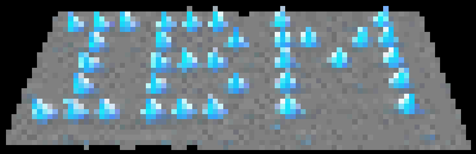
Corporate Environmental Affairs

Nanotechnology as a Tool to Advance Pollution Prevention in the Semiconductor/IT Industry

Airgap Microprocessors: Directed Self-Assembly



Arthur Fong, PhD

US EPA Pollution Prevention
through Nanotechnology Conference

September 25-26, 2007
Arlington, VA

Presentation Outline

- **Overview of nanotechnology in semiconductor/IT industry**
- **Nanotechnology - Tool to enhance performance and advance pollution prevention**
  - Airgap microprocessors: directed self-assembly

Nanotechnology – Hype vs. Substance - 1

- **$1 Trillion business by 2011-2015 (NSF, 2001)**
- **$2.6 Trillion of manufactured goods by 2014 (Lux Research, 2006)**

Nanotechnology – Hype vs. Substance - 2

- **“Nano”? products everywhere**

“Magic Nano” glass and ceramic tile sealant aerosol spray

Pentel - Nanocapsule-imbued scented pencil lead

Aromatherapy + nanotechnology

Nanotechnology – Hype vs. Substance - 3

- **Applied use currently limited, but ramping up fast**
  - Project on Emerging Nanotechnologies, Nanotechnology Consumer Products Inventory
- **Nanoelectronics leads nanotechnology commercialization**

Nanoelectronics Market Data and Forecast

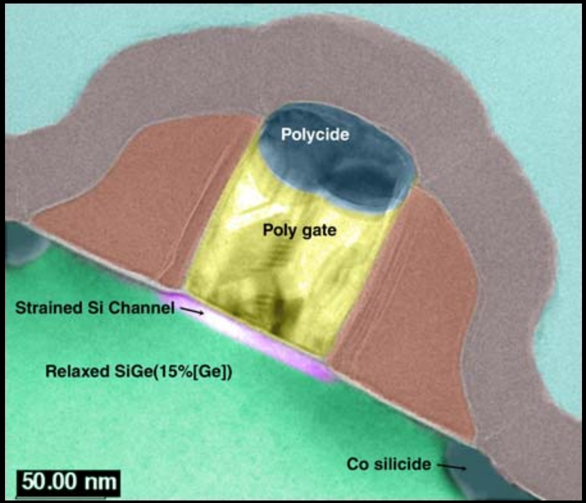
- **2005 Worldwide market ~ US $60 billion**
- **2010 Worldwide projection ~ US $250 billion**

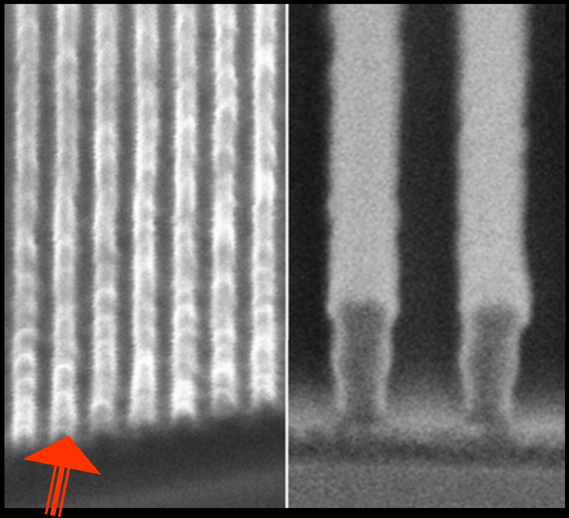
- **Nanoelectronics**
  - Displays – e.g., field emission display
  - MEMS/NEMS – e.g., nano-mechanical data storage
  - Optoelectronics/sensors – e.g., photonic devices
  - Semiconductors – e.g., transistors and interconnects
  - Hard-disk storage – e.g., magnetic storage

SEMI 2006

Nanotechnology is Not New in Semiconductor/IT Industry

- **Early stages**
  - 100 nm Bipolar transistor base (ca. 1970)
  - 100 nm CMOS (complementary metal oxide semiconductor) gate oxide (ca. 1970)
- **More recently**
  - Transistor physical gate length ~ 70 nm (2000)
  - 90-nm Technology node – gate oxide of 1.2 nm, about 4 atomic-layers thick (2003)
  - Electron beam lithography 40-70 nm



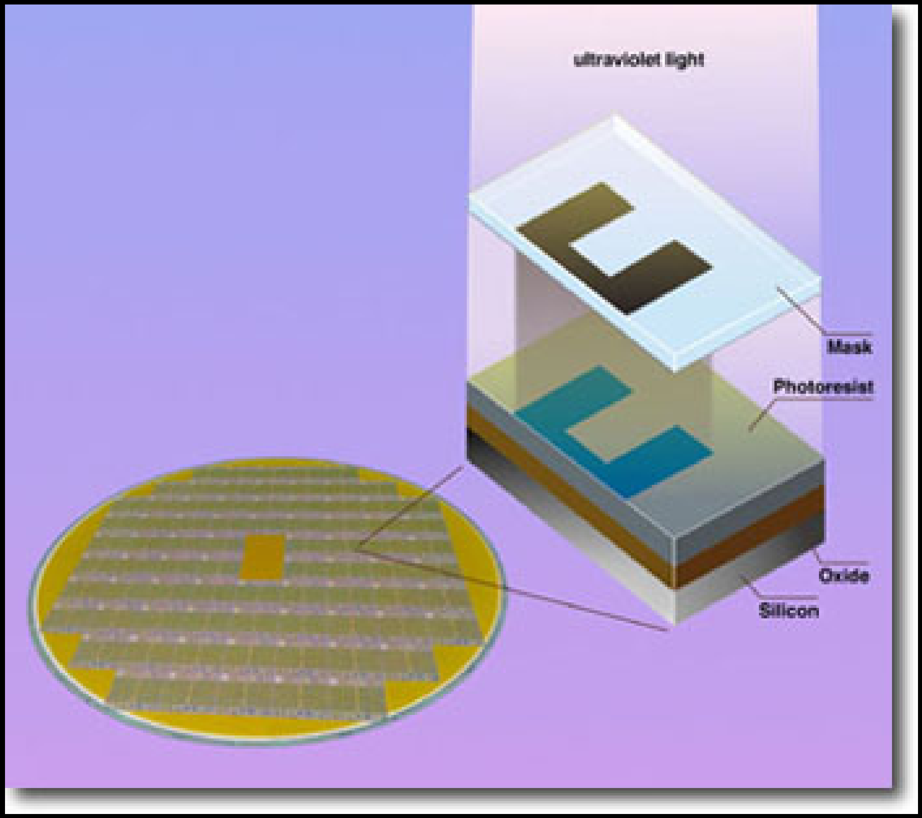


29.9 nm, Deep-UV optical lithography

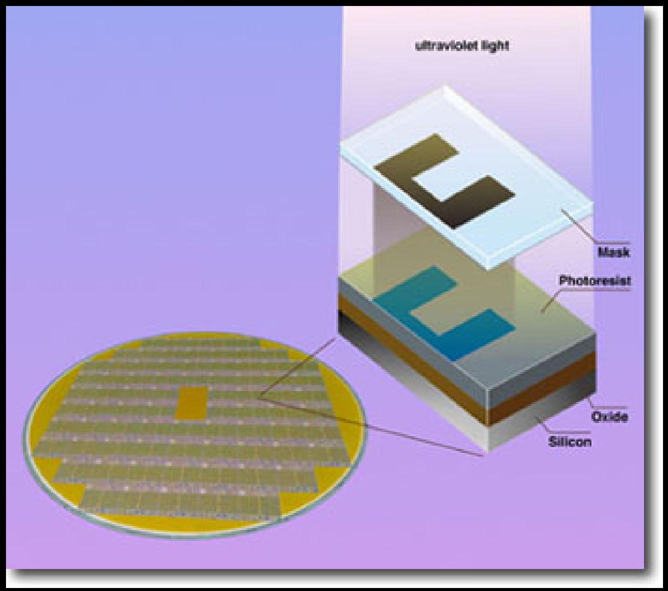
Current Semiconductor/IT Nanotechnology - Photolithography

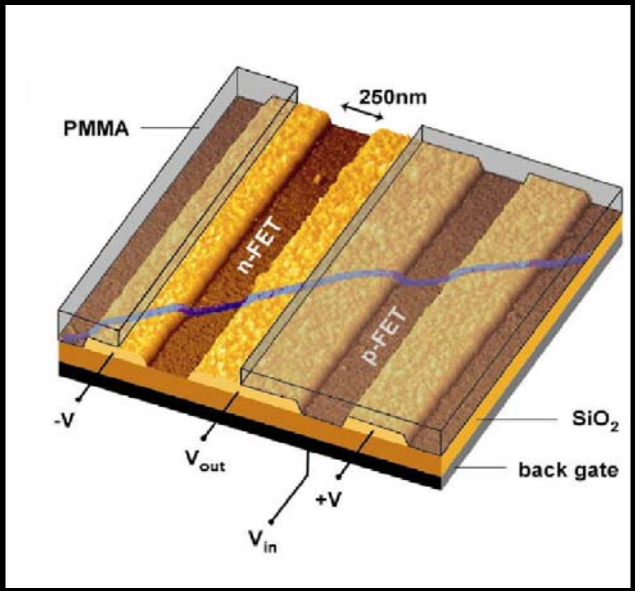
- **Masking**
- **Etching**

- **Examples of chemicals in photolithography**
  - Photoresist (photoactive organic polymers)
  - Developers (tetramethyl ammonium hydroxide)
  - Solvents and cleaning agents
  - Etching (acids, chlorine)
  - Stripping (acids, alkalines)



Traditional Semiconductor/IT Nanotechnology and Engineered Nanomaterials





- **Semiconductor/IT nanotechnology**
  - Minimum feature size of devices - at nanoscale for decades
  - Photolithography
  - "Does not present any unique hazards" (Royal Society & Royal Academy of Engineering, 2004)

- **Engineered nanomaterials**
  - Discrete manufactured nanoparticles, nanotubes, and other nanomaterials
- **Nanomaterials fixed within products**

Nanotechnology – A Critical Key to Future Development of Semiconductor/IT Industry

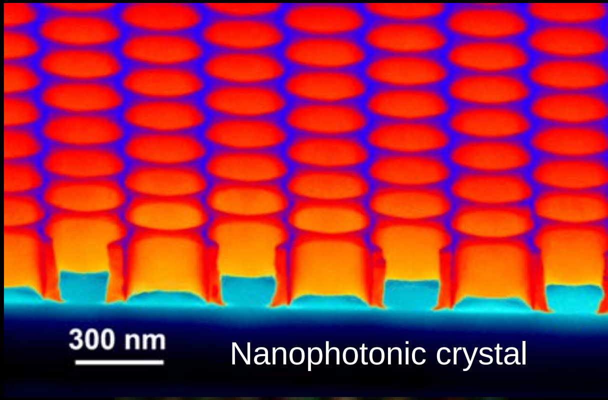
(*International Technology Roadmap for Semiconductors*, 2005, 2006)

- **Potential solutions to technical challenges**
  - Approaching limits of current manufacturing processes and materials
- **Potential solutions to business challenges**
  - Escalating fab costs
  - Opportunity for diversification
- **Tremendous opportunity for environmental, health, and safety benefits – pollution prevention**
  - Energy/resource conservation – manufacturing/processes
  - Waste minimization, e.g., self-assembly
  - Energy efficient products

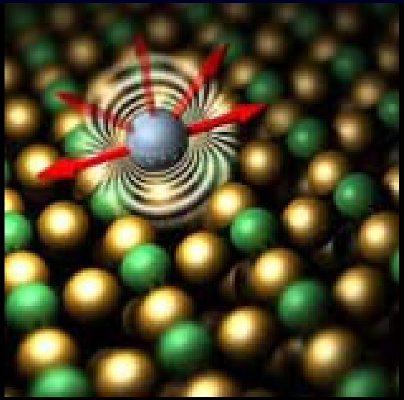
Examples of IBM Nanotechnology R&D
Performance Enhancement and Pollution Prevention

- **By 2010, the codified information base of the world is expected to double every 11 hours**

- **Nanophotonics – Control over light signal**
  - Optical Networks
- **Atomic magnetism – single-atom data storage (08/2007)**
- **Single-molecule switching – molecular computers comprising of just a few molecules (08/2007)**
- **Airgap microprocessors (05/2007)**
  - Directed self-assembly



Nanophotonic crystal


Magnetic orientation of an iron atom

Self-Assembly: How Will We Manufacture at the Nanoscale?

Two visions of nanofabrication:

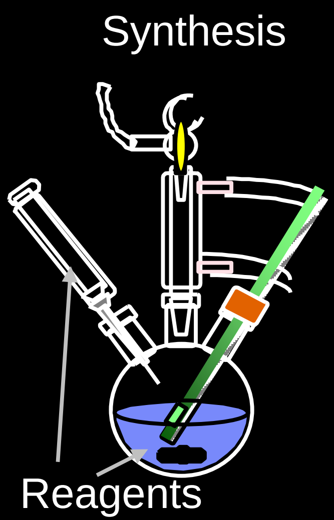
- **"Old"**
- **Top down**
- **Lithography**
- **Digital**
- **Depend on low error rates**
- **Molecular assemblers**

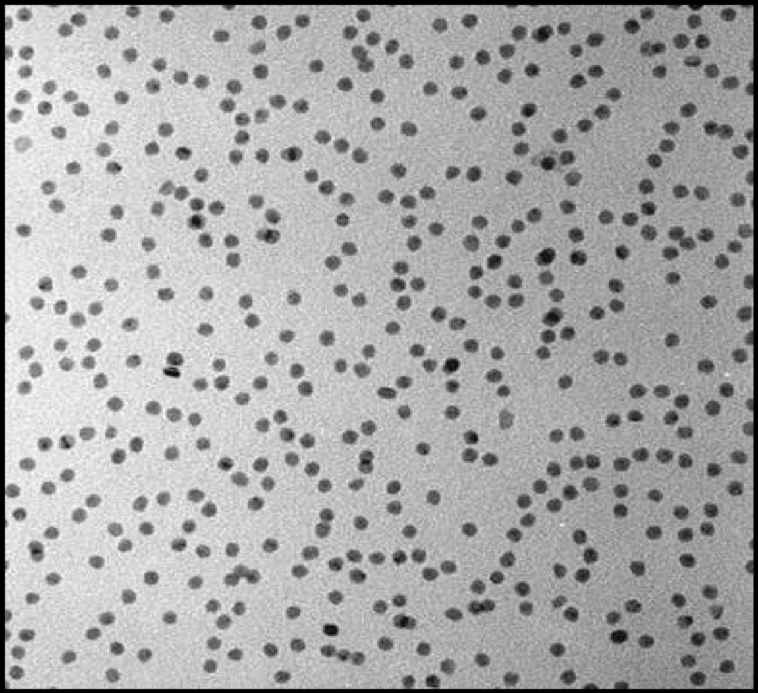
- **"New"**
- **Bottom up**
- **Chemical synthesis**
- **Analog**
- **Tolerate high error rates**
- **Self-assembly**

This is a false dichotomy!

T. Theis, IBM Research

Allowing a Few Components to Approach Equilibrium Will Produce Only Simple Structures

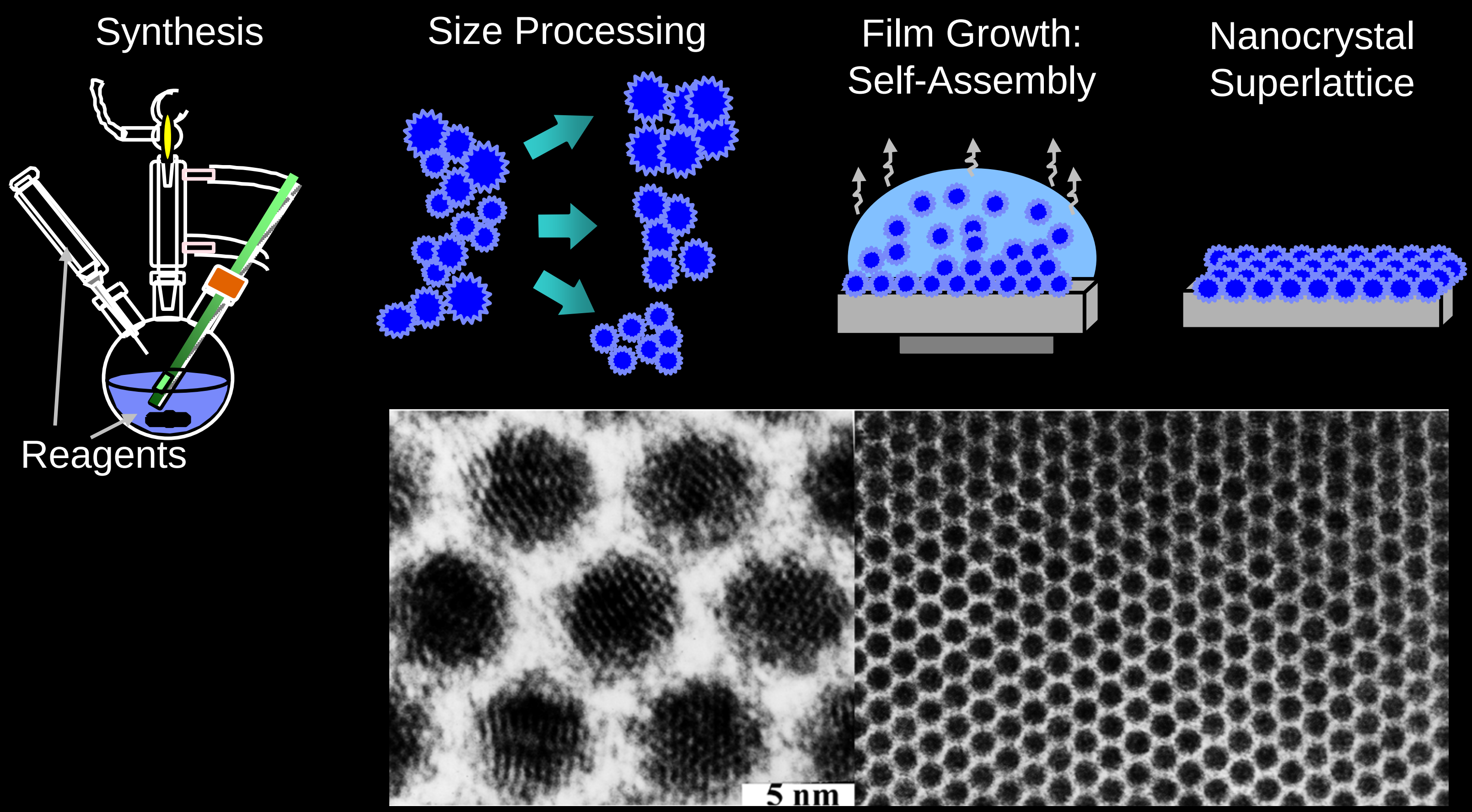




T. Theis, IBM Research

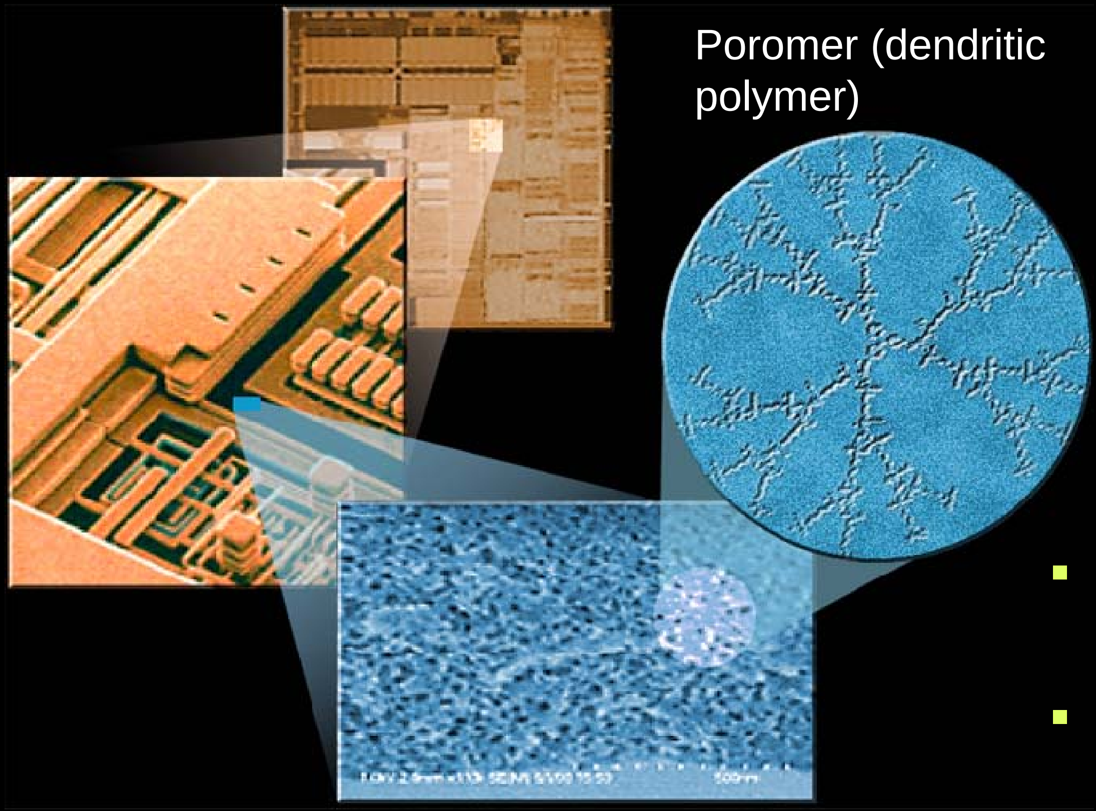
"Guiding" or "Directing" the Equilibration Process:

Semiconductor Nanocrystals

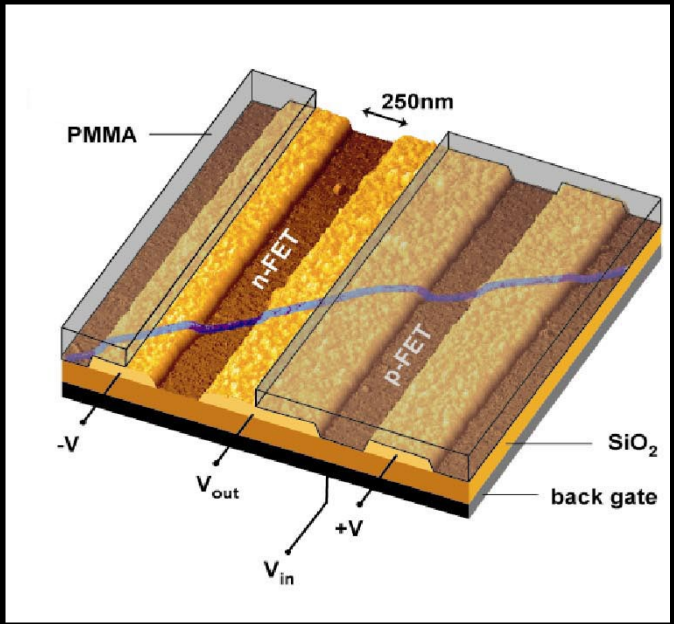


T. Theis, IBM Research

Goal: Incorporate Nanoscale Components in IT Systems



Porous dielectric for on-chip wiring



- IBM - World's first single-molecule (carbon nanotube) computer circuit
- Leading to new class of computers
  – Smaller
  – Faster
  – Consume less power

T. Theis, IBM Research

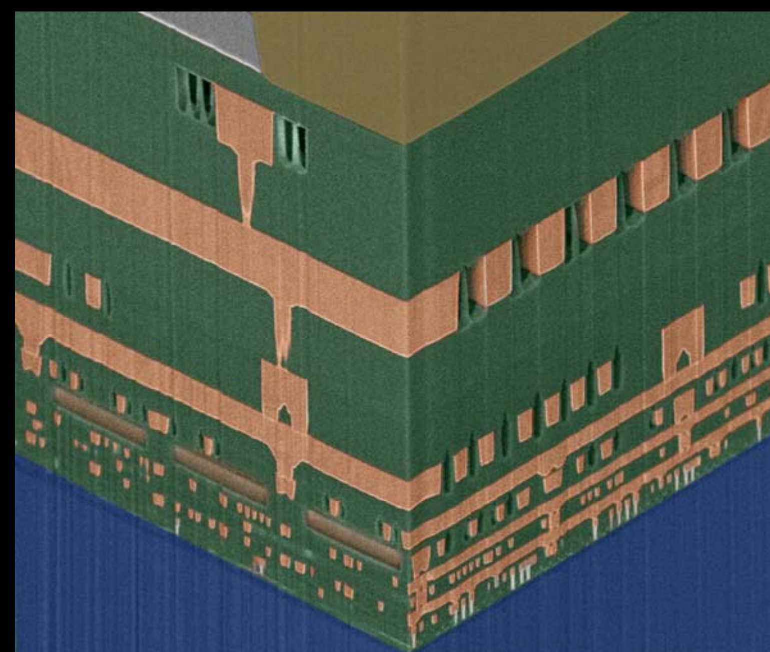
Directed Self-Assembly Nanotechnology to Create Airgap Microprocessors (05/2007)

- **Current process – nanoscale wires in microprocessors insulated with glass-like material**
- **Airgap - vacuum gaps to insulate nanoscale wires**
- **Significant enhancement of performance**
  – Equivalent of two generations of Moore's Law improvement

IBM Fellow Dan Edelstein

Airgap: Directed Self-Assembly

- **Nature's ability to form intricate patterns (snowflakes, sea shells)**
  - Mix of compounds/polymers
  - Pour onto silicon wafer
  - Bake – directed self-assembly
  - Trillions of uniform 20-nm holes (vacuum "airgaps") in wafer



Airgap: Directed Self-Assembly Animation

Breakthrough of Directed Self-Assembly Airgap Nanotechnology

- **Current process – lithography**
  - Masking
  - Etching
- **Examples of chemicals in photolithography**
  - Photoresist (photoactive organic polymers)
  - Developers (tetramethyl ammonium hydroxide)
  - Solvents and cleaning agents
  - Etching (acids, chlorine)
  - Stripping (acids, alkalines)

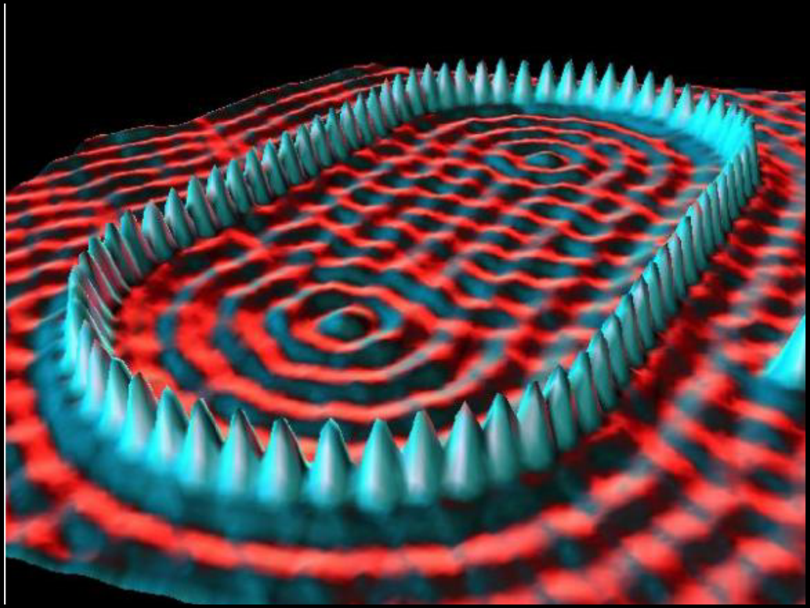
- **Self-assembly - 20-nm vacuum holes**
  - 5x smaller than lithography
  - Not possible with lithography
- **Manufacturing**
  - Resource and energy conservation
  - Waste minimization
- **Product**
  - 35% Faster
  - 15% Less energy consumption

Why Would Even Small Gains in Energy Efficiency Result in Major Advances in Pollution Prevention?

- Last year the world produced more transistors (and at a lower cost) than grains of rice

Thank you

- **Contact information**
  - fonga@us.ibm.com



Using the scanning tunneling microscope (STM), electron formations can be viewed. Above, electrons are surrounded by 48 iron atoms, individually positioned with the same STM used to image them - IBM Almaden Research Center.