

NANOSTRUCTURE, NANOTECHNOLOGIES AND NANOMACHINES

Octavian RADOVICI¹⁾

ABSTRACT

Some spotlights progress in the creation of supramolecular assemblies, nanostructures and devices. The paper departs from biological forms although some of materials discussed certainly have been inspired by biology. The biological path to build a nanostructure is very promising. A second opportunity toward a proto assembler of building blocs is the mechanical path called the mechanosynthesis path. These building blocs should be molecules, synthesized by using conventional technique that could be placed on a work piece and covalently bind to that workpiece structure.

KEYWORDS: nanomachine, supramolecular assemblies, nanostructures.

1. INTRODUCTION

Nanotechnology or Molecular Engineering is the science and art of building complex practical devices with atomic precision. In an effort to construct practical machines molecular nanotechnologists apply the techniques of engineering to the knowledge generated by science that study molecular structures. So to fully understand molecular engineering to be a nanotechnologists requires hard study in several fields such as physics, computer science and especially chemistry, biochemistry and molecular biology.

Because the goal of molecular engineering being the constructions of devices whose components are measured in nanometers (10^{-9} meters) an imaginative exploration of nanotechnology must conceptualize the two essential dimensions of any material system-space and time-as they relate to the molecular world.

First, how big are atoms and molecules. The diameter of a single atom is a little larger than are tenth of a nanometer. The DNA molecule is about 2,3 nanometers wide. Large complex macromolecular structures may be measured in micrometers (cellulose film). Other scales of dimensions are common in physics and biochemistry such as, angstrom (10^{-10} meters or 0,1 nanometer, and dalton, named after the English chemist John Dalton, 1766-1844) which is atomic mass unit nearly equivalent to that of a single atom of hydrogen. The kilodalton is used to indicate the molecular weight of biomolecules [3].

While atoms are incredibly small, there was built the tools to see individual atoms and to manipulate them as well.

The second dimension we need to imagine is the speed with which atoms and molecules moves. In atmosphere, O_2 , N_2 , CO_2 , etc., zip around at up to ten times the speed of sound. The local transformations that molecules are capable of are much more important.

For example the primary event in vision-the mechanical transformations of the molecule retinal form bent to straight- occurs within 200 femtonoseconds (10^{-15} sec), after being struck by a photon. The relative rates of a few biological processes are: Hinge motions in proteins, 10^{-9} sec; unwinding of DNA helix 10^{-6} sec; Enzyme catalyzed reaction, 10^{-3} sec. Although an atoms is small, the nucleus is much, much smaller and of relatively little interest to nanotechnology. The electron cloud that surround, the nucleus determines the effective size of an atom, not the protons and neutron at its core. Nanotechnology as constructive instrument maps atoms together like Lego building blocks, to build molecules structures in processes that are similar to but potentially much more flexible and powerful than the processes used by biological systems.

One of the most important developments for approaches to the design and control of sub-micron systems was the invention of scanning tunneling microscope (STM) in 1981.

This device, first developed by Gerd Binnig and Heinrich Rohrer at IBM Zurich Research Labs, gave us the first direct images of individual atoms, fig 1a and b.

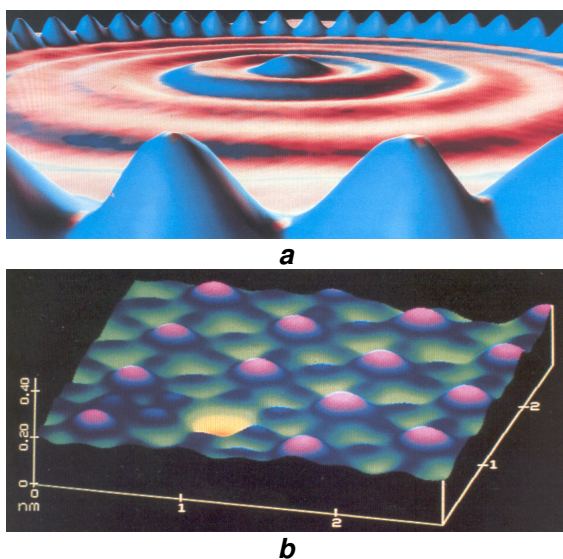


Fig. 1 STM Images

- a) STM Image of 48 iron atoms in a circle on a copper crystal surface - adapted from IBM Corporation Research Division**
b) STM Image of a single atom defect in an iodine adsorbate lattice on a platinum surface - adapted from Digital instruments Santa Barbara California

The technique used involves an ultrafine stylus that hovers slightly above a conducting surface and senses topographic details via tiny fluctuations in the tunneling current that forms between the stylus and the surface. In effect the STM senses the outer surface of the electron cloud that defines an atom. The STM, can image only conducting surfaces, but this limitation was overcome with the development of the atomic force microscope (AFM) in 1986, which can image nonconducting surfaces with similar resolution.

Picosecond time-resolution is being added to the nanometer spatial-resolution of STM. Some IBM researchers report that the ability to combine the spatial resolution of STM with the time resolution of ultra fast optics yields a powerful tool for the investigation of dynamic phenomena on the atomic scale. So this capability extends the imaging capacity of STM from three dimensions to four, allowing observation of molecular interactions in appropriate length and time scale.

2. DISCUSSION

This paper on molecular nanotechnology is focused on conceptual issues which show

how molecular nanotechnology relates to other technologies how it fits in with our understanding of science and of existing engineering practice.

Today molecular nanotechnology is a theoretical applied science. It is theoretical in that one is doing not experiments but computational modeling and theoretical analysis.

It is applied in that the system being studied and modeled are not phenomena of nature, but are designs for artifacts intended to be useful, once built. Many of this will be manufacturing systems.

Manufactured products are made from atoms, and their properties depend on how those atoms are arranged. For example, graphite can be converted into diamond by arranging its carbon atoms. This observation points to a fundamental shortcoming of our technology. The materials world is made of atomic and molecular building blocks, but actually we lack anything like a hand in order to place those building blocks in chosen patterns.

Chemists have achieved remarkable complex molecular structures, given that they have no molecular hands with which to put the part in right places.

Building with fundamental building block (atoms and molecules) was stated by Richard Feynman in a discussion he gave in 1959, "The principles of physics as far as I can see do not speak against the possibility of maneuvering things atom by atom.

Ultimately we can do chemical synthesis. Put the atoms down where the chemist says, and so you make the substance".

Feynman's idea was challenged first time in a work that was published in Journal Nature [1,12].

Figure 2 shows the surface of a nickel crystal covered by dots that are xenon atoms. The atoms were imaged by a scanning tunneling microscope (STM), which moves a sharp tip near the surface with atomic precision. This picture graphically demonstrates that 35 atoms were placed to spell IBM. The positions of the atoms are like states in digital logic, in which every signal is either 'i or o'. It is either exactly right or exactly wrong. If the system is structured correctly, the probability of its being exactly right can be made extremely high.

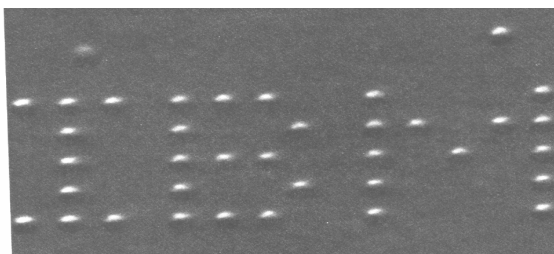


Fig.2 STM Image of a patterned array of xenon atoms on a nickel surface - adapted from IBM Corp. Research Division.

The probability of getting an atom in the right place on the first try is low, and so is difficult to make IBM logo in a short time. This atomic scale logo suggests what is the measuring of a precise construction at the molecular scale. One difficulty with extending this technique is that IBM logo was built using inert gas atoms at a few degrees Kelvin. At room temperature such a structure would not be stable.

Stable atomic scale modifications have subsequently be made by a device more like a hand that is able to hold a molecule and put it where you wanted it, where that molecule is reactive and so can bond to another molecular structure. The products would be stable at room temperature and could serve as a part in a system of molecular machinery. The implications of atomic scale positional control for the manufacture of complex molecular structure can be explained as follows. Models for chemical reactions relate the rates of reactions to the concentrations of reacting molecules. Positional control of reactants can produce a high concentrations at a chosen location and low concentrations elsewhere. To estimate this effect, it is necessary to know how precisely a reacting molecule could be positioned with an manufacturing device (the tip of a AFM fig 3). For example the extent to which thermal motions displace a molecule positioned by the device. The analysis of this process describes the cloud of probability surrounding the point at which the molecule have to be positioned, giving the probability of finding the molecule near each point within that cloud. This probability density describes the concentration of a suitably oriented molecule and it can be as high as 150 molar. The conclusion is that the concentration of the molecule when is necessary to be is 10^2 times higher that at adjacent points only at an atomic diameter away.

Concerning the term nanotechnology there is some ambiguity in what is meaning by nanotechnology.

Nanotechnology based on mechanical control of chemical synthesis is a technology based on molecular machinery, building additional molecular machinery, does not yet exist, but many researchers concluded (on the basis of analysis and analogy with molecular biology), that such a technology can be developed and that is of considerable importance today to understand where we are going, how to proceed and what it means for broader concerns [2,3,7,11].

Molecular nanotechnology refers to complex atomically precise functional structures. The word “nanotechnology” without the word “molecular” has become a buzzword that is often applied to glamorize the production of nanometer-scale blobs [8,9,10].

However microelectronics and computers are made possible by the ability to make micron-scale blobs. Making such blobs, and even smaller (nano-scale blobs) is very useful. This kind of nanotechnology is, in part, about taking enormously important revolution of microelectronics. This is not molecular nanotechnology, it is an extension of microtechnology.

The long term goal of molecular nanotechnology is molecular manufacturing or molecular fabrication.

The basis of molecular manufacturing is mechanosynthesis, the use of mechanical control to guide the placement of molecules so as to build complex objects. Molecular machine systems are the chief enabling technology and the chief intermediate goal in developing molecular nanaotechnology.

Mechanosynthesis and molecular machine systems are two different entry points into a spiraling technology base in which mechanosynthesis is used to make molecular machine systems that are used to perform mechanosynthesis. That spiral leads to advanced molecular nanotechnology.

The importance of molecular manufacturing can be summarized as:

a. Molecular manufacturing can be cleaner than existing process technologies because it involves more precise control of where molecules go and how they are arranged. Molecular manufacturing methods are clean because they do things the first time and produce only the specified products.

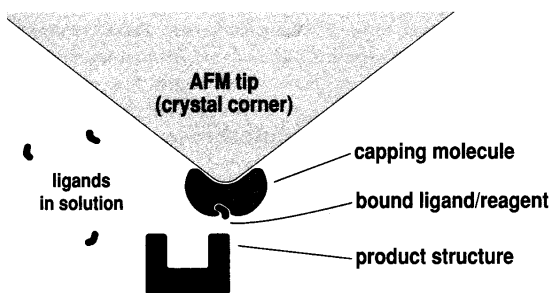


Fig. 3. A molecular manipulator using a protein bound to the tip of an AFM to maneuver small ligand molecules. Adapted from K.Eric Drexler in *Prospects in nanotechnology*

b. With molecular manufacturing, structures can be made stronger because they can be made of perfect graphite or diamond fiber composite. Products are generally lighter.

c. Molecular manufacturing can be highly efficient because is used less material and less energy. The combination of higher strength, higher weight and higher efficiency expands capability.

Table 1 The main characteristics of molecular manufacturing

Characteristics	Results
Strength	About 80 times the strength of aluminium
Densities	About $10^{26} / m^3$
Structure's quality	Nanoscale defects
Cheap inputs	Bulk industrial chemicals
Productive	Processing its own mass in an hour
Low cost	Tens of cents per kg.
Wide size range	Nanoscale to jumbo jet

d. Using common inexpensive materials as CO_2 from atmosphere, as raw materials, and by processing these materials with systems, which are fast and efficient, the manufactured products can be inexpensive and therefore more available. Some characteristics of molecular manufacturing are summarized in table 1.

3. CONCLUSIONS

The important consequences of molecular manufacturing are summarized as follows:

1. A replacement for industry as we know it. A new way of making products of unprecedented performance, quality and low cost.
2. A sustainable basis for global wealth because of low cost raw material, low cost high quality products and because of high efficiency of these technology.
3. Hoping to solve environmental problems. By making it easier for people to get what they want with less environmental impact.
4. An enormous challenge to our institutions. Anything that involves the changes suggested by what was enumerated previously presents an enormous challenge to our institutions and especially to our universities.

REFERENCES:

1. R.P. FEYNMAN, "There's Plenty of Room at the Bottom, Eng. And Sci., 23, (1962), 22-36
2. B. C. CRANDALL, *Molecular Engineering in Nanotechnology. Molecular Speculations on global abundance*. MIT Press, 1996, 1-46.
3. J. COOLMAN, K.H. ROCKH, *Color Atlas of Biochemistry*, Thieme Stuttgart, 2005.
4. I. AMATO, *Scanning Probe Microscopes Book Into New Territories*, Science 262, 1993, 178.
5. N. GROSS, E. SMITH, J. CAREY, *Windows in the World of Atoms*, Business Week, August 1993, 62-64.
6. G. NUNESJR, M.R. FREEMAN, *Picosecond resolution in STM.*, Science 262, 1993, 1029.
7. K. E. DEXLER, *Introduction in Nanotechnology*, pag. 1-22, in *Prospects in Nanotechnology Proceedings of First General Conference on Nanotechnology Development, Applications and Opportunities*, nov. 11-14, 1992, Palo Alto California, Ed. Markus Krummanacker, James Lewis John Wiley, N.Y. 1995.
8. R.E. SMALLY, *Self Assembly of the Fullerenes*, ACC. Chem. Res. 1992, 25, 98-105/
9. R. DOGANI, *The Shape of Things to Come*, C&EN. June 8, 1998, 35-46.
10. R. DOGANI, *Nanostructured Materials Promise to Advance Rouge of Technologies.*, C&EN. Oct. 26, 1992, 18-24.
11. L. SCHREIBER, *Organic Chemistry to Explore Cell Biology*, C&EN, oct.26, 1992, 22-32.
12. D.M. EIGLER, E.K. SCHWEIZER, *Positioning Single Atoms with a STM*, Nature, 1990, 34, 524-536.

AUTHORS

¹⁾ Docent, Professor, University POLITEHNICA of Bucharest, ROMANIA
E-mail: o_radovicic@teh.prod.pub.ro