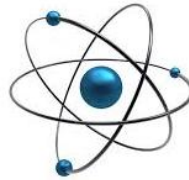


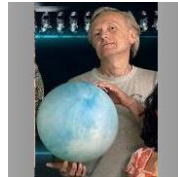
Humankind 2.0: The Technologies of the Future

5. Nanotech

Superconductivity, Quantum Computing



Piero Scaruffi, 2016



See <http://www.scaruffi.com/singular/human20.html>
for the full text of this discussion

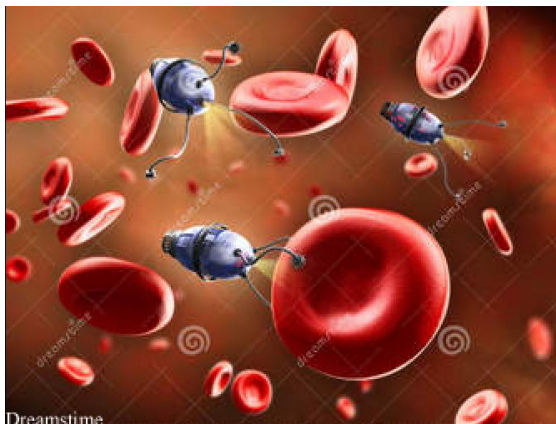
The Future of Technology

- Moore's law has changed our perception of that constitutes a "great" technology: progress now means "smaller", not "bigger“
- A Nvidia GPU is thousands of times smaller than the early computers, and thousands of times faster.
- The future of technology will be invisible: cloud, nano-bots, increasingly small devices and brain-machine interfaces.



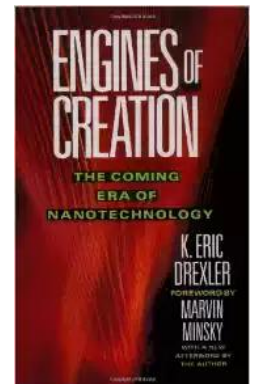
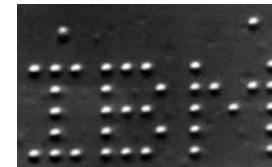
The Future of Technology

- Nano-devices will colonize the human body at the same time that the human body will colonize cyberspace through them.



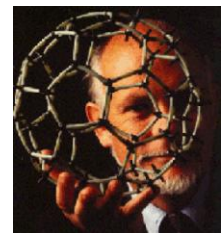
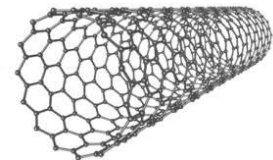
A Brief History of Nanotech

- 1959: Richard Feynman's speech "*There's Plenty of Room at the Bottom*": to operate on single atoms
- 1971: Leon Chua introduces memristors
- 1974: Norio Taniguchi coins the term "*Nanotechnology*"
- 1981: The Scanning Tunneling Microscope is invented
- 1986: The Atomic Force Microscope is invented
- 1986: Eric Drexler's book "*Engines of Creation - The Coming Era of Nanotechnology*"
- 1986: Foresight Institute in Menlo Park
- 1989: "IBM in atoms" demo



A Brief History of Nanotech

- 1991: Carbon nanotubes are demonstrated
- 1996: Mitsutaka Fujita popularizes graphene nanoribbons
- 2001: Richard Smalley's article "*Of Chemistry, Love and Nanobots*"
- 2003: USA's National Nanotechnology Initiative
- 2004: Kostya Novoselov and Andre Geim popularize graphene
- 2015: Nathan Guisinger synthesizes borophenes



Nanotech bubble of 2006

2000-2005: VCs have invested more than \$1 billion in nanotech

2006: 1,200 nanotech startups worldwide 50% in the USA

Harris & Harris: venture capital firm investing only in nanotech

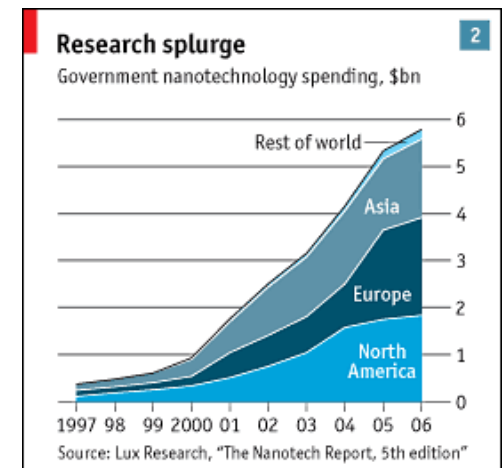
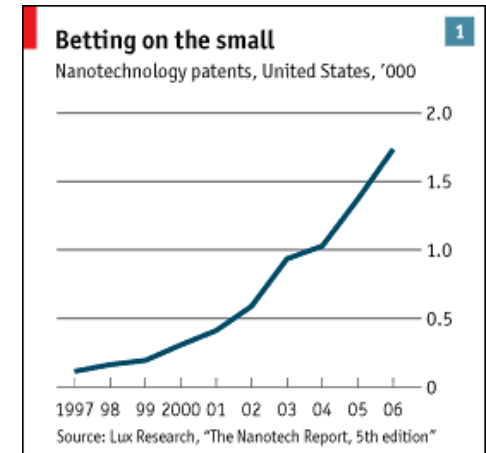


In-Q-Tel (CIA) singles out nanotech as strategic

2000: Bill Clinton doubles national investment in nanotech

2003: George W. Bush further increases national investment

Lux Research's report in 2004: *"In 2014 nanotechnology will be incorporated in products worth \$2.9 trillion in revenue"*



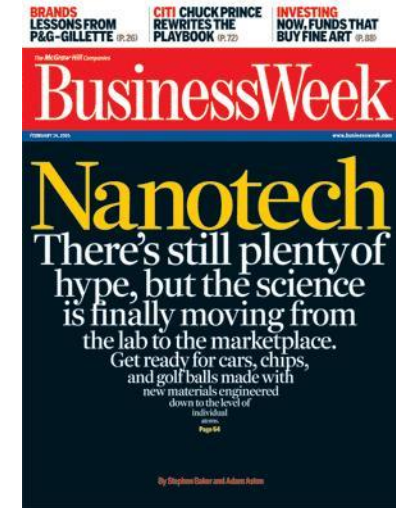
Nanotech bubble of 2006

BusinessWeek's special edition (February 2005)

2006: Invesco's Lux Nanotech ETF and Lux Nanotech Index

2006: Steven Edwards' "The Nanotech Pioneers: Where Are They Taking Us"

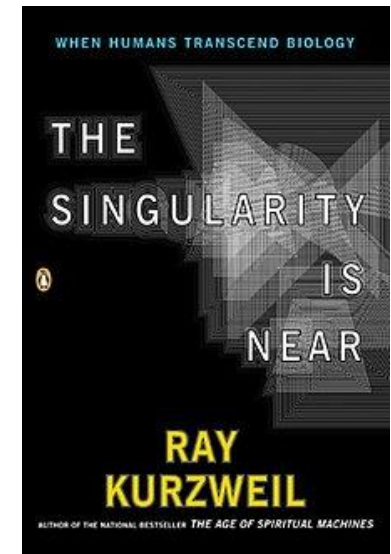
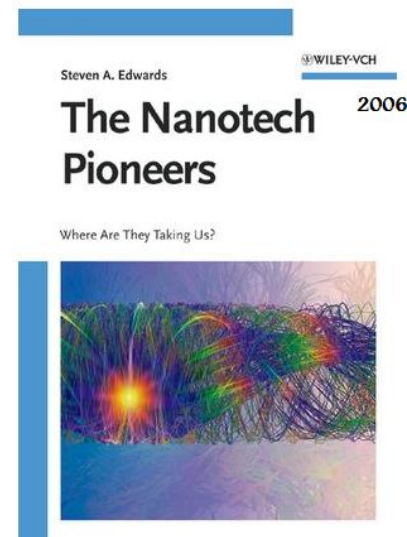
2006: Ray Kurzweil's "The Singularity is Near": "the advent of full-scale nanotechnology in the 2020s"



Nanotech and immortality

2006

Ray Kurzweil, in "The Singularity is Near" proposes a redesign of cells using nanotechnology that would cure disease...and aging.



Nanotech bubble of 2006

- Nanotechnology is not an industry
- Nanotechnology helps progress in many different industries: biotech, displays, batteries, semiconductors...
- Nanotechnology never had its Facebook, and never will
- Time to market for nanotech inventions is very long

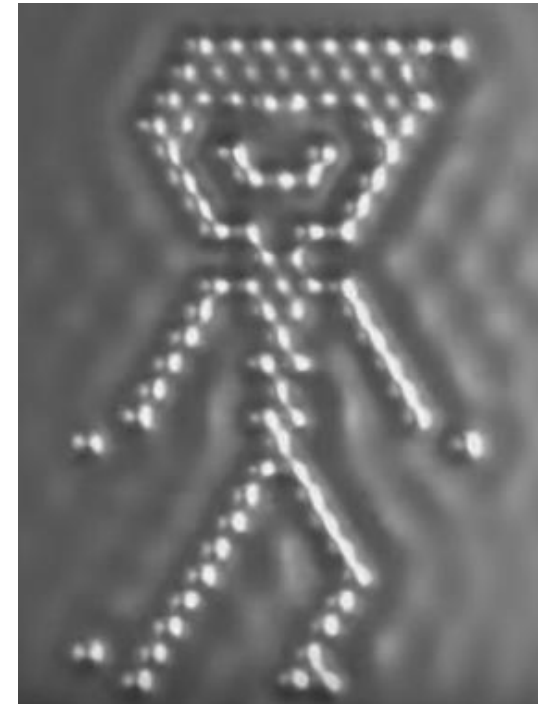


LUX NANOTECH INDEX



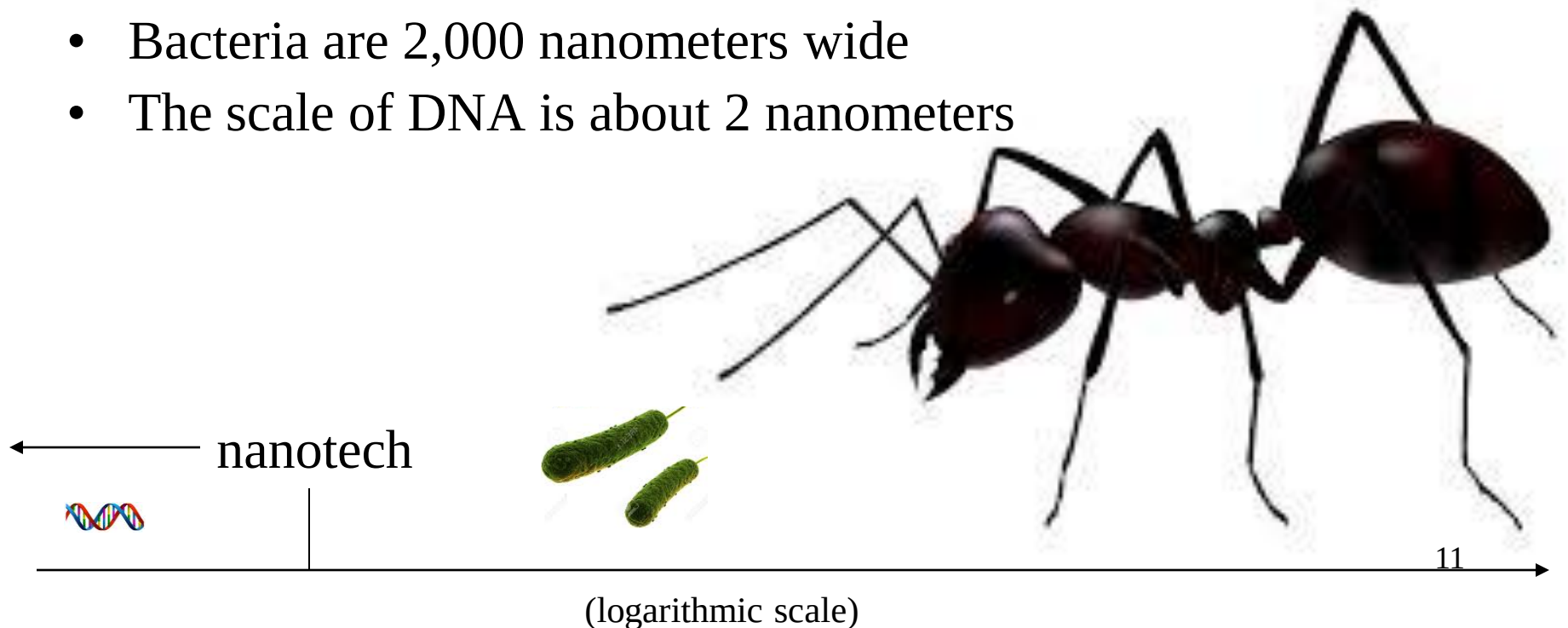
A Brief History of Nanotech

- 2006-7: Semiconductors industry moves to a 65-nanometer manufacturing process
- 2013: Andreas Heinrich's movie "A Boy and His Atom", the "world's smallest movie": the moving dots are single atoms
- 2015: Borophene is synthesized



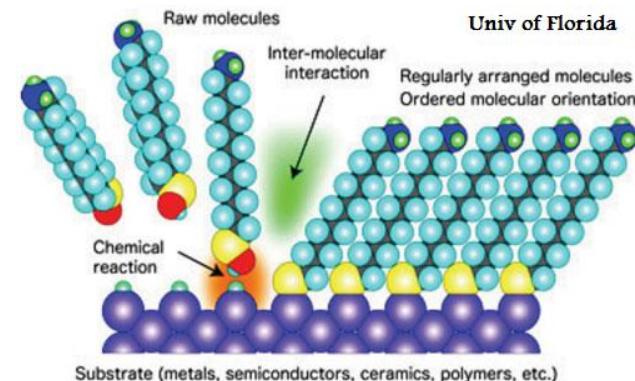
What is Nanotech

- "Nano": technology that operates at the atomic and molecular scale
- 100 nanometers or smaller (a nanometer is one billionth of a meter)
- The size of an ant is 6 million nanometers
- Bacteria are 2,000 nanometers wide
- The scale of DNA is about 2 nanometers

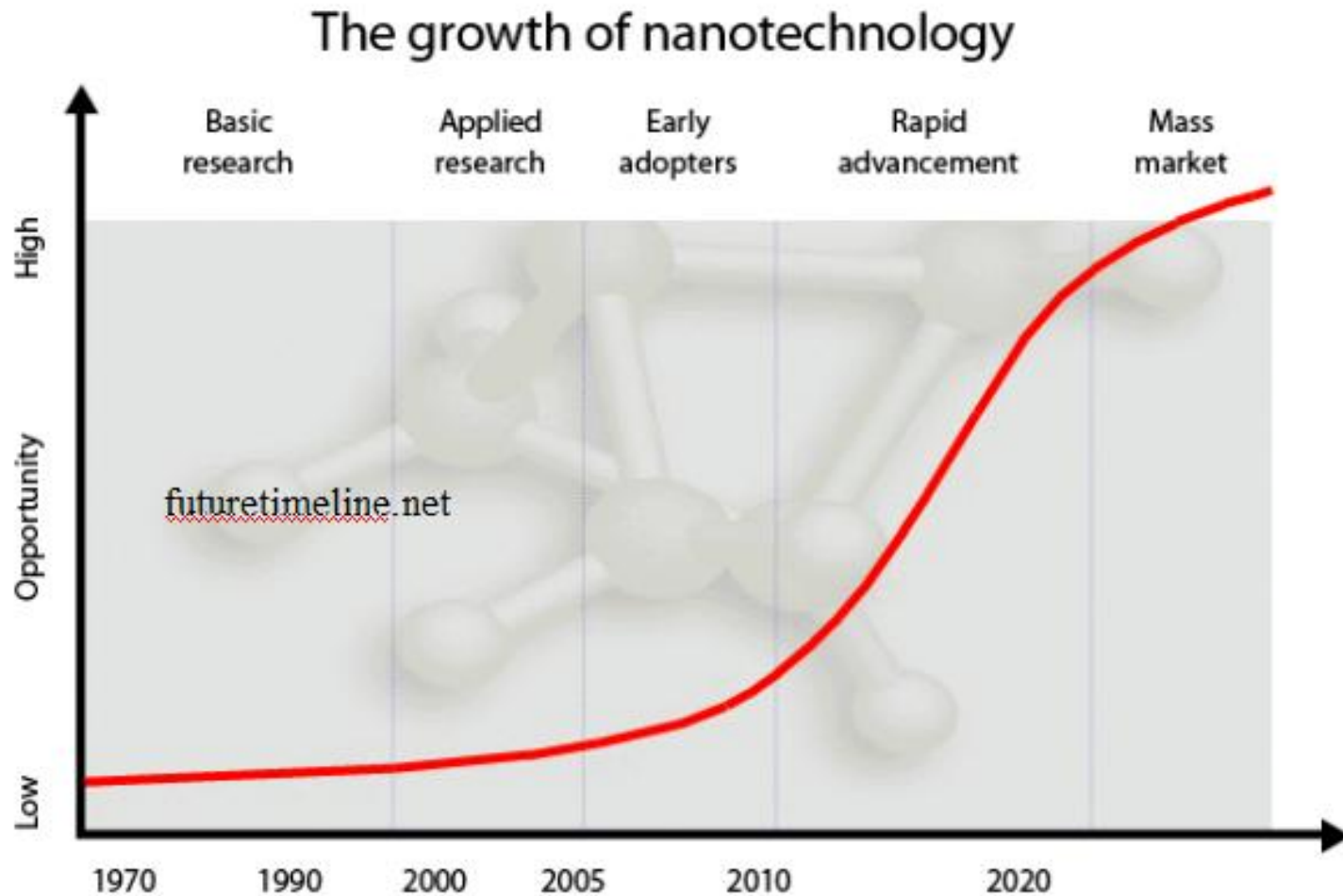


What is Nanotech

- In theory: to pick one atom at a time and place them in the right place to form the object that we desire
- In practice: molecules self-assemble - they bind together spontaneously in the right place - and then a new material is constructed "bottom-up"
- A very expensive field, that requires very expensive equipment.
- “Molecular manufacturing” is not feasible on a large scale

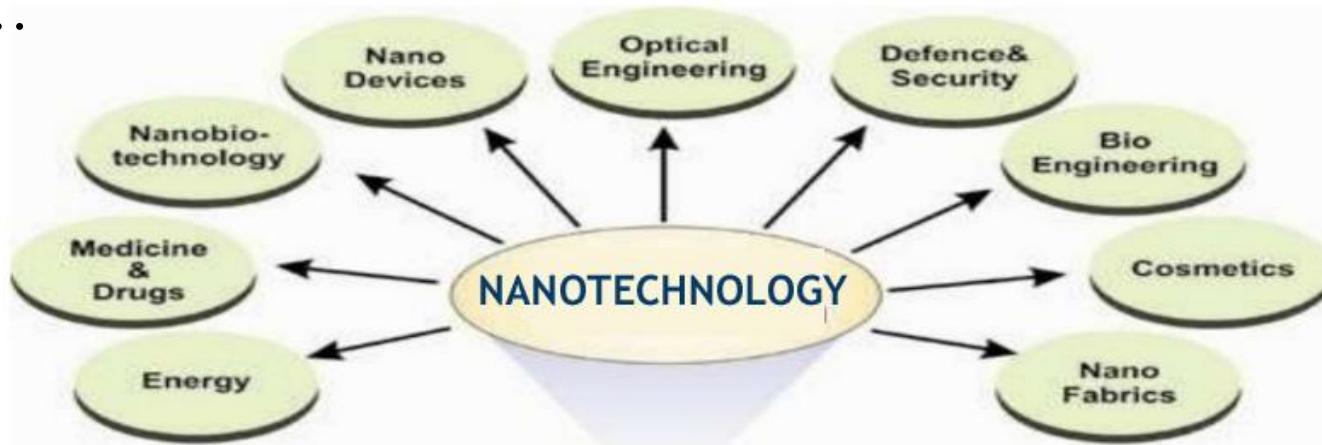


Progress in Nanotech



Applications

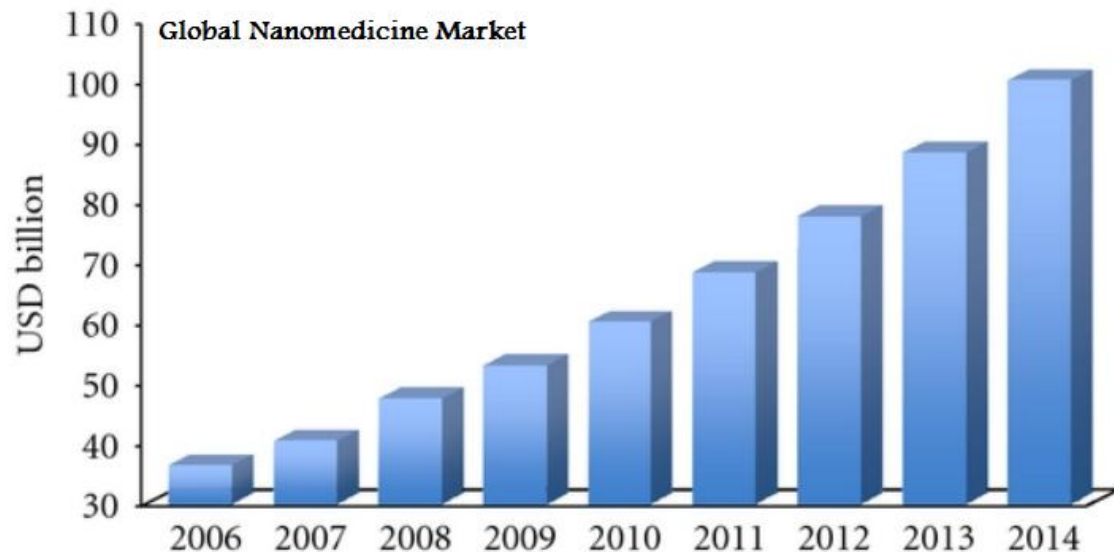
- Stronger and lighter materials
- Clean (solar) energy
- Sustainable materials. (materials that can self-decompose)
- Improved battery technology
- Precision biomedicine
- Faster computing
- ...



Nanomedicine

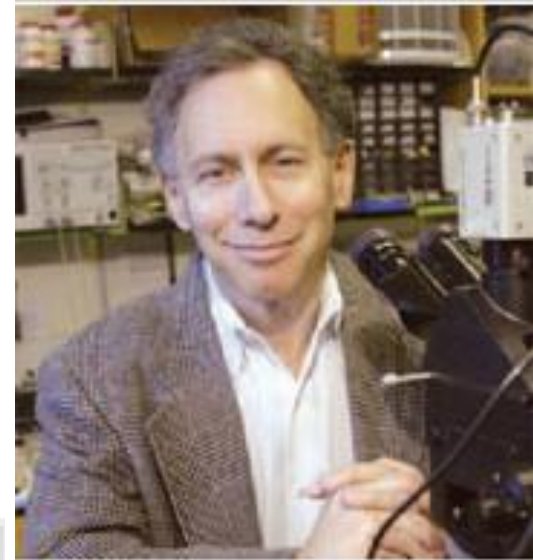
Nanomedicine has the potential to develop radical new therapies

- Targeted drug delivery
- Dissolvable sensors
- Issuing orders to cells
- Early detection of cancer
- Antibiotics



Nanomedicine

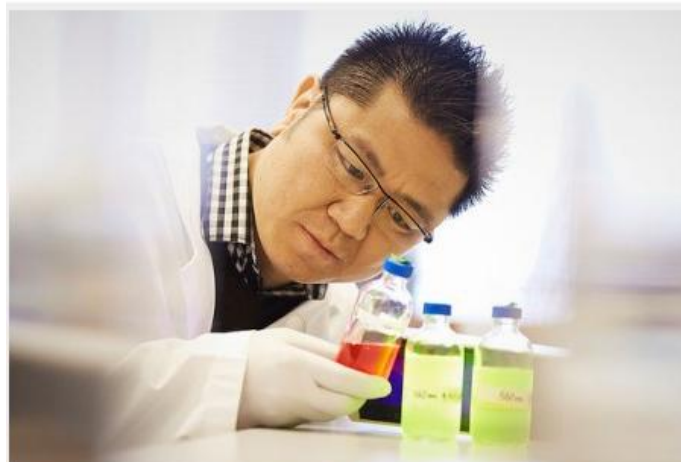
- Targeted drug delivery
 - Robert Langer's nanopolymers (MIT)
 - James Swartz's re-engineered virus (Stanford)
 - Warren Chan's "smart nanoparticles" (Univ of Toronto)



Robert Langer's team have shown the potential of targeted nanoparticles to deliver anticancer drugs.



Professor James Swartz holds an enlarged replica of a virus-like particle. Swartz and his team have re-engineered a virus to deliver therapies to cells.



Professor Warren Chan has spent the last decade figuring out how to deliver chemotherapy drugs into tumours—and nowhere else. Now his lab has designed a set of nanoparticles attached to strands of DNA that can change shape to gain access to diseased tissue. (Photo: NSERC)

Nanomedicine

- Targeted drug delivery

Chemical Engineering Science 125 (2015) 158–164



Contents lists available at [ScienceDirect](http://www.sciencedirect.com)

Chemical Engineering Science

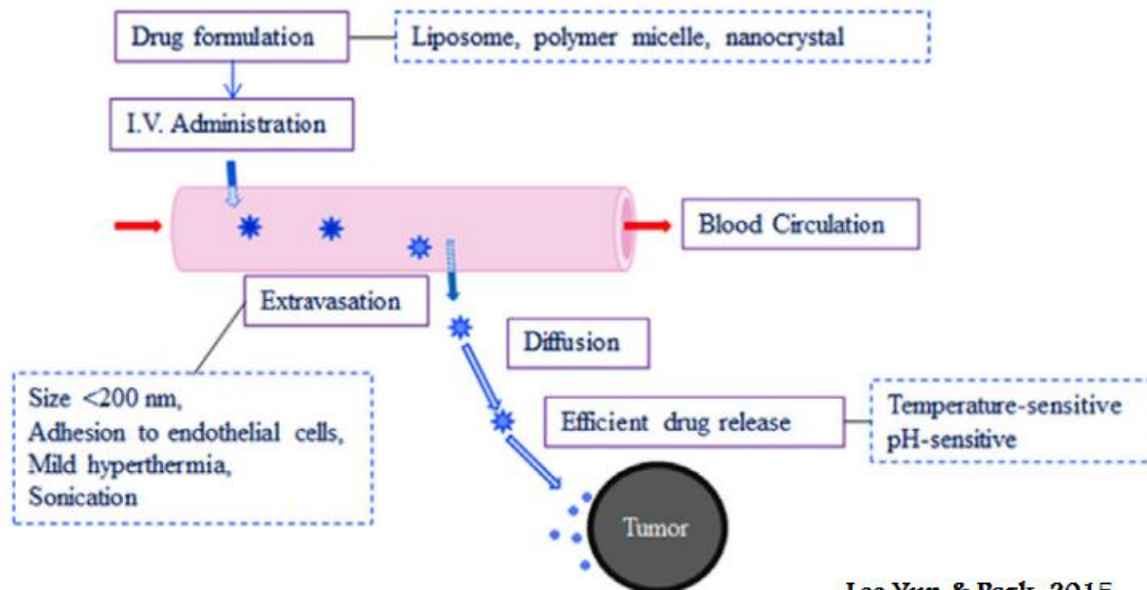
journal homepage: www.elsevier.com/locate/ces

Smart nanoparticles for drug delivery: Boundaries and opportunities

Byung Kook Lee^a, Yeon Hee Yun^a, Kinam Park^{a,b,*}

^a Purdue University, Weldon School of Biomedical Engineering, West Lafayette, IN 47907, USA

^b Purdue University, Department of Industrial and Physical Pharmacy, West Lafayette, IN 47907, USA



Nanomedicine

- Dissolvable sensors
 - Washington Univ in St Louis
(Rory Murphy and Wilson Ray)
and the Univ of Illinois at Urbana-
Champaign (John Rogers)

Dissolvable, Wireless Sensors to Monitor the Brain Injury

NEUROSCIENCE NEWS x JANUARY 18, 2016

Washington University School of
Medicine in St. Louis and engineers
at the University of Illinois at
Urbana-Champaign

Nanomedicine

- Early detection of cancer
 - Rajesh Sardar (Indiana Univ)

Nanotechnology-based sensor developed to measure microRNAs in blood, speed cancer detection

Nov. 17, 2015

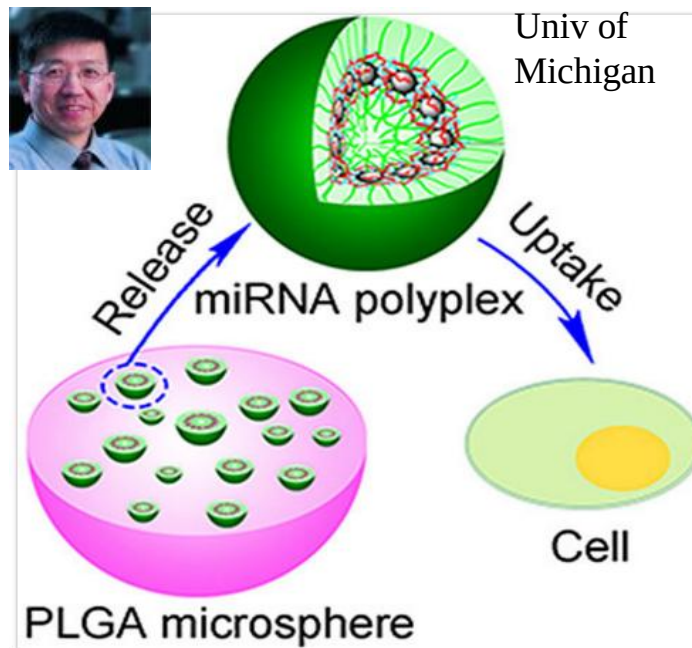
INDIANA UNIVERSITY



Nanomedicine

- Issuing orders to cells
 - Daniel Siegwart (Univ of Texas)
 - Peter Ma (Univ of Michigan)

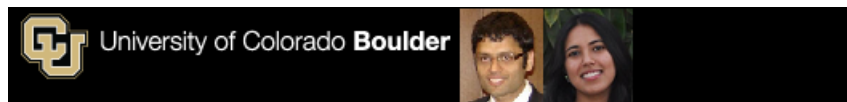
DALLAS – Jan. 25, 2016 – UT Southwestern Medical Center chemists have successfully used synthetic nanoparticles to deliver tumor-suppressing therapies to diseased livers with cancer



The polymer sphere delivers the microRNA into cells already at the wound site, which turns the cells into bone repairing machines. (Image: Peter Ma)

Nanomedicine

- Antibiotics
 - Each year antibiotic-resistant bacteria infect two million people and kill at least 23,000 in the USA alone
 - Prashant Nagpal's light-activated nanoparticles (Univ of Colorado)



Light-activated nanoparticles
prove effective against
antibiotic-resistant “superbugs”

January 18, 2016

Nanobots

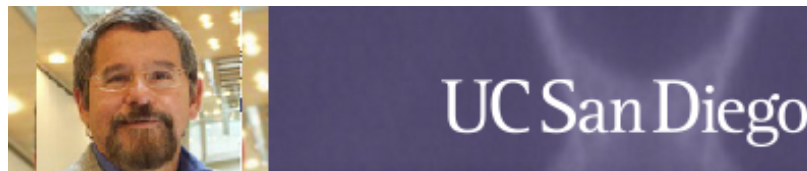
- Peer Fischer's swimming nanobots (Max Planck Inst)
- Charles Cao's and Chen Liu's nanozyme (Univ of Florida)
- Joseph Wang and Liangfang Zhang's self-propelled nanobots (UC San Diego)



Micro- or even nano-robots could someday perform medical tasks in the human body. Researchers from the Max Planck Institute for Intelligent Systems in Stuttgart have now taken a first step towards this goal.

Nanoparticle Completely Eradicates Hepatitis C Virus

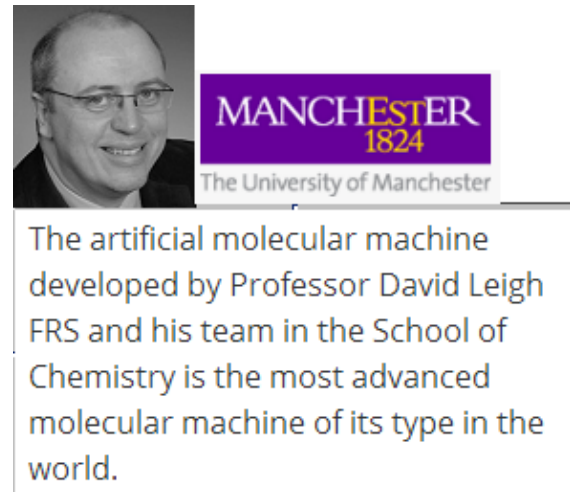
By Dexter Johnson
Posted 17 Jul 2012 | 19:37 GMT



Research in the Wang lab falls within the field of nanobioelectronics, focusing mostly on the design of wearable biosensors and nano- and micromotors for drug delivery and microchip diagnostics. The Wang group's work on nano- and micromotors have advanced the field significantly towards the dream of autonomous machines capable of navigating the circulation to deliver drugs

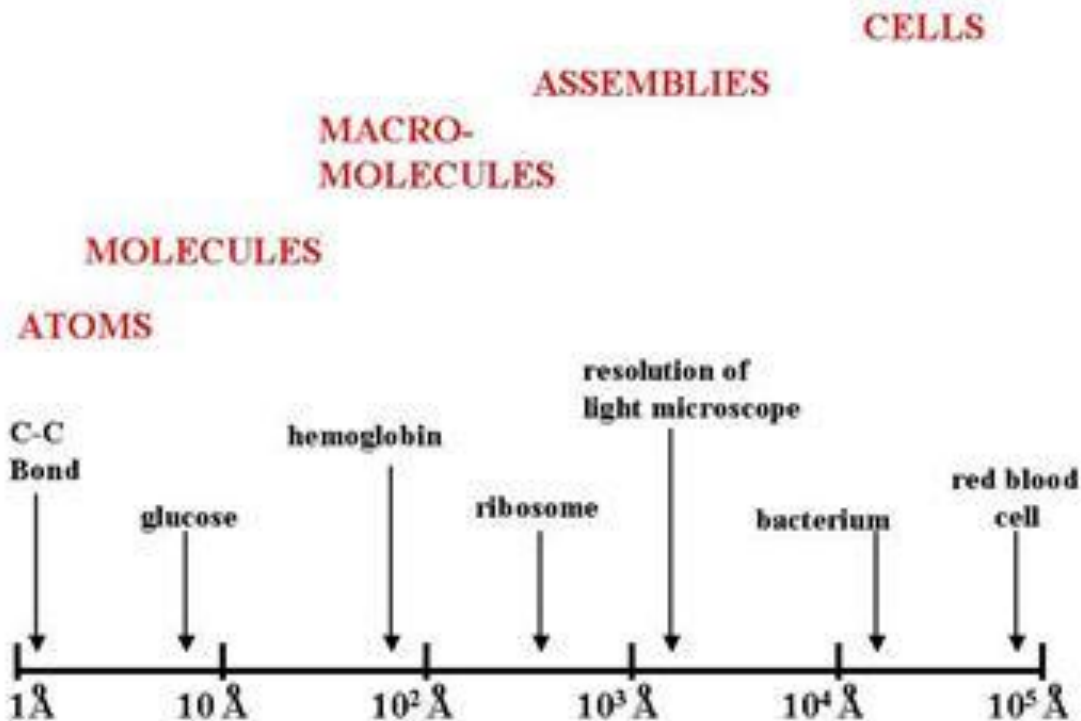
Nanobots

- The nano equivalent of the assembly line
 - David Leigh's nanobots that can pick up a single molecule and move it somewhere else (Univ of Manchester) - Feynman's dream



Nanotech + Biotech

Biology used to stop at the level of the cell
Nanotech allows Biotech to go even below
the atom



Nanotech + Biotech

Trojan horses

Nano-particles can change the way a cell behaves without altering its DNA

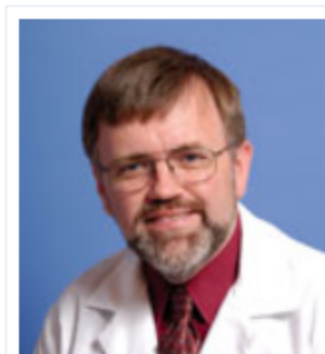
"Trojan horses" inside a cell

Using nanoparticles to kill tumor cells inside the eye

ANN ARBOR, Mich. — Researchers at the University of Michigan Kellogg Eye Center have developed a new nanoparticle that uses a tumor cell's protective mechanism against itself — short-circuiting tumor cell metabolism and killing tumor cells.

"Our work uses a semiconducting nanoparticle with an attached platinum electrode to drive the synthesis of an anti-cancer compound when illuminated by light," says [Howard R. Petty](#).

Howard Petty,
University of Michigan



Nanotech + Biotech

Synthetic fossils

- DNA stores a lot of information in a tiny space
- DNA can last a very long time
- DNA is a highly optimized storage for data that can last for thousands and thousands of years

Data-storage for eternity

13.02.2015 | News



How can we preserve our knowledge today for the next millennia?
ETH researchers have found a way to store information in the form of **DNA**, preserving it for nearly an eternity.



Robert N. Grass (1979) is lecturer in the group of Prof. Stark at ETH Zurich.

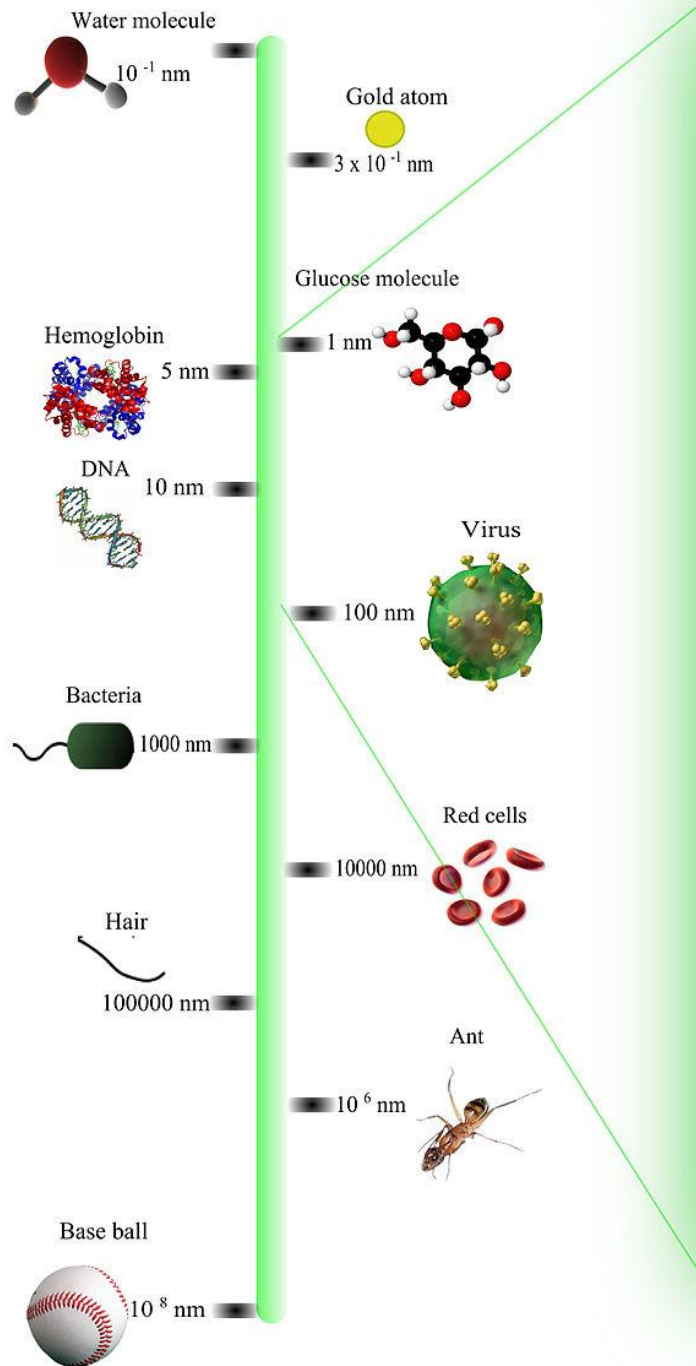
New Materials

- Making new materials is extremely difficult and expensive (except for laser materials, e.g. barcodes)
- Nanotech allows to build
 - Ultra-light hyper-strong materials (carbon nanotubes and graphene)
 - Water-repellent surfaces
 - Self-cleaning surfaces
 - Quantum dots
 - ...

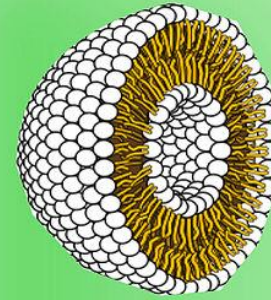
New Materials

- The revolution in materials will fuel the revolutions in Consumer Electronics, Biotech, Internet of Things, and Space Exploration

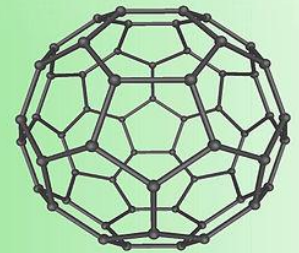
New materials



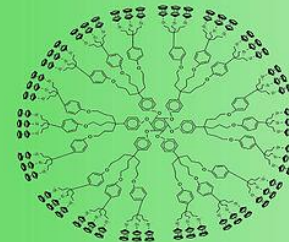
Nanomaterials (1-100 nm)



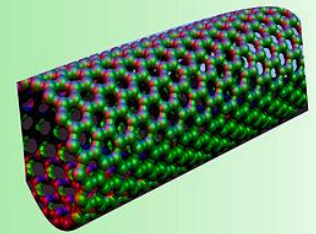
Liposome



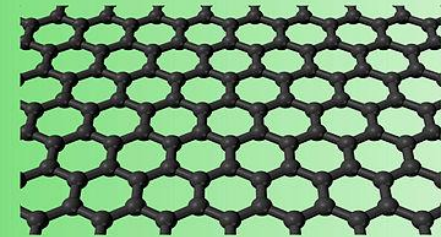
Fullerene



Dendrimer

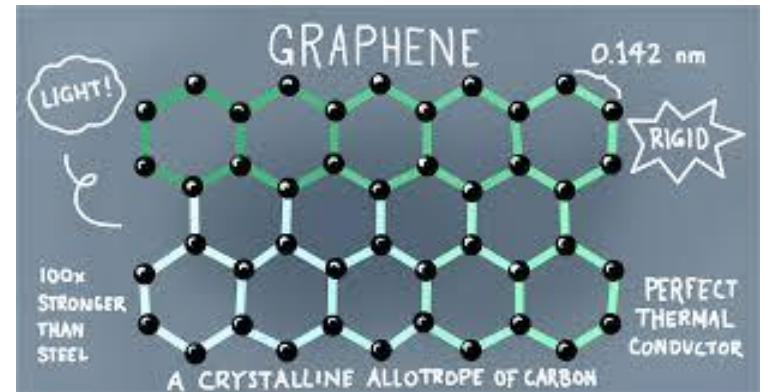


Carbon nanotube

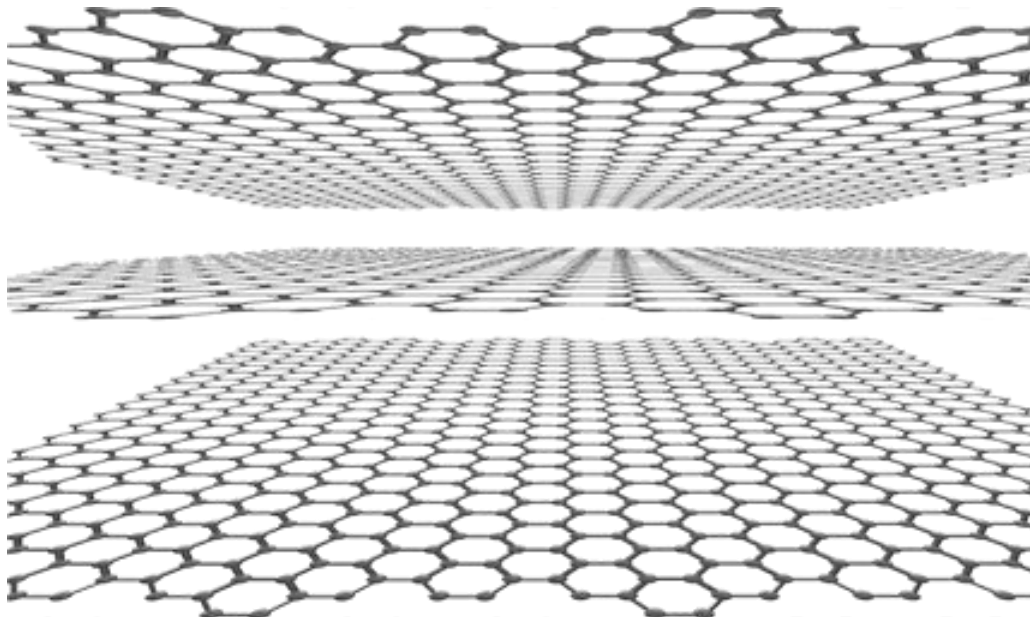


Graphene

New Materials

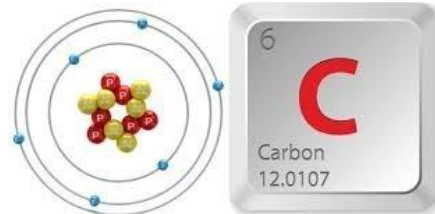


- Graphene: carbon sheets that are only one atom thick



New Materials

- Graphene
 - The lightest material known
 - The strongest material known (200 times stronger than steel)
 - The best conductor of heat at room temperature
 - The best conductor of electricity known (carrying electricity at 1 million meter/sec)
 - Carbon is the 4th most abundant element in the universe (by mass)



Graphene

- Graphene's applications
 - Mobile phones that the user can roll up and put in the pocket
 - TV sets as thin as wallpaper
 - Bend-able electronic e-readers that the reader can fold away just like the old newspapers
 - Replace silicon in computer chips



Samsung



Sony

Graphene

- Graphene's applications
 - Fast-charging batteries
 - Ultracapacitors with better performance than today's batteries
 - Storing hydrogen for fuel-cell powered cars
 - Lower cost solar cells



Professor Jaephil Cho explains his research on fast-charging electric vehicles. (Image from video courtesy **Professor Cho**)

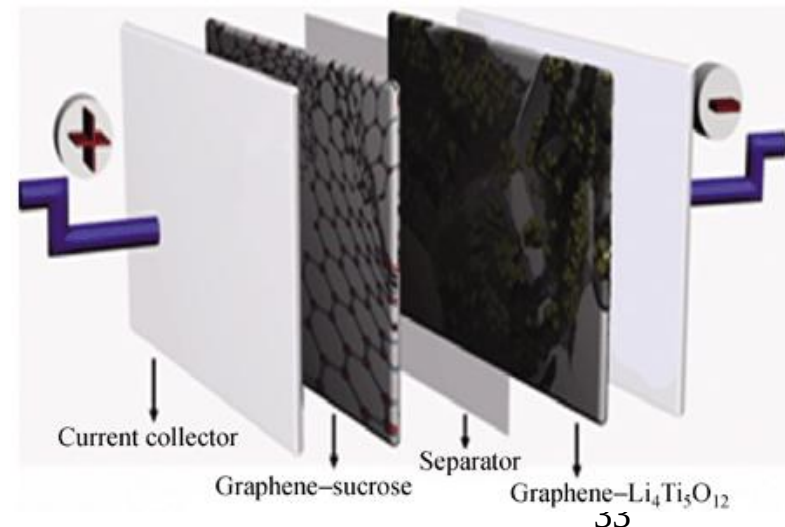
Stanford scientists build the first all-carbon solar cell

Researchers have developed a solar cell made entirely of carbon, an inexpensive substitute for the pricey materials used in conventional solar panels

19 Nov 2012 | Editor



STANFORD UNIVERSITY
GLOBAL CLIMATE



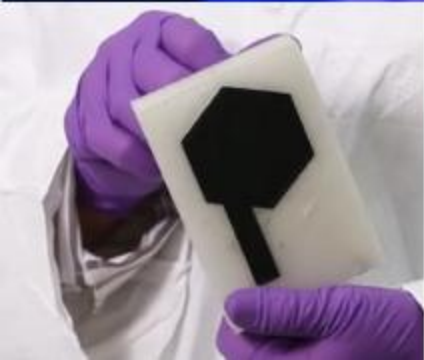
Ultracapacitor (Nankai University, 2013)

Graphene

- Graphene's applications
 - Batteries



3D Printed Battery



All-graphene-battery: bridging the gap between supercapacitors and lithium ion batteries

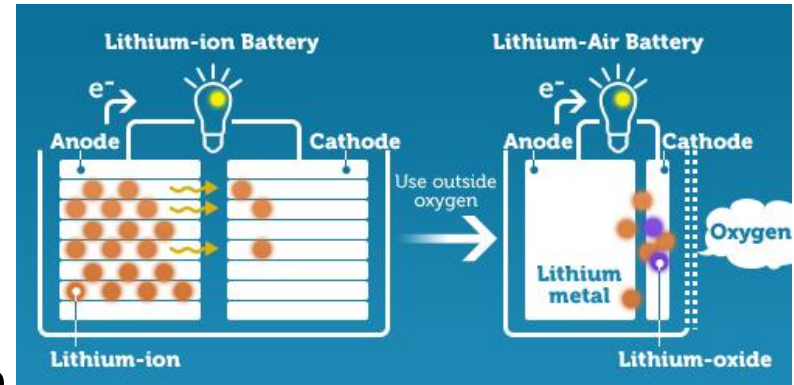
Haegyeom Kim, Kyu-Young Park, Jihyun Hong & Kisuk Kang



Received: 02 April 2014

Graphene

- Graphene's applications
 - Lithium-air batteries
 - Invented in 1996
 - They can store ten times more than today's best batteries
 - But difficult to build
 - 2015: Clare Grey uses graphene electrodes



New design points a path to the 'ultimate' battery

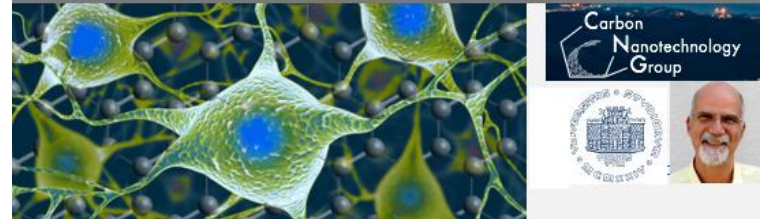
Researchers have successfully demonstrated how several of the problems impeding the practical development of the so-called 'ultimate' battery could be overcome.



Graphene

- Graphene's applications
 - Brain implants (2015)
 - Color-tunable LEDs (2015)
 - Low-cost water desalination (2012)

Graphene shown to safely interact with neurons in the brain



Chinese Scientists Develop Color Tunable Single Graphene-based LEDs

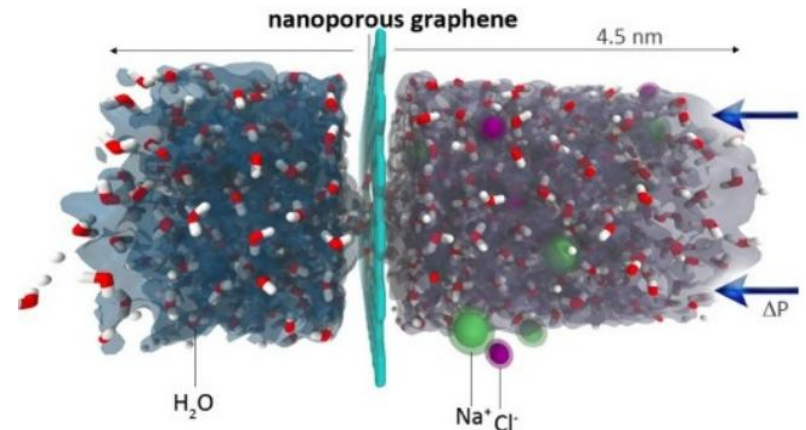


清华大学微电子学研究所
Institute of Microelectronics, Tsinghua University



Nanoporous graphene could outperform desalination techniques

June 22, 2012 by Lisa Zyga feature



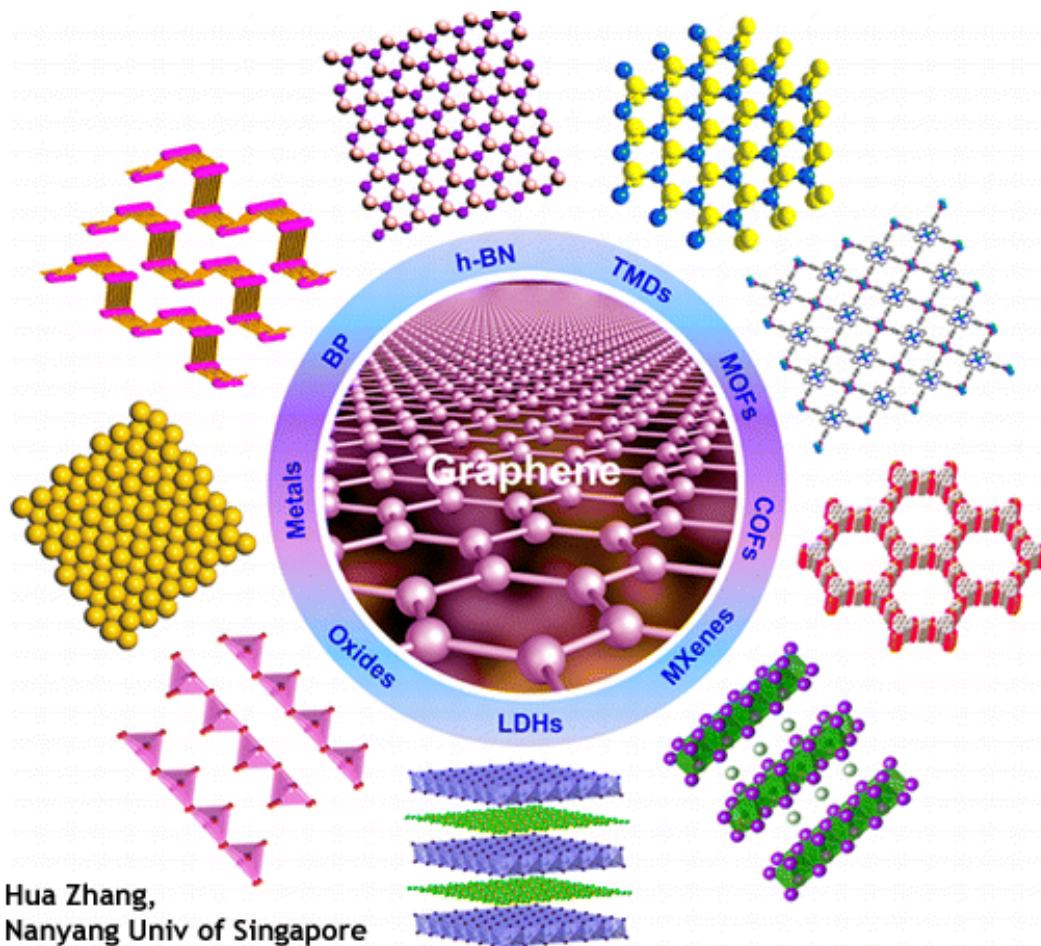
Graphene

- Graphene-based foams
 - Graphene Aerogel (Zhejiang Univ, 2013), the lightest material ever made
 - GO-0.5BN (Rice Univ, 2014)



Graphene

Ultrathin Two-Dimensional Nanomaterials



Graphene

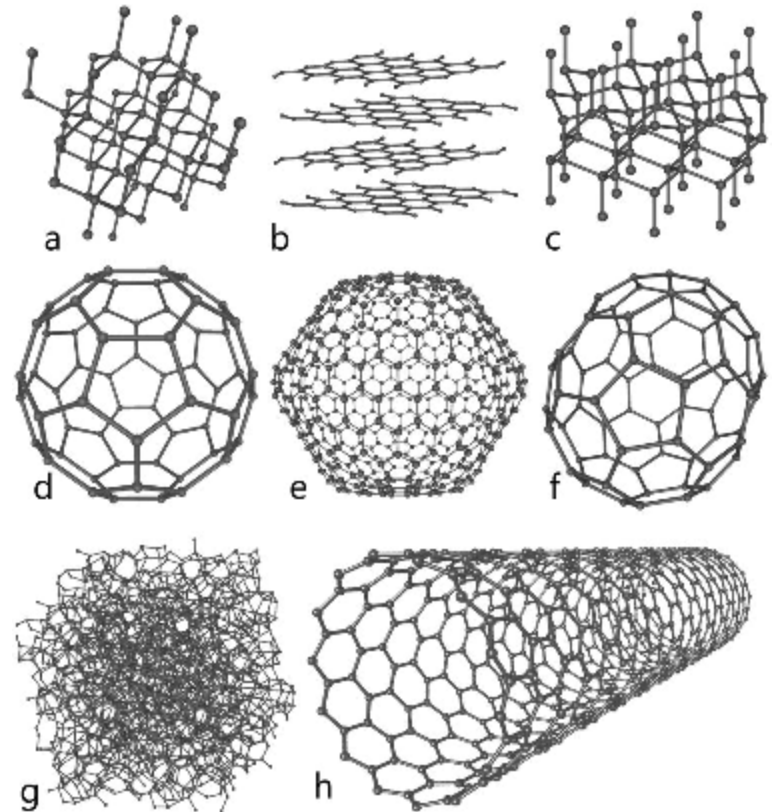
Ultrathin 2D nanomaterials have unique properties that are ideal for the manufacturing of electronic and photonic devices:

- mechanical flexibility
- electrical conductivity
- optical transparency

Carbon Materials

Allotropes of Carbon

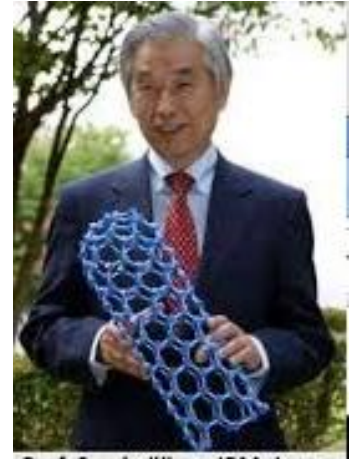
- a) Diamond
- b) Graphite
- c) Lonsdaleite
- d) C60 – Buckminsterfullerene
- e) C540 Fullerene
- f) C70 Fullerene
- g) Amorphous carbon
- h) Single-walled carbon nanotube



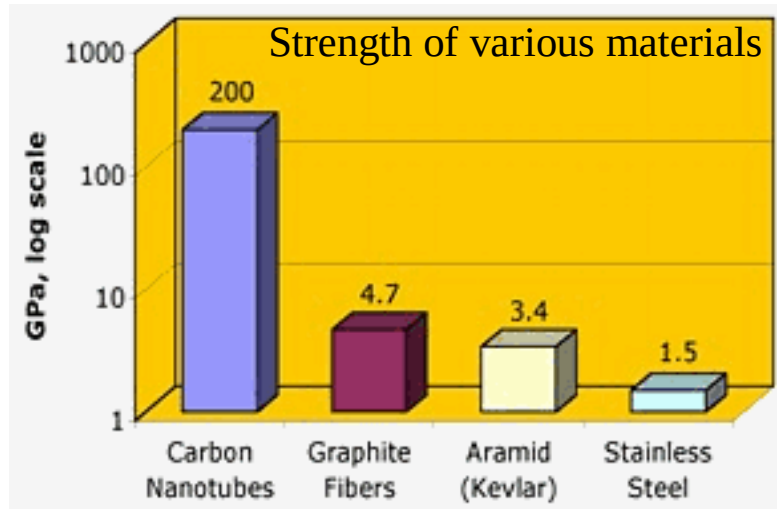
(Source: Michael Ströck)

Carbon Materials

- Carbon Nanotubes
 - A sheet of graphene rolled into a cylinder
 - Discovered in 1991 (Sumio Iijima)
 - Water Desalination (Ben Corry, 2008)



Prof. Sumio Iijima, IBM, Japan



Carbon Nanotubes

- Applications of Carbon Nanotubes
 - Fuel cells

Stanford | News

 MENU



Yanguang Li and Hongjie Dai

Stanford Report, May 29, 2012

'Unzipped' carbon nanotubes could help energize fuel cells and metal-air batteries, Stanford scientists say

Platinum catalysts in fuel cells are too expensive for large-scale production. Stanford scientists have developed a technique that could make carbon nanotubes an attractive, low-cost alternative.

Carbon Nanotubes

- Applications of Carbon Nanotubes
 - Carbon nanotube computers

Stanford Report, September 26, 2013

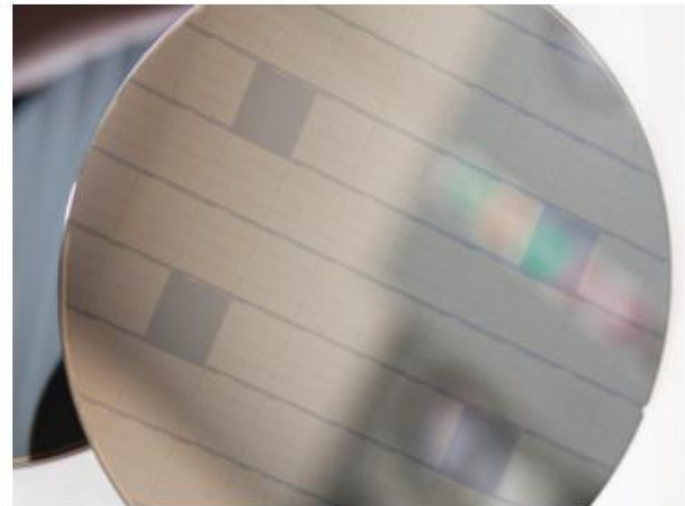
A first: Stanford engineers build basic computer using carbon nanotubes

Unprecedented feat points toward a new generation of energy-efficient electronics.



This wafer contains tiny computers using carbon nanotubes, a material that could lead to smaller, more energy-efficient processors.

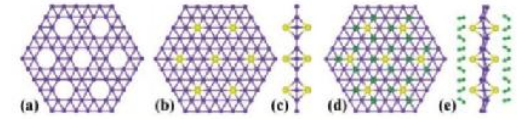
IBM



Chip test: Each chip on this wafer has 10,000 nanotube transistors on it. IBM hopes to be able to put billions of the devices on a single chip soon after 2020.

Borophene

- Borophene: a single layer of boron atoms that form various crystalline structures.
- A two-dimensional material like graphene
- First synthesized in 2015
 - Andrew Mannix of Northwestern and Xiang-Feng Zhou of Stony Brook, working in the teams of
 - Artem Oganov of Stony Brook University
 - Mark Hersam of Northwestern University
 - Nathan Guisinger of Argonne National Laboratory
- Stronger than graphene and more flexible
- Good conductor of both electricity and heat
- Superconductor
- Promising for storing metal ions in batteries



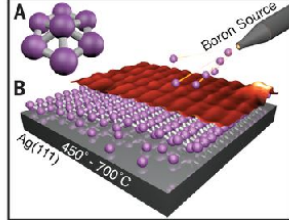
December 21, 2015 **c&en**

Research Teams Make First 2-D Sheets Of Boron

Science

Synthesis of borophenes: Anisotropic, two-dimensional boron polymorphs

Andrew J. Mannix^{1,2}, Xiang-Feng Zhou^{3,4}



Apr 5, 2019 MIT Technology Review

Stony Brook University

**Sorry, graphene—
borophene is the new
wonder material that's
got everyone excited**



Argonne
NATIONAL LABORATORY

Borophene

Science

Science. 2015 December 18

Synthesis of borophenes: Anisotropic, two-dimensional boron polymorphs

Andrew J. Mannix^{1,2}, Xiang-Feng Zhou^{3,4}, Brian Kiraly^{1,2}, Joshua D. Wood², Diego Alducin⁵, Benjamin D. Myers^{2,6}, Xiaolong Liu⁷, Brandon L. Fisher¹, Ulises Santiago⁵, Jeffrey R. Guest¹, Miguel Jose Yacaman⁵, Arturo Ponce⁵, Artem R. Oganov^{8,9,3,*}, Mark C. Hersam^{2,7,10,*}, and Nathan P. Guisinger^{1,*}

¹ Argonne National Laboratory

² Northwestern University,

⁵Department of Physics, Univ of Texas San Antonio

³ Stony Brook University, Stony Brook

⁴ Nankai University, Tianjin

⁶NUANCE Center, Northwestern Univ

Nathan Guisinger (Argonne)



Argonne
NATIONAL LABORATORY

nature
chemistry

PUBLISHED ONLINE: 28 MARCH 2016

Experimental realization of two-dimensional boron sheets

Baojie Feng¹, Jin Zhang¹, Qing Zhong¹, Wenbin Li¹, Shuai Li¹, Hui Li^{1*},
Lan Chen^{1*} and Kehui Wu^{1,2*}

Peng Cheng¹, Sheng Meng^{1,2},

Institute of Physics, Chinese Academy of Sciences, Beijing



Kehui Wu

中国科学院物理研究所

表面物理国家重点实验室 SF09 组

- First synthesized in 2015 by Nathan Guisinger's team in the USA and Kehui Wu's team in China
- Free standing borophene synthesized in 2019 by Nathan Guisinger's team

May 14, 2019

Freestanding borophene synthesized

Nathan Guisinger (Argonne)



Argonne
NATIONAL LABORATORY

Rectennas

- Rectennas: devices that convert AC electromagnetic waves into DC electricity
- Eliminate batteries: convert Wi-Fi signals to electricity
- Traditional rectennas use either silicon or gallium arsenide for the AC-to-DC rectifier
- Traditional rectennas operate at low frequencies: they cannot feed on the gigahertz frequencies of cell phone and Wi-Fi signals

Rectennas

- Tomás Palacios (MIT, 2019): a rectenna made of a 2-D (three atoms thick) semiconducting material, molybdenum disulfide (MoS_2), that is flexible and captures high frequencies

nature

Nature **566**, 368–372(2019)

Letter | Published: 28 January 2019

Two-dimensional MoS_2 -enabled flexible rectenna for Wi-Fi-band wireless energy harvesting

Xu Zhang, Jesús Grajal, Jose Luis Vazquez-Roy, Ujwal...



ng, Winston C... hou, Yuxuan Li...
Ji, Xi Ling, Al... r, Yuhao Zhang...
ey, Jing Kong, Mildred Dresselhaus & Tomás Palacios



New Materials

- Water-repellent electronics
- Self-cleaning materials
- Self-warming clothes

New paint makes tough self-cleaning surfaces

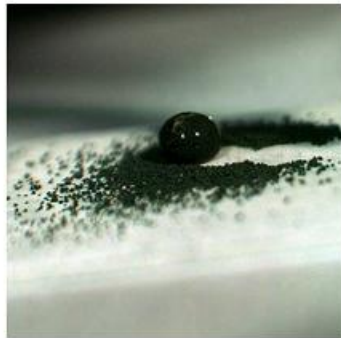
6 March 2015



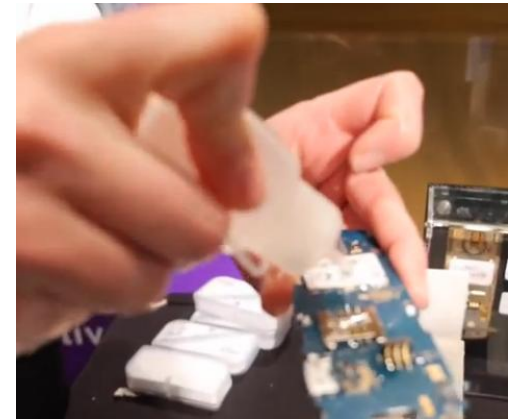
Yao Lu

University College London, London

Nanotechnology, Physical Chemistry, Materials Chemistry



P2i



Nanowire clothing could keep people warm, without heating everything else

Date: January 7, 2015



Quantum Dots

- Semiconducting nano-particles
- Applications
 - television sets
 - solar batteries
 - electron microscopes

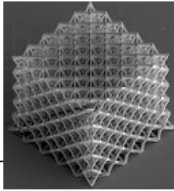
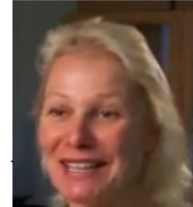


Strong Ultralight Materials

- Julia Greer 's ceramic (Caltech, 2014)
- Xiaochun Li's metal (UCLA, 2015)
- Xudong Wang's two-dimensional nano-sheets that don't exist in nature (Univ of Wisconsin, 2016)



A Caltech scientist creates tiny lattices with enormous potential.



UCLA Newsroom



SCIENCE + TECHNOLOGY

UCLA researchers create exceptionally strong and lightweight new metal

Making New Materials

- Chad Mirkin (1996): a combination of gold and DNA to create a new material
- Pluripotent matter: a material that can transform itself into different materials

Transmutable nanoparticles with
reconfigurable surface ligands

Youngeun Kim^{1,2}, Robert J. Macfarlane^{2,3,*†},
Matthew R. Jones^{1,2,*‡}, Chad A. Mirkin^{1,2,3,§}

Mirkin, C.A., Letsinger, R.L., Mucic, R.C.
& Storhoff, J.J. A DNA-based method for
rationally assembling nanoparticle into
macroscopic materials. Nature 382, 607–
609

Northwestern

ARTICLE in NATURE 382(6592):607-9 · AUGUST 1996
Impact Factor: 41.46 · DOI: 10.1038/382607a0 · Source: P



Metamaterials

and the cloak of invisibility

- Metamaterials
 - Victor Veselago (1968): materials that have properties not found in nature
 - David Smith (2006): you can make an object invisible if you cover it with a material that will bend electromagnetic waves
 - Andrea Alu (2012): a metamaterial cloak for a 3D object in free-space (just a few micrometers thick and only for microwaves)

Nano Manufacturing

- Expensive to build nanomaterials and in general to work at the nanoscale.
- Copy Nature: program nano-particles so that they self-assemble into complex structures?
- Ting Xu's self-assembling nano-particles

Berkeley
UNIVERSITY OF CALIFORNIA



Nano Manufacturing

- Colloidal synthesis (eg, Paul Alivisatos, UC Berkeley)
- Nanoimprint lithography (Stephen Chou, Univ of Minnesota)
- Two-photon-lithography (Jürgen Stampfl, Vienna University of Technology)
- 3D printing (Ho-Young Kim, Seoul National University)
- Colin Raston's Vortex Fluidic Device



Nano Manufacturing

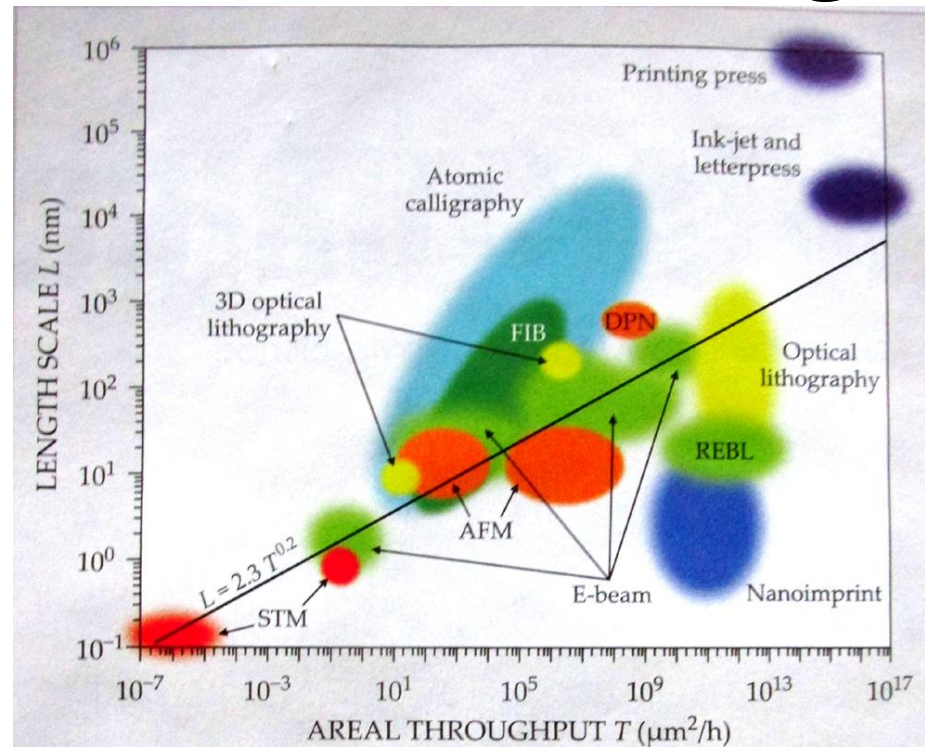
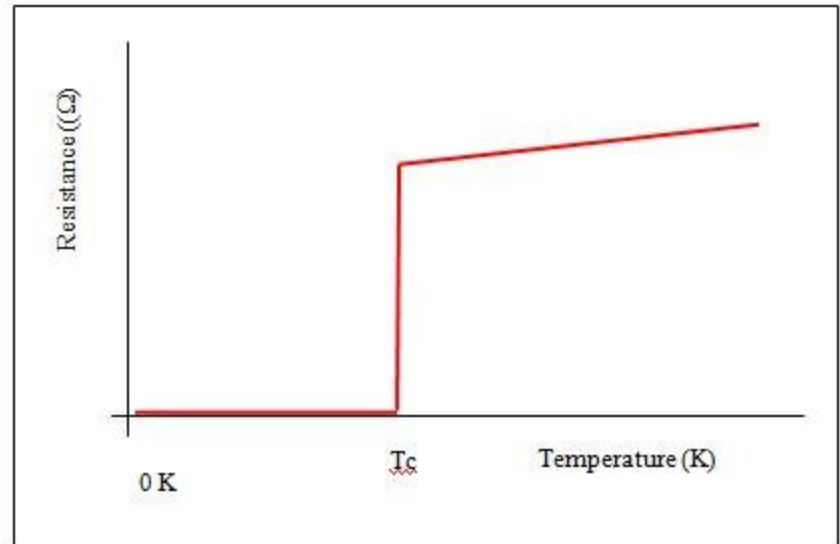


Figure 1. Nanomanufacturing techniques must not only produce structures on a small length scale L but also achieve a high areal throughput T . Tennant's law, which states that T scales as the fifth power of L , holds approximately over a wide range of technologies discussed in the text, including those based on scanning tunneling microscopes (STMs) and atomic force microscopes (AFMs), optical lithography, electron-beam (e-beam) lithography and reflective e-beam lithography (REBL), nanoimprinting, focused ion beams (FIBs), dip-pen nanolithography (DPN), and atomic calligraphy. Beating that trend (shifting the black curve down and to the right) is the challenge of nanomanufacturing. (Adapted from refs. 4 and 17.)

Superconductivity

- A state of matter in which electrons flow without resistance
- Achieved at absolute zero temperature
- Much harder to achieve at normal temperatures



Superconductivity

- Practical applications:
 - Magnetic Resonance Imaging (MRI) used in hospitals
 - Magnetic-levitating trains
 - Power transmission
- Can Nanotech create superconductors that work at room temperature?



Superconductivity

- A brief history
 - 1911 Heike Onnes (Netherlands) discovers superconductivity.
 - 1933 Walther Meissner and Robert Ochsenfeld (Germany) discovers the Meissner effect
 - 1950 Lev Landau and Vitaly Ginzburg (Russia) propose a theory of superconductivity
 - 1956 Leon Cooper predicts that electrons would attract one another at extreme low temperatures in some materials
 - 1957 John Bardeen, Leon Cooper and John Schrieffer (Univ of Illinois) provide a complete theory of superconductivity
 - 1961 Eugene Kunzler (Bell Labs) discovers that niobium-tin can be used to make supermagnets



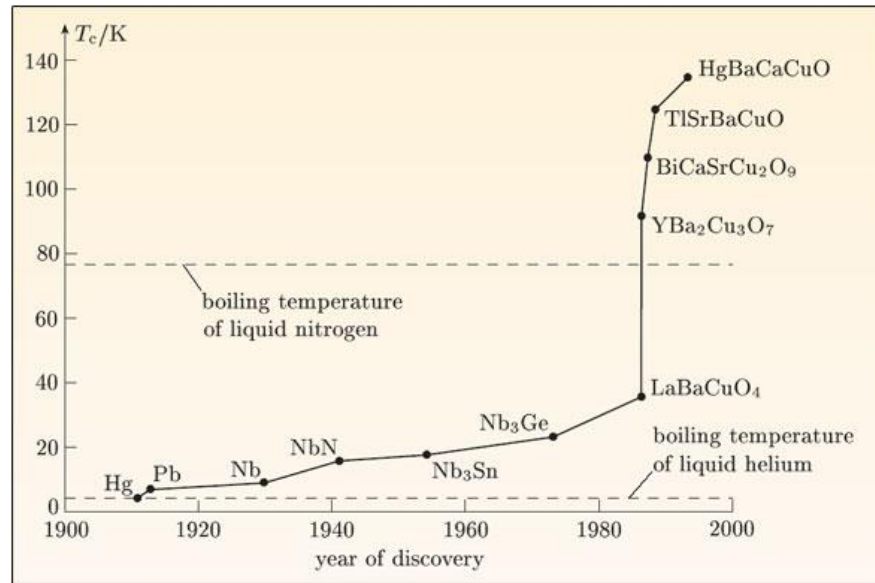
Superconductivity

- A brief history
 - 1962 Ted Berlincourt and Richard Hake (Atomics International, California) discover that alloys of niobium and titanium are suitable for industrial applications, and production of superconducting wires begins at Westinghouse
 - 1962 Brian Josephson (Univ of Cambridge) shows that a supercurrent can flow between two pieces of superconductor separated by a thin insulator
 - 1980 Klaus Bechgaard (Denmark) synthesizes an organic (carbon-based) superconductor
 - 1986 Alex Müller and Georg Bednorz (IBM, Switzerland) discover a high-temperature superconductor (at 35K)
 - 1987 Ching-Wu "Paul" Chu (Univ of Houston) discovers YBCO, the first material to exhibit superconductivity at temperatures above the boiling point of liquid nitrogen (77k), thus making liquid nitrogen feasible as a refrigerant



Superconductivity

- A brief history



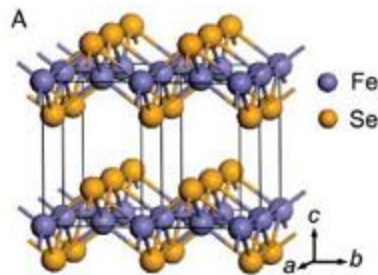
- 1993 Andreas Schilling (Switzerland) achieves superconductivity at 133 K
- 2000 Jun Akimitsu (Japan) discovers a magnesium diboride superconductor

Superconductivity

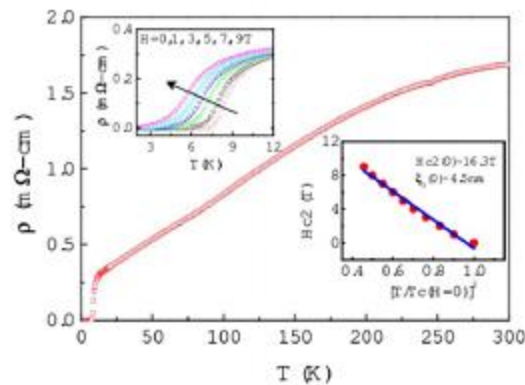
- A brief history
 - 2006 Hideo Hosono (Japan) discovers an iron-based superconductor
 - 2008 Maw-Kuen Wu discovers that FeSe is a superconductor

Superconductivity in the PbO-type structure α -FeSe

Fong-Chi Hsu[†], Jiu-Yong Luo^{*}, Kuo-Wei Yeh^{*}, Ta-Kun Chen^{*}, Tzu-Wen Huang^{*}, Phillip M. Wu[‡], Yong-Chi Lee^{*}, Yi-Lin Huang^{*}, Yan-Yi Chu[†], Der-Chung Yan^{*}, and Maw-Kuen Wu^{*§}



2016



Superconductivity

- A brief history
 - 2014 Andrea Cavalleri (Germany) uses lasers to achieve superconductivity at room temperature (but only for 0.0000000000002 seconds)
 - 2015 Mikhail Erements and Alexander Drozdov (Germany) achieve superconductivity at 203K
 - 2015 Kosmas Prassides (Japan) discovers the Jahn-Teller metal: a substance that exhibits the properties of an insulator, superconductor, metal, and magnet all in one



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Superconductivity

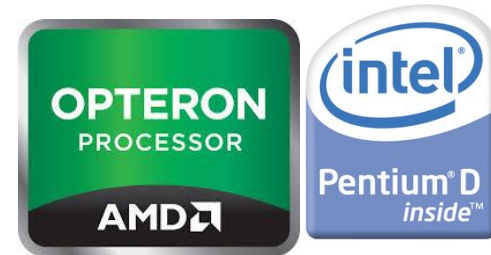
- If achieved at room temperature...
 - More efficient transmission of electricity
 - All the railways that use electricity would become magnetic levitation railways
 - Cheaper electronic circuits
 - Fusion at room temperature

Superconductivity

- If they invent superconductivity at room temperature, invest in a recycling company!
- TV sets, computers, phones, transformers and all the electrical devices that exist today in the world would become obsolete.

Nanotech for Electronics

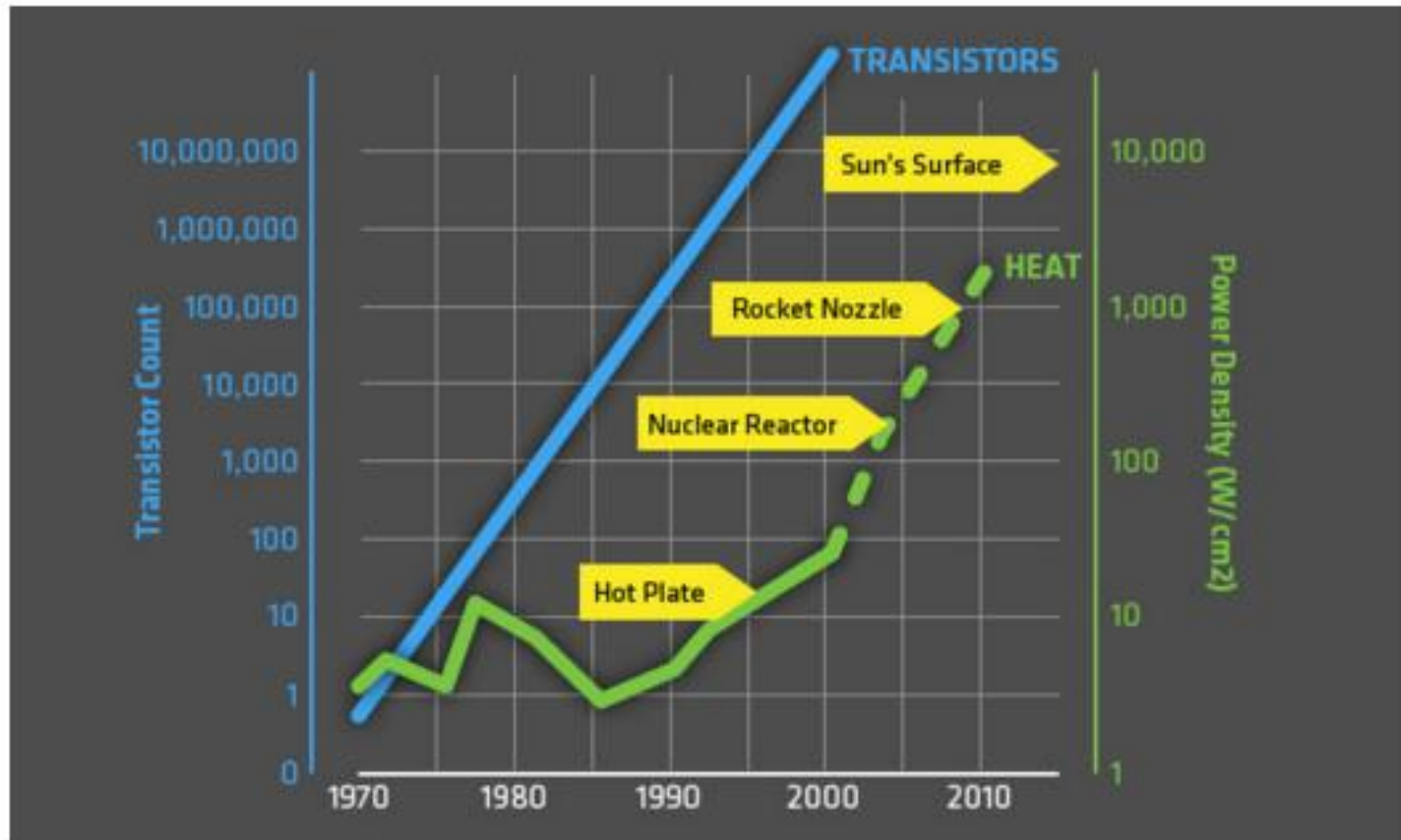
- The limit of Moore's Law: increasing the clock speed of a chip also increases its electrical consumption which also increases the heat it generates
- Moore's Law stopped working in 2005: what is increasing exponentially is no longer the "clock speed" but the number of transistors thanks to multiple cores on the same chip
- The cost per transistor has actually been rising since 2011 (the 28-nanometer chip)



An integrated circuit built with TSMC 28 nm

Nanotech for Electronics

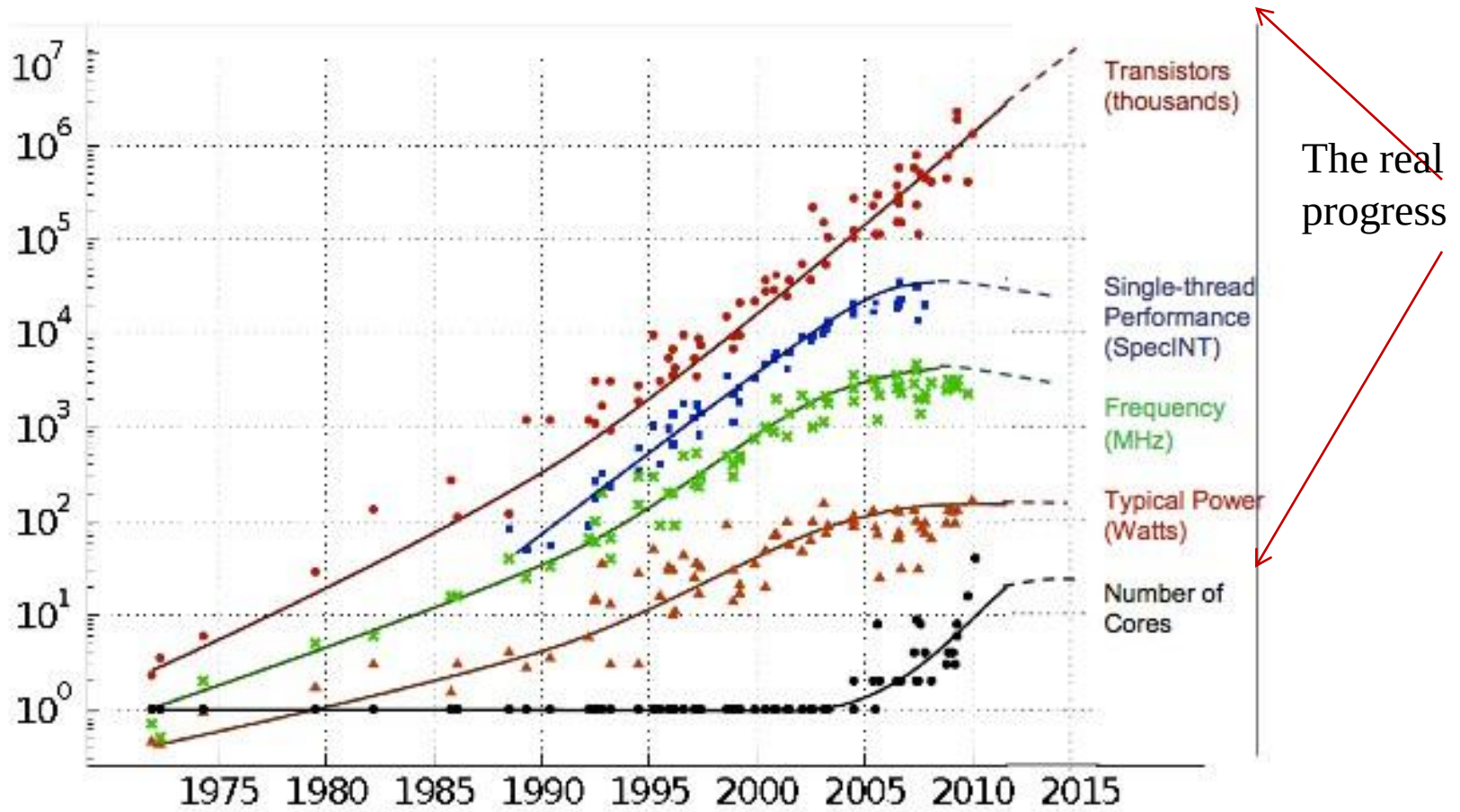
- The problem: the “Gelsinger syndrome”



In 2001, Patrick Gelsinger, an Intel executive, predicted that unless something changed, computer chips would become hotter than nuclear reactors within a few years. *Illustration by Jenna Luecke*

Nanotech for Electronics

- The solution: multiple cores



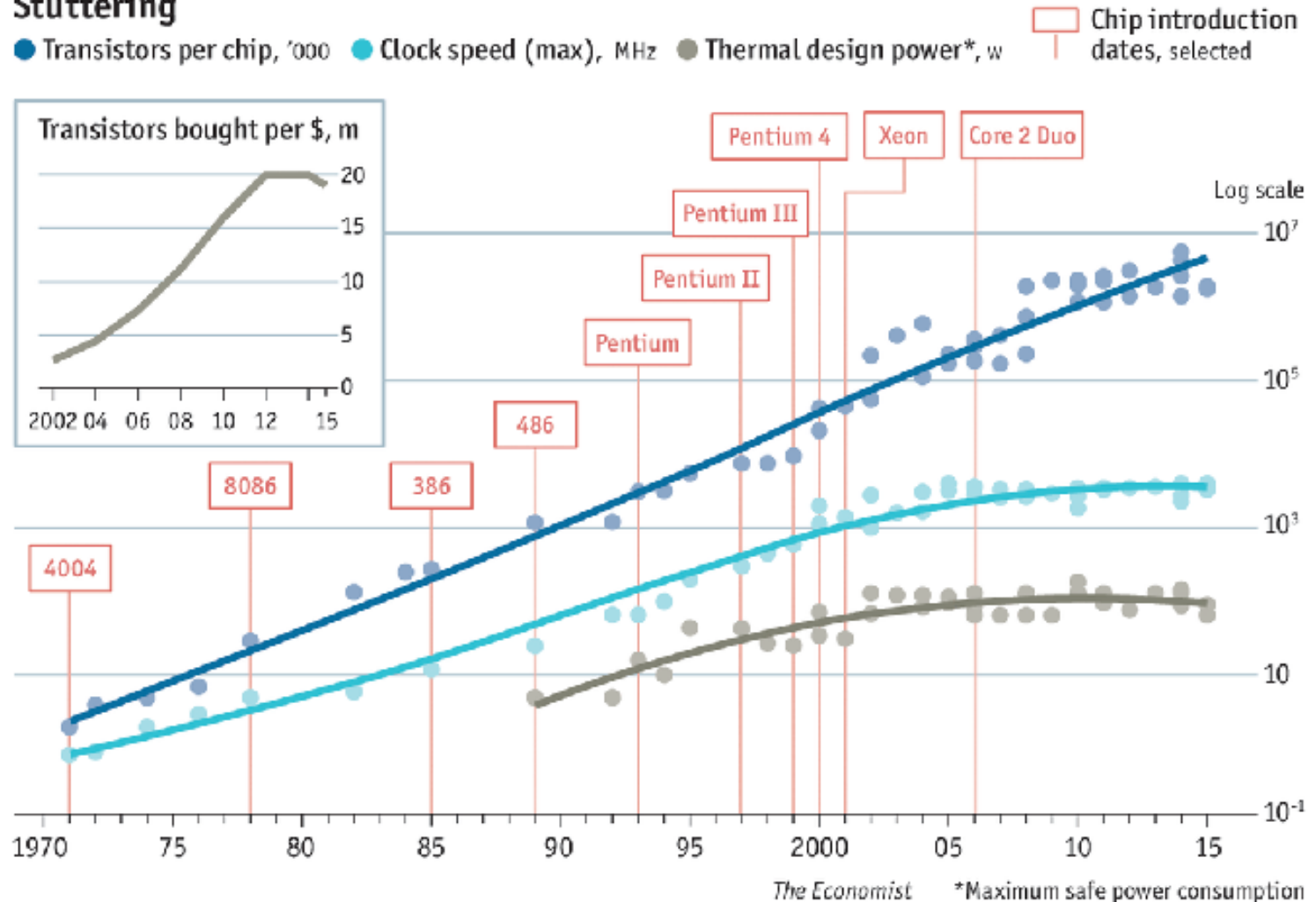
nextplatform.com

Original data collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond and C. Batten
Dotted line extrapolations by C. Moore

Nanotech for Electronics

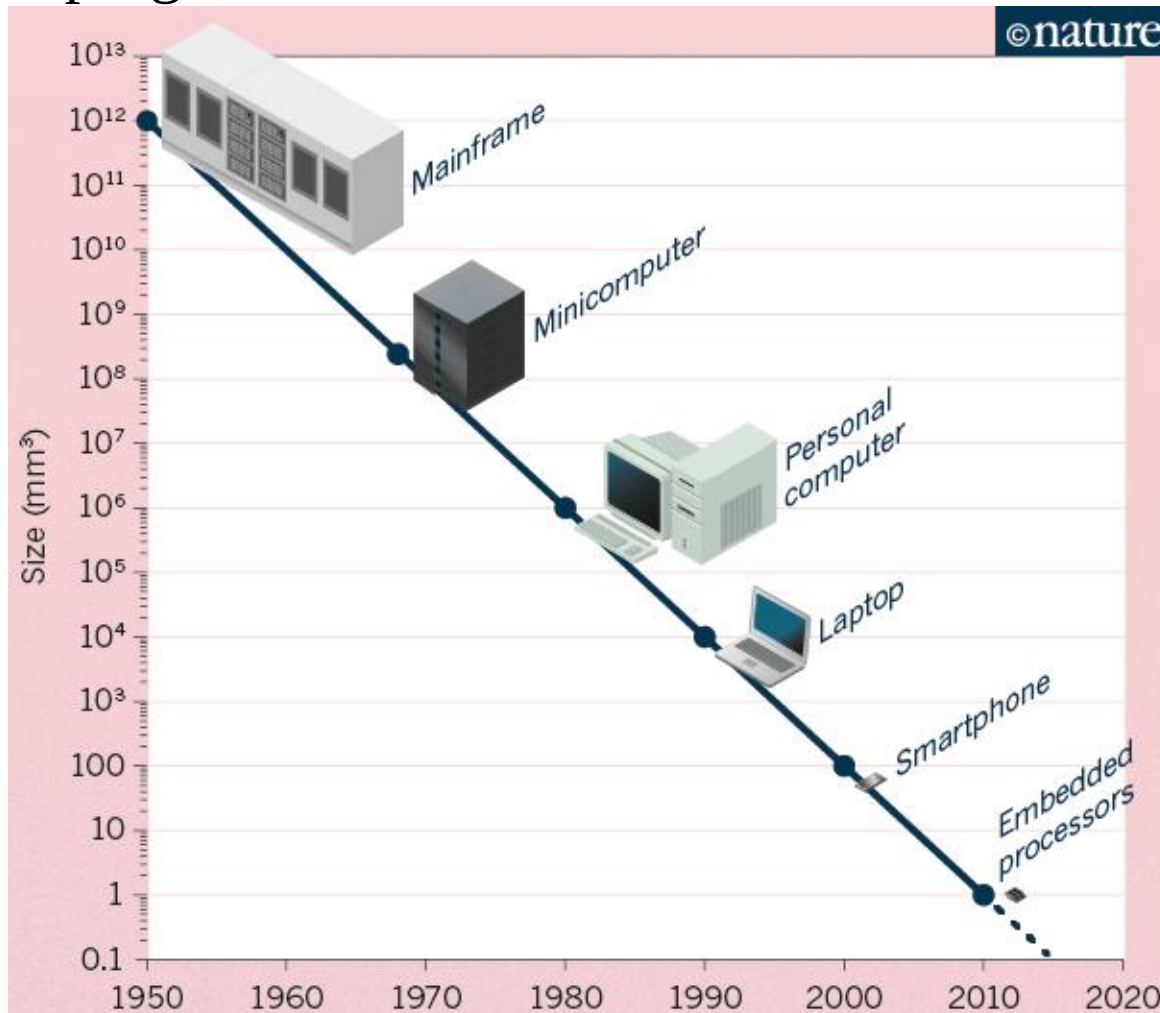
The Economist's version of the same graph (2016)

Stuttering



Nanotech for Electronics

When Moore's Law stops working, what happens to the progress in devices?



Moore's Law has resulted in new generations of devices

Nanotech for Electronics

- Optoelectronics
 - Keep silicon transistors but use light to transfer information
 - Faster speed and lower consumption
 - Rajeev Ram (MIT, 2015)
 - IBM (2015)



**IBM announces silicon
photonics breakthrough, set to
break 100Gb/s barrier**

By Joel Hruska on May 14, 2015 at 4:49 pm

Nanotech for Electronics

- The other solution: new materials
 - Graphene "nanoribbons" could replace silicon semiconductors and
 - transport electrons thousands of times faster than a traditional metallic conductor
 - provide microprocessor clock speeds hundreds of times faster than today's microprocessors
 - increase the density of transistors on a computer chip by as much as 10,000 times

Nanotech for Electronics

- Manufacturing graphene nanoribbons
 - Felix Fischer at UC Berkeley
 - Michael Arnold at the Univ of Wisconsin
 - Paul Weiss at UCLA



Nanotech for Electronics

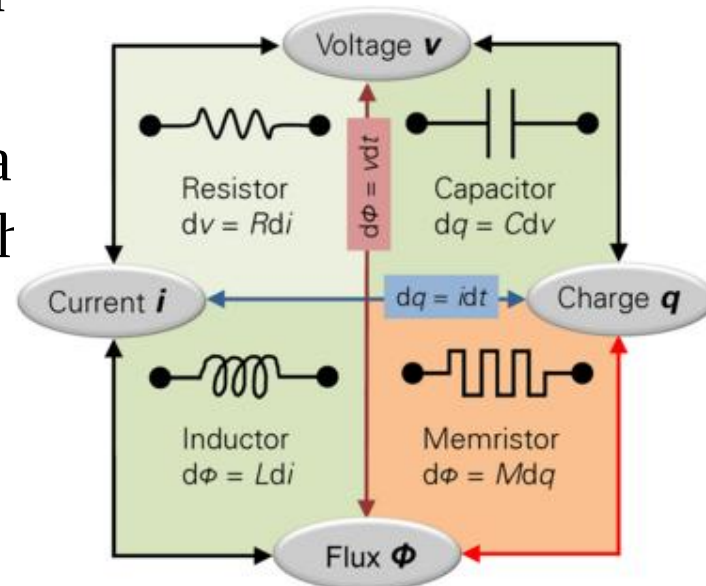
- Graphene electronics
 - Graphene conducts too well – not ideal to replace silicon
 - Andras Kis (Switzerland): a transistor made of TMDC (2010)
 - Madhu Menon (Britain): a new material that is one-atom thick like graphene, but it is a semiconductor like silicon (2016)



Nanotech for Electronics

- Storage
 - Computer memory is made of transistors, which are "volatile"
 - Memristors are a nonvolatile technology: they don't lose their information when the power is turned off (RAM + Hard Disk = Memristor)
 - A memristor is neither a resistor nor a capacitor nor an inductor. It is a fourth fundamental circuit element with properties that cannot be achieved by any combination of the other three.

In 2008 a team lead
by **Stanley
Williams** created
the first memristor



Nanotech for Electronics

- Storage
 - Memristors are similar to synapses, therefore well-suited for neural networks (e.g. Dmitri Strukov, 2015)
 - New Mexico-based Knowm

Startup claims a breakthrough in brain-like computing on chips

SEPTEMBER 3, 2015, 11:11 AM EDT

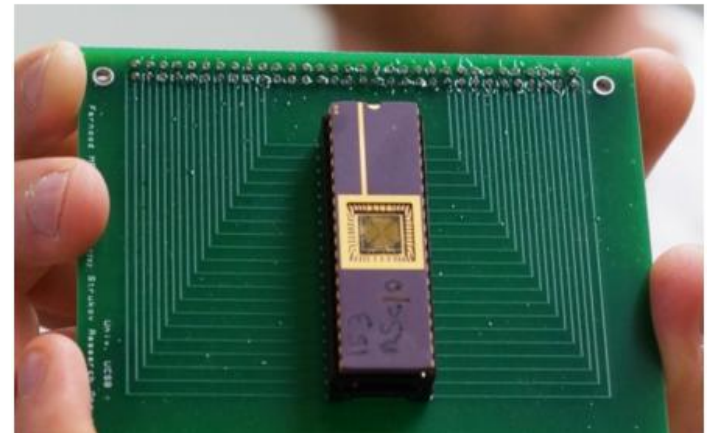


An Important Step in Artificial Intelligence

Researchers in UCSB's Department of Electrical and Computer Engineering are seeking to make computer brains smarter by making them more like our own.

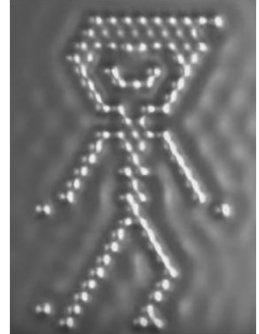
By Sonia Fernandez

Monday, May 11, 2015 - 10:45 Santa Barbara, CA



Controlling Matter at the Atomic Scale

- IBM
 - 1989: “IBM in atoms” demo
 - 2013: “A Boy and His Atom”, the “world’s smallest movie”
- Michelle Simmons at the University of New South Wales and Gerhard Klimeck at Purdue University created a transistor from a single atom (2012)



One and done: Single-atom transistor is end of Moore's Law; may be beginning of quantum computing

Post-Electronics

- Intel already announced it won't go below 7nm with silicon
- A 2nm transistor would be made of only 10 atoms
- Quantum effects would make them unreliable

Intel: we'll have to adopt fundamentally new transistor technologies in 4-5 years, Spintronics is a leading candidate

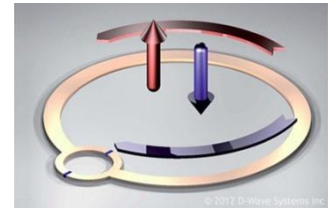
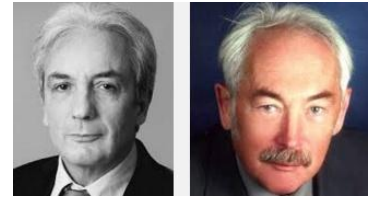


Feb 05, 2016

Intel's technology and manufacturing group leader, William Holt, says that if Intel wants to keep improving its chips, it will soon have to start using fundamentally new technologies. The company does not know which technology will be adopted, but there are two possible candidates at this stage - Spintronics, and tunneling transistors.

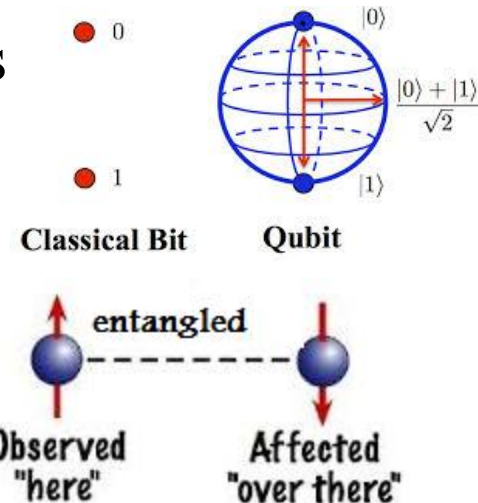
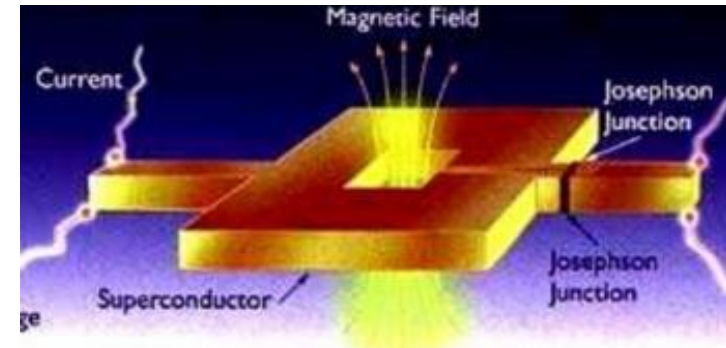
Spintronics

- 1988: Albert Fert (France) and Peter Gruenberg (Germany) discover the Giant Magnetoresistive (GMR) effect, that uses the electron spin to increase the rate at which magnetic states can be read, thus enabling the storage of extremely densely-packed information
- 1997: IBM introduces the first hard disk that uses the GMR effect for its read-out head
- 2006: Freescale/Everspin introduces a computer memory based on GMR, Magnetoresistive RAM (MRAM)



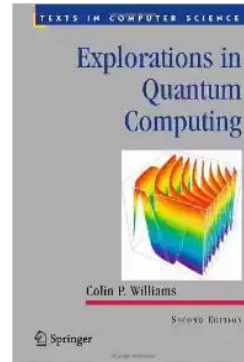
Quantum Computing

- 1964: Ford Labs invent Superconducting Quantum Interference Device (SQUID)
- 1982: Richard Feynman shows that a device can store information "qubits" instead of binary bits
- Multiple qubits can be linked in “entangled” states
- A change in one qubit changes the entire system
- A quantum computer could perform multiple calculations at the same time; for example, perform multiple searches at the same time
- 1985: David Deutsch describes a universal quantum computer



Quantum Computing

- 1994: Peter Shor shows that quantum algorithms can run exponentially faster than classical ones
- 1995: Peter Shor shows that quantum error correction is possible
- 1997: Colin Williams' and Scott Clearwater's "Explorations in Quantum Computing"
- 1997: David DiVincenzo's criteria
- 1997: Anton Zeilinger demonstrates quantum teleportation



Quantum Computing

- 2002: Michael Freedman describes a topological quantum computer
- 2006: Christopher Monroe creates a quantum processor
- 2007: D-Wave demonstrates its first quantum computer
- 2009: NIST unveils a universal programmable quantum computer (two qubits)



Quantum Computing

- 2013: The London Centre for Nanotechnology discovers that the electrons in copper phthalocyanine remain in superposition for long times
- 2014: Delft Univ teleports information between two qubits separated by three meters
- 2016: JQI's five-qubit modules that can be combined together
- 2016: IBM makes a five-qubit computer available on the cloud

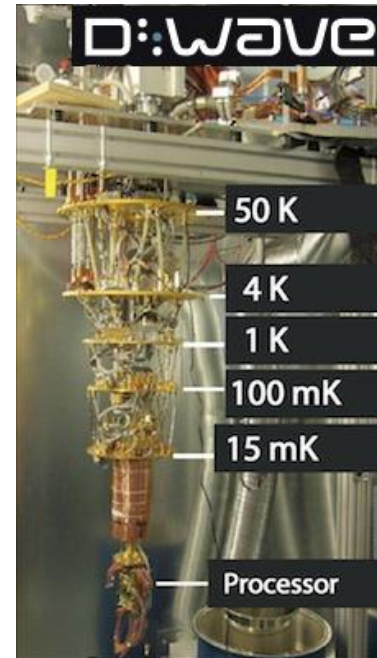


A New Way of Thinking:
The IBM Quantum Experience



Quantum Computing

- Unsolved problems
 - Cooling the superconducting circuits is expensive and cumbersome
 - Superconducting qubits (SQUIDs) are unreliable
- Reliable qubits
 - John Martinis (UC Santa Barbara & Google): nine qubits arranged in a line (2015)
 - Jay Gambetta (IBM): four qubits in a two-by-two array (2015)



Quantum Computing

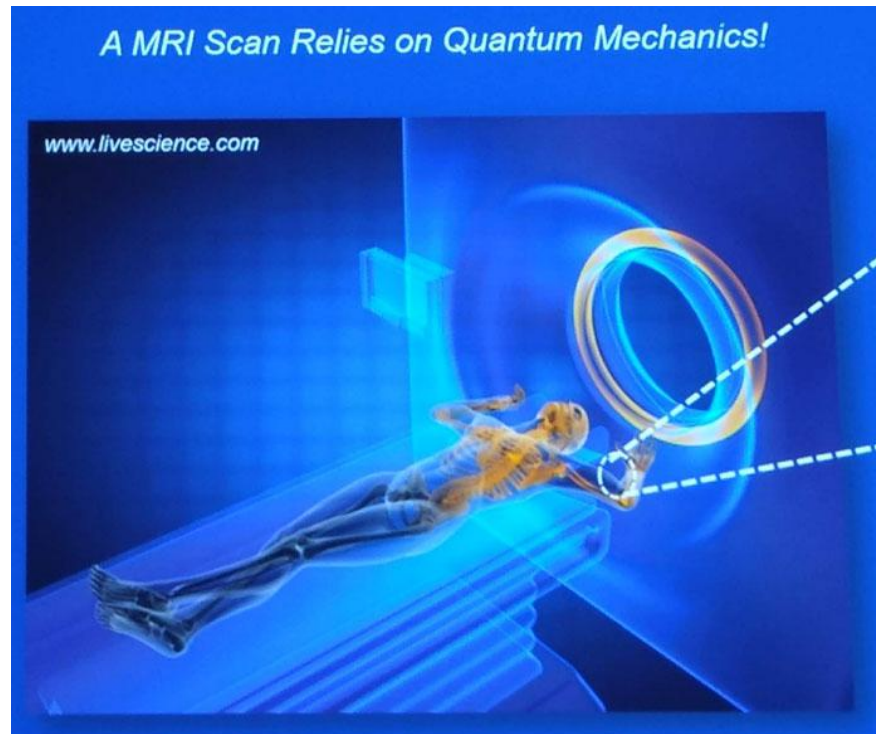
- Qubits via photon quantum states
 - Photons preserve entanglement over long distances and time periods
 - Roberto Morandotti: complex entangled quantum states on an optical chip (2016)

INRS
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Quantum Computing

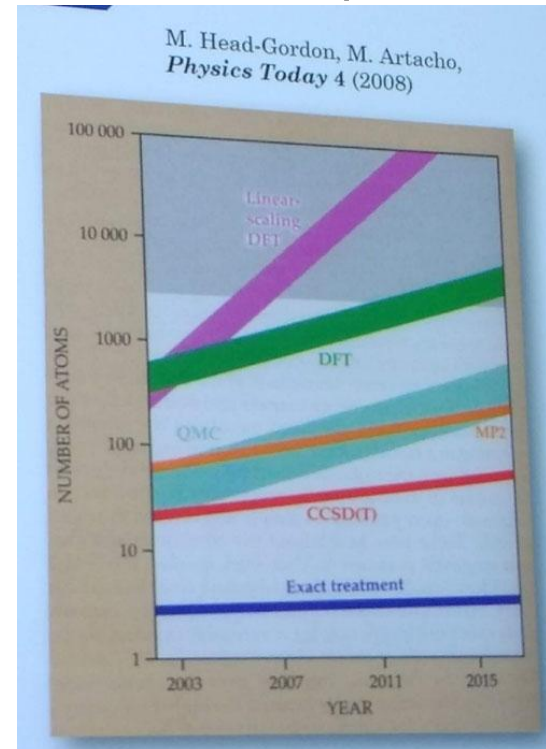
- Quantum Processors
 - Does quantum mechanics work? The MRI!
 - Difference between the MRI and quantum computing: the MRI measures average properties, we need to measure each spin individually



Quantum Computing

- Quantum Processors

- How to make quantum materials: engineers “encourage” nature to assemble stable structures, and nature does the rest
- Problem of entanglement: in order to describe 300 entangled qubits, we need more numbers than particles in the universe
- Many different techniques... see graph of when we expect to be able to describe n entangled atoms
- Superconducting circuits

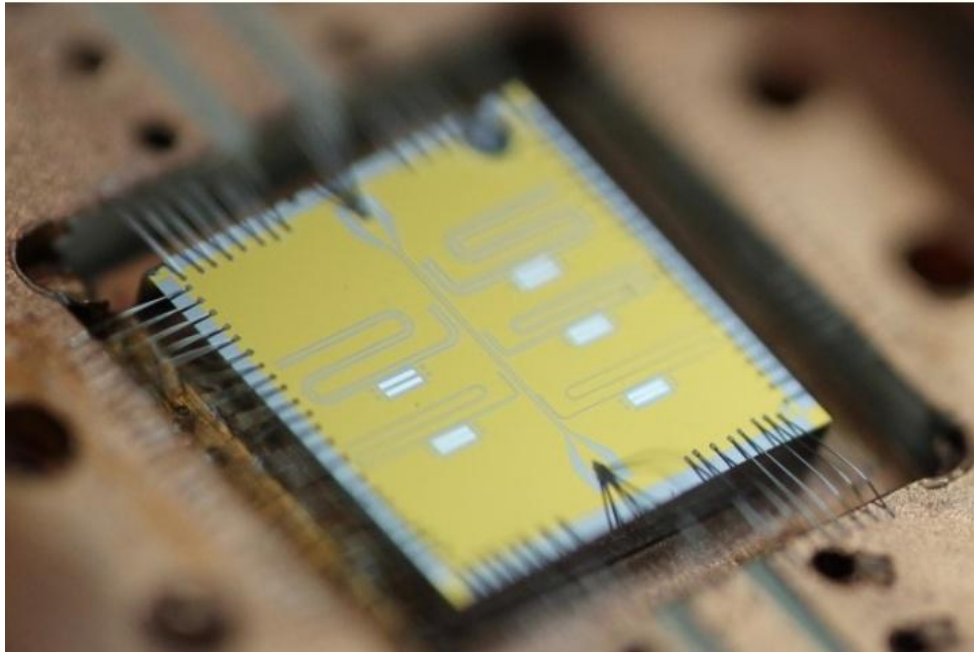


Quantum Computing

- Quantum Processors
 - Superconducting circuits are the most promising platform
 - UC Berkeley

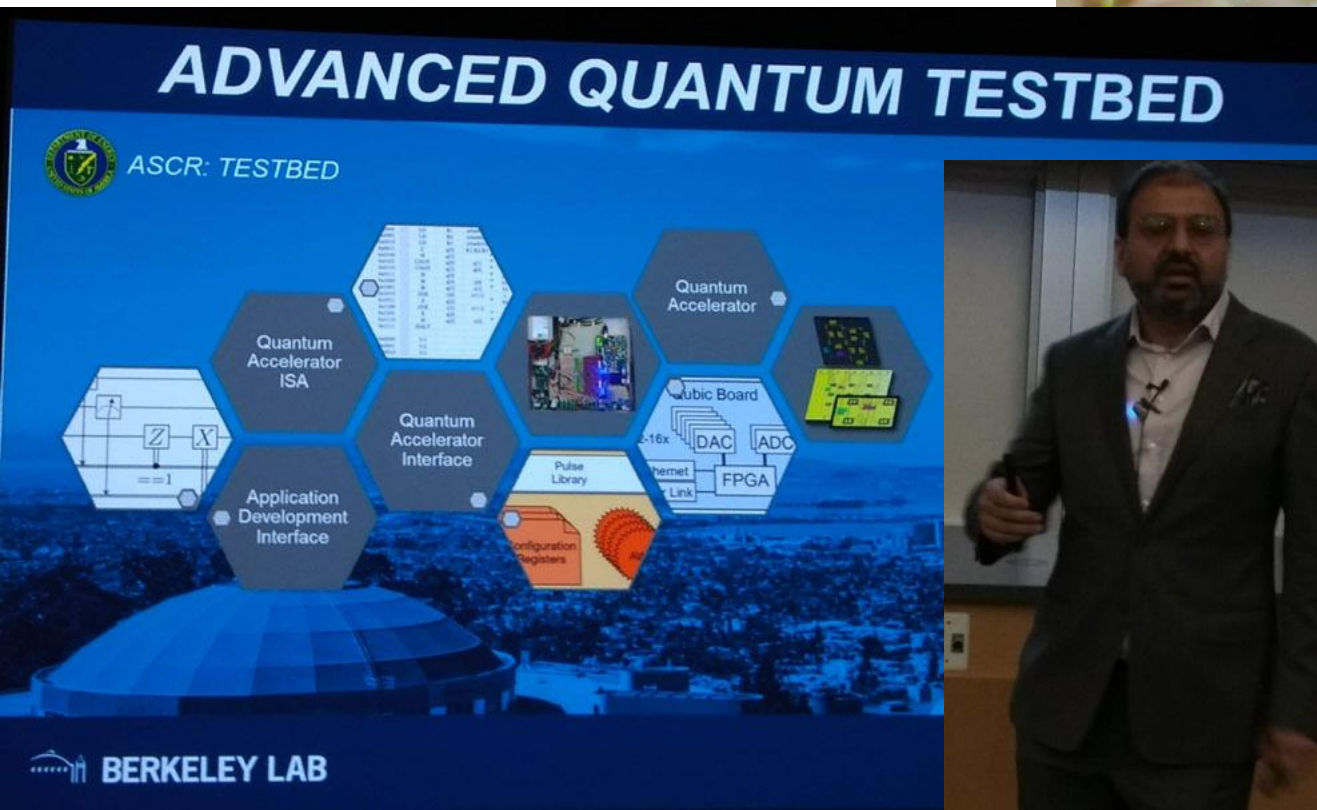
Welcome to the Quantum
Nanoelectronics Laboratory!

Berkeley
UNIVERSITY OF CALIFORNIA



Quantum Computing

- Superconducting Quantum Processors



Irfan
Siddiqi (UC
Berkeley)
28 May
2019

Quantum Computing

- Superconducting Quantum Processors
 - Suitable for specific applications
 - Suitable for improving classical algorithms, eg “quantum recommendation systems” for Netflix and Amazon

Quantum Computing

- Peter Wittek (Univ of Toronto): quantum computing and artificial intelligence



UNIVERSITY OF
TORONTO



For founders pursuing commercial opportunities at the intersection of quantum computing and machine learning.

- Blackbrane (Toronto, Colin Lupton): Virtual quantum machine (cloud-based 128-qubit quantum computer)



Quantum Computing

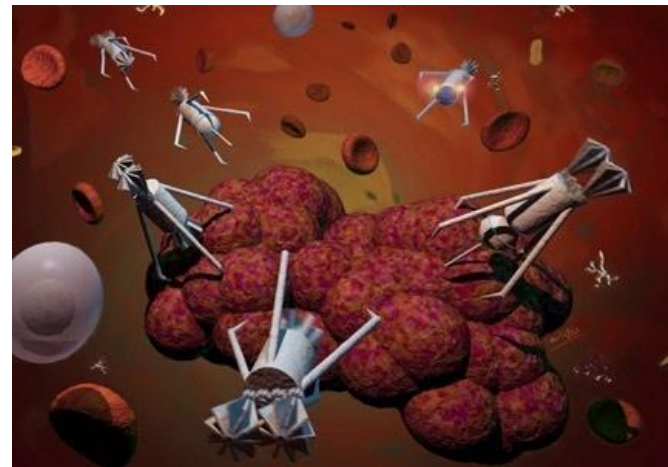
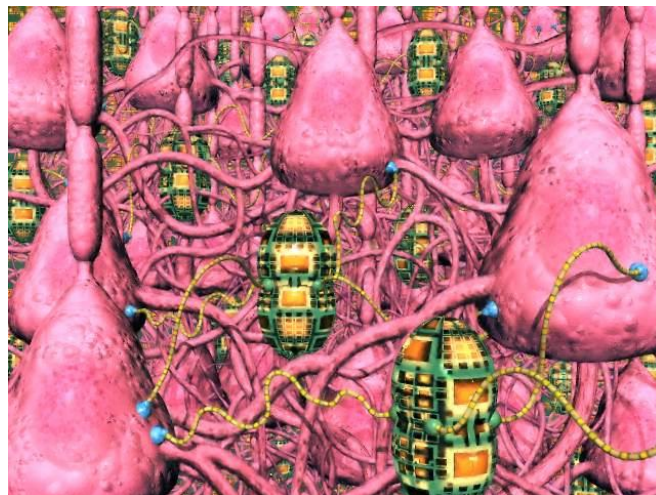
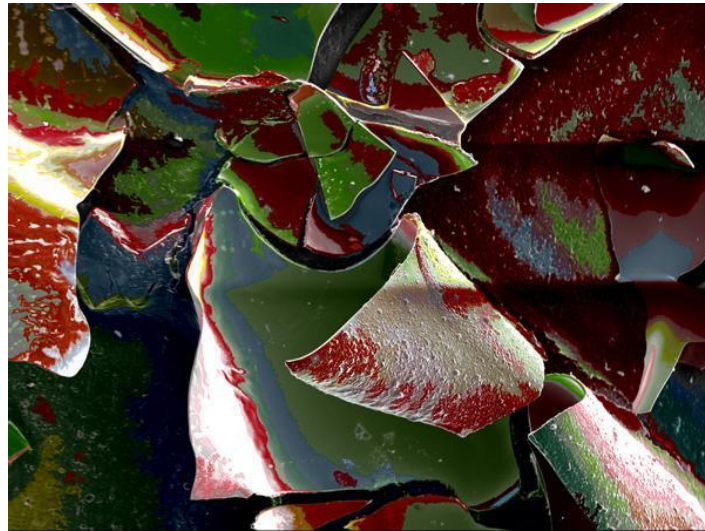
- Scott Aaronson, founding director of the Quantum Information Center at the University of Texas at Austin



The University of Texas at Austin
Quantum Information Center

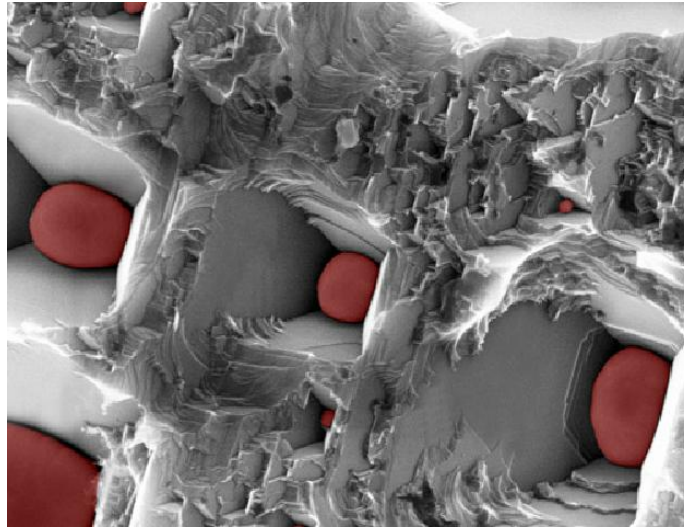
NanoArt

- Cris Orfescu
- Ghim Wei Ho
- Tim Fonseca
- Erik Viktor

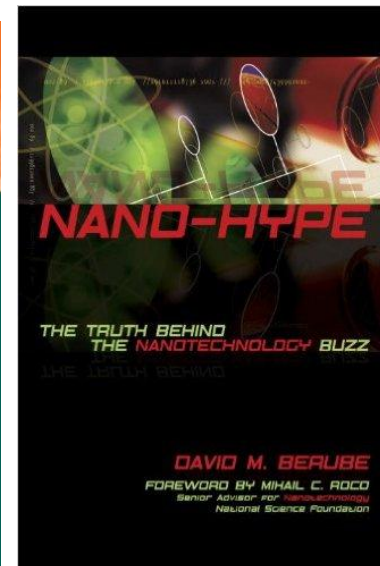
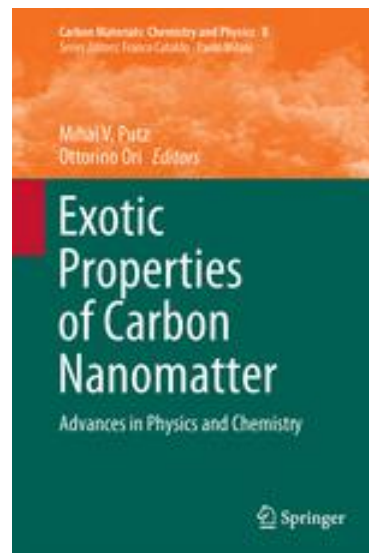
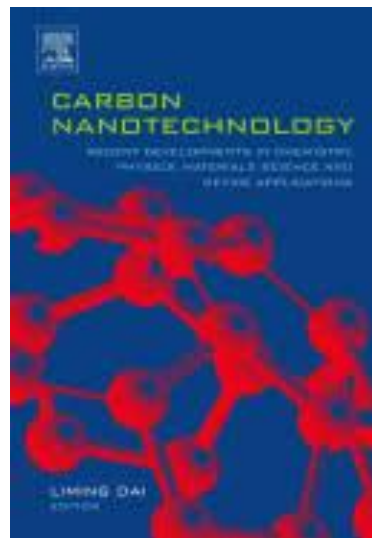
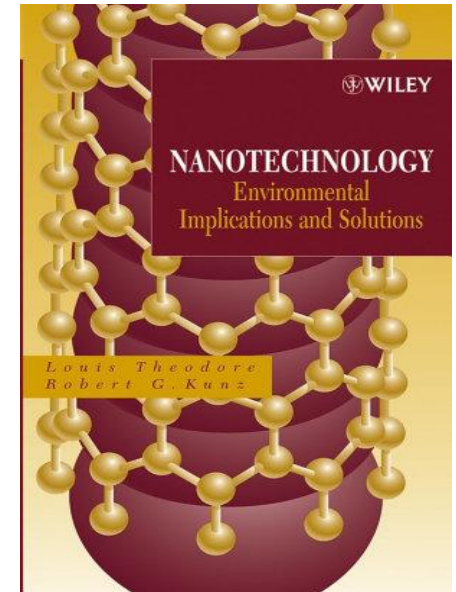
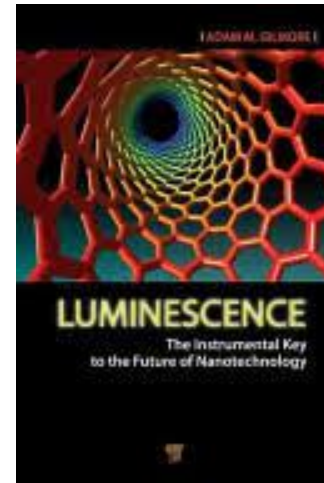
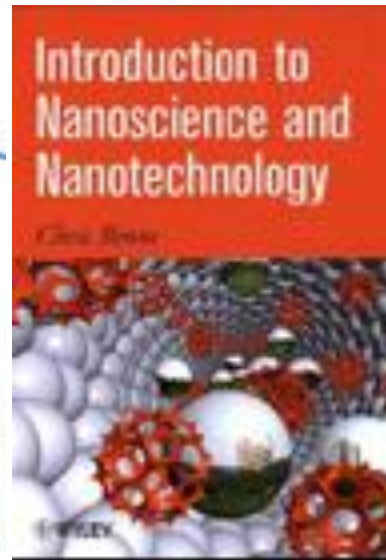
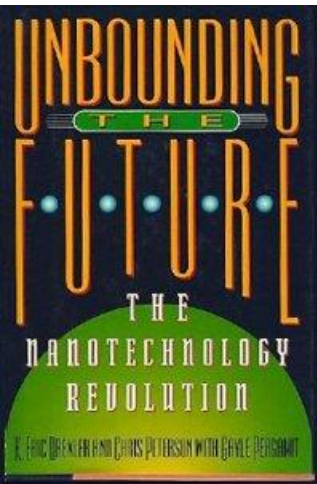


NanoArt

- Maiken Lilley
- Victoria Vesna

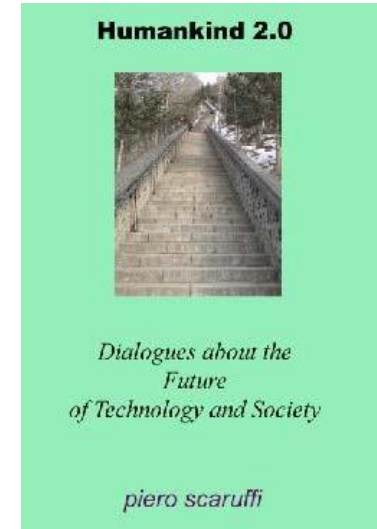
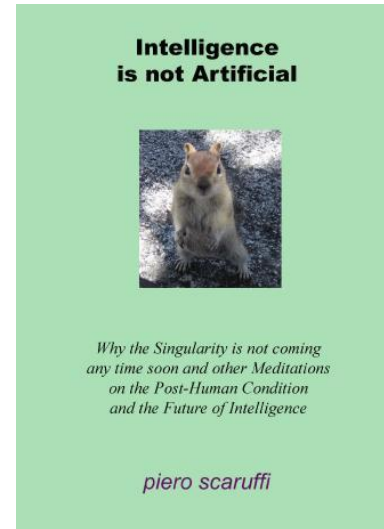
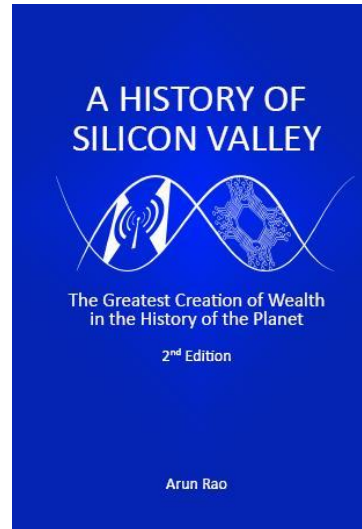


Bibliography



Contact

- www.scaruffi.com



See <http://www.scaruffi.com/singular/human20.html>
for the full text of this discussion