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Nanotechnology: Shaping the world atom by atom

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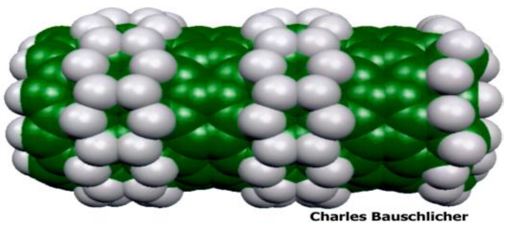
ABSTRACT: *The ability to image, measure, model, and manipulate matter on the nanoscale is leading to new technologies that will impact virtually every sector of our economy and our daily lives. Nanoscale science and technology has the potential, for example, to increase the efficiency of lighting, enhance the performance of electronic devices, decrease waste and pollution during manufacturing, detect and treat disease at the earliest stages, and provide more cost-effective solar energy conversion. At the same time, care must be taken to develop new technologies for widespread use in a responsible manner. Achieving the benefits promised by nanotechnology will depend on advanced research in fields ranging from chemistry and engineering to biology and materials science; development and support of the necessary infrastructure, including user facilities and instrumentation; and education and training of a skilled workforce and an informed public.*

This report presents the strategic plan for shaping the world atom by atom. In developing this plan, I sought extensive advice and input from the academic, industrial, and government research communities and took into consideration the recommendations of the 2006 National Academies report.

Keywords: *1) Nanotechnology 2) Surfaces Galore 3) Nan tubes 4) Quantum 5) Atom*

I. INTRODUCTION



If you were to deconstruct a human body into its most basic ingredients, you'd get a little tank each of oxygen, hydrogen, and nitrogen. There would be piddling piles of carbon, calcium, and salt. You'd squint at pinches of sulfur, phosphorus, iron, and magnesium, and tiny dots of 20 or so other chemical elements. Total street value: not much. With its own version of what scientists call nanoengineering, nature transforms these inexpensive, abundant, and inanimate ingredients into self-generating, self-perpetuating, self-repairing, self-aware creatures that walk, wiggle, swim, sniff, see, think, and even dream. Total value: immeasurable. Now, a human brand of nanoengineering is emerging. The field's driving question is this: What could we humans do if we could assemble the basic ingredients of the material world with even a glint of nature's virtuosity? What if we could build things the way nature does—atom by atom and molecule by molecule? Scientists already are finding answers to these questions. The more they learn, the more they suspect nanoscience and nanoengineering will become as socially transforming as the development of running water, electricity, antibiotics, and microelectronics. The field is roughly where the basic science and technology behind transistors was in the late 1940s and 1950s.

II. WHAT IS NANOTECHNOLOGY?

In the language of science, the prefix nano means one-billionth of something like a second or a meter (see sidebar, p. 3). Nanoscience and nanotechnology generally refer to the world as it works on the nanometer scale, say, from one nanometer to several hundred nanometers. That's the natural spatial context for molecules and their interactions, just as a 100 yard gridiron is the relevant spatial context for football games. Naturally- occurring molecular players on the nanoscale field range from tiny three-atom water molecules to much larger protein molecules like oxygen- carrying hemoglobin with thousands of atoms to gigantic DNA molecules with millions of atoms. Whenever scientists and engineers push their understanding and control over matter to finer scales, as they now are doing on the nanoscale, they invariably discover qualitatively new phenomena and invent qualitatively new technologies For years now, scientists have been developing synthetic nanostructures that could become the basis for countless improved and completely new technologies. The way molecules of various shapes and surface features organize into patterns on nanoscales determines important material properties, including electrical conductivity, optical properties, and mechanical strength. So by controlling how that nanoscale patterning unfolds, researchers are learning to design new materials with new sets of properties. Some of these nanostructures may turn out to be useful as discrete nanostructures. New types of vaccines and medicines come to mind here.

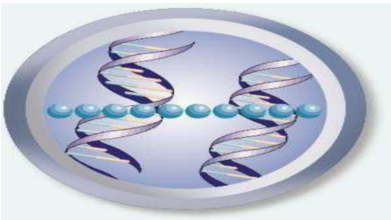
The value of others may emerge only as they are assembled into larger structures like particles or fibers, which then would be processed into yet larger structures like textiles, films, coatings, bricks, and beams. Forward looking researchers believe they could end up with synthetic creations with life-like behaviors. Cover an airplane with paint containing nanoscale pigment particles that instantly reconfigure, chameleon-like, to mimic the aircraft's surroundings. You would end up with an airplane indistinguishable from the sky, that is, an invisible plane. How about bricks and other building materials that can sense weather conditions and then respond by altering their inner structures to be more or less permeable to air and humidity? That would go a long way toward improving the comfort and energy efficiency of buildings. And how about synthetic antibody- like nanoscale drugs or devices that might seek out and destroy malignant cells wherever they might be in the body? For many years futurists steeped in the culture of science fiction and prone to thinking in time frames that reach decades ahead have been dreaming up a fantastic future built using nanotechnologies.

III. THE INCREDIBLE TININESS OF NANO

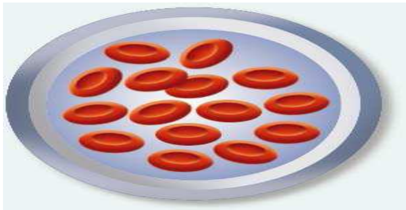
"Nano" derives from the Greek word for dwarf. Use it as a prefix for any unit like a second or a liter and it means a billionth of that unit. A nanosecond is one billionth of a second. A nanoliter is one billionth of a liter. And a nanometer is one billionth of a meter—about the length of a few atoms lined up shoulder to shoulder. The bottom of this letter, "l", spans about one million nanometers. A world of things is built up from the tiny scale of nanometers. Just consider the thousands of cellular proteins and enzymes that do everything from metabolizing hamburgers, to building up muscle fibers, to replicating DNA, whose twisty structure itself is a few nanometers thick. Enzymes typically are constructions of thousands of atoms in precise molecular structures that span some tens of nanometers. That kind of natural nanotechnology is about ten times smaller than some of the smallest synthetic nanotechnology humanity has made so far. The individual components of an Intel Pentium III microprocessor span about 200 nanometers. That's why these chips can harbor several million transistors and can translate a five-inch Digital Video Disc (DVD) into a seamless movie. Nanotechnology researchers say today's microelectronics are mere hints of what will come from engineering that begins on the even smaller scales of nanostructures.

In the summer of 1999, researchers reported making single molecules that behave like transistors. Talk of computers the size of sugar cubes suddenly became less speculative. Just as the prefix "micro" has infiltrated the general lexicon ever since early microscopists began observing the world on finer scales, the prefix "nano" has begun diffusing into popular culture. It's getting into screenplays and scripts for TV shows like the Xfiles and Star Trek: The Next Generation.

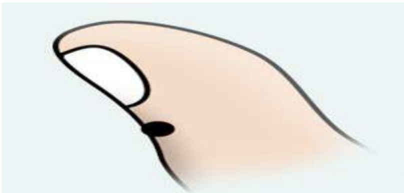
Companies are using it in their names. It's a favorite topic of science fiction writers. And it's on the agenda of corporate executives, deans, and government officials deciding how to allocate funds and resources among the many research and development projects vying for support.



Nanometer: Ten shoulder to shoulder Hydrogen atoms (blue balls) span1 Nanometer, DNA molecules are about 2.5 nanometer wide.



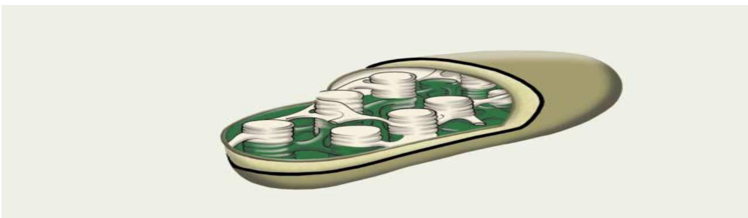
thousands of a nanometer
Biological cell, like these red cells, have diameter in the range given above



A MILLION NANOMETER: The pinhead sized patch of this thumb (circled in black) is a million nanometer across

IV. SOME DEEP ROOTS FOR A NANOTECHNOLOGICAL FUTURE

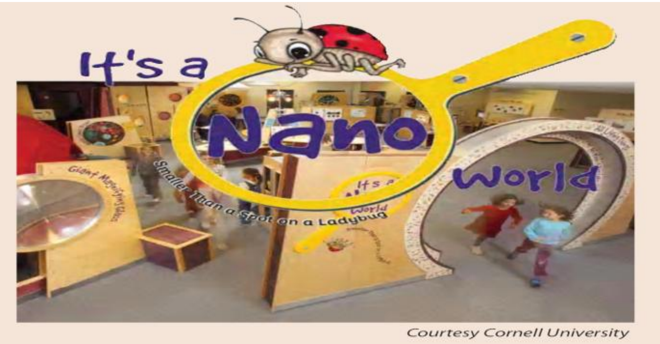
Nanotechnology is a new word, but it's not an entirely new field. Chemical catalysis, which underlies a significant portion of the country's gross national product, is an example of "old nanotechnology." Today, catalysts speed up thousands of chemical transformations like those that convert crude oil into gasoline, small organic chemicals into life-saving drugs and polymers, and cheap graphite into synthetic diamond for making industrial cutting tools. They're akin to biological catalysts—the enzymes in cells that orchestrate the chemistry of life. Most catalysts were discovered by trial and error—by "shaking and baking" metals and ceramics and then seeing how the result affects the reactions and their products. On closer examination with modern tools, many of these catalysts turn out to be highly organized metallic and/or ceramic nanostructures whose specific architectures trigger changes in molecules that temporarily dock to them. Researchers expect



***NATURAL NANOTECHNOLOGY**: Much of the photosynthesis that powers forests unfolds inside tiny cellular power houses called chloroplasts (above). These contain nanoscale molecular machinery (including pigment molecules like* *chlorophyll) arranged inside stacked structures, called thylakoid disks that convert light and carbon dioxide into biochemical energy*.

This nanoscale understanding of catalysis to lead to better, cleaner, and more capable industrial processes. Even an early instance of nanotechnology like catalysis really is young compared to nature's own nanotechnology, which emerged billions of years ago when molecules began organizing into the complex structures that could support life. Photosynthesis, biology's way of harvesting the solar energy that runs so much of the planet's living kingdom, is one of those ancient products of evolution. Scientists often perceive photosynthesis as the result of brilliantly engineered molecular ensembles—which include light harvesting molecules such as chlorophyll— arranged within cells on the nanometer and micrometer scales. These ensembles capture light energy and convert it into the chemical energy (which is stored in chemical bonds) that drives the biochemical machinery of plant cells. The abalone, a mollusk, serves up another perennial favorite in nature's gallery of enviable nanotechnologies. These squishy creatures construct super tough shells with beautiful, iridescent inner surfaces. They do this by organizing the same calcium carbonate of crumbly schoolroom chalk into tough nanostructured bricks. For mortar, abalones concoct stretchy goo of protein and carbohydrate. Cracks that may start on the outside rarely make it all the way through; the structure of the shell forces a crack to take a tortuous route around the tiny bricks, which dissipates the energy behind the damage. Adding to the damage control is that stretchy mortar. As a crack grows, the mortar forms resilient nanostrings that try to force any separating bricks back together. The result is a Lilliputian masonry that can withstand sharp beaks, teeth, even hammer blows. This clever engineering of the abalone shell reflects one of nanotechnology's most enticing faces: by creating nanometer- scale structures, it's possible to control the fundamental properties—like color, electrical conductivity, melting temperature, hardness, crack-resistance, and strength—of materials without changing the materials' chemical composition. The stuff of soft chalk becomes hard shell. Another feat of natural nanotechnology is in continuous operation every time you take a breath, move a muscle, live another second. Known antiseptically as F1-ATPase complexes, they're actually molecular motors inside cells. Each of these motors is a complex of proteins bound to the membranes of mitochondria, the cell's bacteria-sized batteries. About 10 nanometers across, the F1-AT Pase complexes are key players in the synthesis of ATP—the molecular fuel for cellular activity. Scientists have found that F1-ATPase complexes also generate rotary motion just like fan motors whirring in summertime windows. By attaching tiny protein filaments to the hub of F1-ATPase, researchers have visualized this rotary action. And it sets their own nanoengineering imaginations into motion with designs for human made nanometer-scale machines. Scientists using tools like electron microscopes to look at natural structures like abalone shells and protein complexes hope to emulate some of biology's nanoscale engineering. Their aim is to create structural materials for stronger, lighter, more damage-resistant and otherwise better man-made constructions ranging from buildings and cars to batteries and prosthetic limbs.

V. WHAT IS SO SPECIAL ABOUT NANO



Courtesy Cornell University

Nanotechnology stands out as a likely launch pad to a new technological era because it focuses on perhaps the final engineering scales people have yet to master. The pyramids in Egypt, the Brooklyn Bridge, and automobiles are conspicuous monuments to how well and how long people have controlled matter on large scales of meters and miles. The products of Swiss watchmakers even several centuries ago proved that human control over the material world had extended downward a thousand fold to the millimeter scale or so. Over the past few decades, researchers have pushed this control down another hundredfold. Using micro lithographic techniques, they've learned to inscribe silicon with ultra-dense patterns of circuitry whose individual components now are only visible with powerful electron microscopes. And all the while, chemists have been learning to mix, blend, heat, react, and otherwise process chemicals to produce millions of different specific molecular structures. This is about the finest level of material structure relevant for making things. In so doing, researchers have developed recipes and protocols for making the plastics, ceramics, semiconductors, metals, glass, fabrics, composites and other materials of the constructed landscape. But there's a big gap between the scale of individual molecular structures made by chemists and the sub-microscopic components on microprocessors made by electrical engineers. That gap, which spans from about one nanometer to several hundred nanometers, is where fundamental properties are defined. So with every advance researchers make in nanotechnology, they stitch together an unbroken engineering nexus from atoms on up to skyscrapers. Roald Hoffmann, a chemist and Nobel Prize laureate at Cornell University has put it this way: "Nanotechnology is the way of ingeniously controlling the building of small and large structures, with intricate properties; it is the way of the future, a way of precise, controlled building, with incidentally, environmental benignness built in by design."

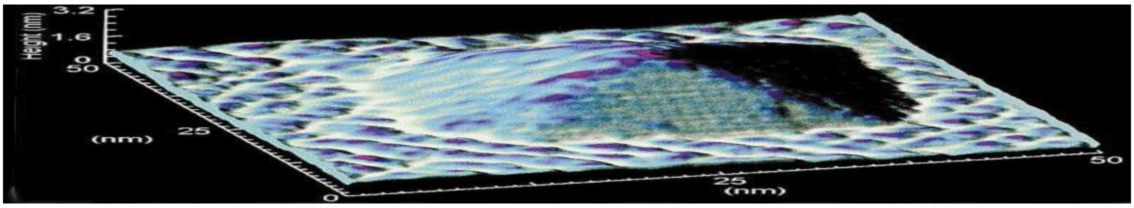
VI. GOING QUANTUM

Many researchers expect that better control over the way atoms and molecules assemble into tiny structures could lead to a host of new technologies based on quantum phenomena that become prevalent only at nanometer scales. In the normal-sized realm of books, bricks, cars and houses, quantum mechanics—the conceptual framework scientists use to describe and predict the properties of matter on the levels of atoms and electrons—doesn't have much direct relevance. As long as bricks hold up the house, who cares about their quantum specifics? But now researchers.

actually are creating nano scale building blocks, such as metallic and ceramic particles, and all-carbon “nanotubes,” that are hundreds of millions of times smaller than bricks used for houses and tubes used for plumbing. So scientists are finding themselves in the middle of quantum mechanics territory. In this nanoscale territory, electrons, for one, no longer flow through electrical conductors like rivers. On this scale, an electron’s quantum mechanical nature expresses itself as a wave. This behavior makes it possible for electrons to do remarkable things, such as instantly tunnel through an insulating layer that normally would have stopped it dead. The payoff of this behavior is that electronic devices built on nanoscales not only can pack more densely on a chip but also can operate far faster—and with dramatically fewer electrons and less energy loss-than conventional transistors. These characteristics ultimately could yield more powerful computers that can help scientists mimic phenomena better and engineers design products better. In some specially designed materials with nanoscale layers made of different semiconductor materials, electrons exhibit behaviors not possible in less precisely organized settings. Researchers already

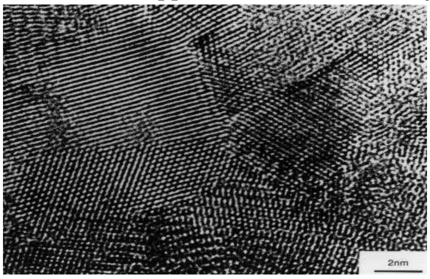
[Modern Pyramids. This nanoscale pyramid of germanium atoms— one kind of quantum dot—formed spontaneously atop a ground of Silicon. It could help researchers develop new generations of tinier electronic devices that are governed by quantum phenomena.]

Have exploited this quantum mechanical reality to design and build new solid state lasers that emit light in wavelengths good for tasks like monitoring pollution, tracking chemical reactions, and optical communications. What’s more, researchers already have taken steps toward so-called quantum computers based on the energy states of atoms and electrons.



VII. SURFACE GALORE

Another major fountain of new technology is likely to spout from a simple fact of material reality: as objects become smaller, the proportion of their constituent atoms at or near the surface rises. Collections of very small particles, therefore, have high surface area compared to their volume. This characteristic is profound because so much of what happens in the world happens at surfaces. Photosynthesis Nano grains.



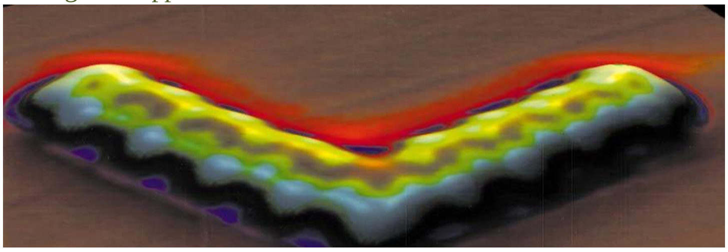
Each region of parallel lines reveals a nanoscale grain of palladium metal. Here, a dozen or so such particles are joined into a nanostructured metal. It has dramatically smaller grains with more internal boundaries than metals made from more conventional grains, and that leads to a stronger metal.

occurs on surfaces inside of cells. Catalysis happens on the surfaces of particles. Ice in the atmosphere forms on the surfaces of floating dust specks. Smaller industrial catalysts, or ones with labyrinthine interiors with nanoscale features, mean there’s more surface area for thousands of chemical transformations. Make a ceramic brick or a metal part, such as a jet engine’s turbine blade, out of nanoscale powder particles instead of conventional micro scale powder particles and the amount of internal surface goes up dramatically. There’s no chemical difference between the two materials; only the size of their constituent particles differs. Yet, just for that the nanostructure brick or metal piece may be harder, less likely to crack, or stronger at higher temperatures, than the conventional brick. That’s important for people who make things like armor or turbine blades for jet engines, which run more efficiently the hotter they become. The shift to nanoscale building blocks for making metal, ceramic, polymer and other material components is enabling researchers to “dial-in” many properties—like melting temperature, magnetic properties (e.g., the magnetic detection ability of materials in the read heads of hard disks), and color—that previously were impossible to obtain for a particular material.

VIII. FORTY YEARS OF GETTING AROUND TO IT

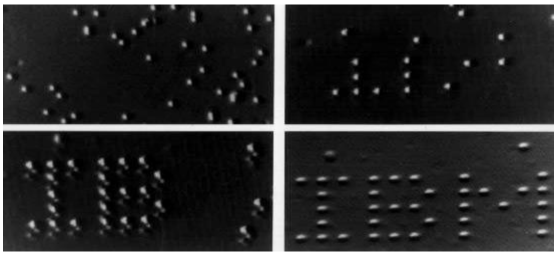
8.1 SEEING ATOMS: One of the biggest steps toward nanoscale control was in 1981 when researchers at IBM’s Research Center in Switzerland—led by Gerd Binning and Heinrich Rohrer—told the world about their scanning tunneling microscope, or STM. It’s essentially a superfine stylus that sweeps over a surface like a blind person’s walking stick. But since the stylus is just a few atom widths away and it has a molecularly or perhaps atomically fine tip, something quantum mechanical happens. Electrons “tunnel” across the gap between the surface and the tip as the tip scans over the surface. This technique enables a computer to construct fantastically enlarged images of atomic or molecular landscapes normally impossible to see. The STM’s inventors received a Nobel Prize because their invention quickly enabled thousands of researchers finally to “see” the atomic and molecular landscapes of things. So taken with the new view of the nanoworld STMs offered, scientists have developed a raft of related instruments now known collectively as scanning probe microscopes (SPMs). Now, besides STM images of surface structures, scientists use SPMs like scanning tunneling spectroscopes and near field scanning optical microscopes to analyze the identities of molecules and atoms on surfaces. They use scanning thermal microscopes to see how heat travels on and through nanostructures such as solid-state lasers, made like a cake with tensor hundreds of nanoscale layers of different semiconductor materials. They use scanning force microscopy to examine magnetic domains on storage media like hard disks.

Atom-by-atom chemistry
Drag 18 atoms of cesium and 18 atoms of iodine together with a scanning tunneling microscope and this is what you get. This is the beaker less, nanotechnology way of doing chemistry—you put the atoms where you want them and where physics will let you



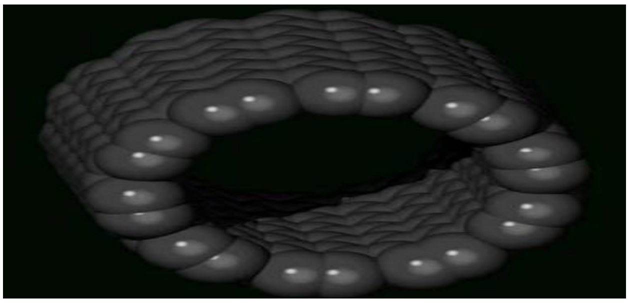
8.2 MOVING ATOMS: SPMs can do more than just peek in on previously hidden nanoscale environments Donald Eigler of IBM's Almaden Research Center remembers the day in 1990 when he and Erhard K. Schweizer, who was visiting from the Fritz-Haber Institute in Berlin, moved individual atoms for the first time. In his laboratory notebook Eigler used big letters and an exclamation mark to write THIS IS FUN! Using one of the most precise measuring and manipulating tools the world had ever seen, the researchers slowly finessed 35 xenon atoms to spell out the three letter IBM logo atop a crystal of nickel. To be sure, it only worked in a vacuum chamber kept at temperatures that make the North Pole seem tropical. But it was the kind of submicroscopic manipulation that Feynman was talking about. The entire logo spanned under three nanometers. Since that feat, more researchers have used STMs to create letters, pictures, as well as exotic physical structures on surfaces one atom at a time. And some researchers now are developing atom- and molecule-moving tools that are easier to use. Consider a nanomanipulator that is being developed by a collaboration based at the University of North Carolina, Chapel Hill. With it, people can manipulate nanostructures in real time using what amounts to a sophisticated joy stick that controls a scanning tunneling microscope. The developers of the system built it with force-feedback so operators even "get a feel" for the atoms and molecules they are moving. What's more, the link between the joystick and the actual nanomanipulator is electronically mediated, which means it even can be controlled via the Internet. Students in a nearby North Carolina high school used this nanomanipulator across the Internet to see, feel and modify individual virus particles. These invaluable tools have opened many new doors of discovery. But using a single tip of a scanning probe microscopeeither for imaging or manipulating surfaces or tiny particles is painfully slow. In the past few years, SPM developers have been hooking up many SPM tips in arrangements that work in parallel. The difference is akin to building a house all by yourself versus getting a dozen friends to help.

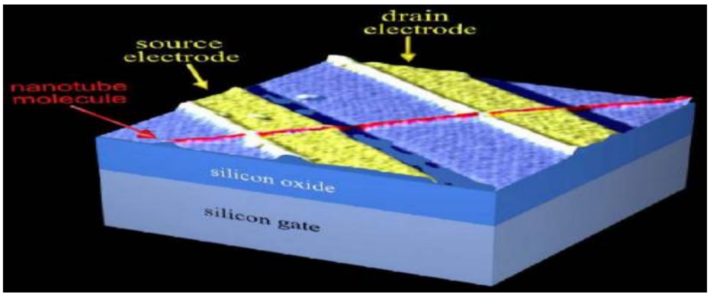
SMALLEST WRITING: This famous set of images, now about 10 years old, helped prove to the world that people indeed can move atoms. The series shows how 35 atoms were moved to form a famous logo.

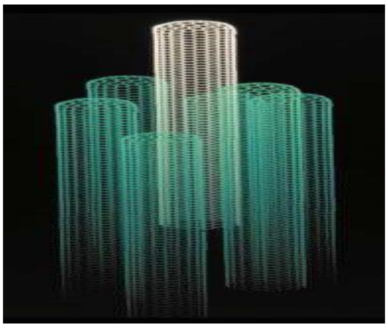


IX. NANOTUBES

All-carbon nanotubes (here with diameters of 1.2 nanometers) are promising for applications ranging from new structural materials that are stronger and lighter weight to electronic components for new supercomputers to drug delivery systems Carbon nanotube transistor by IBM and Delft University







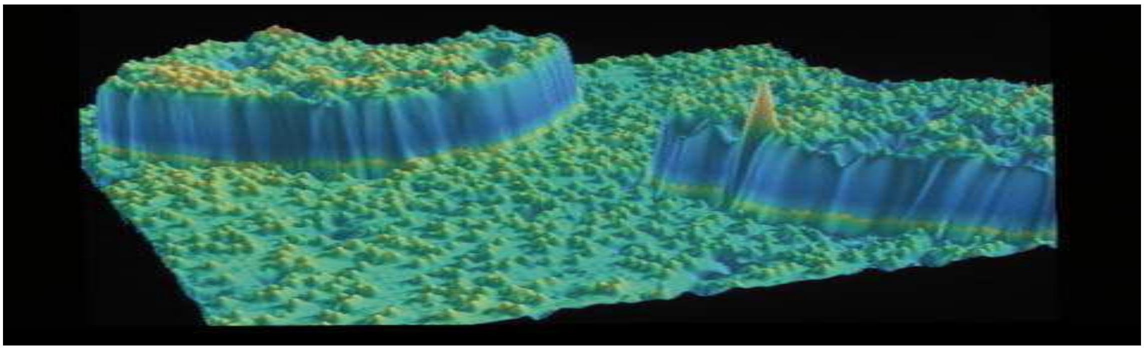
X. THE FUTURE OF NANOTECHNOLOGY

The list of nanotechnologies in various stages of conception, development and even commercialization already is vast and growing. If present trends in nanoscience and nanotechnology continue, most aspects of everyday life are subject to change. Consider these:

a. ***ELECTRONICS CENTRAL:*** By patterning recording media in nanoscale layers and dots, the information on a thousand CDs could be packed into the space of a wristwatch. Besides the thousand fold to million fold increases in storage capacity, computer processing speeds will make today's Pentium IIIs seem slow. Devices to transmit electromagnetic signals— including radio and laser signals—will shrink in size while becoming inexpensive and more powerful. Everyone and everything conceivably could be linked all the time and everywhere to a future World Wide Web that feels more like an all-encompassing information environment than just a computer network.

b. ***NANODOC:*** Nanotechnology will lead to new generations of prosthetic and medical implants whose surfaces are molecularly designed to interact with the body. Some of these even will help attract and assemble raw materials in bodily fluids to regenerate bone, skin or other missing or damaged tissues. New nanostructured vaccines could eliminate hazards of conventional vaccine development and use, which rely on viruses and bacteria. Nanotubules that act like tiny straws could conceivably take up drug molecules and release them slowly over time. A slew of chip-sized home diagnostic devices with nanoscale detection and processing components could fundamentally alter patient-doctor relationships, the management of illnesses, and medical culture in general.

c. ***SMOKELESS INDUSTRY:*** More and more materials and products will be made from the bottom-up, that is, by building them up from atoms, molecules, and the nanoscale powders, fibers and other small structural components made from them. This differs from all previous manufacturing, in which raw materials like sheet metal, polymer, fabric and concrete get pressed, cut, molded and otherwise coerced into parts and products. Bottom-up manufacturing should require less material and pollute less. What's more, engineers expect to be able to embed sophisticated, life-like functions into materials.Even concrete will get smart enough to internally detect signs of weakness and lifelike enough to respond by, say, releasing chemicals that combat corrosive conditions. In effect, the constructed world itself could become sensitive to damaging conditions and automatically take corrective or evasive action like a hand recoiling from a flame.



Memorable Clues: The raised mesas in this scanning tunneling microscope image are made of iron atoms. This atomic landscape forms when chromium deposits onto an iron surface. Nanoscale data like this could lead to new recording media.

d. ***PLANES, TRAINS AND AUTOMOBILES:*** Materials with an unprecedented combination of strength, toughness and lightness will make all kinds of land, sea, air and space vehicles lighter and more fuel efficient. Fighter aircraft designed with lighter and stronger nanostructured materials will be able to fly longer missions and carry more payloads. Plastics that wear less because their molecular chains are trapped by ceramic nanoparticles will lead to materials that last a lifetime. Some long-view researchers are taking steps toward self-repairing metallic alloys that automatically fill in and reinforcetiny cracks that can grow and merge into larger ones, including catastrophic ones that have caused plane crashes.

e. ***BUT, WAIT, THERE'S MORE!:*** Nanotechnology advocates say their field will leave no stone unturned. Their lengthy lists include artificial photosynthesis systems for clean energy; molecular layer-by-layer crystal growth to make new generations of more efficient solar cells; tiny robotic systems for space exploration; selective membranes that can fish out specific toxic or valuable particles from industrial waste or that can inexpensively desalinate sea water; chameleon-like camouflage that changes shape and color to blend anywhere, anytime; and blood substitutes.

XI. CONCLUSION

No one knows how much of nanotechnology's promise will prove out. Technology prediction has never been too reliable. In the March 1949 edition of Popular Mechanics, hardly a year after the invention of the transistor, experts predicted computers of the future would add as many as 5000 numbers per second, weigh only 3000 pounds, and consume only 10 kilowatts of power. Today's five-pound laptops add several million numbers per second using only a watt or so of power. And thumbnail-sized microprocessors run washing machines and kids' toys as well as hundreds of millions of computers.

What's more, computer technology spawned a new social epoch that some dub the Information Age or the Silicon

Age. And yet, many believe nanotechnology may do even more. Despite the advances researchers have made, it is hard to work on the nanoscale. And even assuming something like Feynman's vision of total nanoscale control comes about, the consequences are bound to be mixed. Like any extremely powerful new technology, nanotechnology will bring with it social and ethical issues. Just consider quantum computers. Theorists expect them to be so good at factoring huge numbers that the toughest encryption schemes in use today—which are enabling revolutionary things like e-commerce will become easy to crack. Or consider the claim that nanobiology will enable people to live longer, healthier lives. Longer average lifetimes will mean more people on Earth. But how many more people can the Earth sustain? For the moment, it's nanotechnology's promise that's on most peoples' minds. "Never has such a comprehensive technology promised to change so much so fast... Inevitably nanotech will give people more time, more value for less cost and provide for a higher quality of existence," predicts James Canton, president of the Institute for Global Futures. But maybe not for everyone. Says Canton: "Those nations, governments, organizations and citizens who are unaware of this impending power shift must be informed and enabled so that they may adequately adapt." It no longer seems a question of whether nanotechnology will become a reality. The big questions are how important and transformative nanotechnology will become, will it become affordable, who will be the leaders, and how can it be used to make the world a better place? — Questions that will, in time, are answered.

REFERENCES

[1]. Jack Uldrich & Deb Newberry, *the Next Big Thing Is Really Small* (March 2003)
[2]. Douglas Mulhall, *Our Molecular Future* (March 2002)
[3]. K. Eric Drexler , *Engines of creation: The coming era of Nanotechnology*
[4]. K. Eric Drexler, *Nanosystems: Molecular Machinery, Manufacturing, and Computation* (1992)
[5]. Ed Regis, Nano: *The Emerging Science of Nanotechnology.*
[6]. Robert A. Freitas Jr., *Nanomedicine: Basic Capabilities* (Vol. 1 by 1999 Reviews)
[7]. Glenn Fishbine, *the Investor's Guide to Nanotechnology and Micromachines* (January 2002)
[8]. Mark Ratner & Daniel Ratner, *Nanotechnology: A Gentle Introduction to the Next Big Idea*. (November 2002 Read reviews)