Nanotechnology: An Instant Introduction

A short, informal introduction to
the basic concepts of nanotechnology
and its growing importance in our lives

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Overview

A nanometer is one one-billionth of a meter, a tiny distance most of us have never had to deal with in daily life. Nanotechnology can be thought of as a way of using molecules as building blocks for materials, objects, and devices, and positioning these molecules with precision at this nanometer scale.

Dealing with matter at the nanoscale often identifies subtle differences in the chemistry and physics of the material, as opposed to the properties of the same material at a larger scale (e.g. something we could actually see and/or touch). Much research attempts to understand how these differences might be used.

Current research results suggest Materials, Energy, Computers, and Medicine as major areas of impact.

INTRODUCTION

Our ability to manipulate matter lies at the heart of our technologies and has since our distant ancestors crafted spear points from flint as early as 11,000 years ago.

Clovis Spear Point
South Dakota State Historical Society Archeological Research Center
http://www.sdsmt.edu/wwwsarc/collectn/stone/clovis.html

More recently, the concepts of what is now called nanotechnology were first introduced by Nobel Laureate Richard Feynman in a lecture titled "There's Plenty of Room at the Bottom", delivered to the American Physical Society in December of 1959. The entire text is available online.

There's Plenty of Room at the Bottom
by Richard P. Feynman
http://www.zyvex.com/nanotech/feynman.html

Many people have heard of nanotechnology, very few know what it is, what it isn't, and how it's already shaping our future. This paper will provide a very basic introduction to the concepts of nanotechnology and its growing importance in our lives.

Highlights

- Nanotechnology is being developed now.
- Nanotechnology deals with control of the precision of the process at the molecular scale, not the size of the result, therefore nanotech isn't a "what"; it's a "how".
- Hundreds of products are already available. More (and more complex) products will continue to enter all areas of the market.
- Computers will get smaller, faster, easier to use, cheaper, and smarter.
- The first medical applications (some already in 'Phase I' human clinical trials) should become generally available within 10 years.
- Primary Impacts: materials, energy, computers, medicine.

The future is coming sooner than you think.

Calculators were once thousand-dollar desktop clunkers, but microelectronics made them fast and efficient, sized to a child's pocket, and priced to a child's budget. Now imagine a revolution of similar magnitude, but applied to everything else.
from "A Sketch of Trends"
in Chapter 1: Looking Forward
of Unbounding the Future

WHAT IS NANOTECHNOLOGY?

Nanotechnology is the ability to understand and manipulate matter at the nanometer scale. It can be thought of as:

- precise building at the molecular scale, using atoms and small molecules as "building blocks";
- a refinement of our existing technologies, not new science; and
- interdisciplinary.

What Nanotechnology Isn't?

Nanotechnology does not deal with:

- sub-atomic particles;
- nuclear processes;
- quantum mechanics;
- matter/energy conversion; or
- alchemy.

How Small Is Nano?

"A nanometer (nm) is one billionth of a meter. For comparison purposes, the width of an average (human) hair is 100,000 nanometers. Human blood cells are 2,000 to 5,000 nm long, a strand of DNA has a diameter of 2.5 nm, and a line of ten hydrogen atoms is one nm. "

from: The Future is Coming Sooner Than You Think
The Report of the Joint Economic Committee
of the US Congress
March 2007

Here's a thought experiment to provide some comparison of the nanoscale to ordinary, day-to-day, sense perception.

When the SR-71 Blackbird was retired in the late 1990s, it was the fastest aircraft in use by the U.S. Air Force. It set a number of world speed records. One was a trip from Los Angeles to Washington, DC, a distance of 2,299.67 statute miles in just over 1 hour and 4 minutes, for an average speed of 2,144.83 mph

A radio signal travels 2,299.67 statute miles, the exact same distance, in approximately 0.0123 seconds (slightly over 12 thousands of a second).

That same radio signal will travel only 11.8 inches (30 cm) in a nanosecond, one one-billionth of a second,

What Will Nano Look Like?

Today (October 2009), we don't yet know how nanotechnology will manifest itself in our world and in our lives. We have some general ideas about where nanotechnology will be useful, but, as yet, the details of such use remain elusive.

"Prediction is very difficult: especially about the future."
Nobel Laureate Neils Bohr

The Neils Bohr quote sounds remarkably like Yogi Berra, the legendary catcher for the New York Yankees. Either way, it's true. Accurately predicting the future is a difficult task.

"Any sufficiently advanced technology is indistinguishable from magic."
Sir Arthur C. Clarke

Results – so far – suggest that nanotech will exhibit capabilities very like the Arthur Clarke's "magic".

Disruptive Technology

The term *disruptive technology* was coined by Bower and Christensen and introduced in their 1995 article *Disruptive Technologies: Catching the Wave*. (Bower and Christensen, 1995). A disruptive technology or disruptive innovation is a technological innovation, product, or service that eventually overturns the existing dominant technology or status quo product in the market. Disruptive technologies should not automatically be construed as something negative. They *are* harbingers of change.

In the 20th century we witnessed these examples of disruptive technologies:

- automobiles replaced horses for transportation
- container ships replaced so-called "break-cargo" ships and the stevedores that served them
- semiconductors replaced vacuum tubes in all kinds of electronics
- desktop publishing replaced traditional publishing
- digital photography initially replaced instant photography and now has increasingly replaced all chemical photography
- motion pictures with sound dramatically increased the number of musicians available to orchestras
- cell phones progressively replacing wired phones in all areas of society and bringing communication options to areas of the Third World that had never had any effective access to the world outside the local village
- the Internet

EXPECTED AREAS OF IMPACT / BENEFIT

Nanotechnology's ability to understand and manipulate matter at the nanometer scale is closely related to the ability to understand and manipulate both matter and life at their most basic levels, the atom and the organic molecules that make up DNA.

Initial areas of impact and/or benefit are expected to be:

1. Materials
2. Energy Generation, Distribution, and Storage
3. Computers and Electronics
4. Medicine and Health Care

Benefits: Materials

Since our distant ancestors crafted spear points from flint as early as 11,000 years ago, our technologies have depended on our ability to shape and use materials. Today, we are beginning to craft materials, objects, and devices using atoms and small molecules as the building blocks.

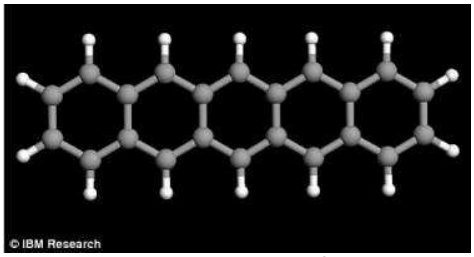
Material Characterization and Tools (IBM)

IBM has no less than six research tracks dedicated to nanotechnology. One of these, "Material Characterization and Tools", is developing a new class of microscope to allow direct visualization of molecules and atoms.

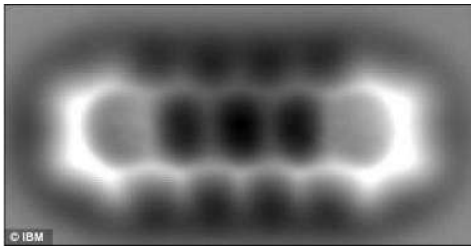
IBM's website says,

"The greatest challenge to developing nanoscale materials and structures is being able to look at what we have created, since many conventional characterization tools lack the resolution necessary to determine which elements are present and how they are distributed. We therefore have a long standing interest in developing innovative tools for materials characterization at the nanoscale."

On August 28, 2009, the IBM lab in Zurich released the first atomic force microscope (AFM) image of a molecule of pentacene, which showed the shape of the molecule, and the bonds between the carbon atoms and the invisible hydrogen atoms on the perimeter.



Computer generated image of pentacene.



Atomic force microscope image of pentacene.

IBM Scientists First to Image the "Anatomy" of a Molecule
Opens new possibilities for exploring the building blocks of future microprocessors and other nanodevices
http://www.zurich.ibm.com/news/09/pentacene.html

Single molecule, one millionth the size of a grain of sand, pictured for first time
http://www.dailymail.co.uk/sciencetech/article-1209726/Single-molecule-million-times-smaller-grain-sand-pictured-time.html

Examples of research and/or products using nano-structured materials:

2008 Jun 10: The Royal Institute of Technology in Stockholm announced paper made from nanofibrils of cellulose that is so strong it can't be torn – it has the tensile strength greater than cast iron.
http://www.nytimes.com/2008/06/10/science/10obpape.html

2007 Jan 05: Rensselaer Polytechnic Institute created the first material that reflects virtually no light. Silica nanorods are deposited at a precise angle of 45 degrees on aluminum nitride. Expected applications include brighter LEDs, more efficient solar cells, and new "smart" light sources.
http://news.rpi.edu/update.do?artcenterkey=1960

2006 Aug 12: Mercedes-Benz announced a nanoceramic paint that is scratch resistant and appears to glow in the sunlight.
http://www.mercedes-benz.ca/index.cfm?NewsID=141&id=611

Benefits: Materials – Carbon Nanotubes

Carbon Nanotubes (What's the Fuss?)

The 1991 discovery of carbon nanotubes by Sumio Iijima of Meijo University in Nahoya, Japan, is one of the landmarks in the history of nanotechnology. The unique properties of nanotubes have made them extremely popular for several areas of research. Nanotubes exhibit the following characteristics:

Best thermal conductivity known:
- better than diamond;
- directional along the axis of the tube.

Extraordinary mechanical properties, including:
- remarkable tensile strength;
- stiff without being brittle;
- 100 times stronger than steel at one-sixth the weight.

Unique electronic properties allow nanotubes to be:
- semiconductors;
- conductors (the only known instance of a molecule being a true metallic conductor)

Benefits: Energy – Generation, Distribution, And Storage

Nanotechnology is helping us find ways to generate energy that are "green" and endlessly renewable, to distribute the energy, new ways to store energy, and ways to use less energy.

Examples of energy research or products using nanotechnology:

2008 Jun 26: Researchers at Rensselaer Polytechnic Institute have shown that adding an invisible layer of copper nanorods to the bottom of a vessel used to boil water reduced the energy requirements to bring water to boil by an order of magnitude. The technology could lead to smaller computer chips and lower energy costs.
http://news.rpi.edu/update.do?artcenterkey=2464

2008 Mar 23: A team of researchers from the Universty of Wisconsin – Madison and the University of Maryland has developed a new chemical catalyst that paves the way for more efficient hydrogen fuel-cell cars. The nanostructured platinum-ruthenium catalyst operates at room temperature.
http://www.news.wisc.edu/14928

2008 Feb 17: Penn State University researchers have a proof-of-concept solar cell that uses sunlight that splits water to produce recoverable hydrogen. The process uses tiny (2nm) clusters of molecules with a center catalyst of iridium oxide surrounded by orange-red dye molecules to absorb sunlight in the blue range.
http://www.sciencedaily.com/releases/2008/02/080217170412.htm

2007 Apr 04: Dr. Wayne Campbell's team at the Nanomaterial Research Centre at Massey University in New Zealand has developed a synthetic chlorophyll that generates electricity from sunlight at a tenth the cost of

current silicon photovoltaics. A second breakthrough has allowed fabrication of this material into ordinary window glass to help meet the energy requirements of buildings.
http://www.sciencedaily.com/releases/2007/04/070405171830.htm

2006 Feb 08: MIT announced the ultracapacitor, with a forest of conducting nanotubes grown on the aluminum electrodes provide up to 100 times the storage capacity of traditional capacitors and are completely rechargeable.
http://web.mit.edu/newsoffice/2006/batteries-0208.html

Benefits: Computers And Electronics

Moore's Law

Moore's Law describes a trend in the history of computing hardware. Since the invention of the integrated circuit in 1958, the number of transistors on an integrated circuit has increased exponentially, doubling approximately every two years. This trend was first identified by Intel co-founder Gordon E. Moore in a 1965 paper. It has continued for over half a century. As of 2005, the trend was not expected to stop for at least another decade.

Nanotechnology is facilitating the development of electronic components so small that they will keep the annual doubling effect of Moore's Law going for decades into the future. These molecular circuits will be small, fast, three-dimensional, and self-assembling.

Examples of electronics research or products using nanotechnology:

2009 Sep 19: NanoLumens of Norcross, Georgia, has produced large, flexible, HD, digital video displays that are thinner and lighter than today's best LCD or plasma screens.
http://www.nanolumens.com

2008 Jun 09: IBM and Los Alamos National Laboratory announced a computing milestone of processing more than 1.026 quadrillion calculations per second on the computer named Roadrunner. Roadrunner is currently the fastest computer in the world.
http://www.cnn.com/2008/TECH/06/09/fastest.computer.ap/index.html?iref=mpstoryview

2007 Feb 05: Scientists at CalTech and UCLA reported in the journal Nature that they have produced a molecular-level memory chip 20 times as dense as today's best silicon. Although it's a long way from production, the researchers say they can record 100 billion bits of information -- the equivalent of 100,000 novels -- in a single *square centimeter*.
http://media.caltech.edu/press_releases/12942

2007 Jan 16: Hewlett-Packard announced a hybrid memory chip design that uses traditional CMOS and nanotech components. The chip will be eight times the component density of current chips, uses about 30% less energy, operates at cooler temperatures, and can be built using current fabrication facilities. The chips are expected to be available in 2010.
http://www.hp.com/hpinfo/newsroom/press/2007/070116a.html

Benefits: Medicine And Health Care

One important area of nanotechnology R&D is medicine. Medical researchers work at the micro- and nano-scales to develop new drug delivery methods, therapeutics and pharmaceuticals. For a bit of perspective, the diameter of DNA, our genetic material, is in the 2.5 nanometer range, while red blood cells are approximately 2.5 micrometers (a thousand times larger).

Note that even within a blood cell there is a great deal of room at the nanoscale. Nanotechnology holds the promise of manipulating individual cell structure and function.

Additional information about nanoscale research in medicine is available from the National Institutes of Health. **http://www.nih.gov/**

Among the expected benefits of medical nanotechnology are:

- Surgical tools will become elegant, more powerful, and less expensive
- Research and diagnosis will be more efficient, allowing for rapid response to new diseases
- Numerous small sensors and implants may allow for continuous health monitoring.
- Less expensive medicine will be more widely available, improve general health, and likely increase life spans.

Examples of medical research using nanotechnology:

2009 Jun 04: Researchers at UC Santa Barbara have developed a nanoparticle that can attack arterial plaque. The new development is described in a recent issue of the Proceedings of the National Academies of Science. The treatment is promising for the eventual development of therapies for cardiovascular disease, which is blamed for one third of the deaths in the United States each year.
http://www.ia.ucsb.edu/pa/display.aspx?pkey=2029

2009 February: Calando Pharmaceutical's lead drug candidate, IT-101, is a biocompatible shell containing the anticancer compound camptothecin for systemic treatment of cancer. Camptothecin has potent anticancer properties against a broad spectrum of tumor cells, interrupting a key process in cell division and replication, leading to cell death.
http://www.calandopharma.com/it-101.html

2008 January: Researchers at University of Glasgow hope to tackle two common forms of blindness with an optical implant – similar to devices in digital cameras – that will help blind people regain their sight. The implant could be available within a decade.
http://news.bbc.co.uk/2/hi/uk_news/scotland/glasgow_and_west/5168862.stm

2007 Jan 02: The Halas Group at Rice University is using gold particles and nanoshells tuned to absorb different wavelengths of light to kill tumor cells with non-invasive treatments that exhibit no chemotherapy side-effects.
http://www.technologyreview.com/Nanotech/17956/

STATE OF THE ART

In the early 1960s, the transistor radio was the state of the art in consumer electronics. At that time, we had yet to see laptop computers, cell phones, instant worldwide communication, or the internet and, for the most part had no idea what the future would bring.

The development of nanotechnology is no further along in 2009 than those transistor radios were in 1960. While we expect near term developments in materials, energy, computers, and medicine, we don't yet know the shape of nanotechnology five, ten, or twenty years from now.

CONCLUSION

Our understanding of nanotechnology in 2009 is like the understanding of the size and shape of our planet was to 15th century explorers. As yet, we only see the "flat earth" extrapolations of our current technologies – how to use nanotechnology to improve what we already know. We have yet to see the shape of the innovations nanotechnology will bring.

What will hold us back from those innovations? Fear of the unknown. But humans are all explorers and need to understand what is beyond the next obstacle in order to survive and thrive.

What will move us forward? As always, knowledge and understanding.

Nanotechnology will provide us with a new, more accurate, detailed, and textured map of the world.

It's our responsibility to decide how we will use that map.

Frank Dolinar has been involved in information technology all of his adult life, doing everything from writing software to running his own consulting firm in a career that spans four decades. His writings, under the general masthead "Diabologic", examine current topics, history, trends, and implications of science and technology, including nanotechnology.

Twenty-three years ago, a chance encounter with a book provided an introduction to and an excitement for nanotechnology – eliminating in one stroke anything like "spare time" in his life. Since 1992, he has given presentations on nanotechnology for general audiences and classes at Michigan State University.

Today, he is the owner of nanoSteps (http://www.nanosteps.net), based in East Lansing, which offers seminars, workshops, and presentations for corporations, business groups, and technical organizations.

He is also a staff consultant for the Firefly Consulting Group of Lexington, Kentucky, which offers management and technical consulting to the workers compensation insurance community.

Frank is a graduate of Lyman Briggs College at Michigan State University. He has been an instructor at Michigan State University, the University of Detroit (Mercy College), and Lansing Community College.

Books

Unbounding the Future
This is an introduction to nanotechnology for general audiences.
The entire text of this book is available online at:
http://www.foresight.org/utf/unbound_lbw/index.html

Articles

"Disruptive Technologies: Catching the Wave" by Bower, Joseph L. and Christensen, Clayton M. (1995)
Harvard Business Review, 73, no.1 (January): 43-53.

"The Future is Coming Sooner Than You Think" (March 2007)
The Report of the Joint Economic Committee of the US Congress
http://www.house.gov/jec/publications/110/nanotechnology_03-22-07.pdf

"There's Plenty of Room at the Bottom" by Richard P. Feynman (December 1959)
http://www.zyvex.com/nanotech/feynman.html

"Understanding Risk Assessment of Engineered Nanomaterials" by Trudy E. Bell. (February 2007)
http://www.nano.gov/html/news/home_news.html

References

Boiling water using less energy – Rensselaer Polytechnic Institute (2008 June)
http://news.rpi.edu/update.do?artcenterkey=2464

Cancer therapy – Calando Pharmaceuticals (2009 February)
http://www.calandopharma.com/it-101.html

Cancer therapy – The Halas Group at Rice University (2007 January)
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http://www.sdsmt.edu/wwwsarc/collectn/stone/clovis.html

Hybrid memory chip – Hewlett-Packard (2007 January)
http://www.hp.com/hpinfo/newsroom/press/2007/070116a.html

IBM Scientists First to Image the "Anatomy" of a Molecule (2009 August)
Opens new possibilities for exploring the building blocks of future microprocessors and other nanodevices
http://www.zurich.ibm.com/news/09/pentacene.html

Mercedes-Benz a nanoceramic paint
http://www.mercedes-benz.ca/index.cfm?NewsID=141&id=611

Molecular memory chip – CalTech & UCLA (2007 February)
http://media.caltech.edu/press_releases/12942

Nanoparticle to Treat Cardiovascular Disease – UC Santa Barbara (2009 Jun 04)
http://www.ia.ucsb.edu/pa/display.aspx?pkey=2029

Rensselaer Polytechnic Institute anti-reflective material
http://news.rpi.edu/update.do?artcenterkey=1960

Retinal Prosthesis – University of Glasgow (2008 January)
http://news.bbc.co.uk/2/hi/uk_news/scotland/glasgow_and_west/5168862.stm

Roadrunner supercomputer – IBM and Los Alamos (2008 June)
http://www.cnn.com/2008/TECH/06/09/fastest.computer.ap/index.html?iref=mpstoryview

Room temperature fuel-cell catalyst – University of Wisconsin and University of Maryland (2008 March)
http://www.news.wisc.edu/14928

The Royal Institute of Technology in Stockholm paper made from nanofibrils of cellulose (2008 June)
http://www.nytimes.com/2008/06/10/science/10obpape.html

Single molecule, one millionth the size of a grain of sand, pictured for first time (2009 August)
http://www.dailymail.co.uk/sciencetech/article-1209726/Single-molecule-million-times-smaller-grain-sand-pictured-time.html

Solar Cell Directly Splits Water To Produce Recoverable Hydrogen (Penn State University)
Science News – 2008 Feb 17
http://www.sciencedaily.com/releases/2008/02/080217170412.htm

Taking Nature's Cue For Cheaper Solar Power (dye-sensitized solar cells using synthetic chlorophyll)
Dr. Wayne Campbell, Massey University, New Zealand (2007 April)
http://www.sciencedaily.com/releases/2007/04/070405171830.htm

Ultracapacitor (MIT) (2006 February)
http://web.mit.edu/newsoffice/2006/batteries-0208.html

Video Displays – NanoLumens, Norcross, Georgia (2009 September)
http://www.nanolumens.com