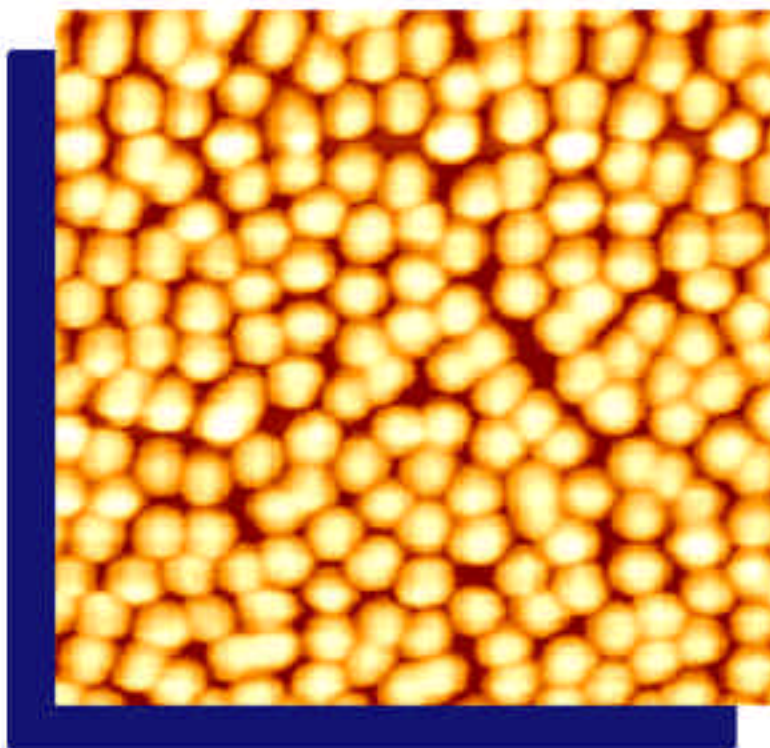


Nanoscience & Nanotechnology



An Overview

Approximately 15 years ago scientists and engineers began discussing a technological revolution that would be as dramatic and far-reaching to society as the industrial revolution - the nanotechnology revolution. At first the primary promoters of the nanotechnology revolution were considered eccentric at best, and a little crazy at worst. However, their ideas and visions are becoming accepted by the mainstream intellectual, scientific and engineering communities. Recently, governments and major corporations around the world have committed several billion dollars per year for the advancement of nanotechnology and nanoscience research and development.

The systematic study, manipulation, and modification of atoms and molecules having nanometer-sized dimensions began several hundred years ago. Society has benefited

greatly because chemists can use chemical reactions to combine several types of atoms to create new types of molecules. With the advent of quantum physics, physicists, chemists and biologists routinely studied the spectra of atoms and molecules. Biochemists discovered the usefulness of all types of molecules from proteins to enzymes to DNA several decades ago.

Until recently however, working with and controlling atoms and molecules was limited to large quantities of these nanometer-sized objects. Realistically, chemists would modify hundreds of trillions of molecules in a typical chemical reaction. When chemists synthesize new molecules, they make them in large quantities by using macroscopic methods such as heat to initiate chemical reactions. Biologists can identify and create new types of genetic material, but only on a large number of molecules.

So What's New?

With all the revolutions in science and technology, there are many driving forces that occur simultaneously facilitating the revolution. The nanotechnology revolution is being driven by a number of developments, ideas, and technical advancements. The primary driving forces behind the nanotechnology revolution are:

Instruments that Measure and Manipulate Atoms and Molecules:

The invention of the Scanning Tunneling Microscope permitted us for the first time to see single atoms on a surface. Before this, using techniques based on electromagnetic radiation, it was possible to view and create images of lattices of many molecules. For example, with x-ray techniques it is possible to recreate the positions of atoms in a complex matrix or lattice. With tunneling electronic microscopes (TEM) it is possible to directly image atoms in a lattice. However, these techniques rely on the scattering of electromagnetic radiation from a collection of atoms, and thus cannot see single atoms.

Another important innovation is the laser "tweezer". By using the momentum of photons it is possible to isolate in a single location collections of several hundred molecules or atoms. Before this invention the possibility of isolating a few molecules or even a few hundred molecules was not considered possible.

The drive to make smaller computer chips & higher density information storage:

Moore's law, popularized in the late 20th century, dictates that there is a relationship between the size of electronic devices such as transistors and time. This relationship has been very effective in predicting advances in the world of microelectronics for almost thirty years. However physicists are predicting that Moore's law will begin breaking down when the size of electronic devices becomes less than 100 nanometers. There is a great effort to discover new methodologies for creating electronic devices with dimensions that are less than 100 nanometers.

The storage of information is considered an essential advancement of modern civilization. At first, recording information and ideas on written paper was a great achievement; books and newspapers allowed the flow of knowledge and information throughout the world. Today information is stored digitally and transmitted electronically. Digital bits with dimensions of less than a micron are stored on magnetic disks and compact discs. There is an ever-increasing need to store and transmit information on smaller spaces and transmit information with faster methodologies.

Emerging belief that it is possible to mimic the mechanisms of biology:

Researchers in the fields of life sciences discovered over the past few decades that there are many fundamental mechanisms that facilitate the recreation and support of all life forms. At a distance these mechanisms can be characterized as machines or engines. They absorb energy and in a very efficient way cause events to occur. For example, a virus will permeate a cell and then integrate with the genetic material of the cell.

Presently, we can observe these activities on a macroscopic scale. In many cases we do not understand how they work or why they work. But there is a belief that we can understand, emulate and even use these fundamental activities or machines that occur in biological systems.

Creation of mechanical devices having nanometer tolerances and motion (MEMS):

To a great extent, the industrial revolution occurred because it became possible to shape mechanical objects, and thus create new types of machines. Before the industrial revolution,

it was possible to routinely make objects that had dimension on the order of a few hundredths of an inch. An artist could paint pictures; a potter could make dishes and pots. After the industrial revolution, it was possible to routinely make machines that had tolerances of a few thousandths of an inch (25 to 100 microns). Of course this gave way to the invention of the steam engine, railroads, the car, and airplane transportation.

With MEMS technology it is now possible to use machining technologies to create machines that are less than the size of a human hair. This ability is presently used in the sensors that activate airbags in cars, set the frequency of computers, and allow digital projection. Applying the scientific method to further understand the behavior of atoms and molecules at the nanometer scale will push forward the frontiers of human knowledge.

Nanoscience

Currently, our vision of the nano-world is based only on evidence that we collect from the macroscopic world that we live in. Presently biologists, chemists, physicists and engineers only have a mental picture of what is occurring at the nanometer scale. In fact, only very recently have they actually seen or directly observed nano-events.

As an analogy, suppose you were presented with a gift that was in a box and wrapped with paper. In an effort to guess what is in the

package, you could shake it or maybe drop it. Based on how the package behaves under this "interrogation", you may get an idea of what is in it (i.e. is it heavy, does it make a noise?). With the Nano-R™ evolution, scientists will be able to open the package... and really see what is inside.

With new ideas and methods, scientists are beginning to further understand how a single atom or molecule behaves. Even more interesting is the direct understanding of how collections of two or three or even a dozen atoms or molecules behave.

Nanotechnology

The fundamental knowledge gained through nanoscience and developments in nanotechnology will certainly accelerate over the next several decades. With the control of materials at the nanometer dimension, engineers are already able to create new types of products and services. As an example the smallest transistors we make today in a factory are about 130 nanometers wide. With future nanotechnology advancements engineers will be able to make chips that have transistors that are two or three nanometers wide. Today, cosmetic manufacturers use liposomes with diameters of a few tens of nanometer to reduce the dehydration of skin.

We expect that the nanotechnology revolution will result in the creation of new types of products and services that will greatly benefit our lives.

What is Possible?

When the ideas and concepts that are discussed as part of the nanotechnology revolution are fully implemented, what is possible? At this point many of the possible advancements that are discussed seem like science fiction. We can only imagine what is possible.

- * All of recorded history will fit in a package that will fit in our pockets. This includes all written documents, all music and all movies.
- * Our world will be safer because the computers and sensing systems that fit in a package the size of a pill will be able to warn us of dangers.
- * Life will be extended because we can create systems and modules that replicate the functions and systems in our bodies.
- * New types of "quantum computers" will make calculations billions of times faster than today's digital computers.
- * We can create new types of molecules with the mechanical assembly of chemical systems instead of today's assembly by thermodynamic chemical reactions.

What is the Atomic Force Microscopes Contribution to Nanotechnology?

Measurement

An atomic force microscope (AFM) creates a highly magnified three dimensional image of a surface. The magnified image is generated by monitoring the motion of an atomically sharp probe as it is scanned across a surface. With the AFM it is possible to directly view features on a surface having a few nanometer-sized dimensions including single atoms and molecules on a surface. This gives scientists and engineers an ability to directly visualize nanometer-sized objects and to measure the dimensions of the surface features.

With an atomic force microscope it is possible to measure more than the physical dimensions of a surface. This is because there is a "physical" interaction of the probe with a surface. An example is that by lightly pushing against a surface with the probe, it is possible to measure how hard the surface is. Also the ease by which the probe glides across a surface is a measure of the surface "friction".

Modification

Just as a pen is used for writing on a paper's surface, it is possible to write on a surface with an atomic force microscope. This new type of "lithography" results in a completely new

method for making surface modifications at the nanometer scale. It is already possible to modify surfaces by physically scratching the surface, by directly depositing molecules on a surface, and by using electric fields to modify surfaces. Presently the use of the AFM is in a very exploratory phase, but showing tremendous promise. One of the important technological issues that must be solved is the writing speed of the AFM lithography systems.

Manipulation

With an AFM probe it is possible to directly move objects across a surface. The objects may be pushed, rolled around, or even picked up by the probe. With such methods it is possible to create nanometer sized objects. One of the important aspects of using an AFM for direct manipulation is the user interface that is used for generating the motions of the probe. There are interfaces that measure the locations of a particle, such as microspheres on a surface, and then automatically move the spheres into a pre-established location. In another type of interface, called the nanomanipulator, the motion of the probe follows the motion of your hand. When you move your hand up and down, the probe moves up and down. Such an interface also allows users to "feel" and "touch" a surface.