Our Nano Future: From Discovery to Innovation

Presented by MATEC NetWorks

NETWORKS

www.matecnetworks.org

Presenter

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Vice-President, Innovative Partnerships,
Semiconductor Research Corporation

Celia.Merzbacher@src.org

Host: Michael Lesiecki

Objectives

- Objective 1: Introduce nanotechnology and its current applications
- Objective 2: Overview nanoelectronics and complex nanomaterials
- Objective 3: Give a perspective on future directions and emerging trends
- Objective 4: Address issues and implications for education and the workforce

Who Am I?

- (Nano)materials scientist
- Technology transfer/IP manager
- Government policymaker
- Industry consortium executive

Audience Poll

Who Are You?

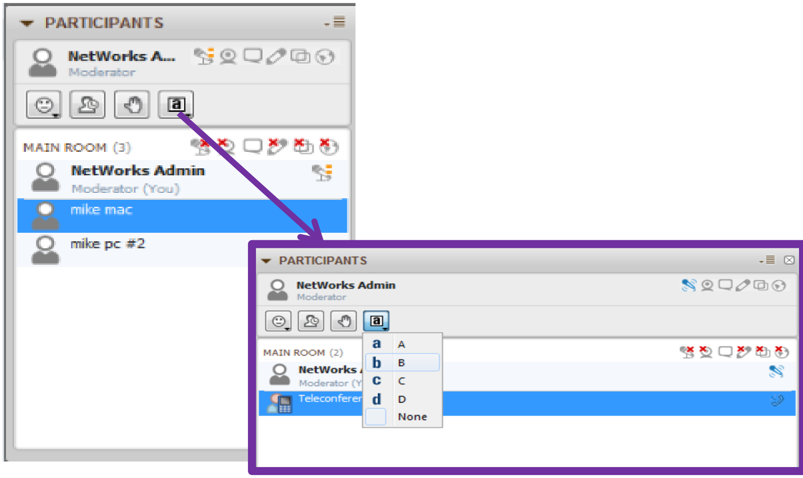
A. K-12 Educator

B. Community College Educator

C. 4-year College/University Educator/Researcher

D. Industry scientist, engineer or technologist

E. Government agency or nonprofit organization



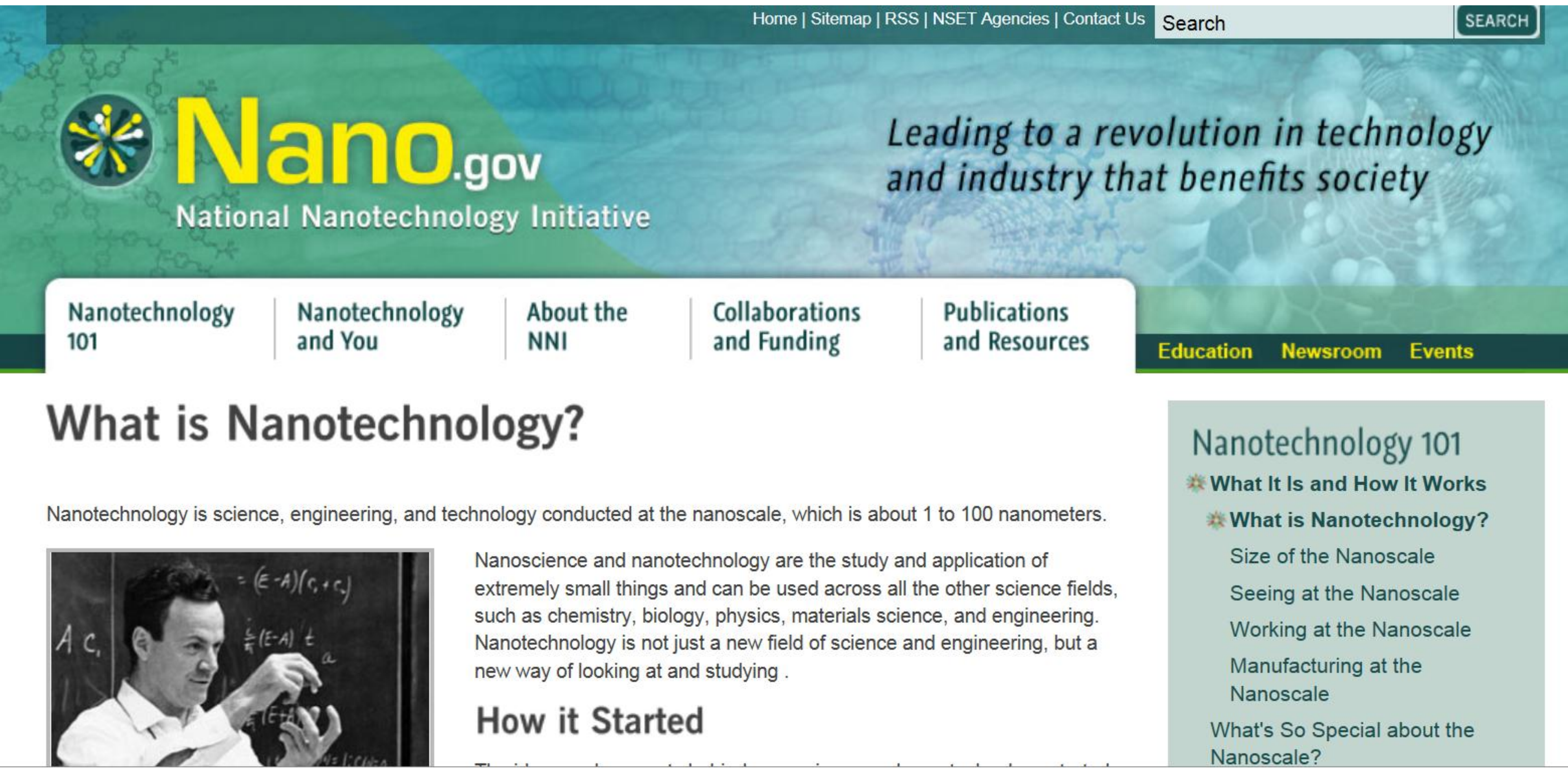
Audience Poll

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. Government agency or nonprofit organization

What is Nanotechnology?

Understanding and using "stuff" that is 1-100 nanometers in size.



Audience Poll

How Small is a Nanometer?

A nanometer is one billionth of a meter.

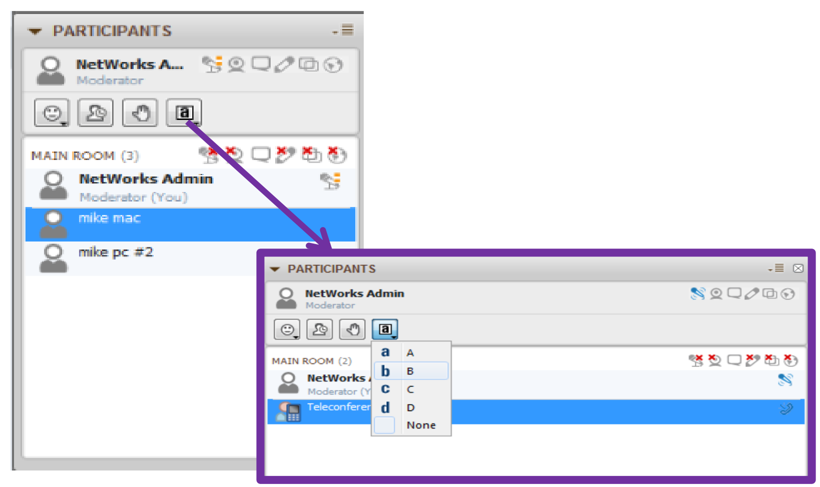
If a nanometer were the size of a marble, a meter would be the size of:

A. The Sun

B. The Earth

C. The moon

D. The Grand Canyon's depth



Audience Poll

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A. The Sun

B. The Earth

C. The moon

D. The Grand Canyon’s depth

Audience Poll

How Small is a Nanometer?

The thickness of a piece of newspaper is about:

A. 10 nanometers

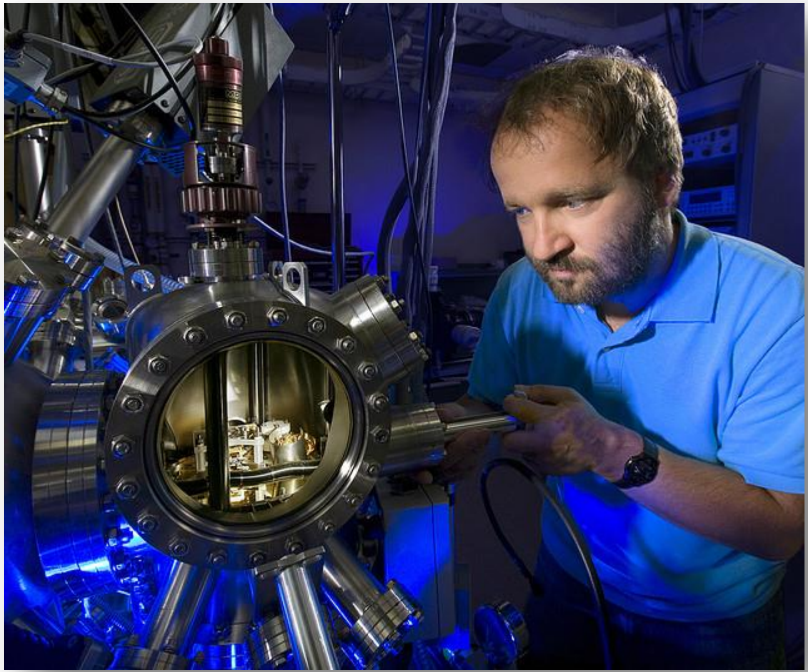
B. 10,000 nanometers

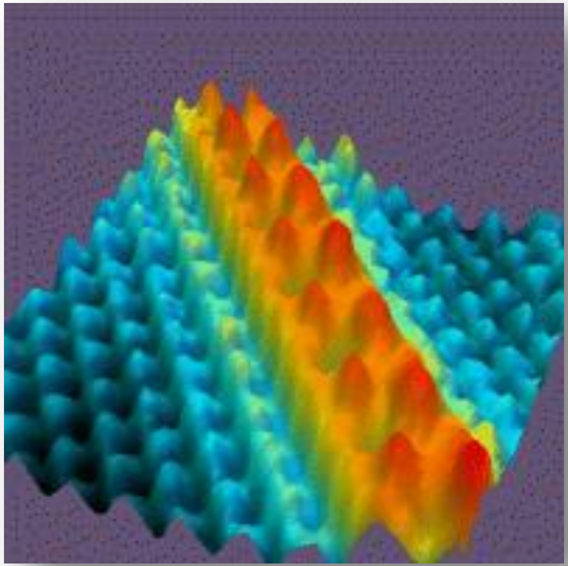
C. 100,000 nanometers

D. 1,000,000 nanometers

Nanotechnology Enabling Advances: Imaging Technology

- Scanning Tunneling Microscope
  - Inventors Binnig and Rohrer received the 1986 Nobel prize in physics

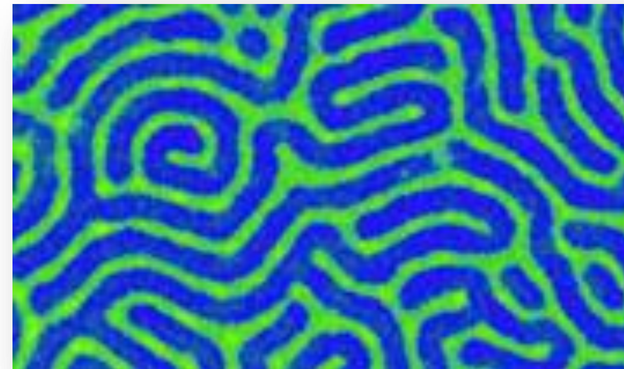




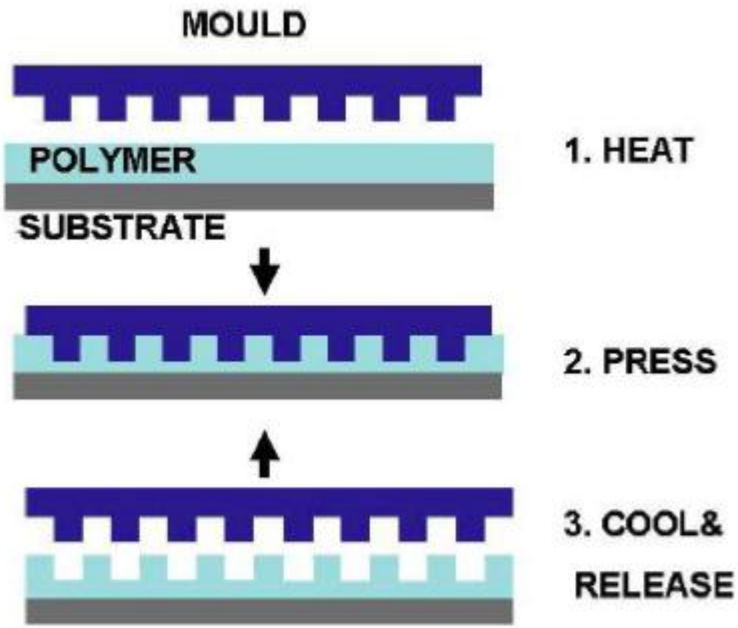
STM image of Cesium atoms (red) on Gallium Arsenide (blue)
Credit: NIST

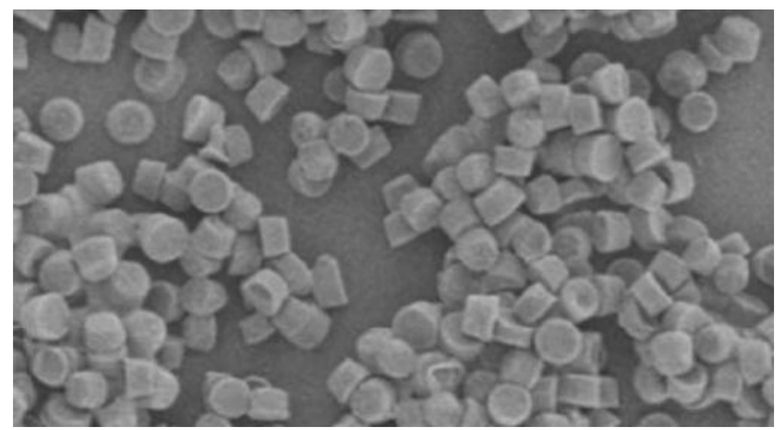
Nanotechnology Enabling Advances: Nanomanufacturing

- Directed self assembly
- Imprinting



Source: NIST

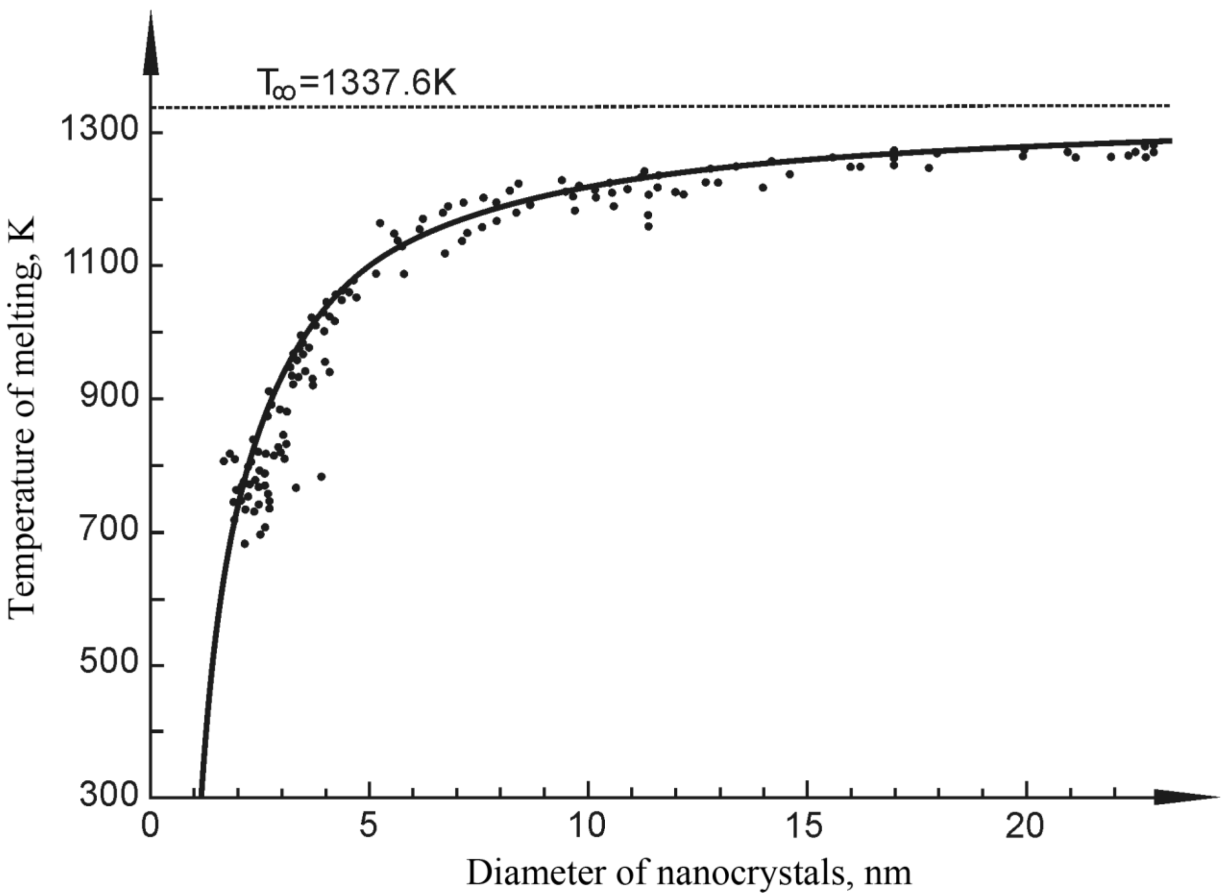




Credit: J. Am Chem Soc

http://nextbigfuture.com/2011/05/stamp-fabrication-by-step-and-stamp.html

Size Affects Properties:
Gold Melting Point Depression



http://www.intechopen.com/books/thermodynamics-physical-chemistry-of-aqueous-systems/heterogeneous-melting-in-low-dimensional-systems-and-accompanying-surface-effects

Controlling Materials at the Nanoscale Controls Their Properties

From left to right: 80 nm silver nanospheres, 20 nm silver nanospheres, 40 nm gold nanospheres, 12 nm gold nanospheres, 200 nm silver nanoplates, 120 nm silver nanoplates, and 60 nm silver nanoplates.

Source: http://nanocomposix.com/kb/general/color-engineering

Controlling Materials at the Nanoscale Controls Their Properties

Size

From left to right: 80 nm silver nanospheres, 20 nm silver nanospheres, 40 nm gold nanospheres, 12 nm gold nanospheres, 200 nm silver nanoplates, 120 nm silver nanoplates, and 60 nm silver nanoplates.

Source: http://nanocomposix.com/kb/general/color-engineering

Controlling Materials at the Nanoscale Controls Their Properties

Chemistry

From left to right: 80 nm silver nanospheres, 20 nm silver nanospheres, 40 nm gold nanospheres, 12 nm gold nanospheres, 200 nm silver nanoplates, 120 nm silver nanoplates, and 60 nm silver nanoplates.

Source: http://nanocomposix.com/kb/general/color-engineering

Controlling Materials at the Nanoscale Controls Their Properties

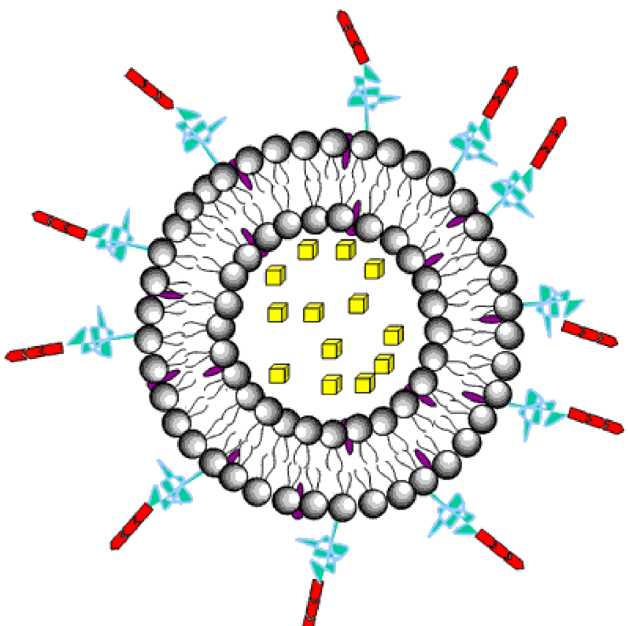
Shape

From left to right: 80 nm silver nanospheres, 20 nm silver nanospheres, 40 nm gold nanospheres, 12 nm gold nanospheres, 200 nm silver nanoplates, 120 nm silver nanoplates, and 60 nm silver nanoplates.

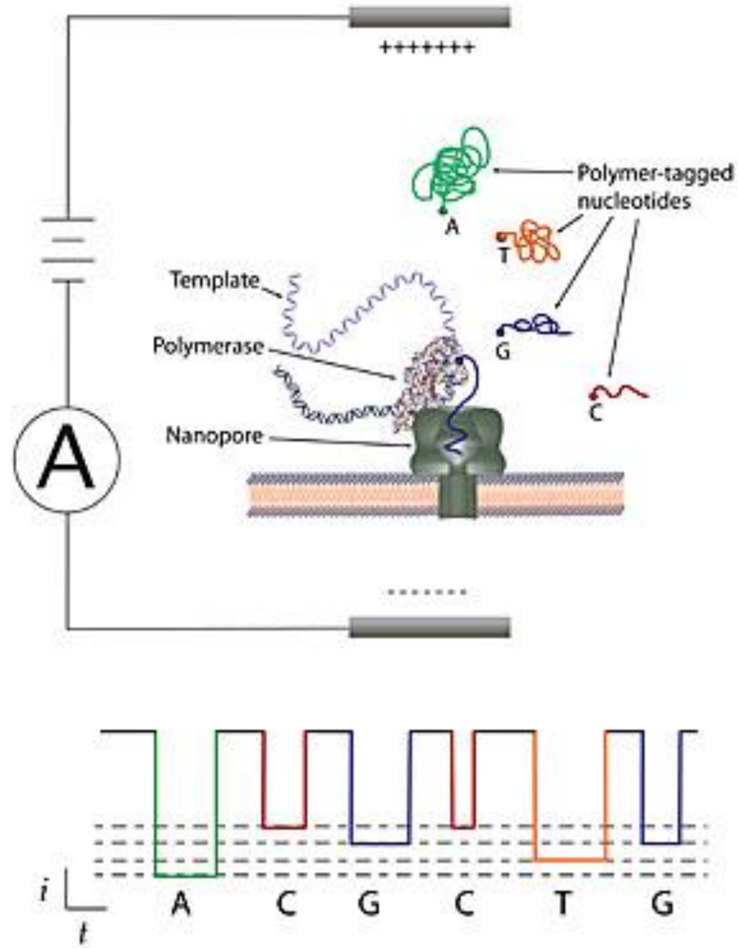
Source: http://nanocomposix.com/kb/general/color-engineering

Nanotechnology for Medicine

- Imaging
- Diagnostics
- Therapeutics



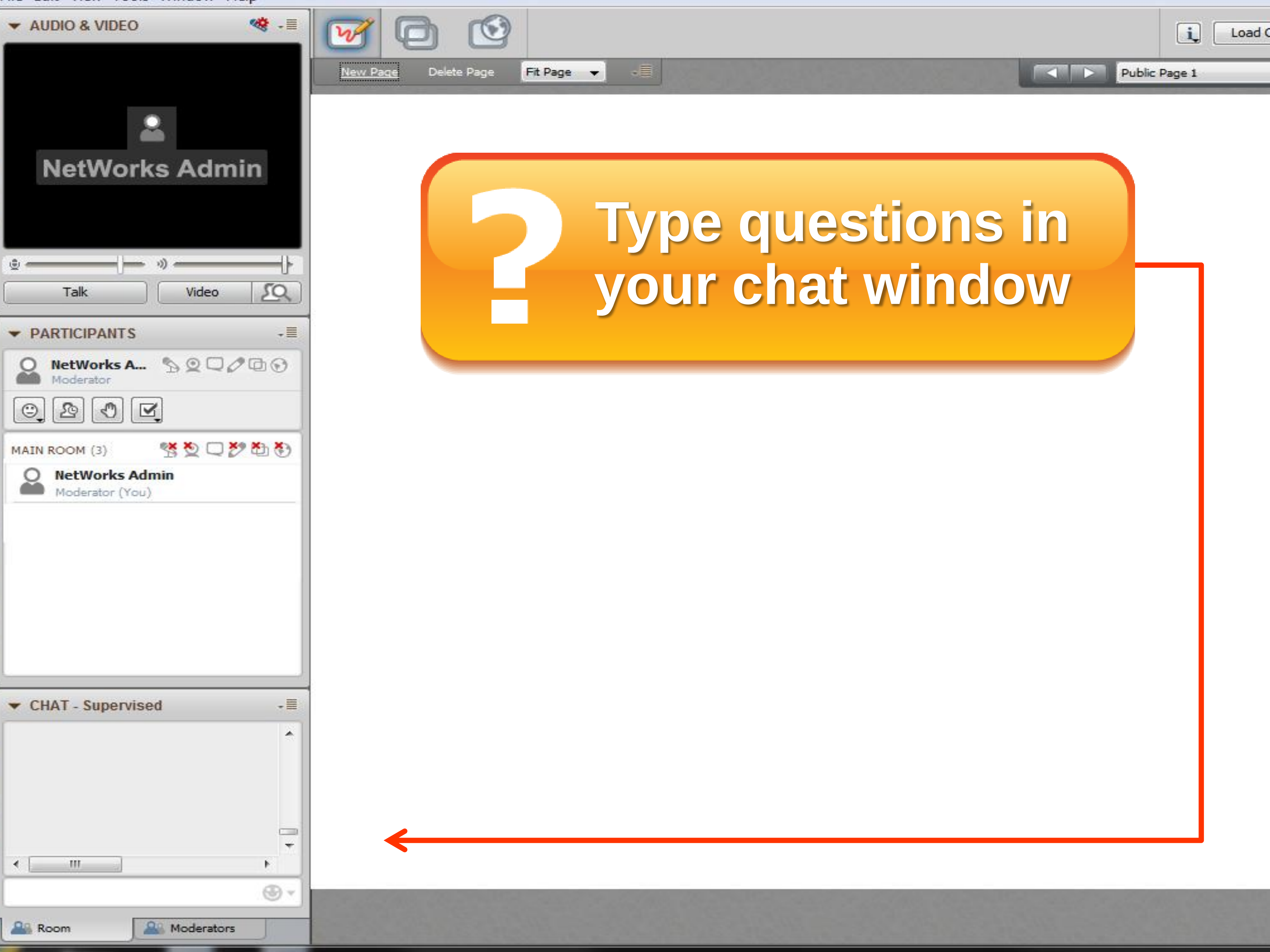
http://www.azonano.com/article.aspx?ArticleID=1538



Source: NIST

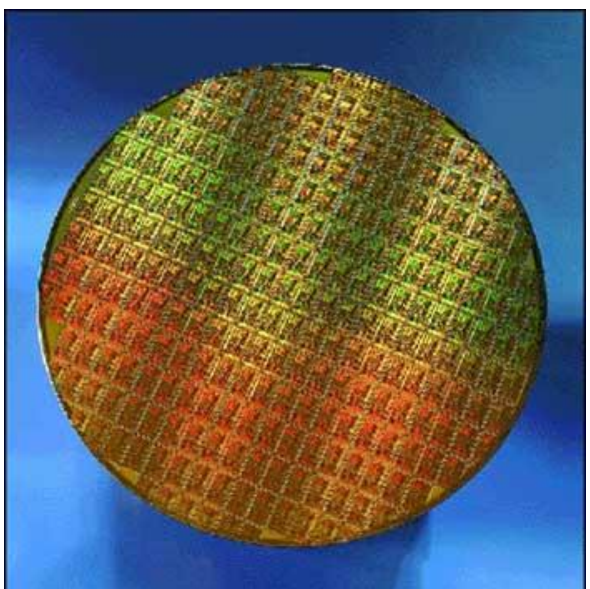
Nanotechnology for Energy

- Solid state lighting
- Solar cells
- Batteries
- Catalysts

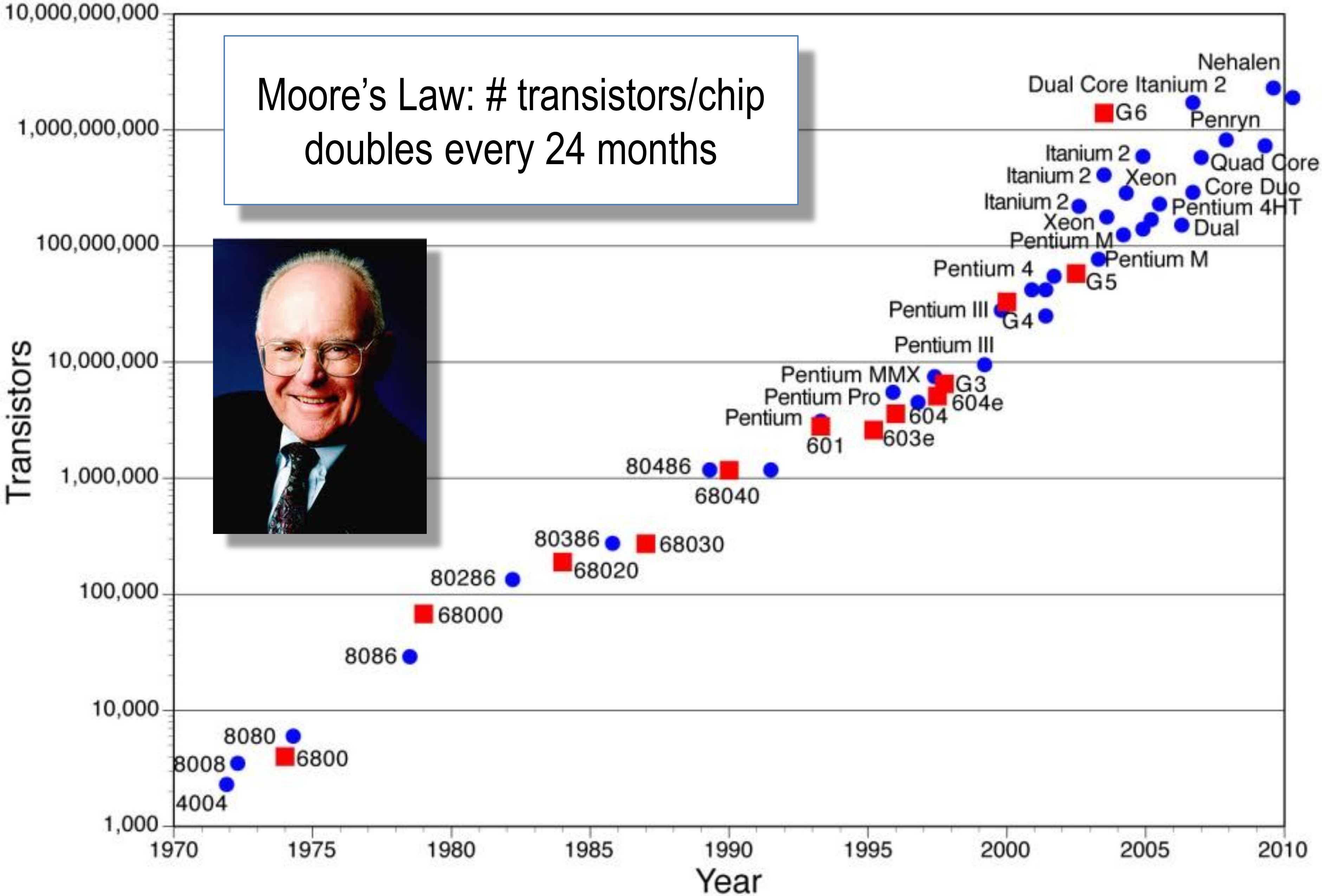

AUDIO & VIDEO
NetWorks Admin
Talk
Video
PARTICIPANTS
NetWorks A...
Moderator
MAIN ROOM (3)
NetWorks Admin
Moderator (You)
CHAT - Supervised
Room
Moderators
New Page
Delete Page
Fit Page
Public Page 1
Load
?
Type questions in
your chat window

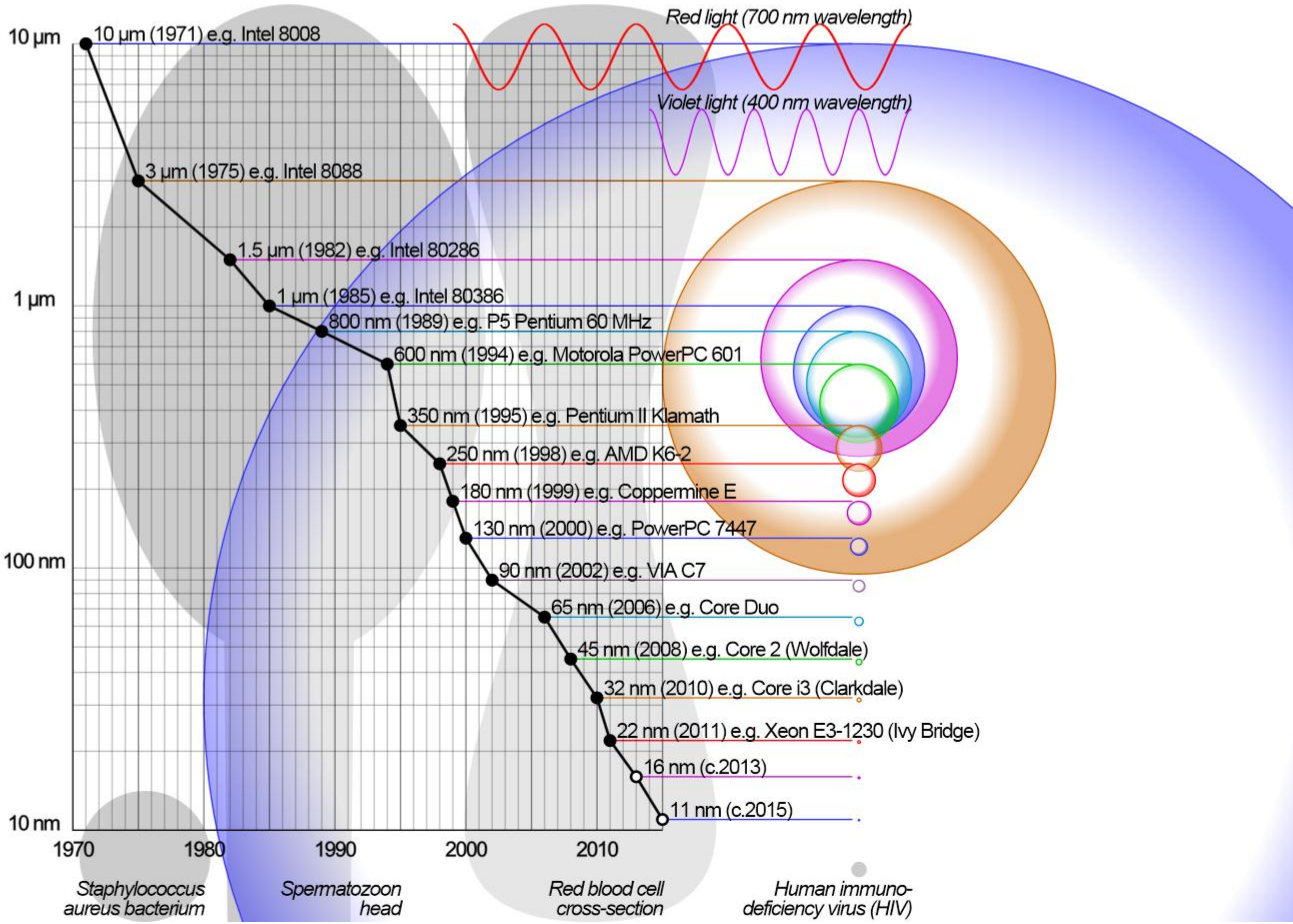
Nanotechnology for Electronics

- More connected
- More mobile
- More data = more knowledge
- More "intelligent" environment



Moore's Law: # transistors/chip doubles every 24 months





Red light (700 nm wavelength)
Violet light (400 nm wavelength)
10 µm
1 µm
100 nm
10 nm
10 µm (1971) e.g. Intel 8008
3 µm (1975) e.g. Intel 8088
1.5 µm (1982) e.g. Intel 80286
1 µm (1985) e.g. Intel 80386
800 nm (1989) e.g. P5 Pentium 60 MHz
600 nm (1994) e.g. Motorola PowerPC 601
350 nm (1995) e.g. Pentium II Klamath
250 nm (1998) e.g. AMD K6-2
180 nm (1999) e.g. Coppermine E
130 nm (2000) e.g. PowerPC 7447
90 nm (2002) e.g. VIA C7
65 nm (2006) e.g. Core Duo
45 nm (2008) e.g. Core 2 (Wolfdale)
32 nm (2010) e.g. Core i3 (Clarkdale)
22 nm (2011) e.g. Xeon E3-1230 (Ivy Bridge)
16 nm (c.2013)
11 nm (c.2015)
1970
1980
1990
2000
2010
Staphylococcus aureus bacterium
Spermatozoon head
Red blood cell cross-section
Human immuno-deficiency virus (HIV)

Audience Poll

How many transistors does Intel sell annually?

A. 1.43 billion/person

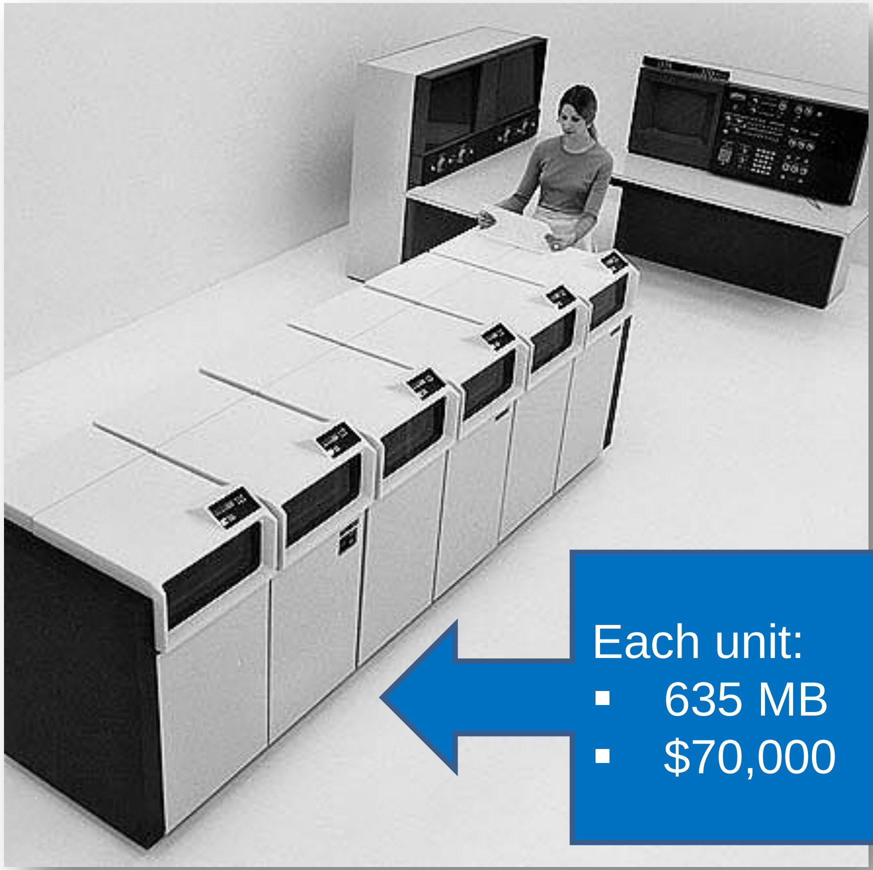
B. 10^{19}

C. 10 quintillion

D. All of the above

What Moore's Law Has Enabled

1976: Best available storage technology was the IBM 3350



Each unit:
- 635 MB
- $70,000

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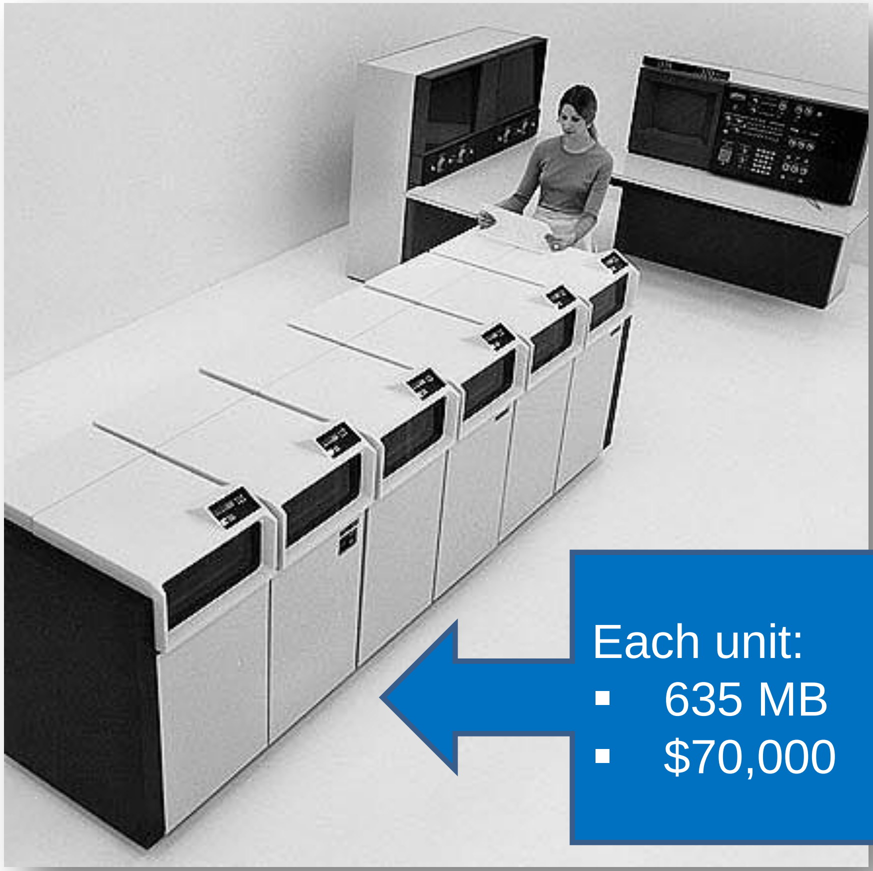


Each unit:
- 635 MB
- $70,000

80Gb cost $9,000,000 !!! in 1976 dollars

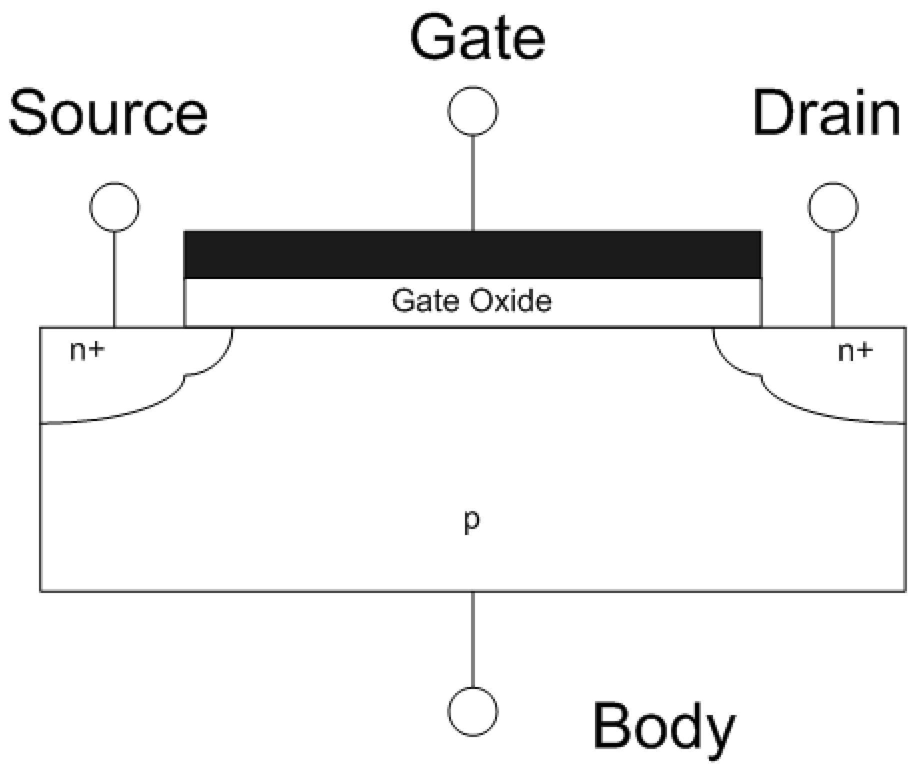
126 IBM 3350's = storage in 1 iPod

2006

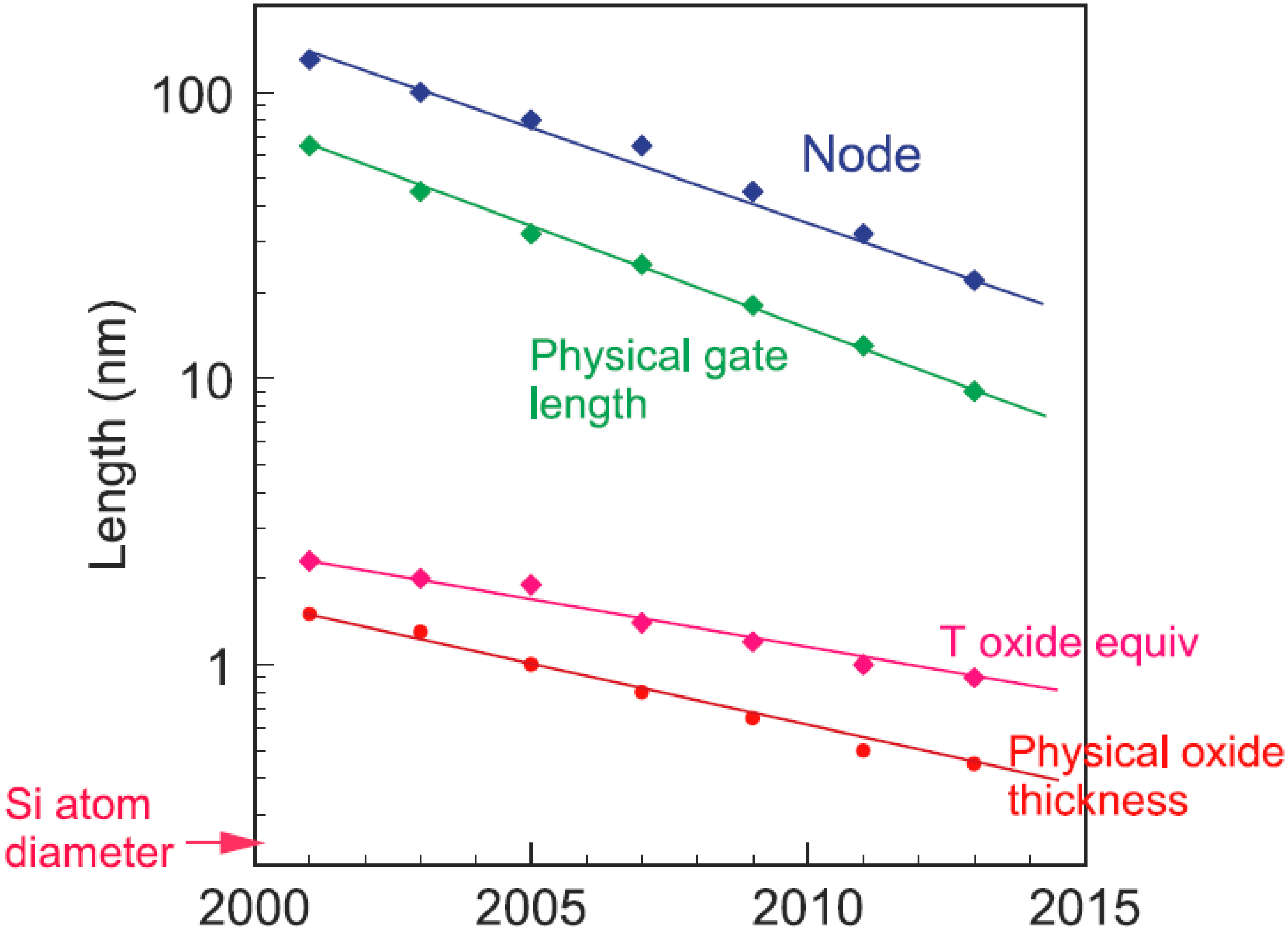
iPod(5G) 80GB

80Gb cost $350 in 2006 dollars

Basic Semiconductor Transistor

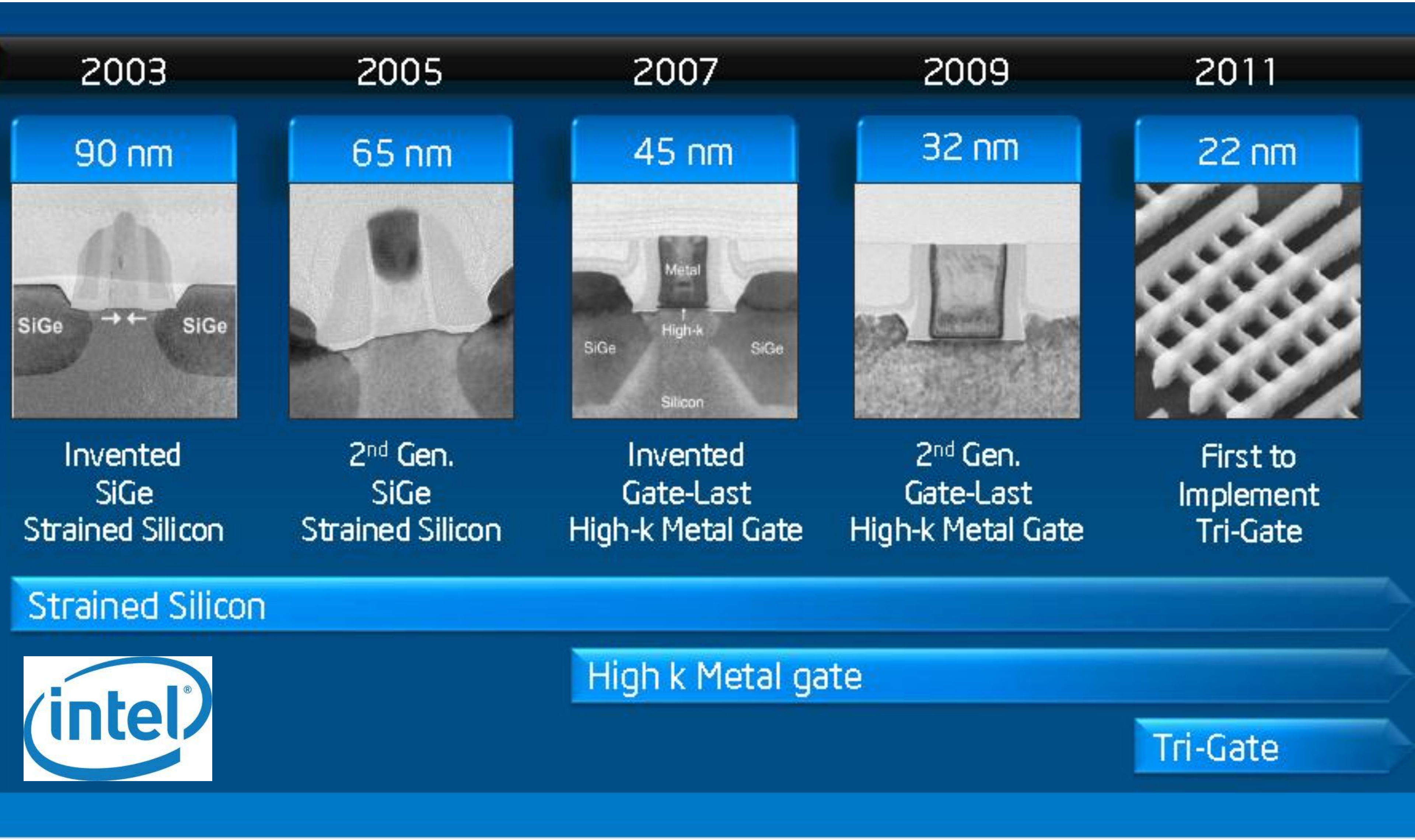


Scaling of Transistor Feature Sizes Push Gate Oxide Material Limits



Source: Robertson, Eur Phys J Appl Phys, 28 (2004) 265

Nanotechnology + Electronics = Today's "Semiconductor" Industry



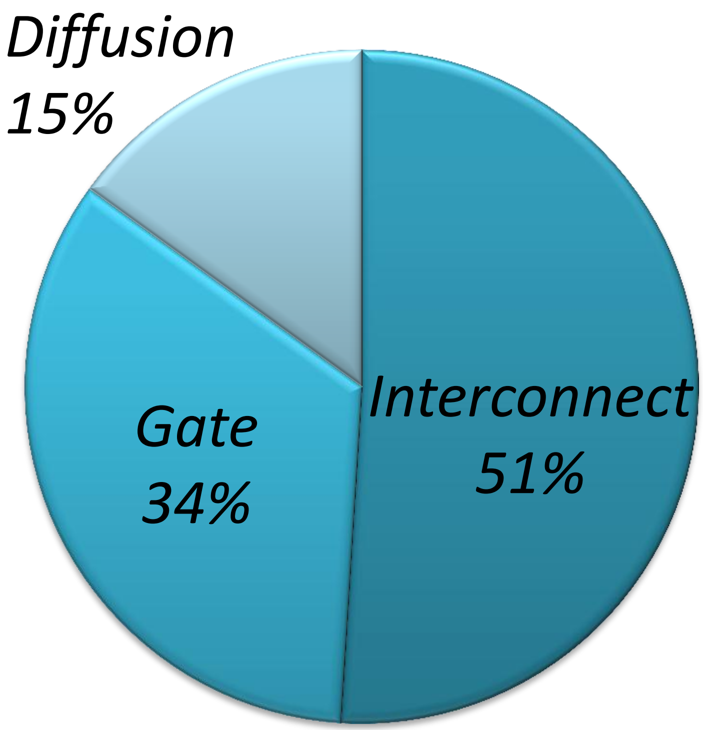
Nano-thick Gate Oxide Layer Requires New High-K Material

	K	Gap (eV)	CB offset (eV)
Si		1.1	
SiO_2	3.9	9	3.2
Si_3N_4	7	5.3	2.4
Al_2O_3	9	8.8	2.8 (not ALD)
Ta_2O_5	22	4.4	0.35
TiO_2	80	3.5	0
$SrTiO_3$	2000	3.2	0
ZrO_2	25	5.8	1.5
→ HfO_2	25	5.8	1.4
$HfSiO_4$	11	6.5	1.8
→ La_2O_3	30	6	2.3
Y_2O_3	15	6	2.3
a-$LaAlO_3$	30	5.6	1.8

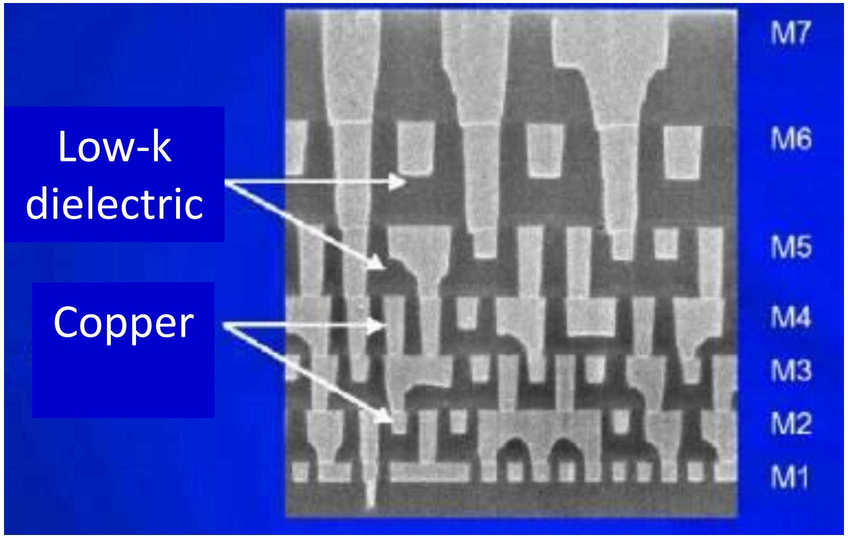
Source: Robertson, Eur Phys J Appl Phys, 28 (2004) 265

As Transistors Shrink, So Do Interconnects

Half of microprocessor power goes to interconnects (> 1 billion transistors; total budget= 200 watts)



New conductive and insulating (nano)materials are needed



Source: NIST

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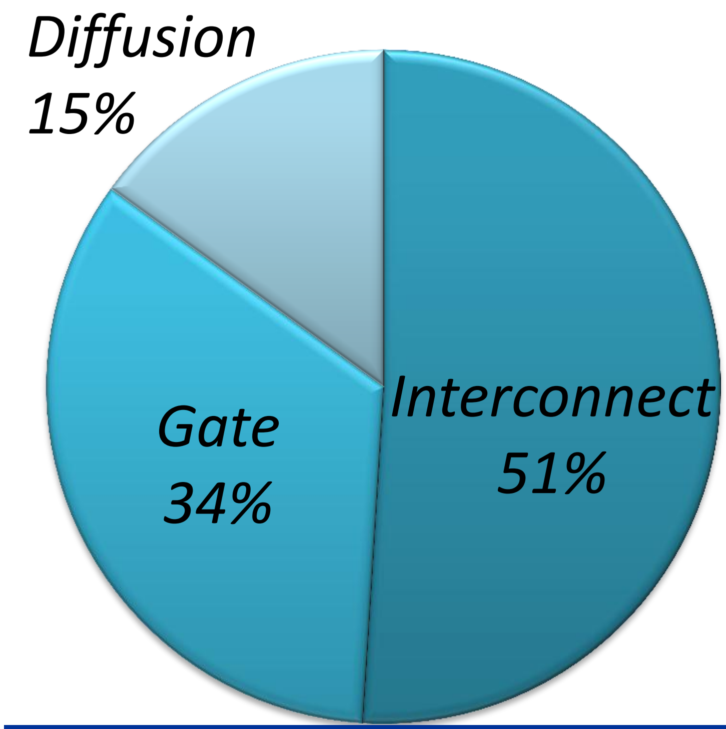

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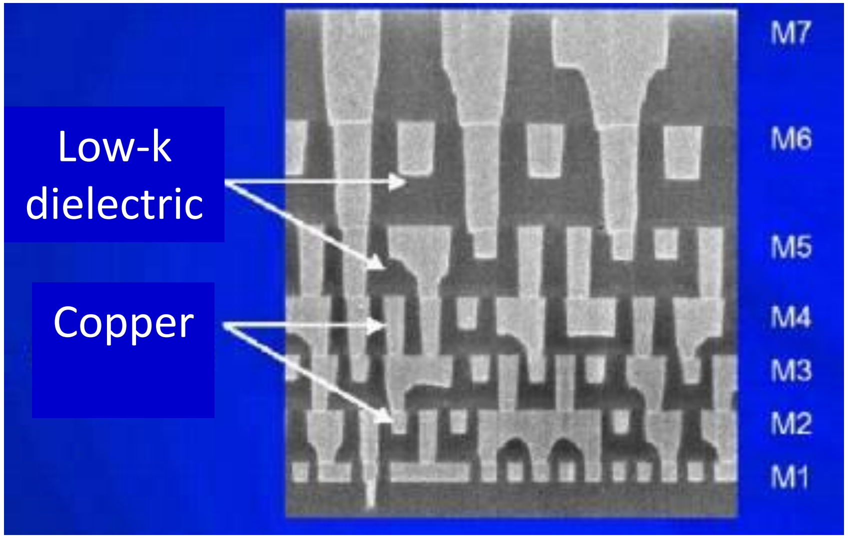
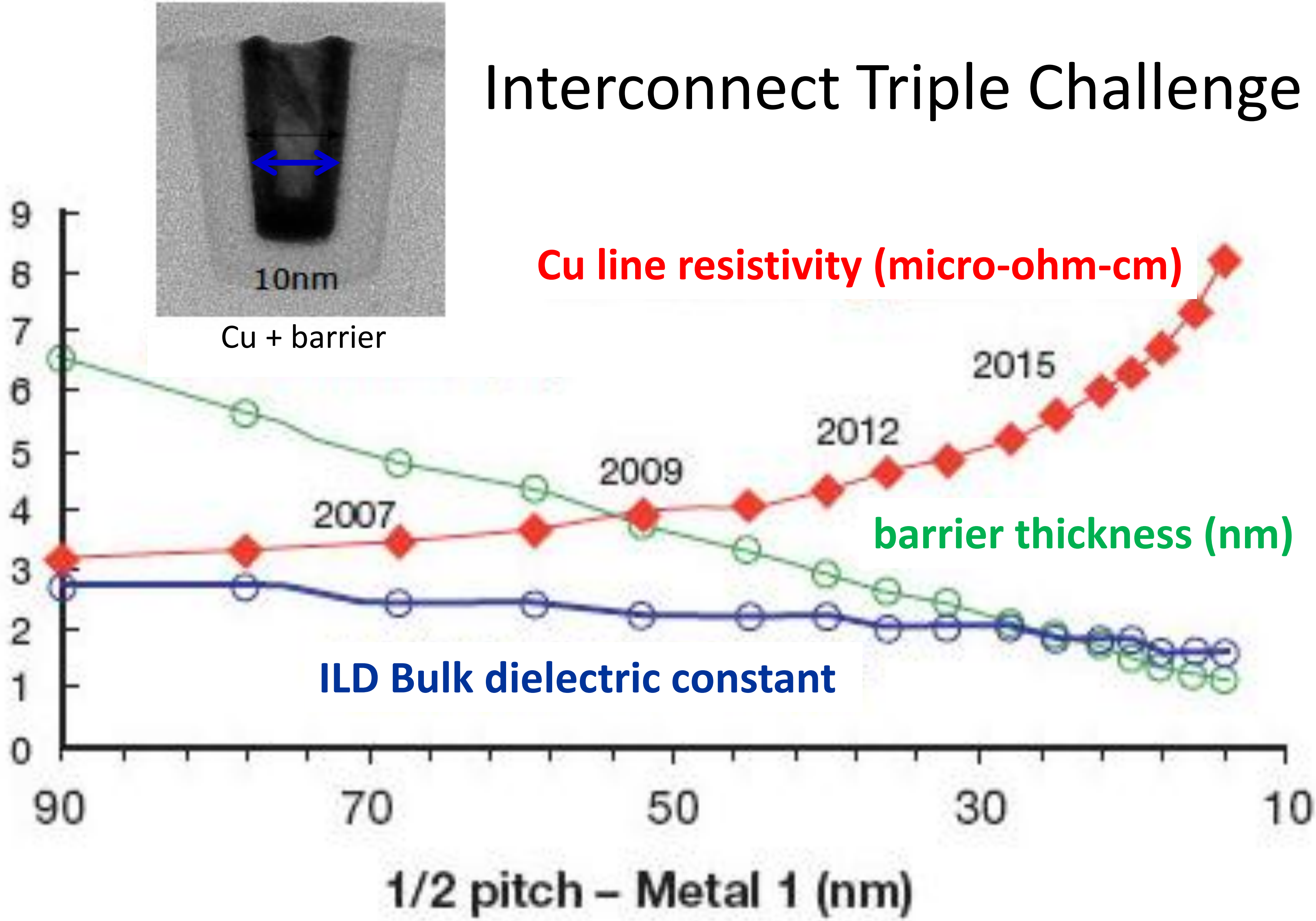


Source: NIST

Length of interconnects in a microprocessor = 36 miles

Interconnect Triple Challenge

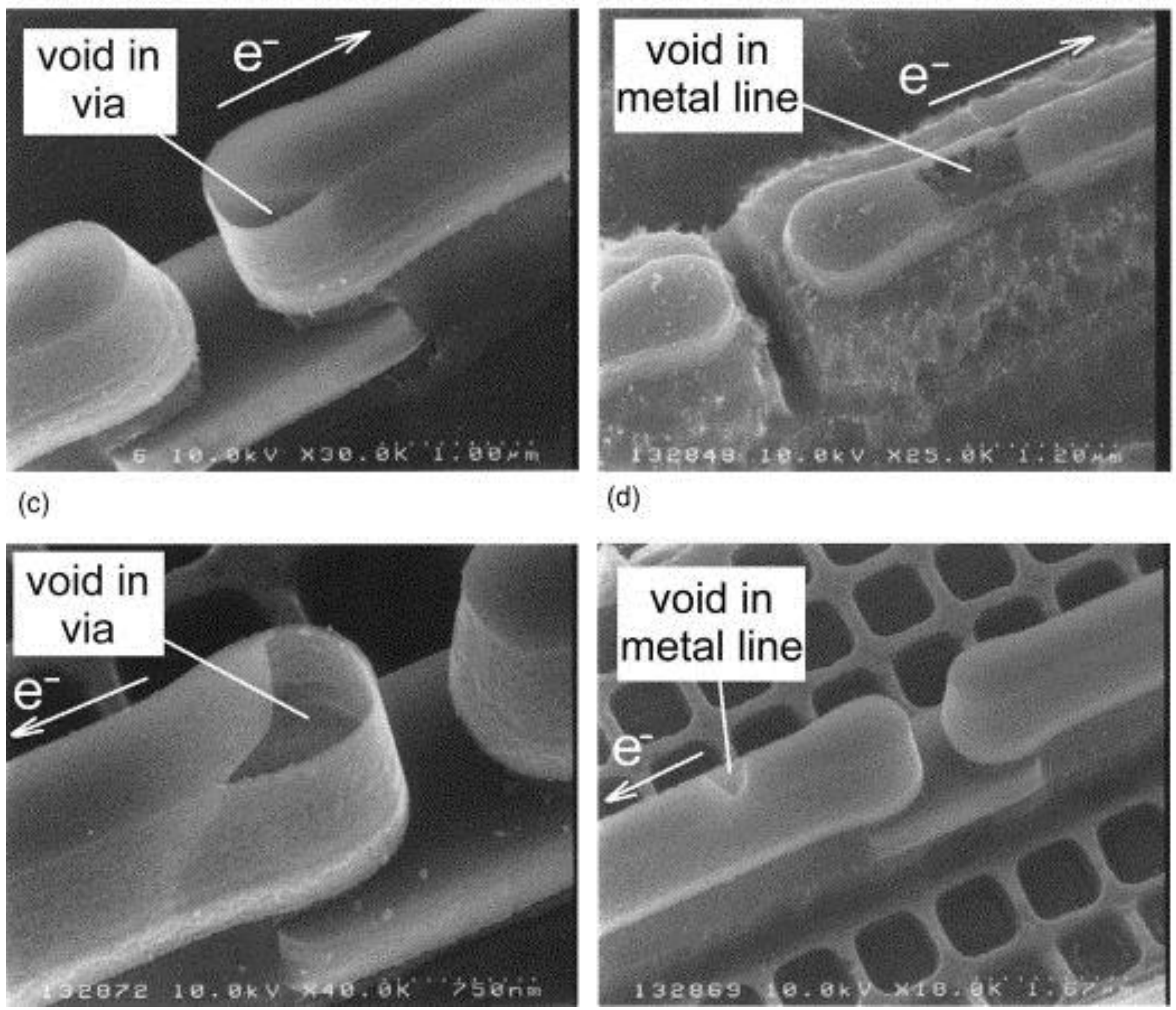


Source: http://www.future-fab.com/documents.asp?d_ID=4414

Better Insulators: Low-k Dielectric Materials

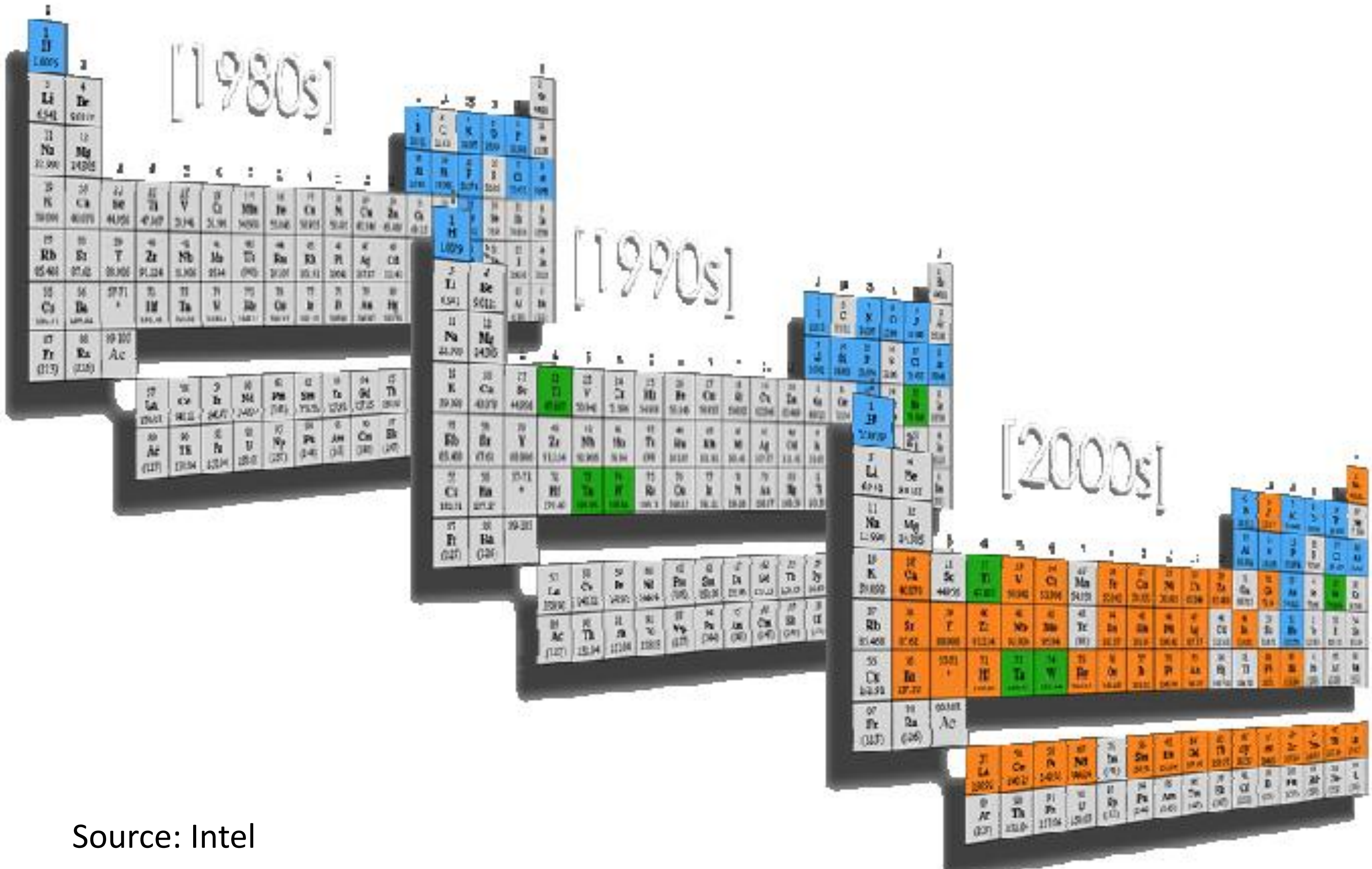
Dielectric	Value of k (@ 1 MHz)
$SiO_x F_y$	3.2 - 3.5
Hydrogen silsesquioxane	3.0
Polysiloxane	2.89
Fluropolyimide	2.8
Benzo-cyclo-butane	2.7
Black diamond	2.7
Polyethylene	2.4
Polypropylene	2.3
Fluoropolymer	2.24
Perylene	2.2
Dupont PTFE-based copolymer AF 2400	2.06
Xerogels	1.2
Air	1.0
Carbon dioxide	1.0

Interconnect Performance Impacted by Scaling: Electromigration Voiding



Source: Fischer et al., Microelectronics Reliability 41 (2001) 445
http://www.sciencedirect.com/science/article/pii/S0026271400002468

“Silicon” Chips are Complex Nanomaterials

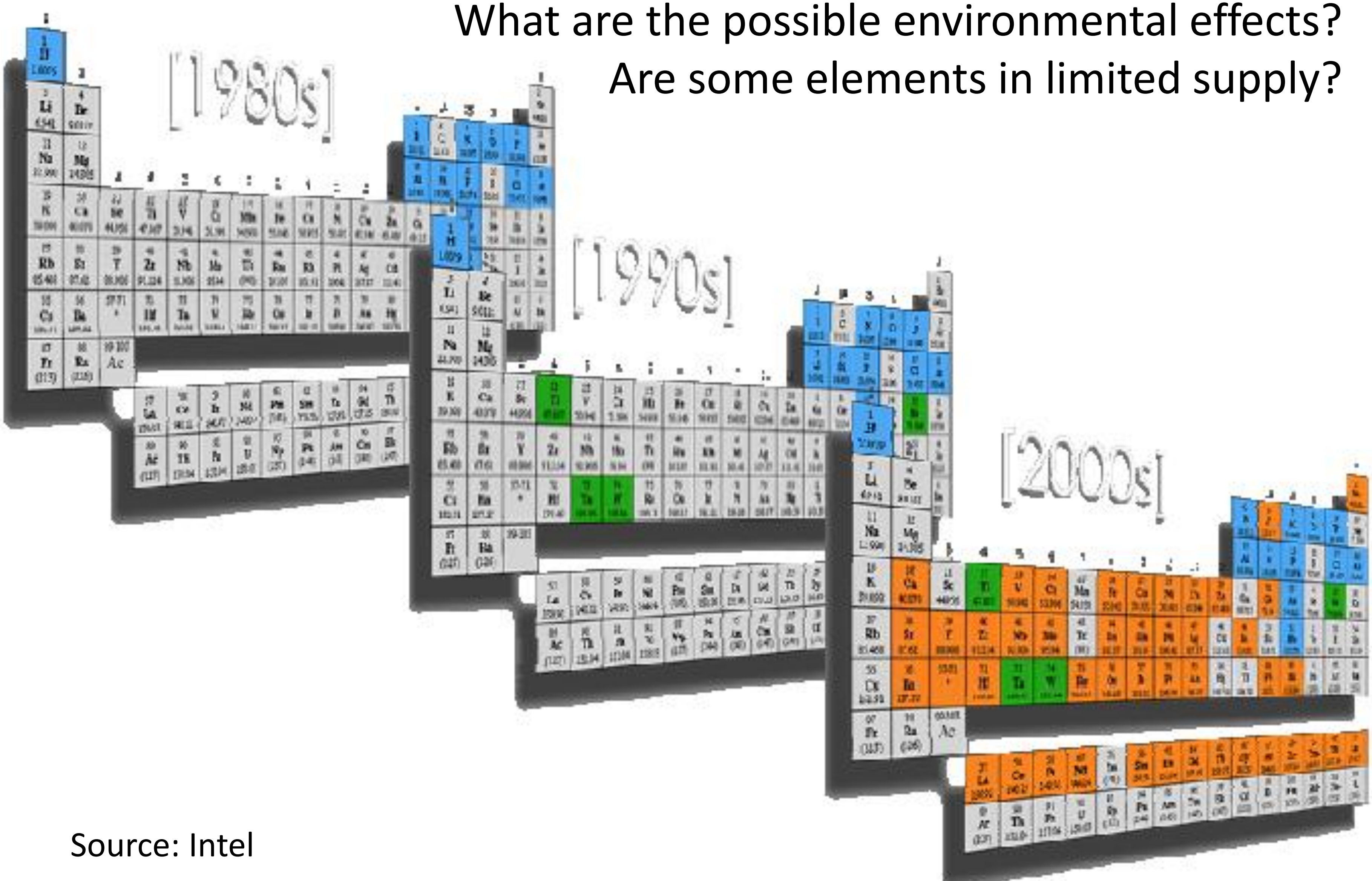


Source: Intel

"Silicon" Chips are Complex Nanomaterials

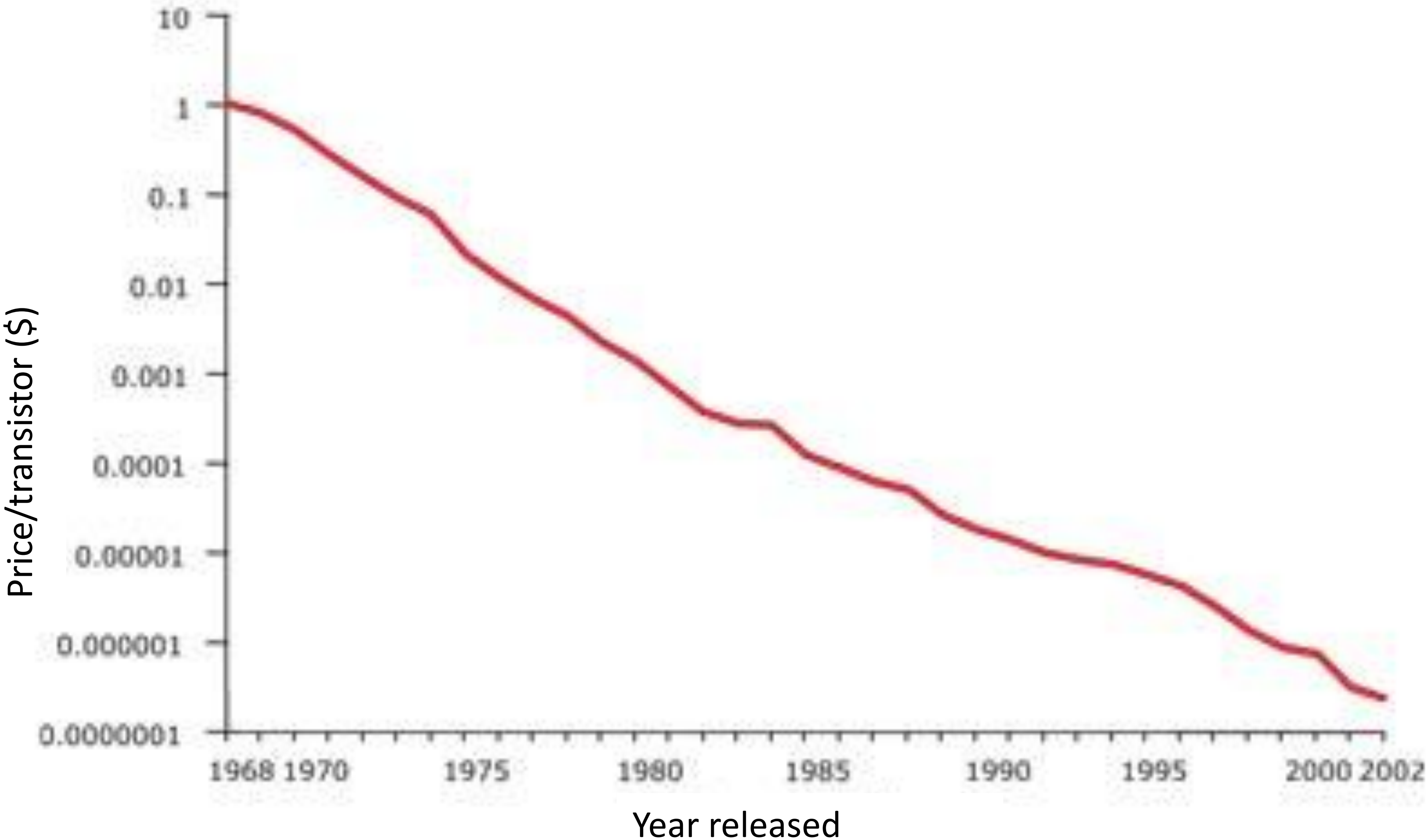
What are the possible environmental effects?

Are some elements in limited supply?

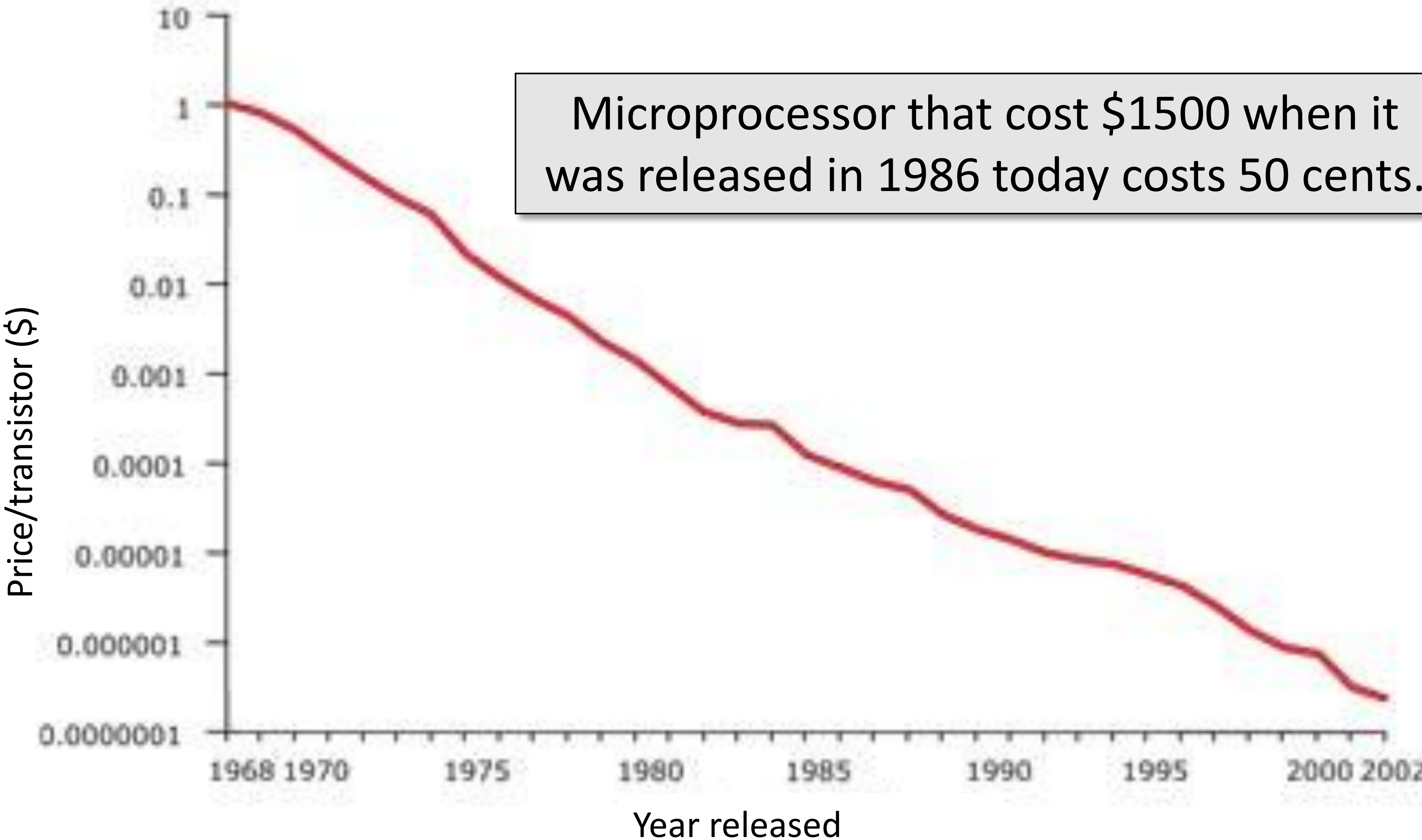


Source: Intel

Transistor/chip ↑ = Price/transistor ↓

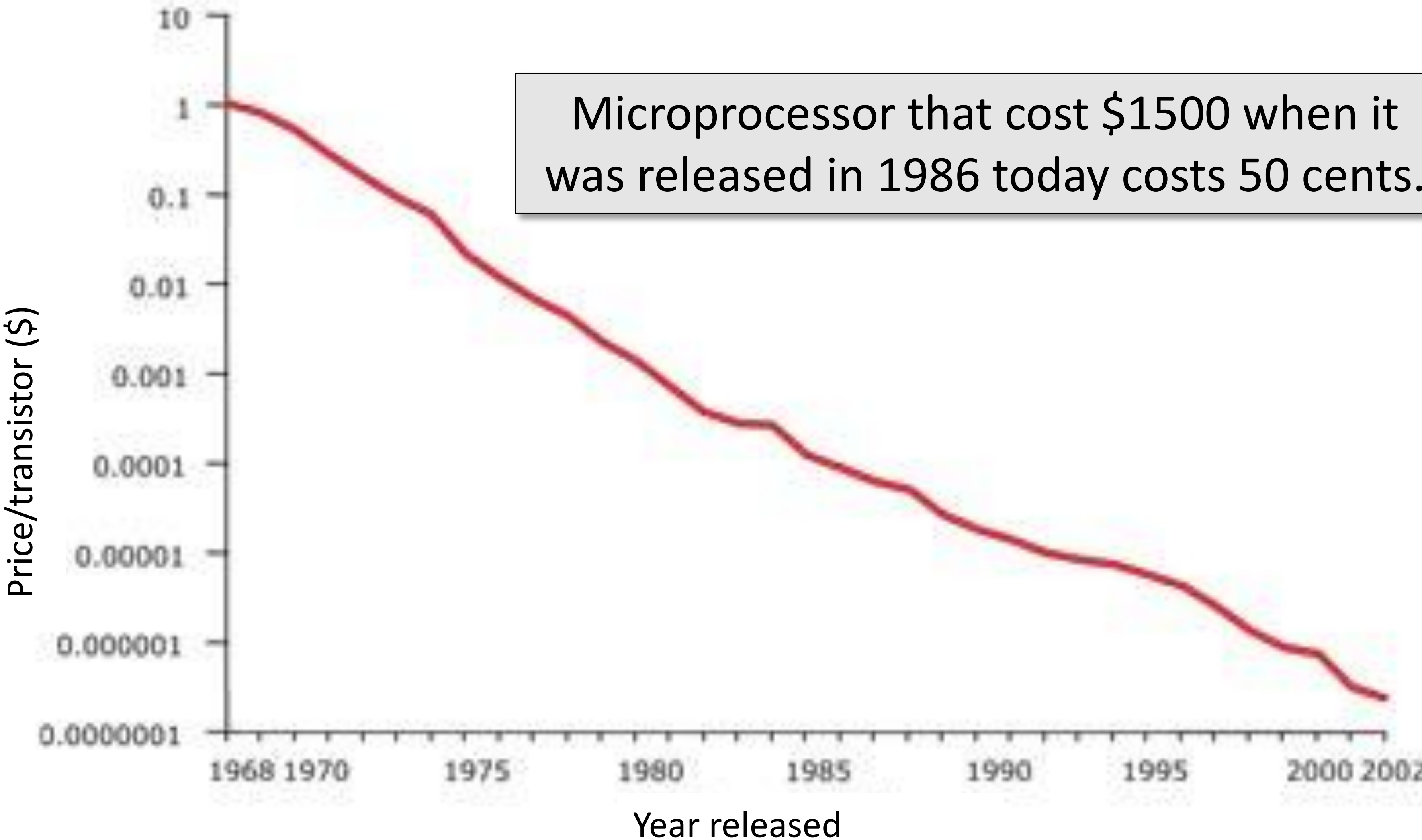


Transistor/chip ↑ = Price/transistor ↓



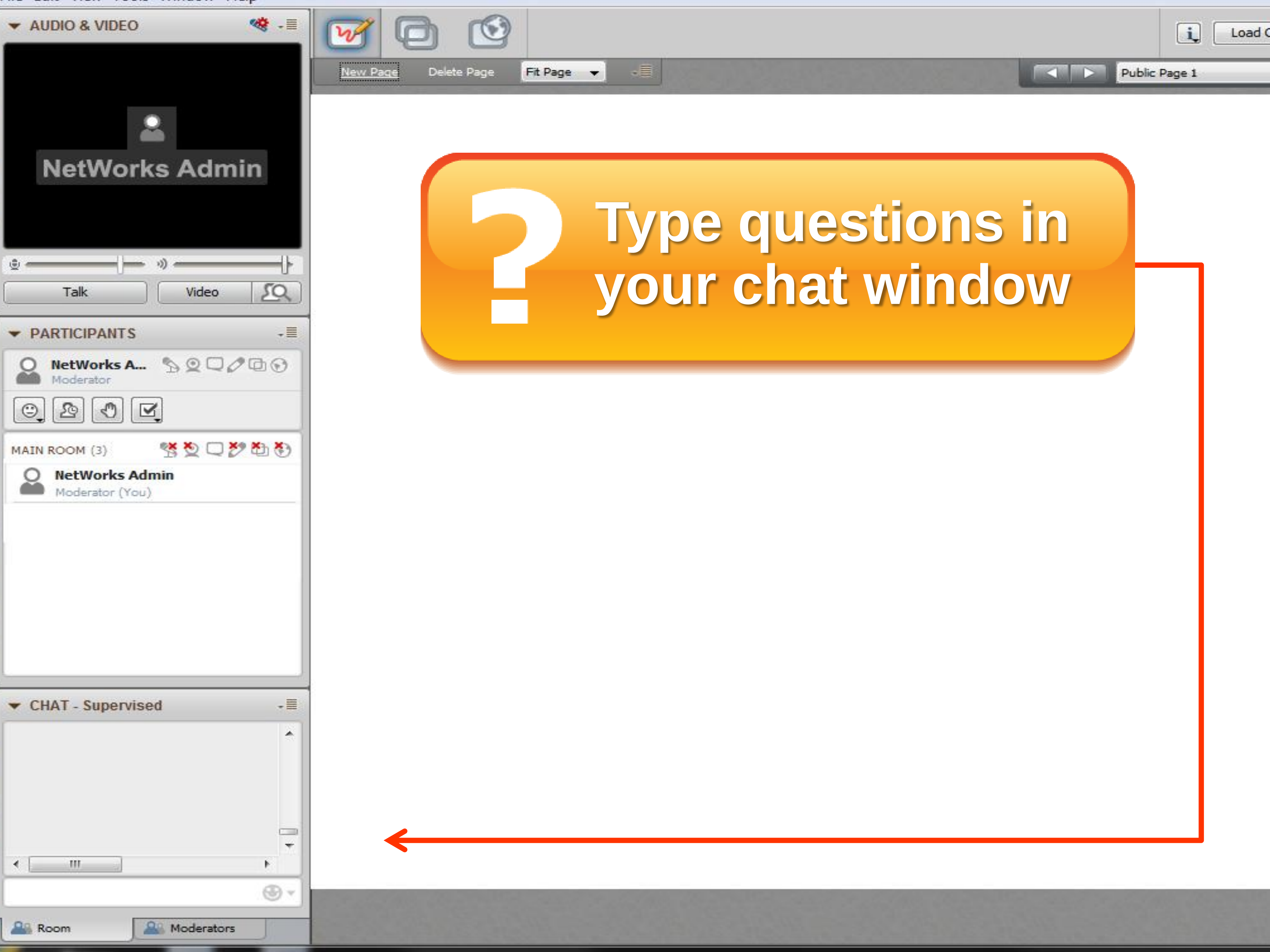
Microprocessor that cost $1500 when it was released in 1986 today costs 50 cents.

Transistor/chip ↑ = Price/transistor ↓



Microprocessor that cost $1500 when it was released in 1986 today costs 50 cents.

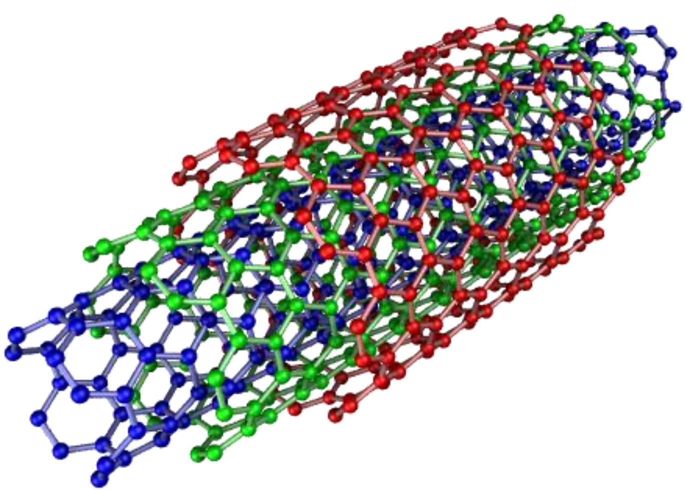
What happens when silicon transistors reach their limits?



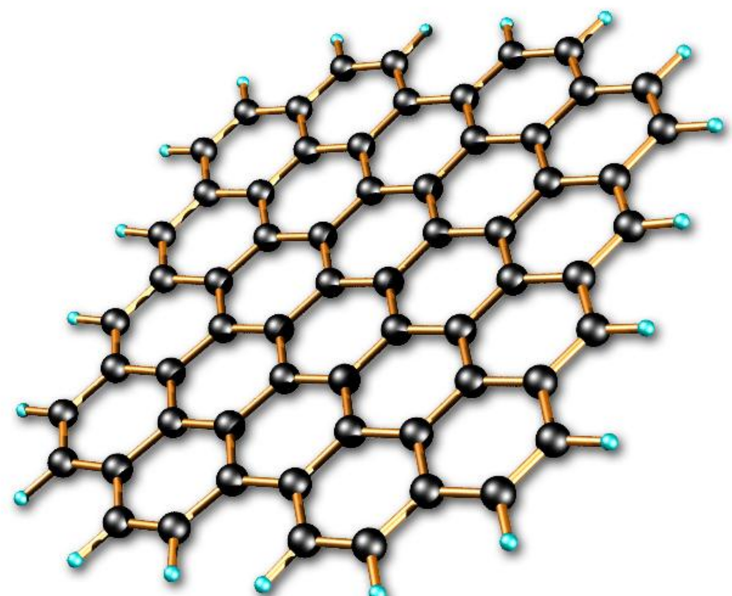
AUDIO & VIDEO
NetWorks Admin
Talk
Video
PARTICIPANTS
NetWorks A...
Moderator
MAIN ROOM (3)
NetWorks Admin
Moderator (You)
CHAT - Supervised
Room
Moderators
New Page
Delete Page
Fit Page
Public Page 1
Type questions in your chat window

Nanoelectronics: Beyond Today's Technology

- Can we store and send 1's and 0's using something other than charge?
- Are there materials that offer advantages?



Carbon Nanotubes



Graphene

Nanoelectronics Research Initiative Industry-Govt Partnership

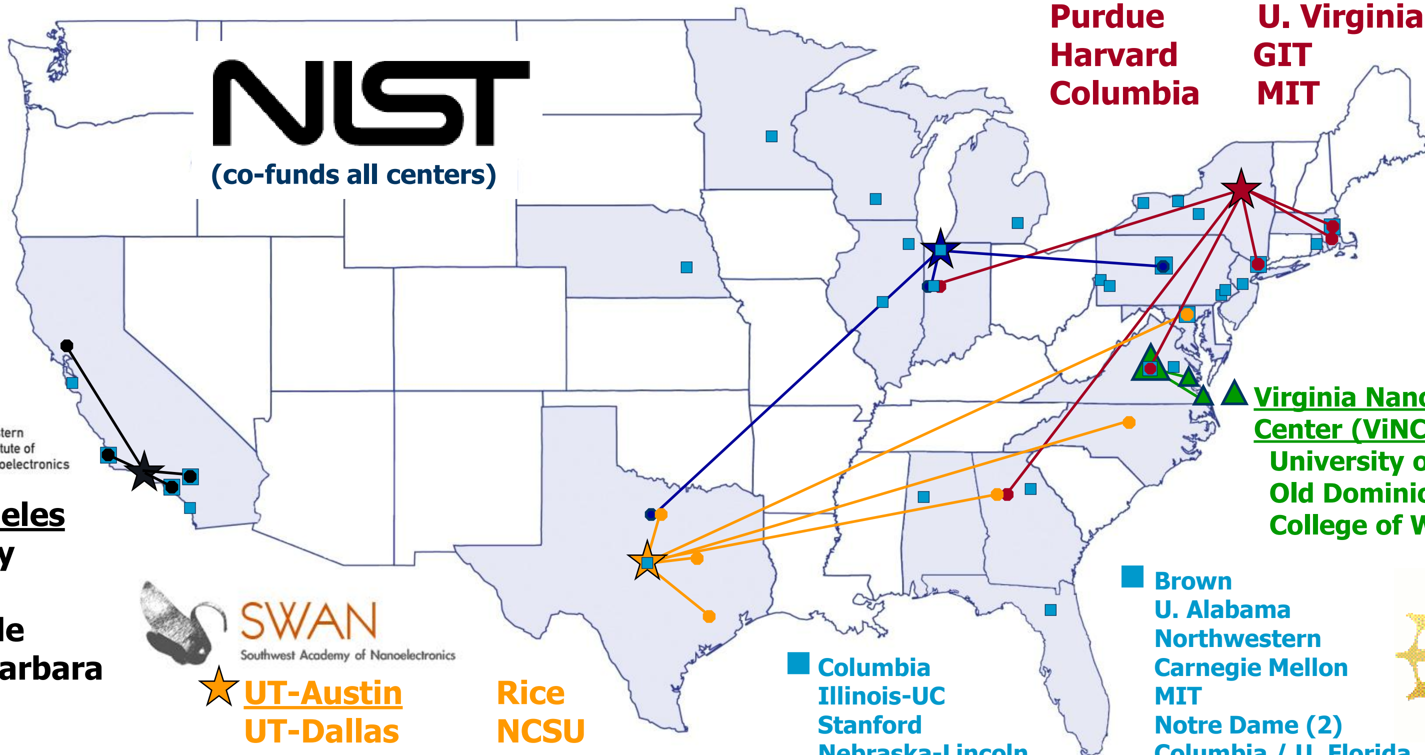
Nanoelectronics • Architectures MIND MIDWEST INSTITUTE FOR NANOELECTRONICS DISCOVERY

★ Notre Dame
Penn State
Purdue
UT-Dallas

INDEX INSTITUTE FOR NANOELECTRONICS DISCOVERY AND EXPLORATION

★ SUNY-Albany
Purdue
Harvard
Columbia
U. Virginia
GIT
MIT

NIST
(co-funds all centers)



WIN Western Institute of Nanoelectronics

★ UC Los Angeles
UC Berkeley
UC Irvine
UC Riverside
UC Santa Barbara

SWAN Southwest Academy of Nanoelectronics

★ UT-Austin
UT-Dallas
U. Maryland
GIT
Rice
NCSU
Texas A&M

▲ Virginia Nanoelectronics Center (ViNC)
University of Virginia
Old Dominion University
College of William & Mary

■ Columbia
Illinois-UC
Stanford
Nebraska-Lincoln
Penn State
Princeton / UT-Austin
UC-Santa Barbara
UC-Riverside / Georgia
Virginia Commonwealth / UC-R / Michigan / U. Virginia
UC-Riverside / UC-I / UC-SD / Rochester / SUNY-Buffalo
U. Pittsburgh / U. Wisconsin-Madison / Northwestern

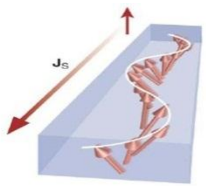
■ Brown
U. Alabama
Northwestern
Carnegie Mellon
MIT
Notre Dame (2)
Columbia / U. Florida
U. of Minnesota
Cornell / Princeton
Drexel University / UI-UC / U. Penn

NSF

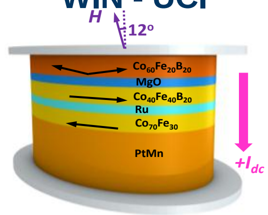
Over 40 Universities in 19 States

NRI: Research on Novel Materials and Devices for "Beyond Moore's Law"

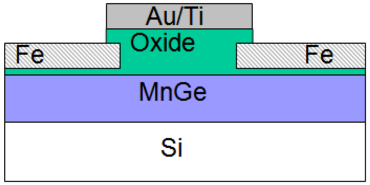
Spin-Wave Device
WIN - UCLA, UCSB



Spin-Torque Device
WIN - UCI

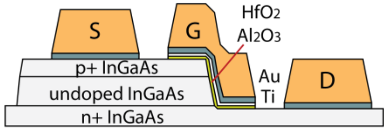


Spin-FET
WIN - UCLA



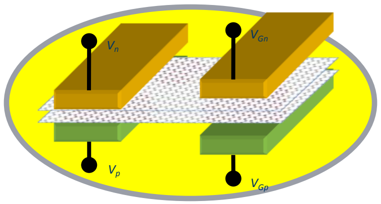
Tunnel Devices
MIND

Heterojunctions
Notre Dame, Penn State

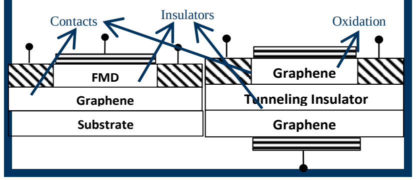


vertical TFET - side gated

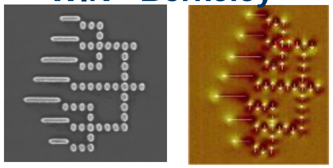
Bilayer pseudoSpin
SWAN - UT Austin



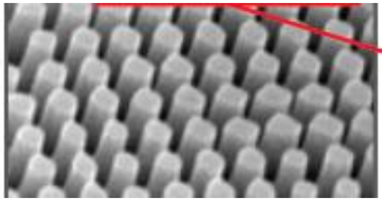
Graphene Processes
SWAN – UT Dallas



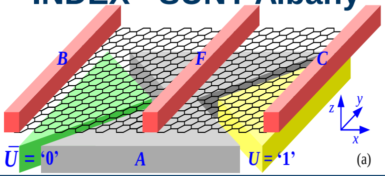
Nanomagnet Logic
MIND - Notre Dame
WIN - Berkeley



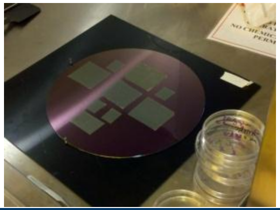
Nanowires
Penn State



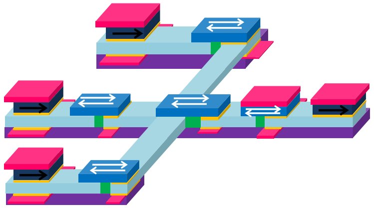
Graphene PN Junction Device
INDEX - SUNY Albany



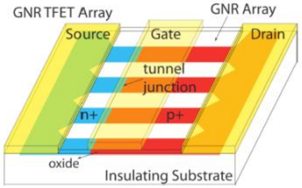
Graphene Integration
INDEX – SUNY Albany



All-Spin Logic
INDEX - Purdue U.



Graphene
Notre Dame



Barriers to Realizing Benefits of Nano

Barriers to Realizing Benefits of Nano

✓ Standards

Barriers to Realizing Benefits of Nano

- ✓ Standards
- ✓ Regulatory certainty

Barriers to Realizing Benefits of Nano

- ✓ Standards
- ✓ Regulatory certainty
- ✓ Scalable manufacturing

Barriers to Realizing Benefits of Nano

- ✓ Standards
- ✓ Regulatory certainty
- ✓ Scalable manufacturing
- ✓ Prepared workforce

Industry is hiring at all levels

GLOBALFOUNDRIES®

About GLOBALFOUNDRIES

Introducing the First Truly Global Foundry

GLOBALFOUNDRIES entered the foundry industry in early 2009 with a simple but ambitious goal to become the world's first truly global foundry. In a short span of time, we have achieved this milestone with manufacturing operations spanning three continents for flexible and secure supply. Furthermore, we are charting a bold new course to completely reshape the landscape of the foundry industry through a collaborative approach to both technology development and customer engagement.

d Content

ration and Innovation
Unique Value Propositions
Leadership Team
Technology Solutions
Advanced Technologies
Design Solutions

Please select a Position

Position	Apply for Position
Failure Analysis Technician	Apply
EHS & Security Technicians	Apply
Fab Systems Setup Technician	Apply
Facilities Dept	Apply
Factory Automation Technician	Apply
Factory Information Control Technician	Apply
Integration Engineering Technician	Apply
Maintenance Technician	Apply
Process Integration Technician	Apply
Process Technician	Apply
Wafer Fab Operator	Apply
Warehousing Log & Mat	Apply
Process Integration & Yield Enhancement	Apply

Ab

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truly g ... s spanning three
contin ... eshape the landscape
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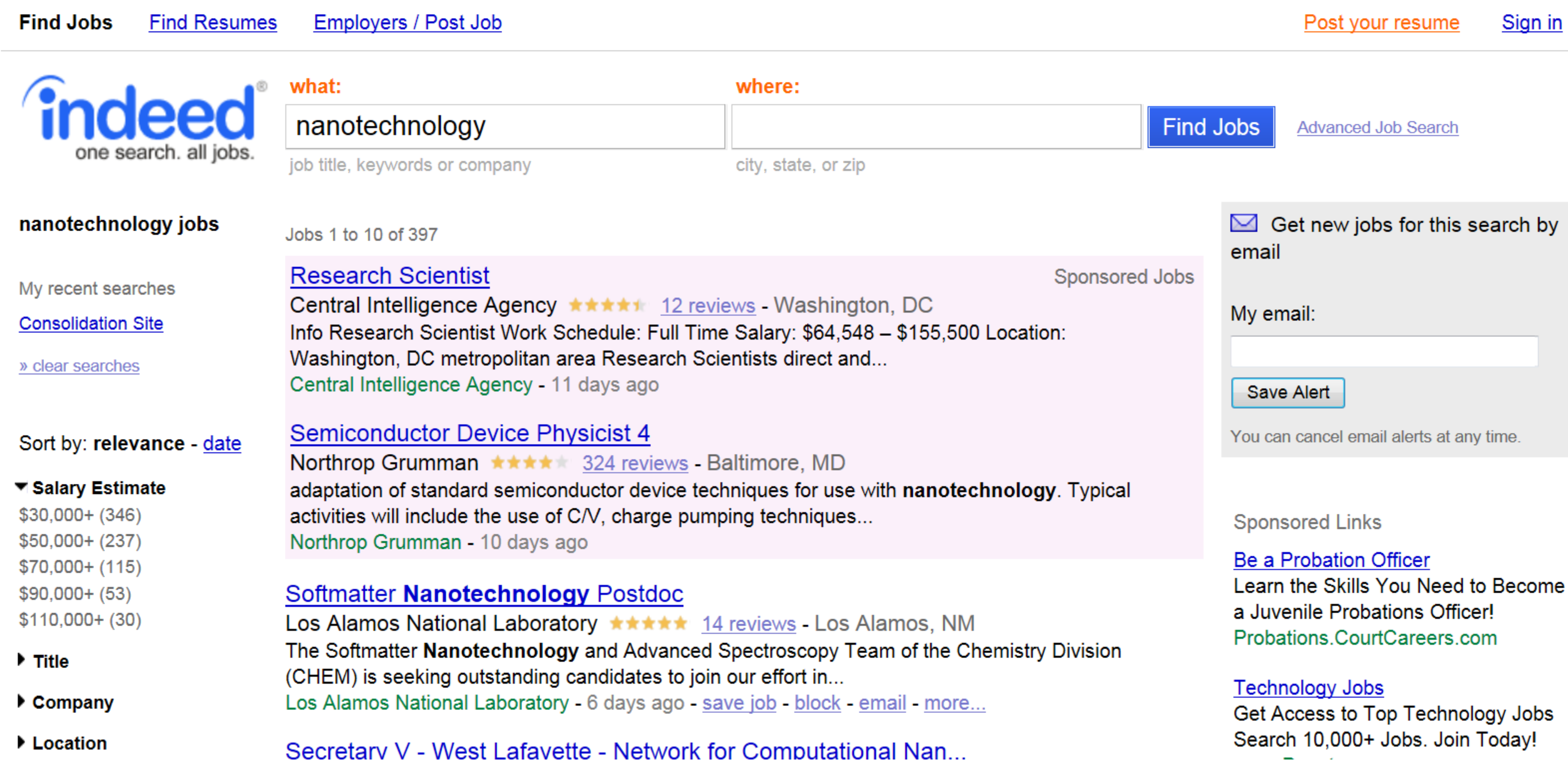
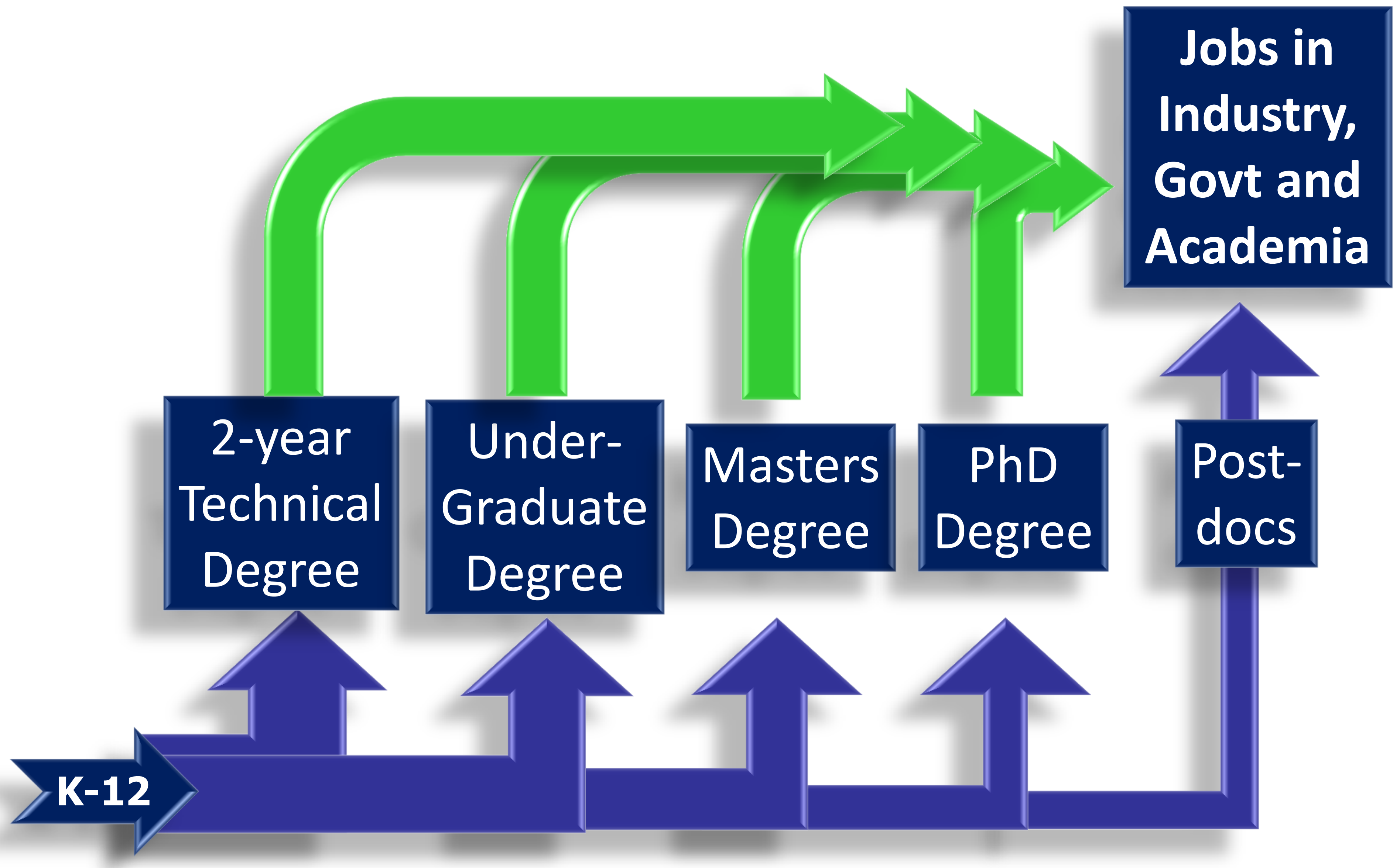
Unique Value Propositions
Leadership Team
Technology Solutions
Advanced Technologies
Design Solutions

Nanotechnology Jobs

- Multidisciplinary
- Varied education requirements
- High paying (1/3 pay $70K or more)



Nano Education Pipeline

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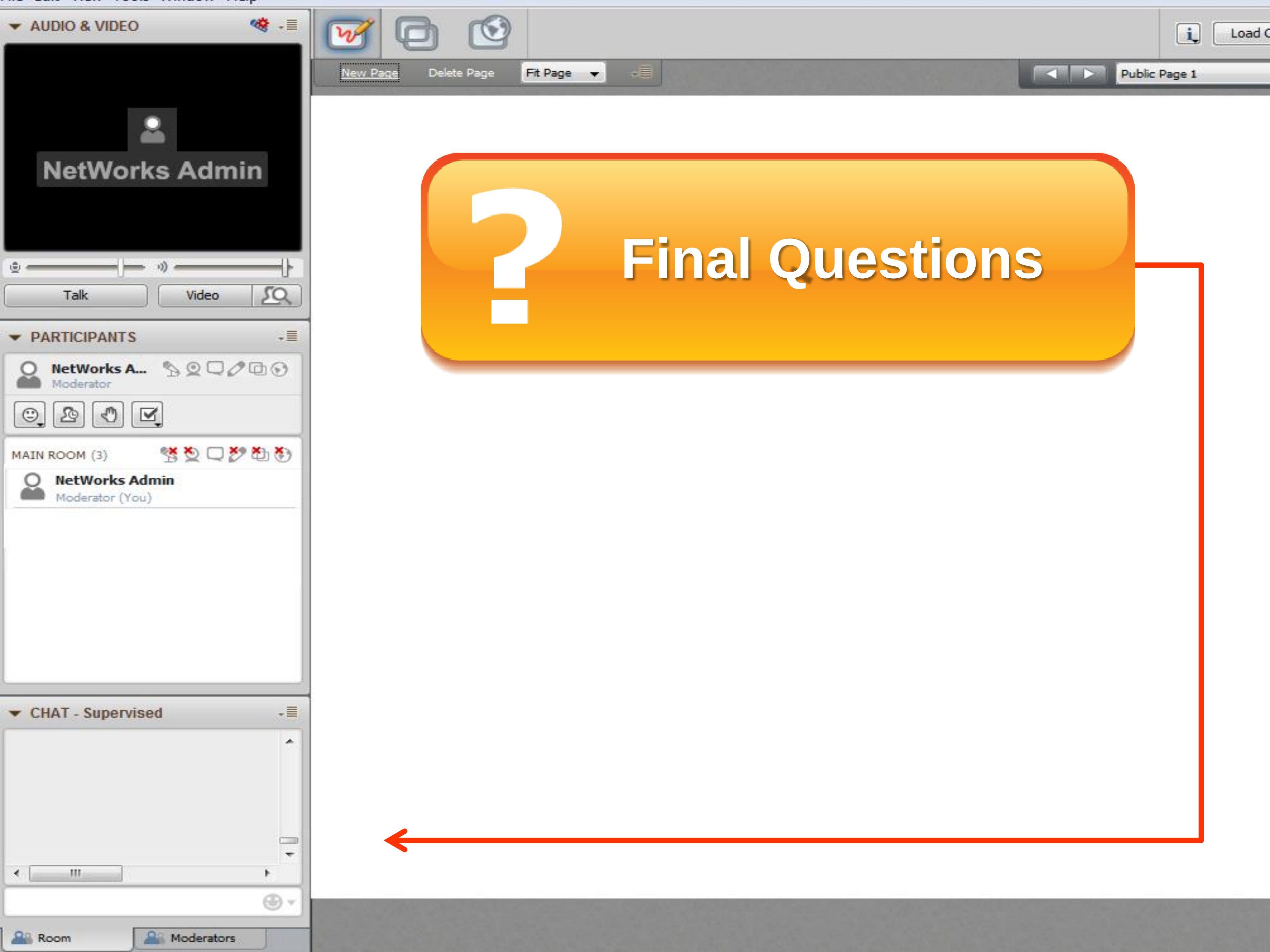
AUDIO & VIDEO
NetWorks Admin
Talk
Video
PARTICIPANTS
NetWorks A...
Moderator
MAIN ROOM (3)
NetWorks Admin
Moderator (You)
CHAT - Supervised
Room
Moderators
New Page
Delete Page
Fit Page
Public Page 1
Final Questions

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Review of Objectives

- Objective 1: Introduce nanotechnology and its current applications
- Objective 2: Overview nanoelectronics and complex nanomaterials
- Objective 3: Give a perspective on future directions and emerging trends
- Objective 4: Address issues and implications for education and the workforce

Presenter Contact Info

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Thank you for attending the
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Our Nano Future:
From Discovery to Innovation