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Nano 101

an Insider's Guide to the World of Nanotechnology

WHAT IS NANOTECHOLOGY?

Until recently, Mother Nature has been the only governing force in controlling intervention and manipulation of atoms and molecules. But after three decades of research, scientists can now work at the nanoscale to manipulate atoms and molecules, and they are able to understand these building blocks of matter like never before.

I define nanotechnology as the precision placement, measurement, manipulation and modeling of sub-100 nanometer-scale matter, or matter that consists of about 4 to 400 atoms. To put that in perspective, one nanometer—a billionth of a meter—is 1/75,000th the width of a human hair. The range below 100 nanometers is important because when we get down to this small size, the classical laws of physics change to give us novel properties that can allow scientists to produce new materials with the exact properties they desire: smaller, stronger, tougher than what we know now.

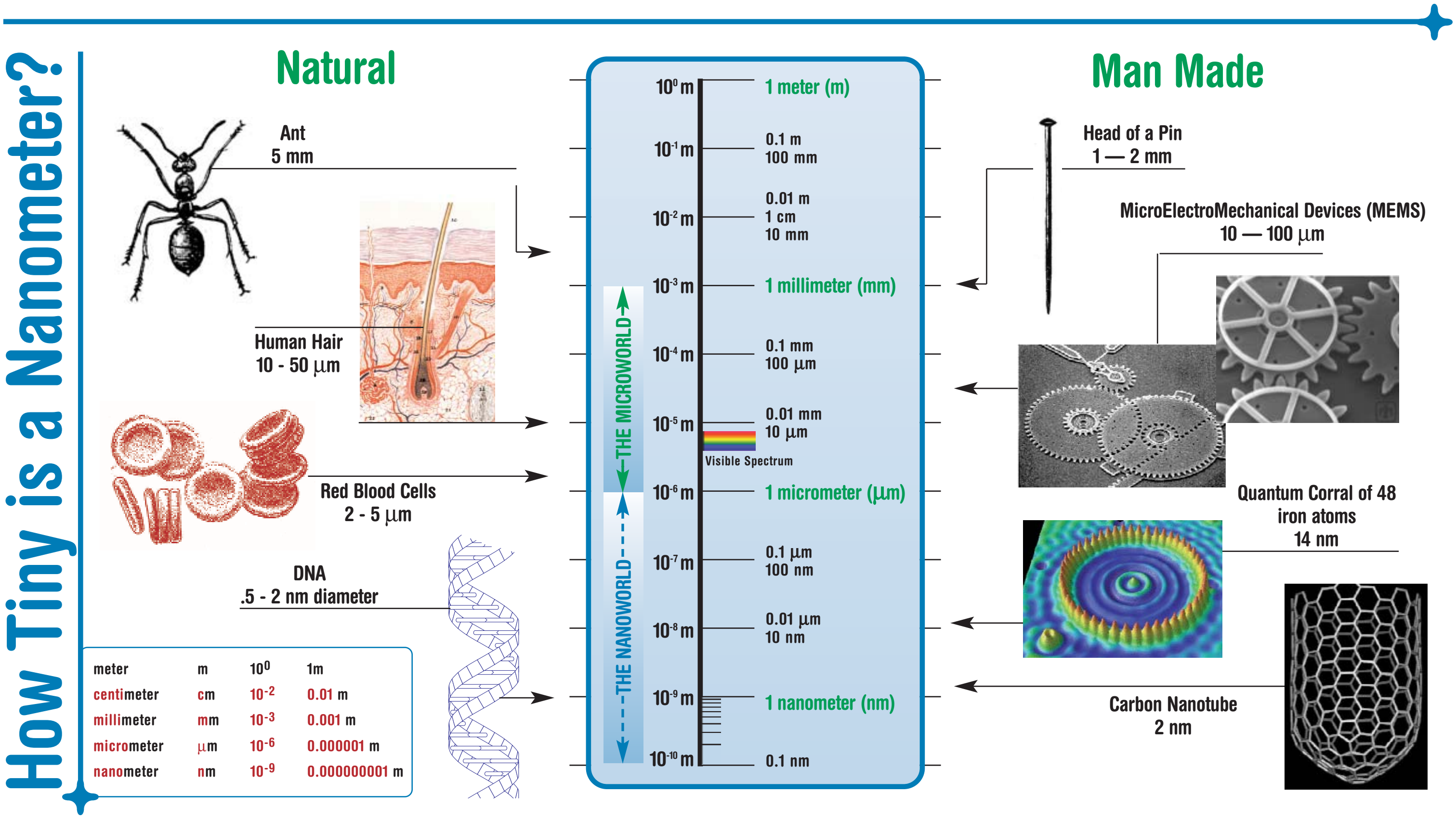
So why should you care? For starters, almost every industry will be affected by nanotechnology. In a recent study, fewer than 2% of 1,000 top executives were able to define "nanotechnology." Less than 5% had even heard of the word. But once the term was explained, 80% agreed that nanotechnology was relevant to their particular industry. In some circles, it promises pre-programmable drug delivery robots swimming inside your bloodstream to battle cancer, the creation of pollution-free energy systems and eternal life. Others, at a more conservative end of the spectrum, say that nanotechnology will be used to create stronger materials, next generation computing, and benign, yet salient, advances predicated on real science. It is the mixture of materials science, engineering, physics, chemistry and biology.

Another reason why you should care: Nanotechnology has got a lot of support. On December 3, 2003, U.S. President George W. Bush signed the 21st Century Nanotechnology Research & Development Act into law. The bill earmarks $3.7 billion in federal funds to nanotech research over the next 4 years. Governments worldwide will spend roughly $4 billion on nanotech in 2004. Besides that, titans of technology such as **IBM** [IBM], **Hewlett-Packard** [HPQ], **ChevronTexaco** [CVX] and **DuPont** [DD] are making major contributions to the advancement of nanotechnology. What all this means is that nanotechnology is poised to take off. Smart investors, who are early to detect where the technology will have the greatest impact, stand to win big.

FROM FEYNMAN TO IBM

The modern history of nanotechnology begins in 1959. Richard Feynman, a Nobel Prize-winning physicist, delivered a speech called "There's Plenty of Room at the Bottom." Feynman told his audience that he was unaware of any scientific laws that suggested it would be impossible to manipulate matter atom by atom. His speech is credited with inspiring scientists to probe into the nanoscale in hopes of precisely moving and controlling individual atoms. Feynman even offered two $1,000 prizes: the first to the person able to create a tiny cubic motor 0.4 mm in each direction; the second to someone able to shrink the page of a book by a factor of 25,000 in each direction (a page about 100 nanometers high). The first prize was actually claimed less than a year after his speech, while the second prize took 26 years to be claimed.

The smaller researchers went, the more difficult it became for them to see what it was they were working with. But a significant barrier to working at the nanoscale was cracked in 1981 by researchers at IBM. They invented a tool called the Scanning Tunneling Microscope (STM) that allowed them to image samples at the atomic level. For their efforts, the researchers received the 1986 Nobel Prize in Physics. The researchers at IBM were again responsible for a major leap for-



ward when they invented another type of microscope, known as the Atomic Force Microscope (AFM), which could be used to probe and image individual atoms. With these new tools researchers were able to view and manipulate matter at the atomic level, but the instruments were not widely available and were quite expensive.

At the same time, a group of researchers at Rice University, led by Richard Smalley, captured public attention by discovering a soccer-ball-shaped molecule of carbon that exhibited properties unlike anything seen before. It was called a "fullerene" or "buckyball" (after geodesic dome designer Buckminster Fuller). It consisted of 60 carbon atoms linked together in a symmetrical pattern. The whole object was roughly just one nanometer across. Fullerenes can conduct electricity and heat. They are also stronger than steel and lighter than plastic. This discovery led to a flurry of excitement over the potential use of the molecule in applications in markets ranging from healthcare to construction and manufacturing. For discovering the fullerene, the discoverers won the Nobel Prize for Chemistry in 1996.

The slow, but steady pace of nanotechnology development continued through the 1980s. In 1989, IBM researchers amazed observers as they used an STM, a tool which IBM had invented years earlier, to arrange 35 individual atoms of Xenon to spell out the letters "I-B-M." This was the first major demonstration of the ability to manipulate and precisely align individual atoms.

As the 1990s came upon us, the flurry of activity and the pace of significant discoveries increased. In 1991, NEC Japan researcher Sumio Iijima discovered carbon nanotubes, a close relative to the fullerene. The nanotube looked like an elongated fullerene and exhibited similar exciting properties such as ultra light weight and prodigious strength. A nanotube is about 1/6th the weight and nearly 100 times stronger than steel.

The pace of scientific advance has accelerated feverishly in the last five years. Monthly announcements have highlighted momentous achievements such as quantum wires, nanotube transistors and single molecule organic switches. One of the most important recent experiments again took place at IBM. Don Eigler and his research team created what is called a "Quantum Corral" by putting a magnetic atom at one end of an ellipse of atoms and observing that it creates a mirage of the same atom directly opposite it. The Quantum Corral showed the potential exists for transmitting information without wires at the nanoscale.

Researchers' enthusiasm for nanotechnology was contagious. In 1999, President Bill Clinton announced the National Nanotechnology Initiative (NNI), the first formal government program to accelerate the pace of research, development and ultimate commercialization of nanoscale applications. Other countries quickly followed suit. In 2001, the European Union approved a budget of more than 16 billion euros for R&D under the EU Framework Programme. Nanotechnology, a major theme and priority, was slated to receive nearly 10% of this funding allocation. Japan, Taiwan, Singapore, China, Israel and Switzerland have all begun similar measures, quickly accelerating what is shaping up to be the first truly global race of the 21st century.

NANOTECHOLOGY vs. THE INTERNET

The hype around nanotechnology can be roughly equated to the hype surrounding the Internet way back in 1993—prior to the Internet boom. Because of this, I believe that the "nano" prefix alone has the potential to create a fury of investment activity that will remind many investors of the same, hot-sector, momentum-driven philosophies that chased the ".com" suffix.

But nanotechnology will be different, and you should be aware of the differences. While the Internet boom relied primarily upon computer science and electrical engineering, nanotechnology requires an integrated understanding of and collaboration between multiple fields of science, including biology, physics, chemistry, materials science, computer science, mechanical engineering and electrical engineering. And, unlike the Internet, nanotechnology companies must have tangible products or processes, and cannot merely rely on information becoming quickly commoditized. Balance sheets will have significant accounts in property, equipment and other assets, all of which can be valuable in raising needed capital down the road. The combination of very high equipment costs, a deep requisite knowledge base and strong intellectual property platforms yields significant barriers to entry for would-be competitors that we did not see during the dot-com era. In general, there is a greater level of sophistication needed for both venture capitalists and entrepreneurs—not to mention individual investors—to make intelligent and informed investments. This is where the readers of the *Forbes/Wolfe Nanotech Report* will have an edge.

HOW TO INVEST IN NANOTECH

I have identified five major sectors that I believe will be the first to benefit from a flow of capital for investment in nanotechnology. They are: Materials, Modeling, Tools, Devices, and Nanobiotechnology. Let me explain these five investment themes:

Materials

Nanowires, Nanocomposites, Specialty Polymers, Nanoparticles, Nanotubes, Quantum Dots

With nanotechnology, it is possible to create materials with desired electronic, optical and chemical properties. However, this is not a new idea. Such materials have been around for the past 100 years in the form of compounds like carbon black—nanoscale carbon particles thrown into rubber to improve the strength and durability of tires.

The media has closely covered the science, discovery and potential uses of two nanomaterials: fullerenes and carbon nanotubes. Fullerenes can be used for applications like medical imaging and drug delivery. Carbon nanotubes look like cylinders of rolled-up chicken wire, but they are stronger and lighter than steel and more conductive than copper. They can be used as nanoelectronic components. Researchers have been able to produce them for more than ten years, but only with recent advances in tools and equipment have the prices begun to drop to the point where commercial uses could be feasible. Three years ago, the cost of buckyballs was around $600/gram. Now one gram costs about $30 and should cost closer to $10 by the end of the year. Major chemical companies will take advantage of new advances and production processes emerging from academia to lessen these costs.

The majority of the nanomaterial companies are focused on organic (wet), inorganic (dry) or metal nanomaterials. Most are characterized at this stage as having a novel production process that may benefit from a defensible intellectual property portfolio. The nascent markets they serve have small demand, and production is mostly limited to research-scale or development-scale quantities.

There are opportunities in both public and private companies, much of the latter in start-up phase. Near-term commercial applications of nanomaterials will be largely found in nanoparticle-reinforced materials and nanoparticle-filled coatings. Nanoparticle-reinforced materials provide additional strength or some other desired property to polymers. Japanese automaker **Toyota** [TM], for example, uses layered silicates in its cars on fan belt covers. It has also combined materials at the nanoscale to make bumpers as strong as traditional ones, but 60% thinner.

Nanoparticle-filled coatings can be used to create scratch resistant surfaces, anti-reflective coatings and corrosion-resistant coatings for various metals. Think plastic windshields, lower maintenance and increased ability for vehicles to brave the elements. Nanoparticles can also have significant advantages over traditional fillers like carbon black and polymer latexes used in paints because researchers can better control and tailor desired properties such as increased heat resistance, stiffness, strength and electrical conductivity.

Nanomaterial start-ups are also looking to create new applications for materials that can be created with novel properties. On the inorganic side, these materials include cosmetics, coatings, displays, batteries, fuel cells and electronics. On the organic side, crossing into biotechnology, nanoparticles are being made for applications such as gold-encrusted nanoshells capable of enhancing drug delivery to certain cells within the body, near real-time biological warfare agent sensors and synthetic heart valve materials made with nanostructured surface features.

Cost-performance analysis, however, will be the big determinate of whether a new material or process is ultimately bought and integrated. There is little incentive to improve from a micron-sized particle to a nanoparticle if the former is priced significantly lower and the quality meets desired standards. Eventually, the market for nanomaterials will grow to a meaningful size, causing incumbent players to enter the market with greater production capabilities that will inevitably drive prices down.

Modeling:

Atomic and Molecular modeling and analysis software

In order to design nanotechnology-enabled systems and structures, it is necessary to base designs on what happens when atoms interact. The problem is, in nanoscale science, conventional molecular modeling fails to accurately simulate the behavior of atoms. Below 100 nanometers, the behavior of atoms and molecules is very different

It's A Small World After All

Major Developments in Nanotechnology

IN THE BEGINNING:

400 BC • Greeks begin to use the terms "element" and "atom" to describe the smallest components of matter.

1897 • J.J Thompson discovers the electron.

1959 • Richard Feynman Gives Caltech Lecture "There's Plenty of Room at the Bottom." Feynman awakens the minds of scientists and engineers in every discipline to consider the possibility of manipulating matter at the atomic scale.

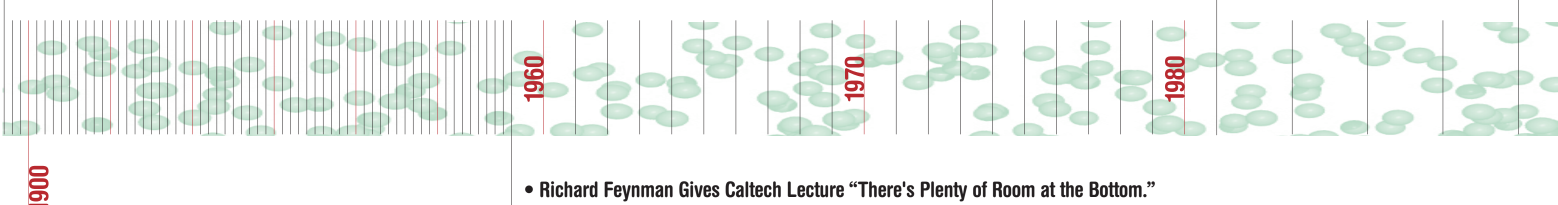
1974 • Norio Taniguchi coins the term "Nanotechnology." The word was created to convey the distinction between engineering at the nanoscale and microscale, a 1,000x difference.

1981 • Scanning Tunneling Microscope (STM) invented. Allows researchers to see individual molecules at atomic resolution. Invented by IBM Zurich Researchers Heinrich Rohrer and Gerd Karl Binnig, who then received the Nobel Prize in 1986.

• First scientific paper on nanotechnology published "Protein Design as a Pathway to Molecular Manufacturing," by Dr. K. Eric Drexler, suggests that complex and functional molecular machines can be constructed.

1985 • Fullerenes (a.k.a. C-60 or "buckyballs") are discovered.

1986 • Atomic Force Microscope (AFM) invented. Cal Quate, Christophe Gerber and Gerd Binnig invent another scanning probe microscope enabling the manipulation of individual atoms via physical contact with a sharp tip.



from what holds true in physics and chemistry. Newtonian, or classical physics, familiar to us as the principles of gravity or kinetic energy, breaks down at the nanoscale. Instead, researchers have to rely on quantum physics, one of the most dizzying and complex areas in advanced science.

New software will emerge that will be custom tailored for the nanoscale. We expect a variety of tools that will be a combination of large-scale databases of molecular knowledge and complex molecular simulations.

There is a rich landscape of unclaimed intellectual property, particularly in algorithms, that underlie visualization of phenomena at the nanoscale. There is also opportunity in algorithms that relate to analytics and data mining, as well as those that focus on how to extract meaningful information from all of the data scientists obtain.

It is not clear yet what existing software languages will play a dominant role, or if new ones will emerge to better meet the needs of researchers. Common practice amongst researchers needing to collaborate will ultimately lead to standards.

Tools:

Atomic and Molecular modeling and analysis equipment

With more than 300 universities and companies conducting research at the nanoscale, the market for nanoscale instruments is growing rapidly. The primary devices used are AFM (Atomic Force Microscope), STM (Scanning Tunneling Microscope) or some derivative of the two.

The STM works by running a very fine metal tip across the surface of whatever is being measured. When the tip comes within 1 nanometer of the surface, a small voltage is applied and electrons flow from the tip to the surface. This is the "tunneling" after which the instrument is named; it describes how electrons pass through the gap distancing the surface from the tip. Feedback to the instrument creates a topographic scan of it. The major limitation here is that the instruments can only be used for materials that conduct electricity.

The Atomic Force Microscopy technique allows for the measurement of both conducting and non-conducting surfaces. The AFM was also invented by IBM in the mid-1980s. AFMs use a cantilever tips, composed of a single atom, to read a surface at the nanoscale directly, much like a needle running over a vinyl record.

Many advances have occurred with the Scanning Tunneling Microscope. STMs are versatile as they can be used in different modes to collect measurements. They can be used to create images of surfaces through tactile or physical force, or via electrical or magnetic force, and can also be used to nudge atoms and move them into place. Don Eigler, a lead researcher at IBM's Almaden Research center, used the tool in

1989

- IBM uses Scanning Tunneling Microscope to spell out "IBM" by moving 35 Xenon atoms into position,

1990

1991

- Carbon Nanotubes Discovered by NEC's Sumo Iijima in Japan

1993

- Scientists at Israel's Weizmann Institute of Science create the first nanostructures to show compelling properties, leading to the creation of nanotube "ropes" and prompting worldwide interest in the physical and chemical properties of carbon nanotubes.
- Warren Robinett of UNC and R. Stanley Williams of UCLA create a nano-manipulator — a device that is connected to an STM which allows researchers to see and feel atoms.

1996

- Richard Smalley receives Noble Prize in chemistry for his 1985 co-discovery of C-60.
- George Whitesides patterns computer chip circuits only 30 nanometers wide. These circuits have the potential to give a single chip the ability to operate at speeds greater than a teraflop, or 4000 times faster than a PC.
- James Tour and colleagues at the University of South Carolina create the first functioning quantum wire, consisting of a single molecular chain that formed a circuit between a gold surface and the tip of an STM.

1998

- Cees Dekker and colleagues at Delft University of Technology in the Netherlands create a transistor made from a carbon nanotube.

1999

- James Tour (Rice) and Mark Reed (Yale) create an organic switch with a single molecule. Validates theory that nanoscale computational devices can be created from individual molecules.

2000

- $422 million National Nanotechnology Initiative launched by President Clinton.
- Don Eigler and colleagues at IBM create a "Quantum Corral."

2001

- IBM researcher Phaedon Avouris creates the first single-molecule logic gate
- Cees Dekker forms a transistor in a single carbon nanotube that can be switched On or Off with a single electron.
- Harvard's Charles Lieber uses nanowires in different formations and combinations to create the smallest light-emitting diode (LED) ever made.
- NNI funding increased by President Bush to $519 million for 2002.
- IBM Zurich researchers develop "Millipede" nanoscale storage device. Potentially can hold one terabit per square inch, more than 40 times what today's hard drives hold.
- EU allocates roughly 1.3 billion euros (U.S. $1.2 billion) from 2002-2006 to nanotechnology research under the EU Sixth Framework program.

2002

- Hewlett-Packard and UCLA receive a U.S. patent for a process to pack a number of different calculating functions into a single nanochip.

THE NANOTECH EFFECT

INDUSTRY	APPLICATIONS
Chemicals	Ability to create custom materials with the specific electronic, optical and chemical properties desired for a given application. New combinations and compounds will add strength, reduce weight, improve resistance or electrical conductivity.
Manufacturing	Realization of cost savings from cheaper and more efficient production methods.
Computing and Storage	Greater than 40x improvements in data storage/retrieval, allowing for the storage of up to 1 terabit of data per square inch. A new frontier of computing where matter is as readily programmable and manipulated as software and lines of code. Non-volatile Flash Memory, eliminating the need to "boot up" computers
Biotechnology	New approaches to drug discovery and drug delivery (enhanced solubility, bioavailability) predicated on advances at the molecular level. Biosensors able to detect agents down to the single molecule. Point-of-care diagnostics and therapeutics.
Semiconductors	Extension of Moore's Law beyond traditional lithography, the method used to make today's semiconductors. Lithography is fundamentally limited by the wavelength of light (between 400 and 700nm). Reduction in capital investment cost of chip fabrication facility, now in the tens of billions of dollars.
Energy/Power	High-quality nanofilters could lead to great cost savings in the petrochemical industry since 80 to 90 percent of refining costs are in separation. Over the next decade, nanostructured catalysts will have a $100 billion impact on the petroleum and chemical processing industries. Also will see advancements in hydrogen storage for fuel cells, lighter-weight materials, anti-static, anti-corrosive properties for downhole drilling, and tethers for off-shore drilling platforms.

1989 to form the letters "IBM" out of 35 xenon atoms.

Caltech has used an STM as somewhat of a modern MRI (Magnetic Resonance Imaging). While traditional MRIs can only image several trillion nuclei at one time, the STM technique used by researchers allows for single nuclei detection. Since the system can be used in aqueous solutions, it has broad implications for identifying single organic molecules and may eventually replace the existing technologies used in biochips and microarrays made by companies like **Affymetrix** [AFFX].

The most important aspect of STMs is not the microscope itself, but the cantilever probes with nanoscale tips that are used with it. There would be tremendous value in creating probes that can integrate multiple functions, such as the detection of thermal, electrical, magnetic, and optical signals at the nanoscale, onto a single tip.

One of the STM's weaknesses is that it does not provide chemical data about a material and is not capable of imaging a sample in three dimensions. This weakness opens up a large opportunity for new instrument techniques that can achieve nanometer-scale resolution, while incorporating three-dimensionality and multiple-variable measurement.

Government support, coupled with the creation of new laboratories in academia and private industry, will further stimulate the need for metrology tools to ultimately observe and manipulate matter at the atomic and molecular level. Manufacturers of STMs and AFMs, accessories such as tips, and other instrument enhancements will be poised for rapid industry growth.

Devices:

Fabrication Systems, Sensors, Information Technology, Semiconductor and Electrical Components

Nanotechnology promises the next leap in computing and information technology. When software and data are downloaded today, the structure of magnetic disks inside our computers is rearranged at the micrometer level to represent the information. This process will one day approach the nanometer level, allowing the same type of things to occur with individual atoms and molecules.

Many of these developments will not appear for some time, but IBM has made a significant advance in data storage with its Millipede system, which should hit the market in 2005. It uses a 64x64 array of 4,096 AFM probe tips to make 50 nanometer indentations in a polymer. This has the potential to create storage systems that would hold one terabit per square inch, a 40-fold increase in data density over current technology. Even more impressive, it would require less energy than currently used magnetic methods. It should hit the market in about two years.

Molecular computation (also known as chemical computation) seeks to process information on the molecular level. There are a variety of approaches to molecular computing, ranging from molecular switches, which are logic gates that use single molecules to do computations, to combinatorial methods, such as putting together different molecules like nanotubes and fullerenes to mimic modern circuits. A related approach is through a combination of molecular computing and electronics, often called molecular electronics. For instance, rotoxanes are molecular structures that switch their state, going from open to closed upon addition or removal of an electron. This means that they are an electronic switch about two times smaller than current silicon transistors.

The semiconductor industry is also looking to use nanotechnology to ensure the continuation of Moore's Law, which states that computing processing power (and more specifically the number of transistors on a chip) doubles every 18 months. Intel's first chip, the 4004 had 2,000 transistors when it was released in 1971. Today's most advanced chips have 100 million. This can be attributed to ever smaller wires and transistors: less size, higher density, less power used.

Ultimately, Moore's Law hits a brick wall, as the lithography techniques used to make today's semiconductors are fundamentally limited by the size of a wavelength of light (between 400 and 700 nanometers). Even now, line widths are approaching the nanoscale. Nanotechnology, in the form of Atomic Layer Deposition, a technique which places atoms or molecules on the wafer a single layer at a time, is one of the most promising solutions.

At the microscale and above, mechanical motion is typically controlled either by coupling to other mechanical motion (e.g., gears), electronic potential (e.g., actuators) or chemical explosions (e.g., fossil fuels). The motion of nanoscale devices, however, can be controlled by a wide variety methods which take advantage of quantum physics. For instance, IBM's Millipede is a micromechanical device that uses cantilevers to read and write to nanoscale pits. The tip interacts with the nanoscale pits by means of thermal coupling. It either melts a small pit into the polymer surface or deletes the pits by heating the entire recording surface.

As in the Millipede, MicroElectroMechanical Systems (MEMS) will be essential for accessing information from the nanoscale devices, or for providing energy and information input to NanoElectroMechanical Systems (NEMS). While MEMS have encountered problems with friction, multi-walled carbon nanotubes do not exhibit wear and can therefore serve as strong mechanical bearings. In fact, the space between the different nanotubes is on the order of nanometers, leaving no possibility of contaminants getting into the bearings.

Nano-Biotechnology:

Tissue Engineering, Sensors, Drug Delivery, Drug Discovery, Point-of-Care Diagnostics and Therapeutics

Look no further than your own body to find true nanotechnology in action. The biological systems at work in our cells and in the nature around us all contain nanoscale systems. Whether it's our DNA storing and transferring information about our genetic makeup or increased understanding of the calcium carbonite nanostructures used in seashell construction, nanotechnology holds massive potential for the health care and life sciences market.

Nanotechnology enables drug delivery mechanisms that can send biologically active materials directly to the location where they are beneficial. This could reduce side effects and make pharmaceuticals more effective. For example, BioSanté Pharmaceutical's BioAir Products is capable, through using calcium phosphate nanoparticles, of increasing insulin delivery to the bloodstream and prolonged effectiveness within the body.

Nanocrystals are even being used in the biocompatible tissue engineering and implant markets. MIT startup Angstrom Medica has developed a strong bone substitute, entitled NanOss, designed to replace conventional metal screws. It allows patients to avoid the stress fractures and discomfort associated with large, irregular grains in implants. And the screw dissolves safely inside the body.

Despite the litany of advancements in health care and life sciences, the biotechnology market heralds the most exaggerated notions of nanotechnology's promise. Investors must be cautious of claims of nanoscale robots one day swimming in our bloodstreams looking to eradicate cancers popularized by movies such as *Innerspace*. As with any enabling technology, perhaps nanotechnology could one day lead to this. For near to medium term investors, however, this is one area that should definitely be passed over.

NANOTECHOLOGY GLOSSARY

Atom — A particle of matter that uniquely defines a chemical element. It consists of a central nucleus that is usually surrounded by one or more electrons. Each electron is negatively charged. The nucleus is positively charged, and contains one or more relatively heavy particles known as protons and neutrons.

Atomic Force Microscope (AFM) — An instrument that allows for the measurement and high resolution mapping of both conducting and non-conducting surfaces. The instrument operates by scanning the sample with a sharp tip (typically micromachined silicon nitride) attached to the underside of a microscale cantilever.

Atomic Resolution Storage — Devices that use individual atoms to represent bits of logic (0's and 1's) to store data.

Bottom-up — The integration and organization (assembly) of atoms and molecules to create more complex structures.

Carbon Nanotubes — Boast incredible strength (100 times stronger than steel at only 1/6th the weight), and have the ability to be semiconducting, conducting or insulating. They are much better conductors of heat than silicon, making them ideal for nanoelectronics.

Defense Advanced Research Projects Agency (DARPA) — The central research and development organization for the Department of Defense (DoD). It manages selected basic and applied research, as well as technology development projects.

"Dry" Nanotechnology — Science and technology dealing with inorganic materials, such as metals.

EU Framework Program — A European Union program designed to support and coordinate regional EU research, technology and development actions.

Feynman Prize — Prestigious award given annually by the Foresight Institute to recognize accomplishments in molecular nanotechnology. Two separate prizes are given: one for theoretical work and one for experimental work.

Fullerene (a.k.a "Buckyball") — A nanospherical phase of carbon in which 60 carbon atoms are arranged like a soccer-ball. Named after geodesic dome creator Buckminster Fuller.

Informatics — The software tools (database management and integration, and complex mining algorithms) that allow the scientists to capture, visualize and analyze life sciences (bioinformatics) and chemical data (cheminformatics).

Lab-on-a-chip — The integration of micro- or nano-fluidic (*see "microfluidics" and "nanofluidics"*) devices to create the possibility of automated chemistry on a small device, potentially the size of a microchip. Automated chemistry uses a device instead of a human lab technician to conduct experiments and analyses.

Logic Gate — An elementary building block of a digital circuit. Always in one of the two binary conditions: low (0) or high (1). Change is controlled by voltage levels.

Metrology — The science and industry dealing with measurement. Nanoscale metrology tools include the Scanning Probe Microscope (SPM), the Atomic Force Microscope (AFM) and the Scanning Tunneling Microscope (STM).

MicroElectroMechanical Systems (MEMS) — Microscale systems with moving parts that can be controlled externally through electronic means.

Microfluidics — Designing, manufacturing and formulating microscale devices and processes that can handle volumes of fluid on the order of nanoliters. Microfluidic systems have diverse and widespread potential applications, including blood-cell-separation equipment, genetic analysis and drug screening.

Micron — One micron is 1/1000th of a millimeter. 1 micron is equal to 1,000 nanometers.

Millipede — Nanoscale data storage device developed by IBM and set for commercial release in 2005.

Modeling — Simulation and rendering of matter to let nanotechnology researchers more accurately understand nanoscale phenomena.

Molecular Computing — Uses individual molecules as the components of logic devices including switches, transistors and capacitors.

Molecular Electronics — Any system with electronic devices of nanometer dimensions, especially if made of discrete molecular parts rather than the continuous materials found in today's semiconductor devices.

Molecule — The smallest particle of a substance that retains the chemical and physical properties of that substance and is composed of two or more atoms.

Moore's Law — Conceived by Gordon Moore in 1965. States that computing processing power (more specifically the number of transistors packed on a microchip) doubles every 12-18 months.

Nano — The prefix "nano" refers to a billionth of something, usually a unit of measurement (e.g., nanosecond, nanometer).

Nanocrystal — A nanometer sized crystal, typically less than 10 nanometers. Currently used as flourescent markers for the study of biological materials, but potentially could be used as components in magnetic storage devices.

Nanodots (a.k.a. "Quantum Dot") — A nanoscale device containing a single unit of charge. It emits different colors of light depending on its size. Useful for biological labeling.

NanoElectroMechanical Systems (NEMS) — Electromechanical systems constructed of nanoscale components. At present, most NEMS in existence, like living cell elements such as ribosomes or mitochondria, are biological in nature.

Nanofluidics — The science of designing, manufacturing and formulating nanoscale devices and processes that deal with controlling volumes of fluid on the order of nanoliters or picoliters (one millionth of one millionth of a liter).

Nanometer — One billionth of a meter.

Nanoscale — Refers to all things that exist or may occur at the size of several nanometers.

Nanotechnology — The precision placement, measurement, manipulation and modeling of sub-100 nanometer scale matter.

Nanotube — A one-dimensional fullerene (*see "Fullerene"*) with a cylindrical shape. Can act as conductors or semiconductors.

Nanowires — A wire with nanoscale width and height (or diameter). Nanowires differ from larger wires in that the conductivity changes in a stepwise fashion in response to a change in voltage.

National Nanotechnology Initiative (NNI) — Unites States government initiative in nanotechnology funding. In 2003, President Bush allocated $774 million to the program and proposed increasing the NNI to $847 million for 2004.

National Science Foundation (NSF) — Independent U.S. government agency that invests over $3.3 billion per year in almost 20,000 science and engineering projects.

Optoelectronics — Pertaining to any device that converts electrical energy to optical energy (light) or vice versa. Examples include photocells, solar cells, and LEDs (light-emitting diodes).

Quantum computing — Area of study focused on developing computer technology based on quantum theory. The quantum computer, following the laws of quantum physics (atomic and subatomic), would gain enormous processing power through the ability to be in multiple states, and to perform tasks using all possible permutations simultaneously. Current leading centers of research in quantum computing include MIT, IBM, Oxford University and the Los Alamos National Laboratory.

Scanning Probe Microscope (SPM) — Creates images of two dimensional surfaces by scanning a sharp tip (the probe) over a surface.

Scanning Tunneling Microscope (STM) — A type of SPM able to image and topographically map surfaces that conduct electricity to atomic accuracy. Invented by IBM in 1981.

Self-assembly — The spontaneous formation of an ordered structure from a given material or object without external direction.

Self-replication — The process in which an object is able to create a replica of itself. Differs from reproduction in that self-replication results in an exact copy of the original.

Top-down — The simplification of complex structures by breaking them into smaller, fundamental components that can be more easily understood.

"Wet" Nanotechnology — Science and technology dealing with organic materials, such as DNA.