# The Nanotechnology Revolution

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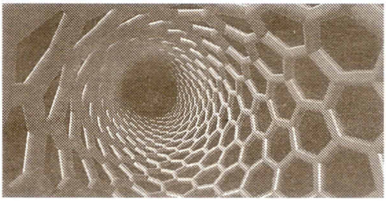
Nanotechnology or nanotech in short refers to the technology of creating materials, devices and functions using atomically manipulated matter. A study of this kind of matter which has new properties, constitutes an emerging branch of science, namely, nanoscience. Nanotechnology is derived from the discoveries in this area of science, just as all the technologies we are familiar with emerge from corresponding science.

## The Nanotechnology Revolution

What does this technology mean to us? To understand this, we need to step back a little and look at the technologies of the past. Long years ago, in the Neolithic era, man was a hunter and he used tools such as axes, which were made of stones. Using such tools, one could do only limited jobs; they were largely intended to catch prey. The human race made several types of tools as part of its evolution and the great works of art and architecture of later years were created with such tools. Today we manipulate matter such as silicon with optical methods so that transistors and integrated circuits are made, with which we built the era of information technology. The dimension of materials manipulated got systematically reduced with time and the modern Core i7 chip has above 700 millions of transistors in it (developed based on 45 nm fabrication process). Thus, one may say that the course of human development is based on the evolution of human capacity to manipulate objects in finer details. This capability has given birth to the knowledge era where information of the world is available in hand-held computers. Rapid growth requirements in computing capabilities necessitated smaller and smaller transistors so that devices could shrink in size; this is popularly referred to as the Moore's law which may be stated as, 'number of transistors in an integrated circuit double in every 18 months'. This so called 'law' is roughly followed all through the history of integrated circuits. To double in every 18 months, more transistors have to be packed in the same size or devices have to shrink. To what size can they shrink to? Well, ultimately to objects as small as a few atoms or molecules. Thus, the technology of tomorrow needs objects manipulated at the atomic level. Such technologies have a role in every area of human endeavour, not only in information technology.

## What is atomically manipulated matter?

All matter is composed of atoms. A piece of gold, such as a 1 gram coin of it, contains a billion trillion atoms. Roughly it contains 3x1021 atoms. Even a grain of sand contains such a large number of atoms. Numbers of this kind are difficult to comprehend. For example, the population of India is 1.2 billion or 1.2X109 or 120 crores. Imagine seeing 120 crores of people as you stand in front of your portico. A gram of gold means seeing a trillion times that many atoms, AT ONCE! Even a grain of gold that one may extract from the river bed (this is how it was found in certain locations long ago) contains billions of atoms. All the properties of gold that one is familiar with such as its colour, characteristic reflectivity, malleability, melting point, unusual chemical inertness, etc. are all associated with the properties of collections of such large number of atoms. The smallest grain that we can see also has such properties. These pieces of dust are a few micrometers in size. However, all these properties of gold will disappear completely as the size of the constituent particles of gold is brought down to a few nanometers! Such gold, composed of particles of size less than a few nanometers, will show different colours, depending on their size. Particles in the range of 5-30 nanometers will be red in colour and above that they will have varying shades of blue. Particles can be in many different shapes such as spheres, rods, wires, triangles, prisms, etc. and all of them exhibit different colours. Much smaller particles of gold, below one nanometer, are not only coloured due to absorption but also emit differently coloured light intensely. This kind of light emission is called luminescence. Colour is one of the most striking characteristics of any material. When it changes, it means that the electronic structure of matter is changed as electronic transitions give rise to colour. Electronic transitions reflect electronic properties and therefore these properties change. What does it mean by electronic properties? The answer is ALL properties! Chemical, physical and



*Nanotube*

mechanical properties come about as a result of the characteristic electronic structure. Thus, matter at smaller length scales results in completely different properties. As a result of this, one can introduce new properties in the material just by changing its size. New properties hitherto impossible have been discovered in a number of materials, just by changing size. For example, gold is now known to be a good catalyst and gold based catalysts are known to convert carbon monoxide to carbon dioxide. What does this mean to people? New kinds of catalysts may be deployed to control hazardous automobile emissions. Nanoparticles may help in cancer diagnosis and treatment. New materials for solar energy harvesting may be devised with nanoparticles.

Atomically manipulated structures can be made by chemical or physical methods. Generally speaking, there are two ways to make them: bottom-up and top-down methods. In the first, matter of nanometer size are made by assembling atoms, i.e., from the bottom. There are chemical methods available today with which this synthesis is possible in simple steps requiring minimal resources. Typically such synthesis is made in the solution phase and under controlled conditions.

## The Prefix

Nano is a prefix added to several subject areas such as nanomechanics, nanobiology, nanochemistry, nanomachines, nanoelectronics, etc. Nano is a prefix added to several types of matter, such as nanotubes, nanorods, nanowires, nanotriangles, etc all of which relate to new types of matter at nanometer length scales.

Such a process can also be done in the gas phase so that molecules or atoms are linked together in an organised fashion. In the top-down method, matter in the bulk or top in the hierarchy is brought down to smaller and smaller pieces by physical methods so that the pieces become nanometer in size. The breaking of matter to smaller dimensions is achieved by physical techniques, such as milling, in contrast to chemical methods mentioned above. In both the cases, the matter so prepared resembles ordinary materials, when taken in large quantities. It is just that a kilogram of nanogold will not appear like gold. It may be black or brown or red or pink in colour. It may show very different properties than ordinary gold such as it may be soluble in water or kerosene. Gold of this kind may be reactive and it will easily disappear in an acid, while one of the standard tests of gold is its inertness upon exposure to acids.

## What is specific to nanoscale?

Why is that properties get modified at the nanoscale? Why no change occurs in the micron scale? The specific size at which properties start changing depend on the type of matter under study. Generally speaking, properties start changing when electrons in the piece of matter feel 'confinement'. To use an analogy, although not the most appropriate, confined or caged animals start behaving differently when the dimension of the cage gets smaller and smaller. They do not feel this in the wild. In fact this happens when the animal feels that its motion is restricted. In the case of a metal, the electrons in a piece of it are free to move in the whole material, from one end to the other. These free electrons possess a characteristic energy. Corresponding to it, they have a characteristic velocity. As electrons move as waves, as per the principles of quantum mechanics, they have a characteristic wavelength. This wavelength for gold is 0.53 nm, called the Fermi wavelength. Thus, in a typical piece of matter, even in a piece of dust having 10 micrometer size, 20,000 such wavelengths can be contained as electron passes through. In this condition, we may say that the electron is free. In other words, the electron motion, in the form of waves, does not see the effect of the particle size. In terms of the previous analogy, the animal will make its natural movements. When the dimension of the matter reduces to near about Fermi wavelength, the electron feels that its motions are restricted or it is confined. Depending on the energy it possesses, the length at which it feels the effects of confinement vary. This is the reason for different elements and compounds to manifest nanoscale effects at different length scales. Typically effects are seen below 100 nm in dimension and as a result, a matter with constituent units smaller than 100 nm is called a nanomaterial; where properties differ drastically from bulk matter.

Zero, one, two and three dimensions

In nanoscale objects, one typically encounters matter in spherical shape. To represent this object, all that one needs is one parameter, namely the diameter. Such a matter is normally referred to as zero dimensional matter as it can be represented as a dot, which has no

### Graphene

Graphene is a rival of silicon that will eventually revolutionise electronic devices ranging from supercomputers to cell phones. Graphene-based nanoelectronic devices will be faster, less power-consuming than silicon, and much thinner.

dimension. These are called by various names such as quantum dots, nanodots, nanospheres, nanoparticles, etc. Here the electron motion is confined in all the three dimensions. The electron is not free to move in any direction. Such a dot can also be a tiny cube with one length parameter. A nanomaterial can also be a long wire with one dimension, namely the length is very large in comparison to the width or diameter. This kind of an object is a one dimensional object. There are several examples such as quantum wires, nanotubes, nanowires, nanorods, etc., which belong to this category of materials. Electron motion occurs along one direction, the length. In the case of a two dimensional object, such as a sheet, two parameters are needed to describe it, as in the case of a sheet of paper. The other dimension is much smaller than the width and the length; an example of which is called graphene, which is attracting a lot of attention these days. In this kind of an object, electron motion is possible in two dimensions. Along the other, the motion is restricted. Various names are used to call these such as quantum wells, nanosheets, etc. In the three dimensional object, three separate dimensional parameters are needed to describe the system. If the particle size is large, such a material will constitute a bulk material and electron motion occurs in all the three directions. The objects with varying degrees of dimensional freedom are represented in Figure 1.

## Historical outline

One may say that we have already celebrated the golden jubilee of Nanotechnology. On December 29, 1959, Professor Richard P. Feynman (Nobel Laureate, 1965) delivered the celebrated talk, 'There's plenty of room at the bottom', which predicted the era of nanotechnology. He envisioned a new kind of technology by assembling things atom by atom, in today's terms, 'molecular nanotechnology'. The terminology, nanotechnology itself came into being in 1974, due to Professor Norio Taniguchi. Molecular nanotechnology is a controversial concept attributed to Dr. Eric Drexler originating from his book, 'Engines of Creation' (1986). Feynman talked about writing the entire Encyclopaedia Britannica on the tip of a needle; he envisioned that one day the entire information of the world could be contained in an envelope! He forecasted that little motors could move within blood vessels and do surgeries, as if the surgeon has gone inside. Feynman said, "The principles of physics, as far as I can see, do not speak against the possibility of manoeuvring things atom by atom." No talk was talked about so extensively as this one in the history of science, except probably the 'Candle light lectures' of Faraday.

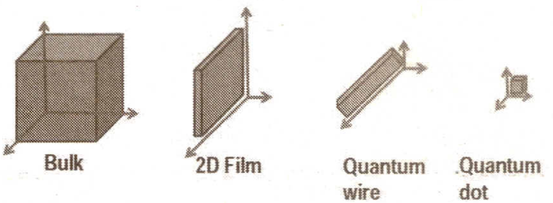



*Figure 1: Variation in the dimensionality of materials (restricted dimension is indicated by reduced length of the arrow).*

The predictions of Feynman, to a large extent, have been realised today. Since 1990, we move atoms one at a time to create structures. A well-defined structure made by Eigler in 1993 was called a 'quantum corral', a confinement or cage or corral was made with atoms. Electrons were confined within this cage. This was

*Figure 2: The Lycurgus Cup made from glass appears red in transmitted light and green in reflected light. The glass contains 70 nm particles as seen in an electron microscopic image. The cup itself is dated to 4th century AD, but the metallic holder is a later addition. 'Nano: The Essentials,' McGraw-Hill, 2008 10. T. Pradeep.*

made with 48 iron atoms on a copper surface. The methodology to see and place atoms is called scanning tunnelling microscopy, discovered by Binning and Rohrer in 1981 (awarded Nobel prize in 1986 for this discovery). But, no one makes molecules in the lab by assembling atoms this way, as it is an expensive proposition, in contrast to synthetic chemistry, which can make any complex shape using a few elements. Besides, such chemical processes make macroscopic quantities, not just one molecule. In fact chemists have been practicing nanotechnology, that is, assembling atoms one at a time for hundreds of years.

One must however, realise that smaller nanoscale objects were made long ago in history. The earliest nanoparticles of gold with different colours were made in 4th century AD and such particles have been used to stain glass. A famous product of craftsmanship of those days is Lycurgus cup made by Romans (Figure 2). The colour of the glass, red in transmitted light and green in reflected light, now we know, is due to the presence of gold-silver alloy nanoparticles of about 70 nm across. Although it was not known then that the properties are the result of such particles, these methods were perfected in those times that in later years several works of art were made using nanoparticle coloring agents. As said earlier, depending on the size of the object, the colour can be varied at will. These particles are now seen in the window panes of old churches and the craftsmanship to create these structures has been lost. In the past 400 years there have been several examples of nanoscale gold and other metals, and their use in dyeing and medicine. The first example of artificially designed matter at the nanoscale was by Faraday in 1856. He made colloidal gold, which was ruby red in colour. He said "...they are simply cases of pure gold in a divided state; yet I have come to that conclusion, and believe that the differently-coloured fluids and particles are quite analogous.... ". In order to come to this conclusion that change in the properties of the material happen as a result of mere change in size and not due to any other chemical change in gold, Faraday conducted a variety of experiments. To make that bold statement at a time when no experimental tool was available to observe particles at this length, one has to be prophetic. Just as in many other important discoveries, Faraday made that unusual prediction here as well. The synthetic methodology has improved tremendously in the past several years and today matter of any kind can be made at nanoscale in a variety of sizes and shapes. Although the synthetic methodology is not perfect to design structures of any kind, it is possible to come up with a variety of strategies to make structures of desired size and shape. Some of the most fascinating discoveries of nanoscale matter are, C60 (made in gas phase in 1985 and in the solid state in 1990), carbon nanotubes (1991) and monolayer protected gold particles, dissolvable in organic media (1994). The discoverers of C60, Kroto, Curl and Smalley were awarded the 1995 Nobel prize in chemistry.

## Nanotools

While synthetic capabilities have improved tremendously, there have also been a number of improvements in scientific instrumentation. Matter smaller than 72 micrometers cannot be seen by our naked eye. This dimension is typically one-tenth of the width of human hair. To see still smaller objects such as bacteria, we need microscopes. They use visible light to illuminate an object and lenses to enlarge the image. Microscopes have a problem that limits the smallest size that they can see. This is called the diffraction limit. This is roughly one half of the wavelength of light used for illumination. If we use green light of 500 nm for illuminating an object, the smallest size we can see is nearly 250 nm, much larger than the size of a nanoscale object. For us to see something much smaller, we need to use light of still smaller wavelength such as X-rays. However, there are no X-ray lenses and therefore there are no X-ray microscopes to see objects of this kind. The other way to see nanoscale objects is to use wavelengths much smaller, having a diffraction limit smaller than nanometers. This is what happens in electron microscopes. Electrons of very high energy are used to image objects. Such electrons can be focused to very small spot sizes, as small as a nanometer and the transmitted electrons can be used to image the object (instrument fabricated on this principle is called transmission electron microscope). It is also possible to collect electrons coming out of the object for imaging. In this case, the primary electron beam is scanned and the secondary electrons coming out as results of the primary electron beam impact are collected for imaging (instrument fabricated on this principle is called scanning electron microscope).

The other way to see objects is to probe them with an atomically sharp tip. The effect of this tip-based scanning is measured. It can be a tiny current that gets passed through the tip to the sample or a weak attractive or repulsive force between the tip and the sample. These two tools are called scanning tunnelling microscopy and atomic force microscopy, respectively. These can be used to image things as small as atoms. As a result of such an imaging, in general called, scanning probe microscopy, atomically resolved images of surfaces can be obtained. The surfaces may have DNA, proteins, chromosomes, etc. or it can even be the process of reaction between two molecules.

While objects as small as a molecule or an atom can be seen, how do we know its chemical identity? The best way to know materials and their properties is by their spectroscopic signatures. Spectroscopy refers to transitions between energy levels present in matter. There are techniques to measure spectra from objects as small as nanoparticles. A variety of spectroscopic techniques can be implemented at this length scale and images can be collected using the spectroscopic properties. What this means is that the presence or absence of a specific species having characteristic signatures can be visualized at nanometer

### Molecules in Jeans as Solar Cells

Molecules, typically used in blue jeans and ink dyes, have been used for building an organic framework that could lead to economical, flexible and versatile solar cell.

length scale. Imagine one is interested in the presence of a specific type of molecule in a nanometer thin wire. It is not that we can see only static molecules. Their motions, random fluctuations, diffusion, association, interaction, etc. can be seen. Imagine seeing the penetration of a particle into a human cell and the nucleus at which the particle acts. Imagine seeing the assembly of particles resulting in macroscopic structures.

## The Current Capabilities

It is possible today to direct tiny diagnostic and therapeutic objects into the body and even into specific cells. Although Feynman's 'surgeons' do not travel through the blood vessels as of now, diagnostic and therapeutic agents do. Single elements of electronic storage are now in nanoscale so that the entire libraries can be written in hand-held devices. Molecules have been shown to store information. Designed molecules can travel specific distances. Planned motions have been done by atomically designed matter. However, atomically designed matter move only atomic distances!

It is now possible to see the evolution in size, shape and properties of pieces of matter, atom by atom– as the object is made. As a result, we can probe questions such as the electrical conductivity of a single DNA strand or strength of single chemical bond. When one looks at matter closely, new phenomena are discovered. For example, one can make gold emitting light in all colours-from blue to red! New phenomena have made natural sciences most exciting.

## Expanding Nano Horizon

Global nanotechnology research budget is substantial. In US, the projected budget for FY 2010 is $1.6 billion. A sum of $10.1 billion was spent in this area in the US during 2001-2009. Indian efforts have been small, the government has started a Nano Mission two years ago with an investment budget of Rs. 1000 crores for five years. Nanotechnology is expected to influence the properties of goods and services worth $2.6 trillion in the year 2014 globally. A total of about 400,000 research papers and 100,000 patents have already come out in the area. Annual research publications are 59,000 in 2009. It grew five fold in 2000-2009 period. According to www.hck22.com, there are 2,580 products in the market using nanomaterials or nanotechnology right now.

What would nano do to the world? Will it be another peak in the unending chain of scientific excitements? Nanotechnology implies the power to manipulate matter at the atomic level. It is the power of the creator, as all are constructed with atoms. Once this capability is comprehended fully, nothing that matter can deliver is impossible. Naturally, promises are plenty.

## Future Nanotech Possibilities

Predicting future is an important step in

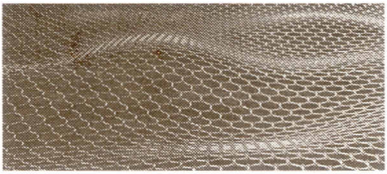
### Memristors - A Memory and Logic Device

Researchers at Hewlett - Packard have shown that nanoscale circuit elements called memristors, previously built into memory devices, can perform full Boolean logic, like in computer processors. Memristor logic devices are quite smaller than devices made from transistors, enabling packing more computing power into a given space. Memristor arrays performing both logic and memory functions would eliminate transfering data between a processor and a hard drive in future.

the evolution of mankind; it often carries substantial risk of implementation. It is always a mix of hits and misses. But it is possible to look into the future from the current understanding of the present. This attempt to look at nanotechnology-enabled future showcases some of the most exciting areas of its applications. As no technology is in isolation, these predictions have inputs from many other areas.

**1. Novel materials:** Super-tough, super-light, super-insulating, etc. materials are going to be made routinely. How about constructing aircrafts, buildings, automobiles, etc. with super-strong wires and pipes which are 1000 times stronger but ten times lighter? May be one can make a bicycle with frames as thin as a pencil. One can wear ultra thin clothing and walk into fire! Such materials will change manufacturing completely. How about manufacturing an entire car body from metallic powders in a new kind of press within one minute? This will change the way we look at factories and assembly lines.

**2. Functional World:** New molecules, materials and artificial structures are now made in the lab, which are functional. Such materials change properties with external stimuli. Imagine buildings which absorb toxic gases, emit perfumes, change colours, absorb ultraviolet, self clean, etc. Imagine a dress which senses the atmosphere around and a helmet which measures biological functions and interacts with the hospital! There can be numerous such devices and materials which will make the world outside work for you the way you desire. This is as if the world outside responds to your taste.



*Graphene nano material*

**3. Solar Energy:** Solar energy conversion will be much more efficient and cheap. This will make solar driven cars affordable to Indians. Solar houses become a reality. Most of the energy of the world will come from solar energy. Clean energy hunt will intensify and new forms of captive energy which requires no external raw materials may come into homes. More power may be generated at homes than consumed from the grid.

**4. Water:** New generation water purification will implement principles of nature. As a result, water will be purified molecule-by-molecule in a much more energy efficient fashion than reverse osmosis. As this technology is likely to take time, several interim solutions will be made to have affordable clean water. Looking far into the future, new technologies will be developed to harvest clean water, not just purify it.

**5. New diagnosis and therapy:** Diseases will be diagnosed using molecular principles. Detecting cancer at the single cell level will become a reality. Hundreds of diseases and conditions will be screened in one go, in easy to use and throw away chips, with one drop of blood, or saliva. Diagnosis of several of the health risks will be known years in advance. As a result, therapy will shrink to cell level or molecule level.

**6. Transport:** Internal combustion

### Print Display Almost Anywhere

Ntera, a US-based company, has developed a nanotechnology to mass-produce electronic displays on a wide range of paper, packaging, ticket and greeting card products.

engines which make energy from fuels will gradually disappear and new ways of generating and storing energy in environmentally friendly manner will become a reality. Such batteries and fuel cells will become integral parts of mobility and life.

**7. Communication:** Communication is likely to link human thought to machines. As a result, web searches are going to get done by thought and data are going to be delivered with text, graphics, video, speech, etc. as if information is available endlessly. Search engines and computing resources are likely to become so powerful that search delivers the expected result instantaneously. Distances are not going to be felt as virtual reality arrives in the living room.

**8. Human capabilities:** Human capabilities will be enhanced significantly so that it is possible to hear, see and feel beyond the current capabilities. Imagine night vision without goggles. As understanding of human functions such as alertness, memory, etc. improve, enhanced human capabilities arrive. This will make average life expectancy go well beyond 100 years. Artificial organs and molecular medicine will make people at 60 young.

**9. Human Perception:** With all these changes, the way we look at each other is likely to change. Education, publication, searches, networking, etc. become online. Network will become the most essential service, apart from water, air and food. On-line becomes a state of mind.

**10. Environment:** New materials and processes will come into existence to reverse climate change. But whether climate will return to normal will not be decided by science. However, every process is going to be understood from the way environment is going to be altered. Ultimate chemistry, physics, engineering, etc. will be similar to biology and it will be taught that way in schools.

## Nanotechnology in Education

Realising the significance of nanotechnology, there have been global efforts in creating a nanotechnology workforce. It is important to realise that today's young will live in the nanotechnology-enabled future. There is a need to have more and more inventions in the area for which more educators, scientists, engineers, biologists, medical professionals with a background in nanotechnology will be necessary. As nanotechnology is a discipline of convergence and it requires adequate training in fundamental areas, post-graduate level programmes are being designed in universities. In India, several universities are offering M.Tech. and PhD level courses in this area. Several universities are offering one semester courses introducing nanotechnology for the final year undergraduate students. Several textbooks are available which provide a background to this area and a book of this author10 is used by several universities for this purpose.

At present nanotechnology graduates have to look at research or higher education as the most important career option. However, a number of private industries are opening up nanotechnology laboratories. Indian opportunities in this area are rapidly expanding.

## Environmental implications of Nanotechnology

While the chemistry of nanoparticles is unique due to novel properties, their high energy surface results in the system attempting to minimize the surface energy through protection or chemical transformation or agglomeration. The same properties of nanomaterials (increased surface area, chemical reactivity, etc.) which confer unique functional abilities may also render them to interact with human biology in different ways. A number of properties of the material (electronic structure, particle dimensions, surface functionalities, chemical stability and accumulation) have to be carefully examined before a judgement can be made on the safety of these materials. Thus, it is important that for longevity of nanomaterials used in commercial applications, preventive care is taken to minimize the side-effects, till those are known. During the intermittent time, several important aspects should be considered for the judicious use of nanomaterials in commercial applications.

- As far as possible, the use of nanoparticles supported on suitable substrates should be preferred, than separate or free particles. There are many advantages of supported nanoparticle chemistry: minimum leaching of nanoparticles into the environment, easy nanoparticle separation and lower loss in the efficiency of nanoparticle chemistry.
- Quantitative studies on the release of nanoparticles from supports under varying environmental conditions
- Appropriate mechanisms for the recovery of nanomaterials have to be designed.
- Use nanosystems made of materials with minimum toxicity.

## What does it mean for India?

Nanotechnology, as any other technology would not make miracles. Every technology brings advantages only if it is implemented properly with commitment and responsibility. However, one of the bigger and most important aspects of nanotechnology is that there are benefits from it to each section of the population, whether they live in the city or in the village, whether they have electricity or piped water supply. Therefore, implications of nanotechnology to the country depend upon the challenges we foresee and how we envision solutions.

In India for some of our biggest challenges, nanotechnology is likely to provide answers. These include, energy, drinking water, food, sanitation, health care and environment. Each one of them is composed of a multitude of issues which have national and regional complexities. For example, drinking water in the country has very high levels of contamination and those who are intensely affected cannot afford conventional solutions. The contaminants are many and there are regional variations. Availability of water, piped or otherwise and power are issues. Even in the worst affected areas, people do not have other alternatives, except to live with what they have. It is because of these, the problem is very much Indian and a solution or many solutions, as one may not fit for all, is(are) needed. There are indications that such solutions are very much feasible. Nanotechnology based solutions are available for almost all the drinking water issues such as microbial, organic, heavy metal and anion contamination. They can be implemented in the field at affordable cost. The materials required for such processes can be made locally in an environmentally sustainable fashion. It is possible that these technologies are

### Nanorobots

In the fields of molecular computing and robotics, researchers in Caltech, USA, have created robots the size of a molecule that can move freely across a nanoscale track. The achievement would lead molecular robots to fix individual cells or assemble nanoproducts. The project involves reprogramming DNA molecules to perform in specific ways.

implemented in the areas where people suffer such that the solutions themselves contribute to wealth creation. More effort is certainly needed in several other areas such as the removal of salinity. Completely new nanotechnology based solutions are being worked on.

In the long run, availability of water itself is an issue of concern and new solutions to harvest water have to be evolved. Thinking of such possibilities, this is what is going on in Nature. All the carbohydrate which plants cook in their leaves, to keep us going, is made atom by atom, from carbon dioxide and water, using sunlight. In the way we convert that food to energy and then to work, very little wastage occurs. If biological machinery were to be as inefficient as our motors, the food we produce cannot even sustain one tenth of the population. Thus, biology is nanotechnology in perfection. Similarly best chemistry is nanotechnology. It converts atoms to molecules in a clean and green manner, chemists say with high atom efficiency. All physics is ultimately that is done at the atomic level. This convergence of disciplines at the nanometer level is probably one of the biggest impacts of nanotechnology.

## Satellite Communication

Over the last 45 years, since the launch of the first Intelsat, communication satellites have advanced phenomenally, changing the way the world communicates. Services have moved up from speech-only to multimedia. The potential of satellites for communication put in a geostationary orbit was first realised by Arthur C. Clarke in 1945. The geostationary satellite's 24 hours orbit period precisely matches the earth's rotation allowing a single satellite to provide fixed coverage over a large region. Man-made satellite era began in October 1957 when the former Soviet Union launched the first artificial earth satellite, Sputnik I. The first true telecommunication satellites, Telstar I and II, were launched in July 1962 and May 1963, respectively. Live television links and multiplexed telephone circuits were established across the Atlantic Ocean and proved the feasibility of satellite communication. The first geostationary satellite that worked well was SYNCOM III, launched in 1964. The satellite was used to telecast 1964 summer Olympics held in Tokyo. Soon GEO satellites proved very profitable. India started deploying regional GEO system INSAT-I in 1982 for telecommunication, television distribution and meteorology. Today, in India, the bulk of traffic through communication satellites is for television, VSATs, education and telemedicine. Over the last 40 years, all technologies related to satellite communication evolved and changed considerably resulting in more powerful and reliable satellites, shaped beam antennae, onboard Lithium-ion batteries, solar cells, etc. Today, we can have satellites with up to 150 transponders and life of 15 years.

In the years to come, use of very small aperture terminals for business and rural applications is expected to grow further in all parts of the world. Residential and rural VSATs are expected to provide broadband services with a significant reduction in tariff. Future mobile satellite systems will provide mobile video, navigation and emergency assistance services.Use of DTH broadcasting is expected to increase in many parts of the world.