Nanotechnology and its Recent Application

Scientific Revolutions

The rock was our first tool. Once certain types of rocks become useful to serve different purposes. The use of these tools increased the food supply and allowed the new specialists to spent their time hunting. The discovery of tools was probably the first step in humankind's revolution to control the planet and its own destiny. Other development speeded from this, as Table 1 [1]

Table 1: History of useful science

Discovery type	Name	Age	Start date
Industrial	Tools	Stone	2200000 BC
Industrial	Metallurgy	Bronze	3500 BC
Industrial	Steam power	Industrial	1764
Automation	Mass production	Consumer	1906
Automation	Computing	Information	1946
Health	Genetic Engineering	Genetic	1953
Industrial	Nanotechnology	Nano age?	1991

One valuable tool was fire. Around 5000 to 6000 years ago, someone put a rock containing copper ore on a campfire. The copper melted out and was collected. Now people had access to new metallurgical materials and not only the boundaries of basic sciences but also technology expanded rapidly through-out the world. Humankind made new materials that were not visibly present in nature. After the Rock age, Iron and Bronze age came.

Millennia passed, and all of industry until the 18^{th} century was powered by the energy of human or animal's muscles or by natural energy sources like river water and wind. During this time steam power was a big invention for railways. Then petroleum as a source of energy came for cars, jet planes and spacecrafts. Two different types of discovery followed. These were techniques for mass production and computers. Mass production was a very important step for humankind because it made the rate of supply faster than the rate an individual human could deliver. It was the product of discovery and use of electricity. Today's computers, fabricated using micro transistors are efficiently handling mathematical transformation and data processing for mass production of a number of products in different factories. Before this, any computation or information processing required the human brain and could only proceed at the speed of a human could work.

Genetic engineering, the ability to elucidate and modify the nature of genes in DNA, is a major revolution that is happening now. During these revolutions, pioneers make wealth. A lot of people are already making plenty of money from last two revolutions. While the knowledge of the old science is also important, something new development is rapidly taking place during the last two decades. This new and wonderful development is the realm of nanoscience and nanotechnology.

What is Nano?

When Neil Armstrong stepped onto the moon, he called it a small step for man and giant leap for mankind. ‘Nano’ may represent another giant leap for mankind, but with a step so small that it makes Neil Armstrong look the size of a solar system.

The origin of the term “nano” comes from the Greek “nanos” (or Latin “nanus”), meaning “Dwarf”, but in science “nano” means one billionth. One nanometer (abbreviated as 1 nm) is one billionth (1/1,000,000,000) of a meter and is the unit of length that is generally most appropriate for describing the size of single molecule. To get a sense of nanoscale, a human hair measures 50,000 nm. Nanometer objects are too small to be seen with naked eye. The smallest things seeable with the unaided human eye are 10,000 nm across.

Introduction to Nanoscience and Nanotechnology

Nanoscience is, at its simplest, the study of the fundamental principles of molecules and structures with at least one dimension roughly between 1 and 100 nanometers. Nanotechnology is the application of these nanostructures into useful nanoscale devices. Nanotechnology is an anticipated manufacturing technology that allows through, inexpensive control of structure of matter by working with atoms.

The concept of nanotechnology is attributed to Nobel laureate Richard P. Feynman in a lecture that he delivered in 1959 and which was published in 1960 [2] entitled “*There is plenty of room at the bottom*”. In this famous lecture the great scientist uttered these famous words “*The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom*”. In 1981, Binnig and Rohrer were the first to see atoms (Discovery the Scanning Tunneling Microscope, STM) and hence make nanotechnology a possibility [3]. In the last decade, new dimensions of modern research, broadly defined as ‘nanoscale science and technology’ have emerged.

Nanotechnology is about to affect almost every field of human life. It is an enabling technology that will impact electronics and computing, medicine, materials and manufacturing, catalysis, energy and transportation. It will revolutionize future world by changing the current using materials in durability and reactivity. We have great opportunities to make things smaller in size, lighter in weight and stronger.

Classification of Nanomaterials

Nanomaterials can be classified dimension wise into following categories as Table 2.

Table 2: Classification of Nanomaterials

Classification	Examples
1 dimension < 100nm	Nanorods, Nanowires etc.
2 dimensions < 100nm	Tubes, fibers, platelets, etc.
Zero or 3 dimensions < 100nm	Particles, quantum dots, hollow Spheres, etc.

On the basis of phase composition, nanomaterials in different phases can be classified as,

- Single phase solids include crystalline, amorphous particles and layers, etc.
- Multi phase solids include matrix composites, coated particles, etc.
- Multi phase systems include colloids, aero gels, Ferro fluids, etc.

Nanoscale Materials is Intermediate between Atomic and Bulk Matter

Nanoscale materials frequently show behavior, which is intermediate between that of a macroscopic solid and that of an atomic or molecular system. Consider, for example, the case of an inorganic crystal composed of few atoms. Its properties will be different from those of a single atom, but we cannot imagine that they will be the same as those of a bulk solid. The number of atoms on the crystal’s surface, will have large influence on the over all properties of the crystal. We can easily imagine that this crystal might have a higher chemical reactivity than the corresponding bulk solid and that will probably melt at lower temperatures. Consider now the example of a carbon nanotubes (CNT), which can be thought of as a sheet of graphite wrapped in such a way that the carbon atoms on one edge of the sheet are covalently bound to the atoms on the opposite edge of the sheet. Unlike its individual components, a CNT is chemically extremely stable because the valences of all its carbon atoms are saturated.

Moreover, that CNTs could be good conductors because electrons can freely move along these tiny, wire-like structures. Once again, we see that such nanoscopic objects can have properties, which do not belong to the realm of their larger (bulk) or smaller (atoms) counterparts.

Nanoscience and Physics

Physics is the mother of natural sciences. In principle, physics can be used to explain everything that goes on at the nano scale. There is active physics research going on in nanomechanics, quantum computation, artificial atoms etc. At nanometer scale physics is different. Properties not seen on a macroscopic scale now become important- such as quantum mechanical and thermodynamic properties. Rather than working with bulk materials, one works with individual atoms and molecules. By learning about an individual molecules properties, we can put them together in very well-defined ways to produce new materials with new and amazing characteristics.

Some Physical Properties of Nanomaterials

Materials reduced to nano scale can suddenly show very different properties compared to what they exhibit on a macro scale, enabling unique applications. For instance:

- Copper which is an opaque substance become transparent.
- Platinum which is an inert material become catalyst.
- Aluminum which is a stable material turns combustible.
- Silicon insulators become conductors.
- Gold which is solid, inert and yellow on room temperature at micro scale becomes liquid and red in color at nano scale on room temperature. It also gets unusual catalytic properties not seen at macro scale. Figure 1 [4] shows dependence of melting point on the particle size.

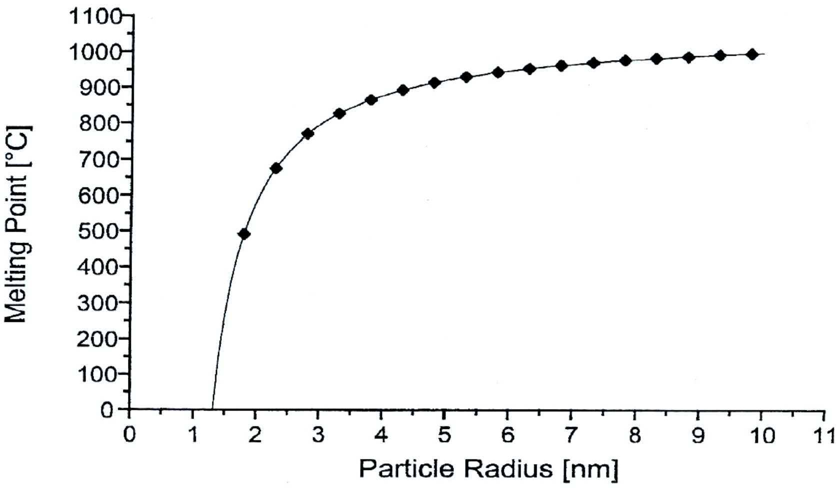

Fig. 1: Dependence of melting point of gold on particles size.

Manufacturing Approaches

There are mainly two major approaches to get nanomaterials. One is the bottom up and the other is top down approach.

Bottom up manufacturing would provide components made of single molecules, which are held together by covalent forces that are far stronger than the forces that hold together macro-scale components. Furthermore, the amount of information that could be stored in devices build from the bottom up would be enormous. For example, use of AFM, liquid phase techniques based on inverse micelles, sol-gel processing, chemical vapor deposition (CVD), laser pyrolysis and molecular self assembly use bottom up approach for nano scale material manufacturing [5-9].

Top down method for manufacturing involves the construction of parts through methods such as cutting, carving and molding. Using these methods, we have been able to fabricate a remarkable variety of machinery and electronics devices. However, the sizes at which we can make these devices are severely limited by our ability to cut, carve and mold. Milling, Nano-lithography, hydrothermal technique (for some materials), laser ablation, physical vapor deposition, electrochemical method (electroplating) uses top down approach for nano-scale material manufacturing.

Nano science can use every element of periodic table depending upon the target material which someone is going to fabricate. The range of nano materials starts from nano medicine and goes up to nano concrete via nano electronics. Nanotechnology provides us the opportunity to synthesize nano scale building blocks with control on size, composition etc. Further assembling into larger structures with designed properties will revolutionize materials manufacturing. Metals, polymers, ceramics etc can be manufactured at exact shape without machining.

Applications of Nanotechnology

The potential applications of nanotechnology in different fields are the following:

- Electronics
- Health and Medicine
- Transportation
- Energy and Environment
- Space exploration

Nanotechnology in Electronics

Nanotechnology has already reached the electronics industry with features in microprocessors now less than 100 nm in size. Smaller sizes allow faster processing times and also more processing power to be packed into a given area. However, these advances are really only a continuation of existing microelectronics, and will reach their limit sometime around the end of the next decade when it will be both physically impossible to “write” or “etch” smaller features in silicon, and also because at extremely small sizes (less than 20 nm) silicon becomes electrically “leaky” causing short circuits.

Some of the areas under development include:

- Improving display screens on electronics devices. This involves reducing power consumption while decreasing the weight and thickness of the screens. This can be achieved using carbon nanotubes (CNT) [7-9]. They can be used as field emitters with extremely high efficiency for field emission displays (FED).
- Increasing the density of memory chips. Researchers are developing a type of memory chip with a projected density of one terabyte (TB) of memory per square inch or greater. Integrated nanosensors are used for collecting, processing and communicating massive amounts of data with minimal size, weight, and power consumption
- Reducing the size of transistors used in integrated circuits. One researcher believes it may be possible to "put the power of all of today's present computers in the palm of your hand". Processors with declining energy use and cost per gate, thus increasing efficiency of computer by 106.
- Allowing the refrigeration without the need of refrigeration fluids. This can be done if nanoparticles with large magnetic moments and adequate coericivity can be obtained then the magnetocaloric effect may allow refrigeration on a practical scale.

Nanotechnology in Health and Medicine

Mankind is still fighting against a high number of serious and complex illnesses like cancer, cardiovascular diseases, multiple sclerosis, Alzheimer’s and Parkinson’s disease, and diabetes as well as different kinds of serious inflammatory or infectious diseases (e.g. HIV). Nanotechnology has also its applications in field of health and medicine called nanomedicine. The approaches to nanomedicine range from the medical use of nanomaterials, to nanoelectronic biosensors, and even possible future applications of molecular nanotechnology [10]. The medical area of nanoscience application is one of the most potentially valuable, with many projected benefits to humanity.

- Nanomedicine has the potential to enable early detection and prevention, and to essentially improve diagnosis, treatment and follow-up of diseases.
- Biological tests measuring the presence or activity of selected substances become quicker, more sensitive and more flexible when certain nano scale particles are put to work as tags and labels.
- Nanodevices can make gene sequencing more efficient. Gold nanoparticles tagged with short segments of DNA can be used for detection of genetic sequence in a sample.
- Nanotechnology can help to reproduce or to repair damaged tissue. This so called tissue engineering makes use of artificially stimulated cell. It might replace today's conventional treatments, e.g. transplantation of organs or artificial implants.

Carbon nanotubes have recently become promising functional materials for the development of advanced biosensors with novel features. These sensors are being used for astrobiology to study origins of life. The technology is also being used to develop sensors for cancer diagnostics. CNT, though inert, can be functionalized at the tip with a probe molecule. Their study uses AFM as an experimental platform.

i. Probe molecule to serve as signature of leukemia cells identified

ii. Current flow due to hybridization will be through CNT electrode to an IC chip.

iii. Prototype biosensors catheter development

Nanotechnology in Transportation

The transportation industry will experience many enhancements from nanotechnology. It will allow cars and planes to become safer and cheaper. Nano materials and new fuel sources will permit travel to become farther and more financially feasible, by reducing the weight of heavy structural materials. It may be possible to make carbon based fibers which are 100 times stronger than steel and only one sixth of weight [11].

- Nanotechnology will enhance aerospace application and space flight as new materials will allow space shuttles to become lighter and tougher.
- Emissions from cars contain many different noxious gases, including several known human carcinogens. But now it looks as though nanotechnology may be able to reduce health risks. NanoTwin Technologies has recently released an air filter, which uses nanotechnology principles, to remove hazardous chemicals from the air in car cabins.
- Improved catalysts could reduce or eliminate the emission of pollutants from engines.
- Nanocoating of metallic surfaces to achieve super-hardening, low friction, and enhanced

corrosion protection; "tailored" materials for infrastructure and vehicles; and "smart" materials that monitor and assess their own status and repair any defects resulting from fatigue, fire, etc.

- Cerium oxide nanoparticles are used in diesel fuel to greatly increase fuel efficiency. Introducing the nanoparticles reduces fuel deposits on pistons and cylinders, increasing fuel efficiency by about 10% [12].
- Nanoparticles of inorganic clays and polymers will replace carbon black tires and therefore we will have environmental friendly, wear resistant tires.

Fig 2 gives good illustration of how nanotechnology will effect transportation in future [13].

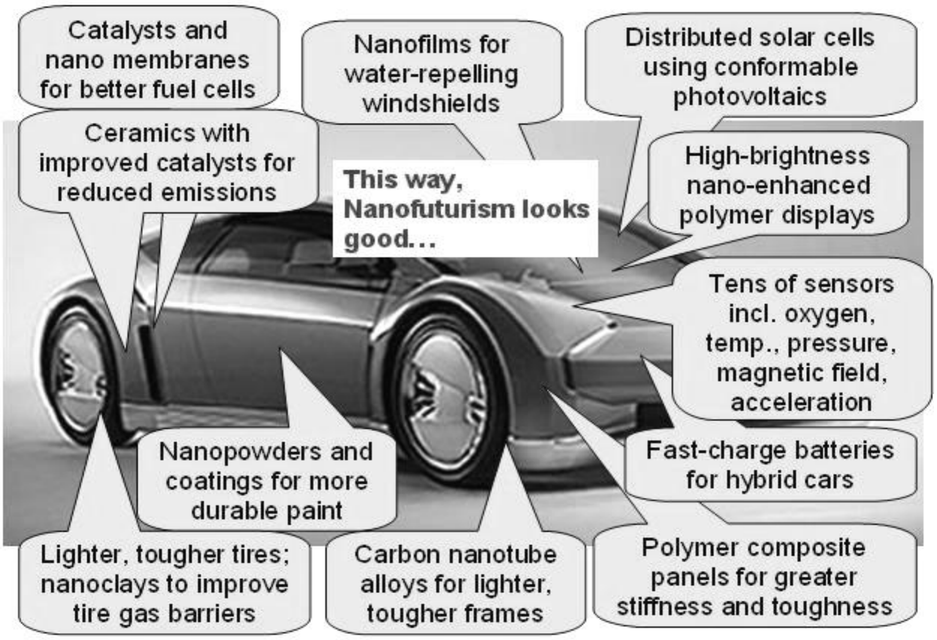

Fig. 2. Nanotechnology will affect the every aspect of transportation.

Nanotechnology, Energy and Environment

Nanotechnology is fundamental over the next 50 years to providing sufficient energy for a growing world and to protecting the environment in which we live. There is an energy/environmental storm gathering and we must pay attention. Under all practical solutions nanotechnology will play a critical role in any successful outcome. The most advanced nanotechnology projects related to energy are: storage, conversion, manufacturing improvements by reducing materials and process rates, energy saving e.g. by better thermal insulation and enhanced renewable energy sources.

- Nanotechnology is having on renewal energies, from solar technology, to nano-catalysis, fuel cells and hydrogen technology. Thus using nanotechnology more clean and less expensive ways for energy production have been found.

- Carbon nanotube fuel cells are being used to store hydrogen. These are the environmentally friendly form of energy. Researchers are trying to increase effectiveness of CNT at storing hydrogen. This has the potential to power cars.
- Nanotechnology can contribute to the further reduction of combustion engine pollutants by nanoporous filters, which can clean the exhaust mechanically, by catalytic converters based on nanoscale noble metal particles or by catalytic coatings on cylinder walls and catalytic nanoparticles as additive for fuels.
- Nanotechnology can help in developing new environmental safe and green technologies that can minimize the formation of undesirable byproducts or effluents.
- A reduction of energy consumption can be reached by better insulation systems, by the use of more efficient lighting or combustion systems, and by use of lighter and stronger materials in the transportation sector. Currently used light bulbs only convert approximately 5% of the electrical energy into light. Nanotechnological approaches like LEDs (Light-emitting diodes) or QCAs (Quantum Caged Atoms) could lead to a strong reduction of energy consumption for illumination

Nanotechnology in Space Exploration

Most of today's rocket engines rely on chemical propulsion. Real rocket scientists though are actively researching new forms of space propulsion systems. One heavily researched area is electric propulsion (EP) that includes field emission electric propulsion (FEEP), colloid thrusters and other versions of field emission thrusters (FETs). EP systems significantly reduce the required propellant mass compared to conventional chemical rockets, allowing increasing the payload capacity or decrease the launch mass. A new EP concept proposes to utilize electrostatically charged and accelerated nanoparticles as propellant. Millions of micron-sized nanoparticle thrusters would fit on one square centimeter, allowing the fabrication of highly scaleable thruster arrays [14].

The greatest challenges in the space craft are

(i) performance
(ii) reliability and safety
(iii) cost

Nanotechnology can improve the situation and some specific benefits given below [15]

- Nanotechnology can make the structure of space planes much lighter thus can greatly improve their viability.
- Nanotechnology can improve the performance of laser sails. Using nanotechnology sails

with 20 nm thickness can be constructed making them light and more durable.

- Performance can also be increased using solar powered ion engines with nanotechnology.
- Using a combination of Artificial Intelligence (AI) and nanorobotics, computer controlled manufacturing systems will reduce the time and cost of developing new technologies.
- Making exterior of crafts using nanosensors and nanorobots will increase mission rates at lower cost.

Conclusion

In this way we see that nanotechnology is about to affect almost every field of human life. It is an enabling technology that will impact electronics and computing, medicine, materials and manufacturing, catalysis, energy and transportation. Nanotechnology will have an impact on war, crime, terrorism and the massive industries that go with them namely security and law enforcement. The military has a great interest in nanotechnology, especially optical systems, and also in nanorobotics, nanomachines, smart weapons, nanoelectronics, virtual reality, massive memory, new ultra hard materials for armour, new energy-absorbing nanobased materials for stopping bullets and bio-nanodevices to detect and destroy chemical and biological agents. In the future, nanorobots may be able to repair defective airframes or the hulls of ships before any damage develops. It will revolutionize future world by changing the current using materials in durability and reactivity. We have great opportunities to make things smaller in size, lighter in weight and stronger in strength.

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[13] http://nanopedia.case.edu/NWPrint.php?page=transportation.

[14] http://www.nanowerk.com/spotlight/spotid=1668.php

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> "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… experts predicted computer of the future would add as many as 5000 numbers per second, weigh only 3000 pounds, and consume only 10 kilowatts of power."