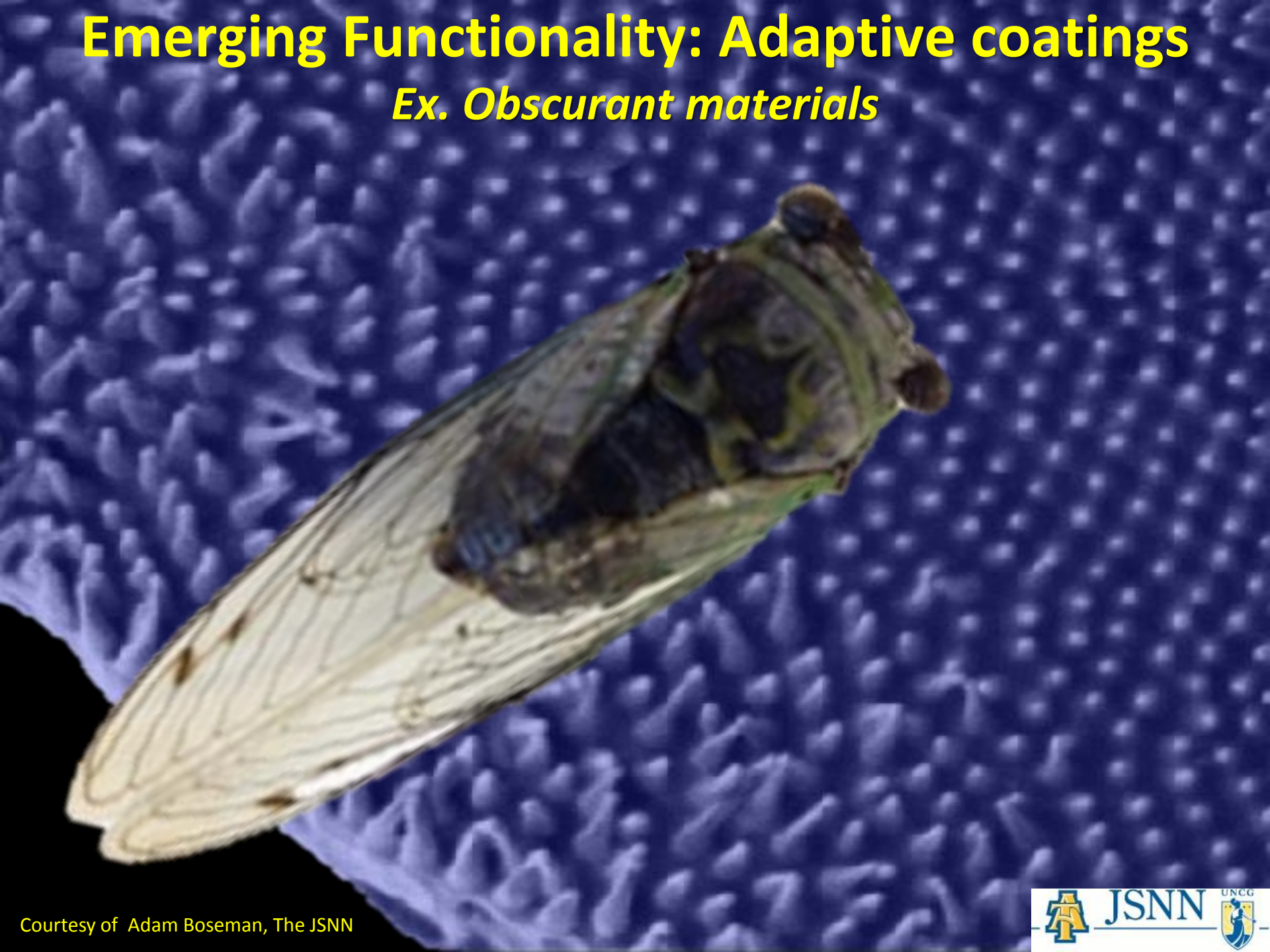


Fruit Fly Foot

Gekko Foot

Emerging Functionality: Adaptive coatings

Ex. Obscurant materials

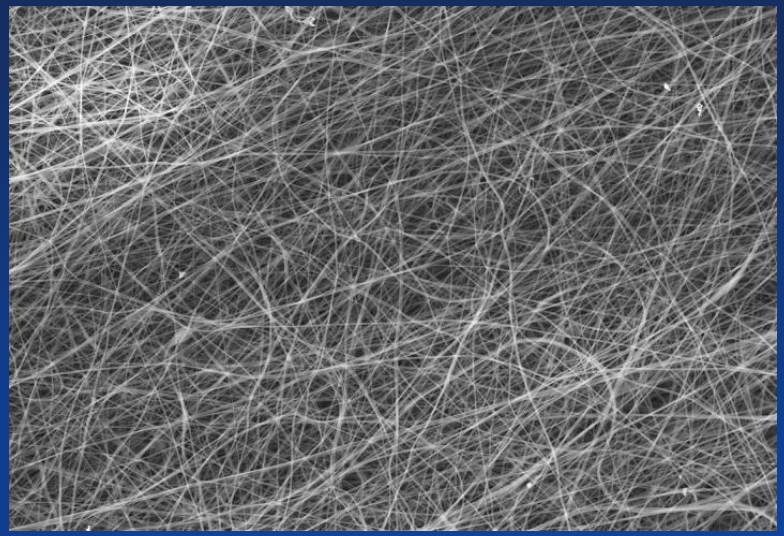


Courtesy of Adam Boseman, The JSNN

Structural Nanocomposite Materials

Smart/Protective Skin, Fuel Cell Powered, Nano-Composite Vehicles

Spun Nanoglass Fiber Matrix



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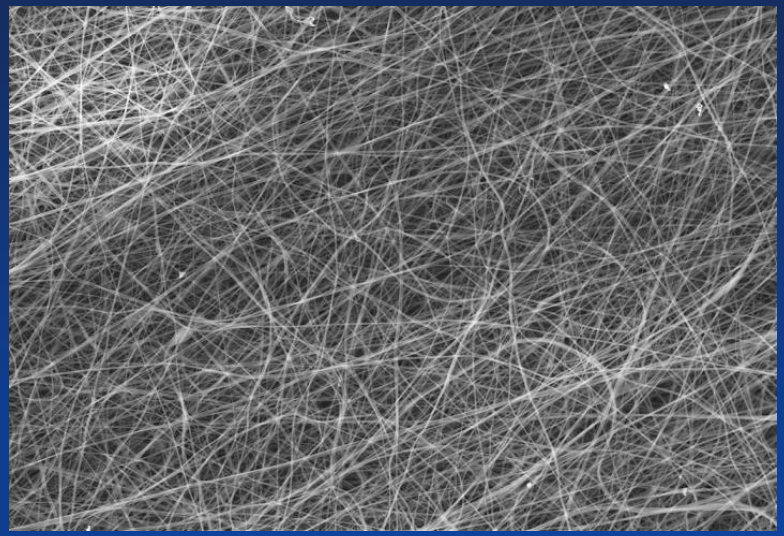


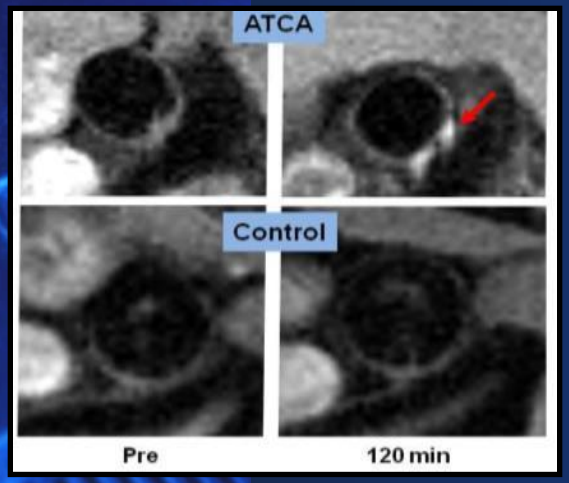
Light and Strong Nanocomposite Structures

Nanocarbon Laminate

Nanobiology

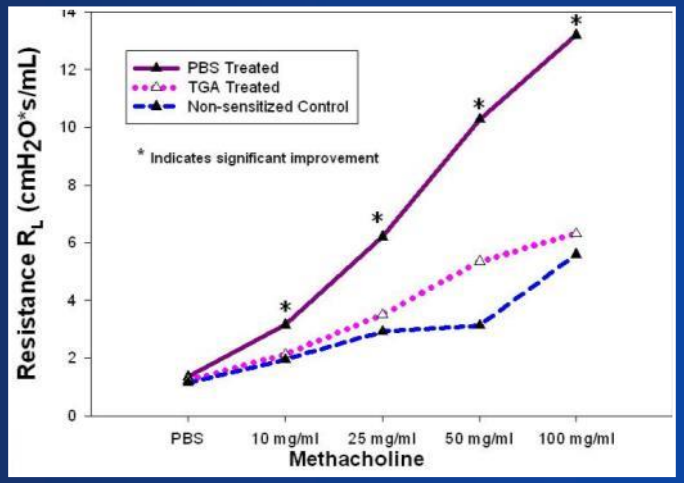
Nanotheranostics (C. Kepley)

Atherosclerosis



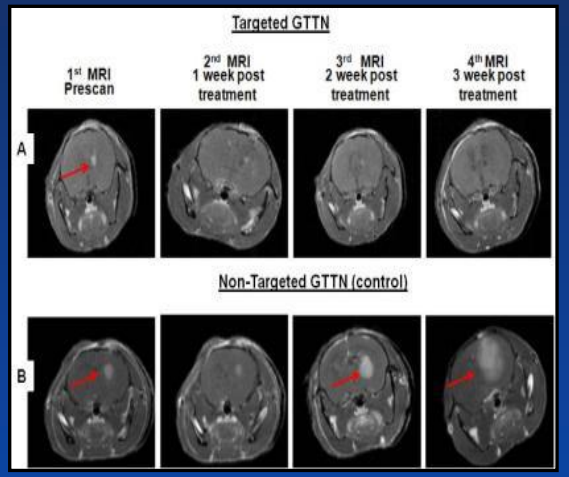
Atherosclerotic-plaque targeting contrast agents (ATCA) can detect plaque in vivo.

Inflammatory disease-asthma



Fullerenes improve asthma symptoms.

Cancer



Glioblastoma targeting theranostics (GTTN) shrink brain tumors.

Nanobioelectronics

Integrated Nerve Stimulation Device (J. Starobin and S. Aravamudhan)

3D high-density peripheral nerve-electrode interface in order to re-establish nerve conductivity

(Regenerative Microchannel-based Electrode Interface - ReME)

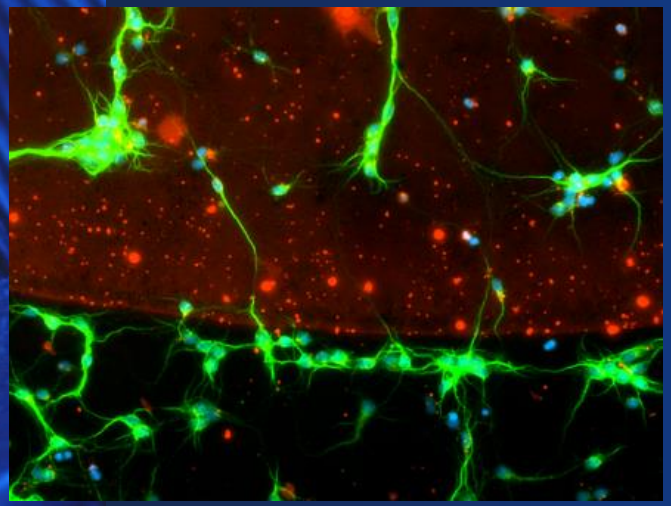
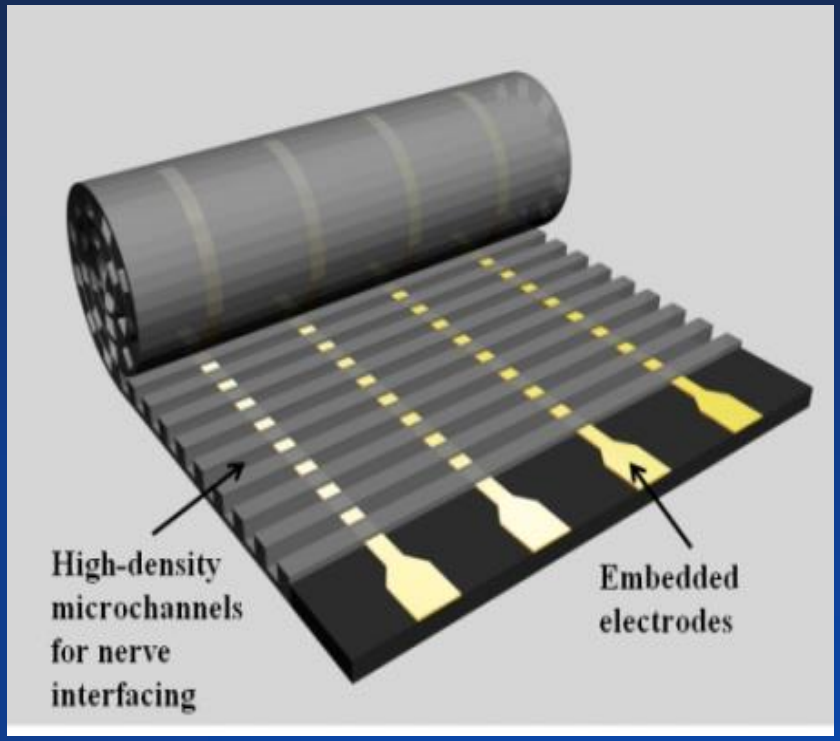


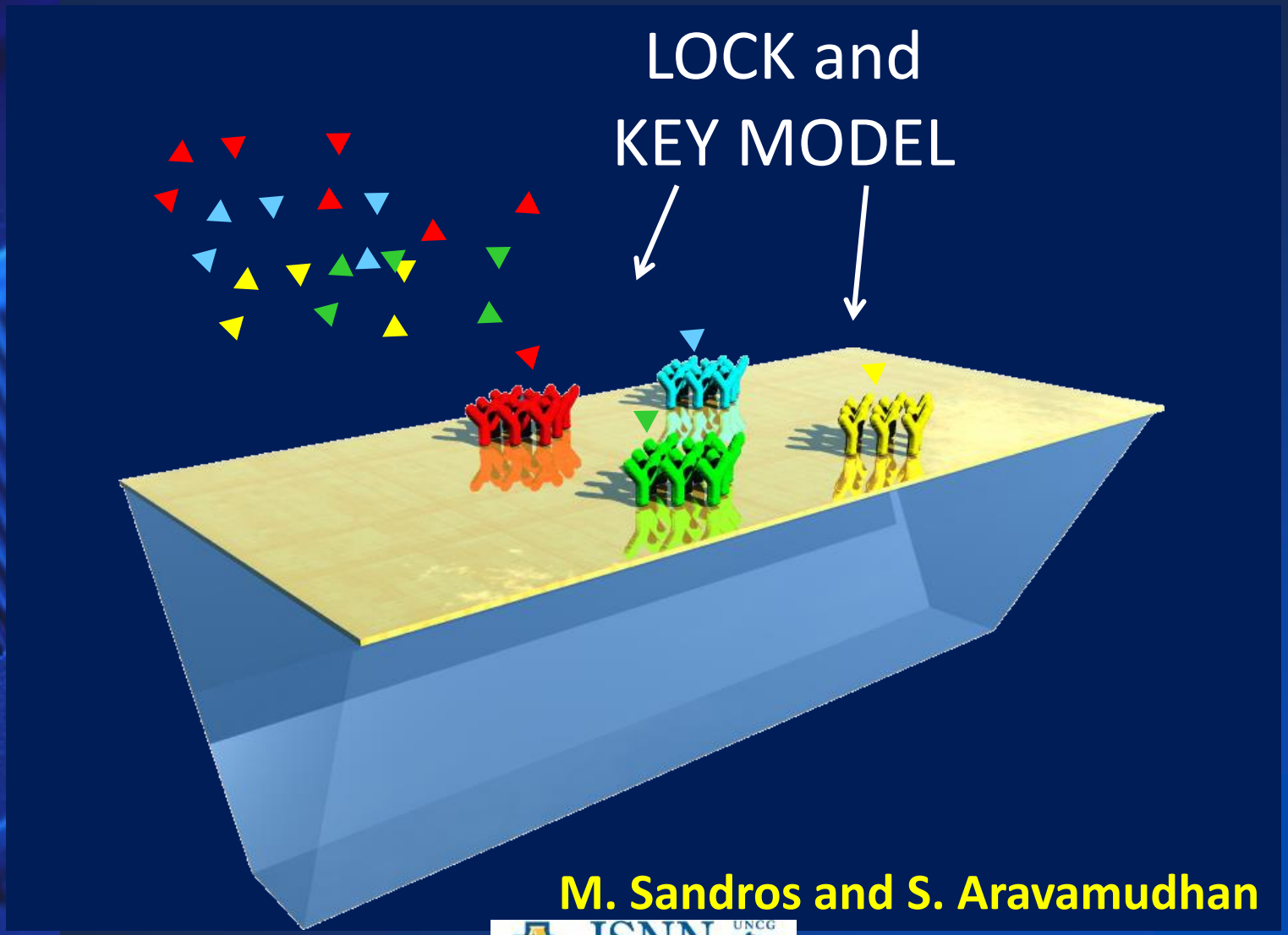
Image of stained neuronal cells on electrodes



3D micro-channel array embedded with electrodes for stimulation of nerve fibers

Emerging Functionality: Bioelectronics

Ex. Portable platform for detecting moderate traumatic brain injury



M. Sandros and S. Aravamudhan

JSNN

Bioinspired Functionality: Convergent Integration Opportunities

Typical Functionality Integrated Within a Cell

Energy	Generation Conversion Storage Utilization Architectures	***Communication***	Transmission Filtering Novel A/D Interconversions Low Energy Approaches Reception
Sensing	Physical Chemical Multimode Multiscale Subsurface	***Bioelectronics***	Personalized Medical Diagnostics Prosthetics and Implantable Devices Biotic/Abiotic Interfaces Multiproperty Imaging Noninvasive [Tricorder-like]
Actuation	Analog Digital Hybrid Approaches Hard and Soft/Adaptive Systems Autonomous Emergent Behavior	***Adaptive Coatings***	Dynamic Local Mapping Camouflage Obscuration Smart Physical Changes Remotely Directed Adaptations

D. Herr, SRC SemiSynBio Workshop, February 2013

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D. Herr, SRC SemiSynBio Workshop, February 2013

Emerging Opportunities:
Convergence between traditional and nano- technologies

Ex. Bioelectronics - Lab-on-a-chip:

Selected lab test market opportunity

~ $10T per year

Question Break

A Story: The Return of U.S. Manufacturing

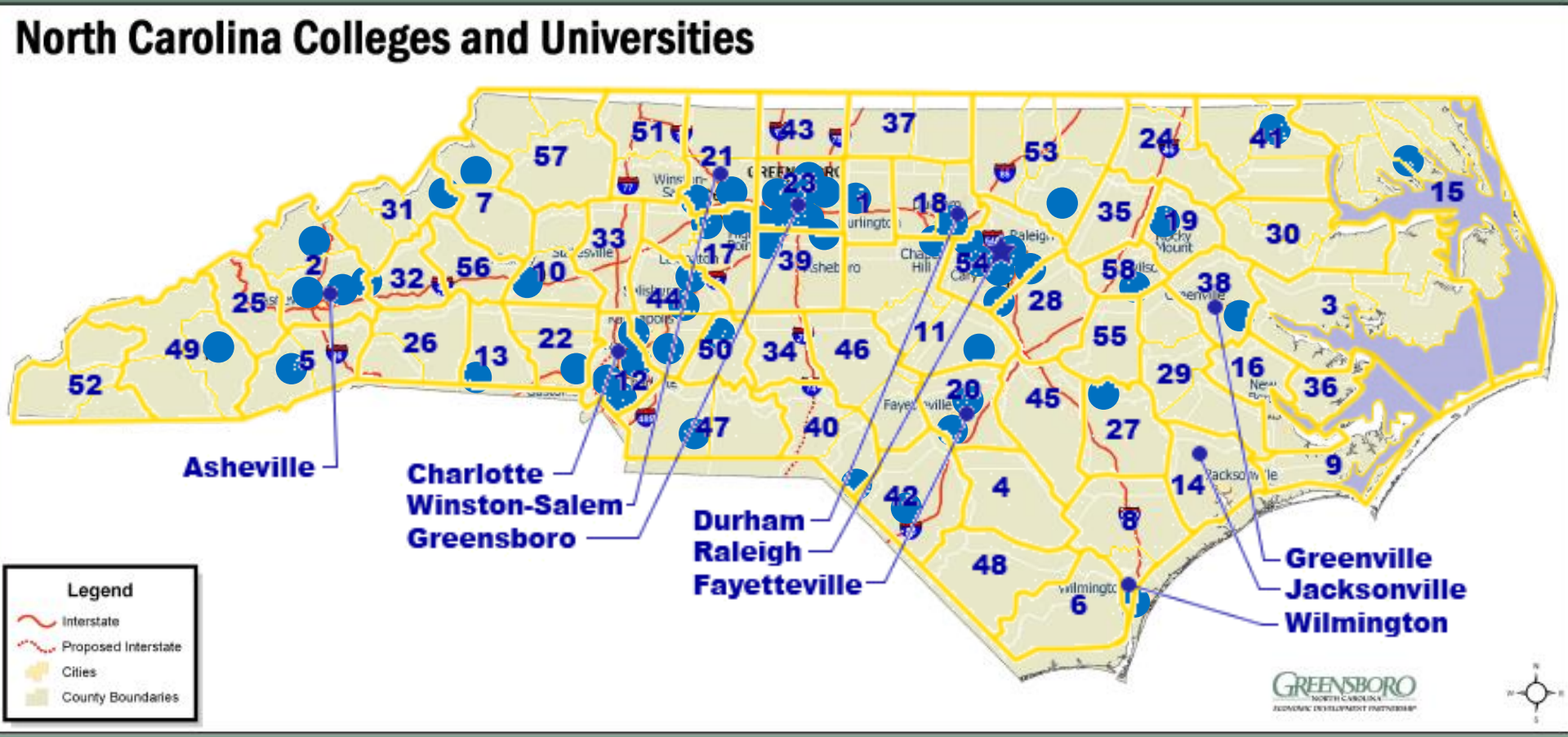
S. Kinkaid

As the *Boston Consulting Group reported in May*,

"**Within the next five years, the United States is expected to experience a manufacturing renaissance** as the wage gap with China shrinks and certain U.S. states become some of the cheapest locations for manufacturing in the developed world. We expect net labor costs for manufacturing in China and the U.S. to converge by around 2015. As a result of the changing economics, you're going to see a lot more products 'Made in the USA' in the next five years."

Courtesy of S. Kinkaid (March 30, 2012)

Potential for Innovative Educational Networks



We need to nurture a collaborative and well leveraged education, research, and development supply chain

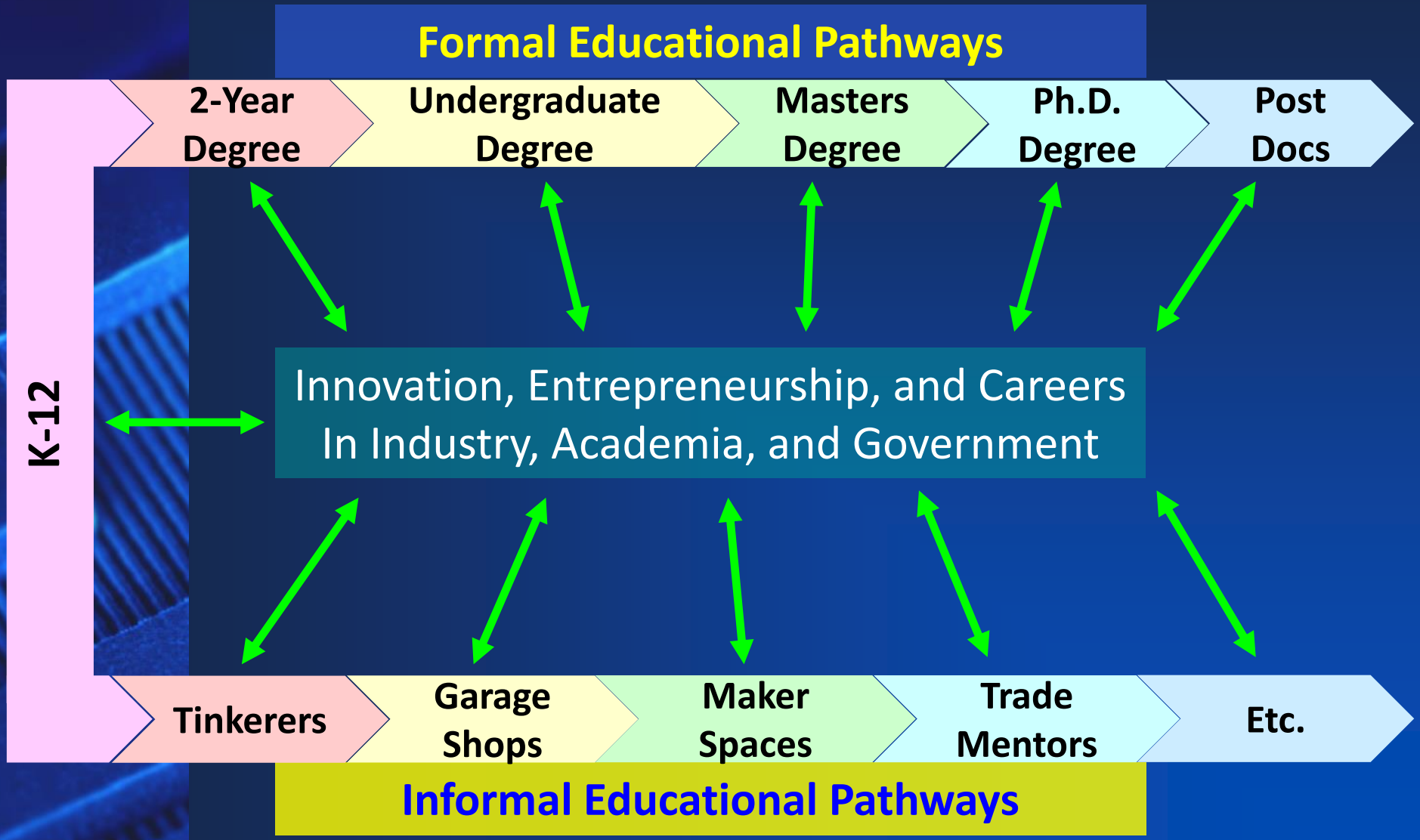
ForsythTech

More Than You Know

Workforce Education and Training with the qNano

Kevin Conley, Forsyth Tech, 2013

The Dynamic Innovation Infrastructure:
Nanoeducational-Entrepreneurial Pipeline



The Dynamic Innovation Infrastructure:
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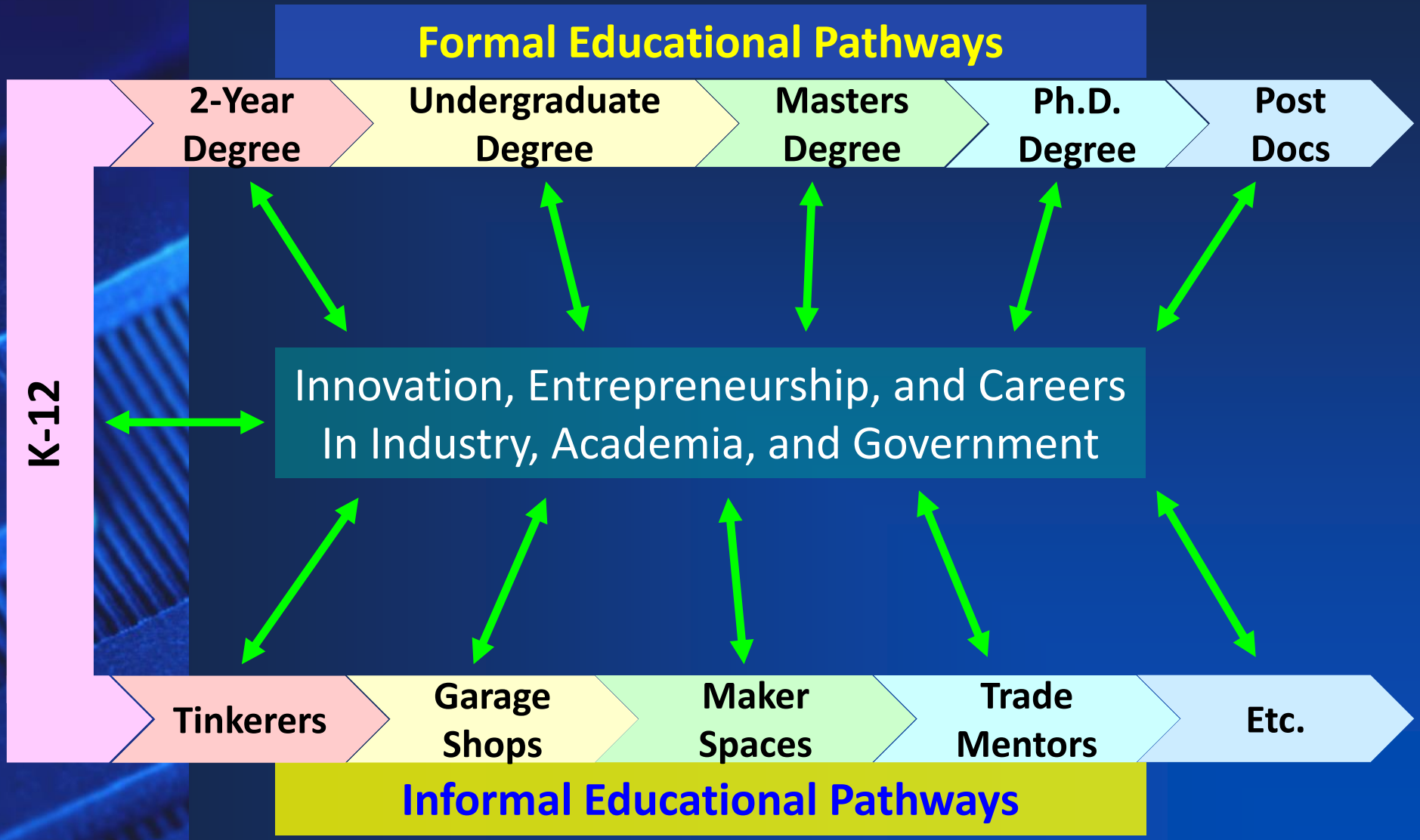


Anyone can innovate, create value, and enhance our workforce.

Invention and Innovation are Needed

Beyond ~ 2020, a completely different approach to information processing will be needed.

We are likely to see a revolution in convergent technologies comparable to the monolithic integration of transistors more than fifty years ago.

The seeds of the next wave of innovation have been planted and nurtured in unexpected places all along the formal and informal educational and entrepreneurial supply chain.

Building Small Stuff

Ex. Some emerging high impact fabrication options

Role to role patterning

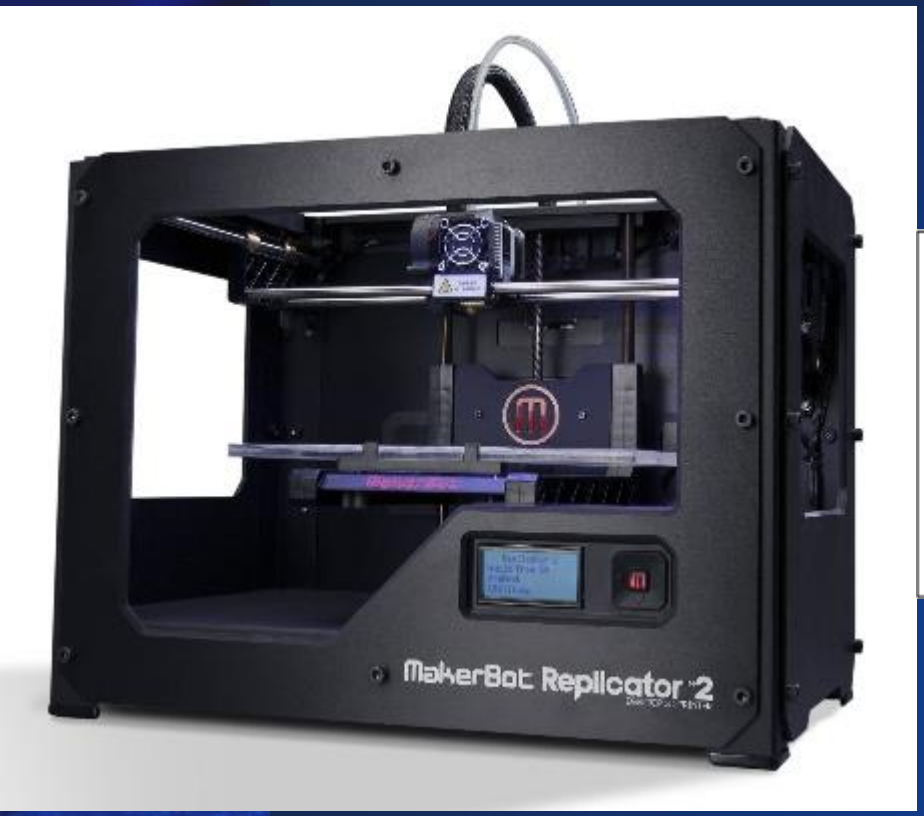
2D ink-jet printing

3D Fabrication

Electrospinning

Arrayed dip-pen patterning

3D Fabrication:
Ex. MakerBot



MakerBot Replicator 2 Desktop 3D Printer

By MakerBot Industries
3.6 out of 5 stars See all reviews (7 customer reviews)

Price: $2,199.00 & FREE Shipping. Details

Only 10 left in stock.
Sold by MakerBot and Fulfilled by Amazon.

http://www.amazon.com/MakerBot-Replicator-Desktop-3D-Printer/dp/B00BFZOVGI/ref=sr_1_1?ie=UTF8&qid=1372867551&sr=8-1&keywords=replicator+2

The 3D Fabrication: Child's play?

Ex. Falling Water: Lego and 3D printed version

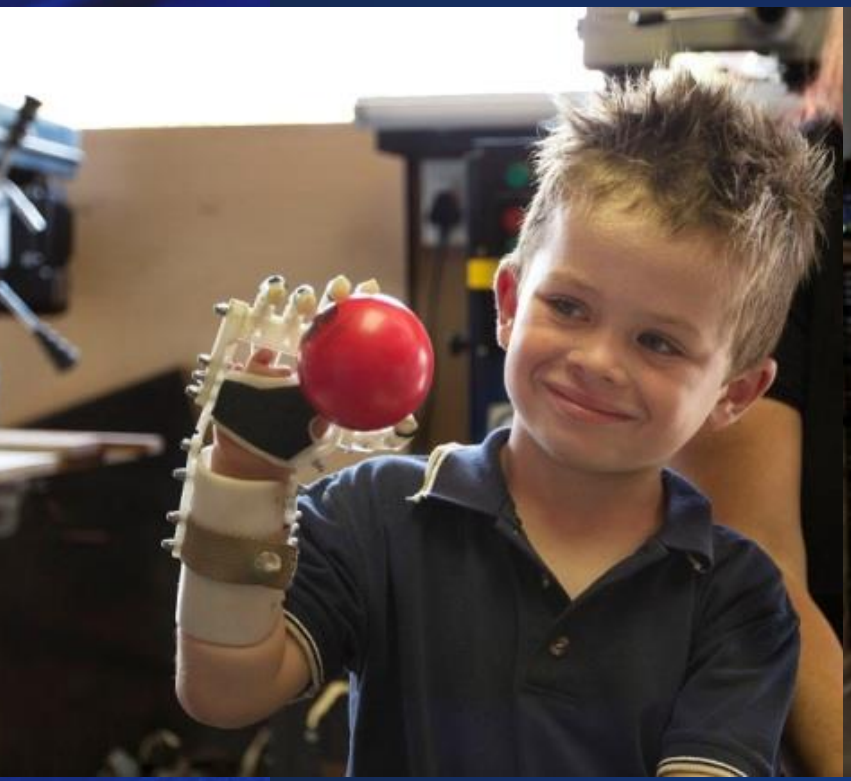
These systems could use functional electronic materials.

http://www.robertsoninnovation.com/another-cool-way-to-generate-a-3d-model-minecraft/

Replace colors with functional materials.

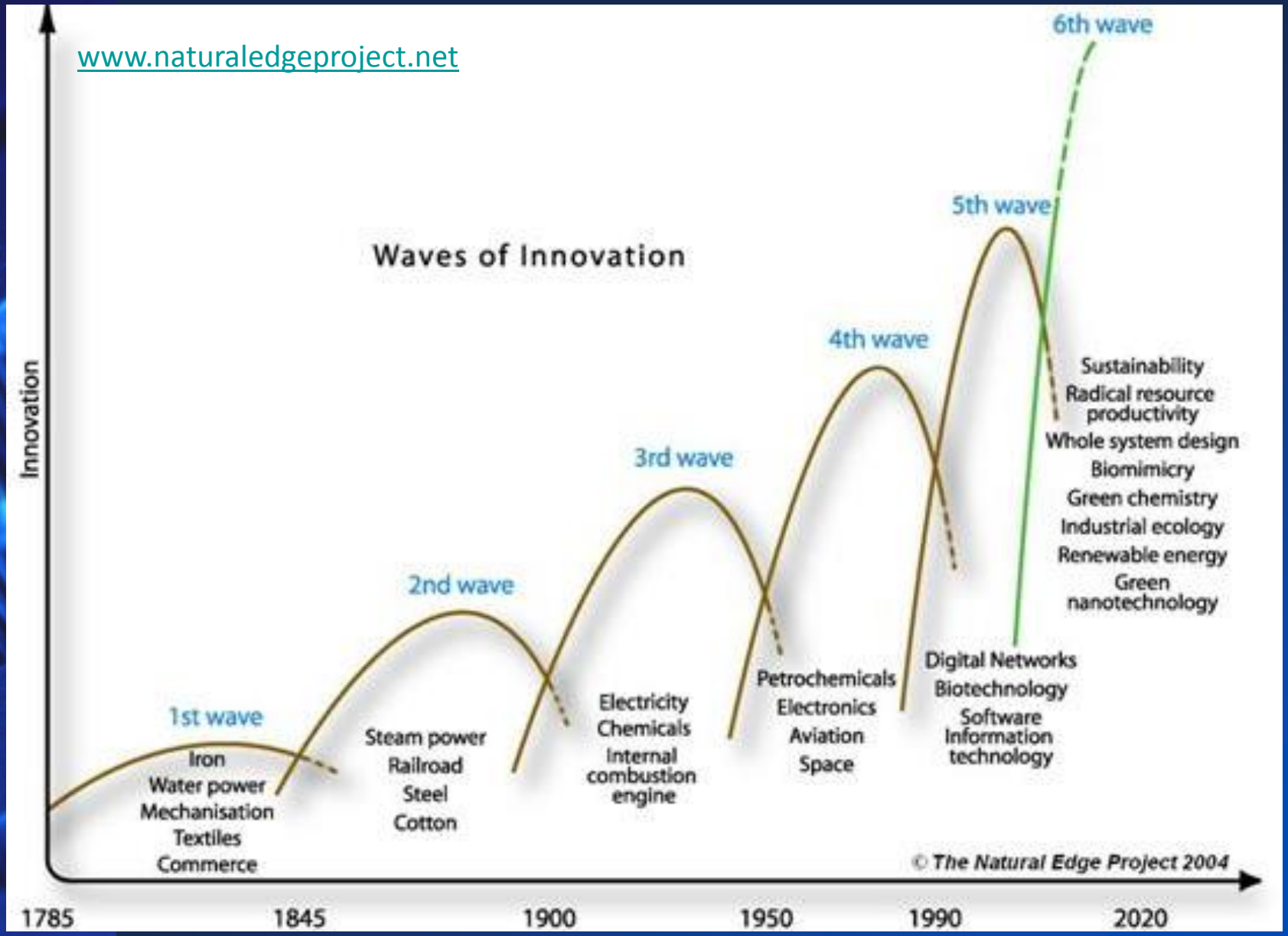
The 3D Fabrication: High impact

Ex. Robohand



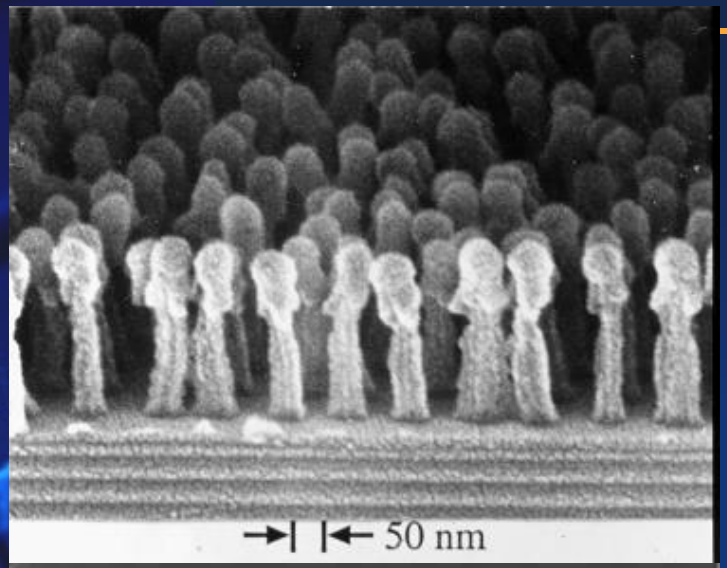
http://www.youtube.com/watch?v=A6isKsPWubA

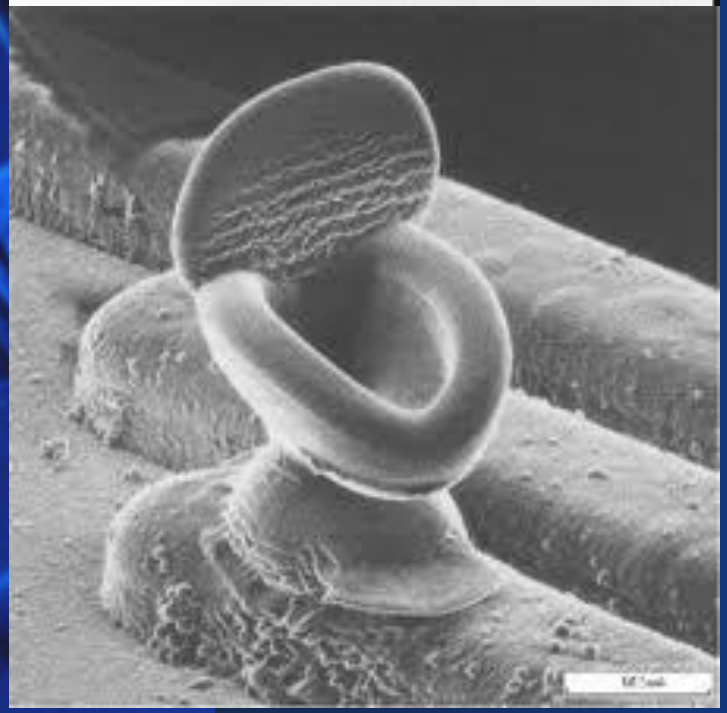
Waves of Innovation



Nontraditioanl Convergent Opportunities:

Nanoart





An activated gene chip F. Cerrina(UW-M)

Key Messages

- Today's nanomaterials and tools provide **unprecedented opportunities for today's students, scientists, engineers, innovators and entrepreneurs to support each other and create high value products** that address emerging societal needs.
- This is a good time for innovators to **question some of our basic assumptions about designing and building value added products** in the micro- and nano- domains.
- **It is imperative that educators keep current with these rapidly evolving technologies** to ensure that workforce entrants have the knowledge, skills and abilities they will need.

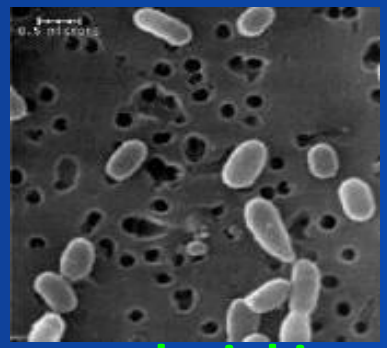
Have we reached the tipping point?

I welcome your thoughts and hearing about the challenges that are capturing our children's imagination.

How small can we go?

How small can we go?

Ultra-micro-bacteria (~200 nm)



Extracted from a glacial ice core sample, 120,000 years old Miteva (2005)

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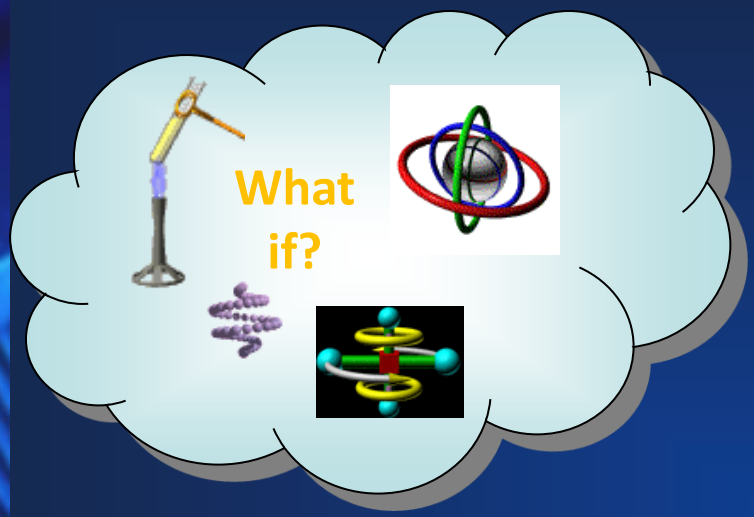
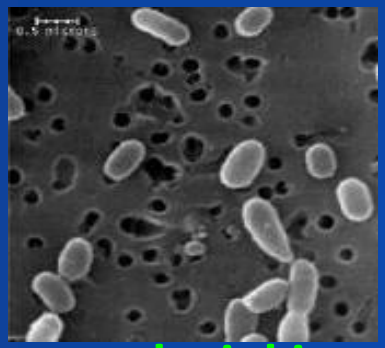


djherr@uncg.edu

Thank You

Ultra-micro-bacteria (~200 nm)



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Questions?

Please type all questions into the Chat Box

How Can We Better Serve You?

Whether you are joining us live or watching the recorded version of this webinar, please take 1 minute to provide your feedback and suggestions.

http://questionpro.com/t/ABkVkZQFNf

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nano4me.org/webinars.php

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If you attended the live version of this 1.5 hour webinar and would like a certificate of participation, please email:

sbarger@engr.psu.edu

2013 – 2014 Events Calendar

Nov. 12-14: *Workshop*	Hands-on Introduction to Nano for Educators
January 31: *Webinar*	K-12 Resources in Nanotechnology
March 28: *Webinar*	RET Experience: Activities for the HS Classroom
April 7-10: *Workshop*	Nanotechnology Course Resources Workshop 1: Safety, Processing, and Materials

Want more events? Visit www.nano4me.org/webinars for more details about these and other upcoming workshops and webinars in 2014.

Thank You!

Thank you for attending the
NACK Network webinar

Catching the Nanotechnology Wave:
Needs, Risks, and Opportunities