Nanotechnology : the Next Industrial Revolution ?

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The essence of nanotechnology is the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new properties. Nanostructures offer a new paradigm for materials manufacture by submicron-scale self-organization and self-assembly to create entities from the "bottom up" rather than the "top down" method. Nanometer structures will foster a revolution not only in information technology hardware but also in advances healthcare, therapeutics, diagnostics, environment and energy.

1. INTRODUCTION

Two important events have marked the nanotechnology story [1].

First, Richard Feynman delivered in 1959 his now famous lecture, "**There is Plenty of Room at the Bottom**." He stimulated his audience with the vision of exciting new discoveries if one could fabricate materials and devices at the atomic/molecular scale. He pointed out that, for this to happen, a new class of miniaturized instrumentation would be needed to manipulate and measure the properties of these small—" nano"— structures.

Second, at the beginning of the 1980s, near-field microscopes (scanning tunneling microscopes -STM, atomic force microscopes-AFM) were invented providing thus the "eyes" and "fingers" required for nanostructure measurement and manipulation. Examples of STM capability are shown in Fig 1.

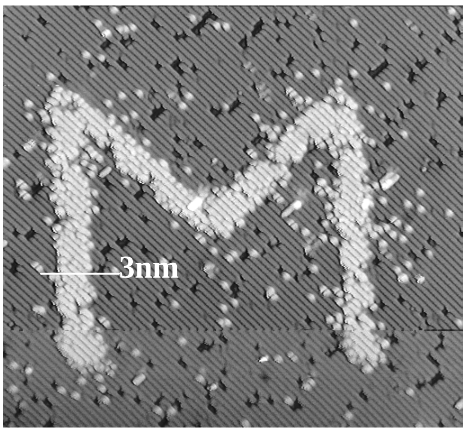


Fig 1a: Letter written by STM on hydrogenated silicon surface. Letters of this size verify Feynman prediction.

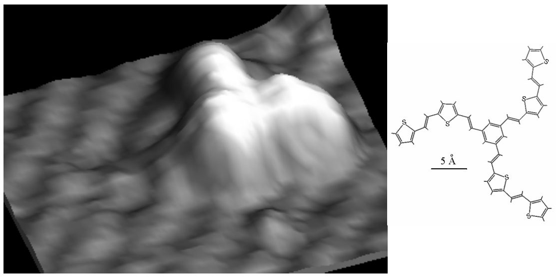


Fig 1 b: picture of a three branches molecule deposited on a silicon surface.

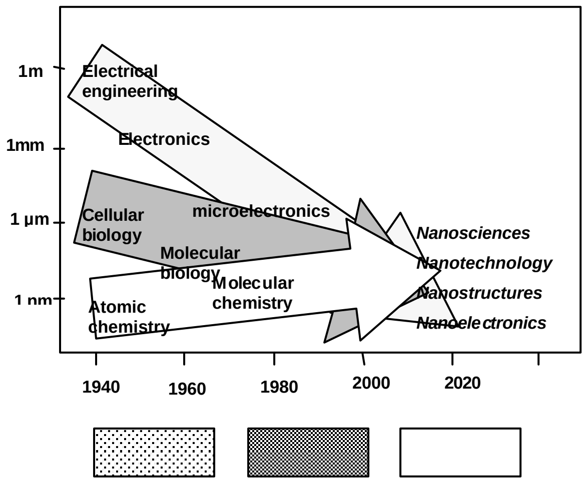
In a parallel development, expansion of computational capability now enables sophisticated simulations of material behavior at the nanoscale. It should be noted that traditional models and theories for material properties and device operations assume that the physical quantities are described by continuous variables and are valid only for length larger than about 100 nanometers. When at least one dimension of a material structure is under this critical length, distinct behavior often emerges that cannot be explained by traditional models and theories. In the semiconductor device field for instance, quantum effects (tunnel effect, discrete energy levels, …) appear when the active layer thickness is smaller than 10nm. Reducing the dimensions of structures leads to entities, such as carbon nanotubes, quantum wires and dots, thin films, DNA-based structures, and laser emitters, which have unique properties.

2. NANOSCIENCES, NANOTECHNOLOGY, NANOSTRUCTURES

The essence of nanotechnology is the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization. Nanotechnology is concerned with materials and systems whose structures and components exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes due to their nanoscale size. Several important points should be noted:

- New behavior at the nanoscale is not necessarily predictable from that observed at large size scales.
- The most important changes in behavior are caused not by the order of magnitude size reduction, but by newly observed phenomena intrinsic to or becoming predominant at the nanoscale, such as size confinement, predominance of interfacial phenomena and quantum mechanics.
- Once it is possible to control feature size, it is also possible to enhance material properties and device functions beyond those that we currently know or even consider as feasible. Such new forms of materials and devices herald a revolutionary age for science and technology, provided we can discover and fully utilize the underlying principles.

- Nanotechnologies are multidisciplinary by nature (Fig.2).



Physics Biology Chemistry

Fig. 2 : Experimental sciences are converging toward the' nanoworld'

3. NANODEVICES, NANOELECTRONICS.

A number of examples of devices in the microelectronics and telecommunication industries rely on nanoscale phenomena for their operation. Thus, two dimensional systems such as two-dimensional electron gas can be considered as one dimensional nanotechnologies, quantum wires as two dimensional nanotechnologies and quantum dots as three dimensional nanotechnologies. The extension from one to three nanodimensions is not straightforward but the payoffs can be enormous. Breakthroughs in attempting to produce three-dimensional nanodevices include the following:

- Demonstration of coulomb blockade, and single electron memory and logic elements operating at room temperature [2,3]

- Integration of scanning probe tips into sizeable arrays for lithographic and mechanical storage applications [4](Fig 3.)

- Fabrication of photonic band-gap structures [5] (Fig.3)

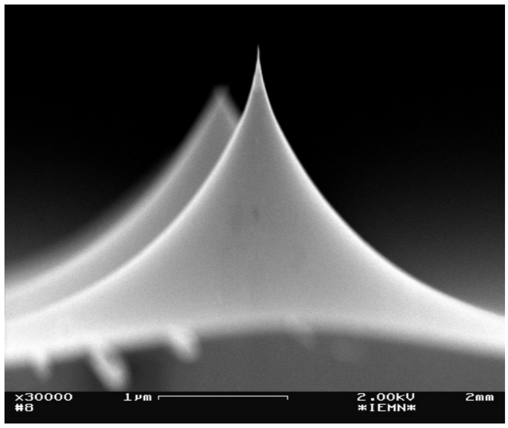


Fig.3a. 30 nm tip on GaAs. (Courtesy of A. Vanoverschelde, IEMN)

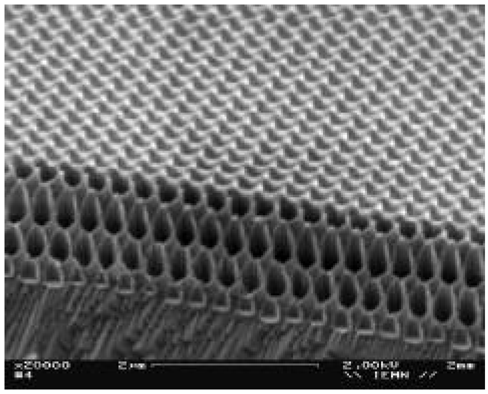


Fig.3b Array od nanoscaled tips on GaAs(Courtesy of A. Vanoverschelde, IEMN)

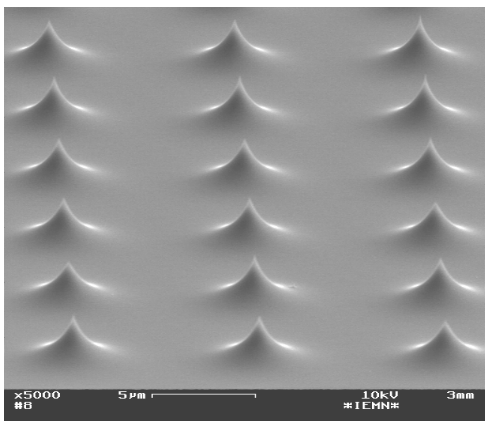


Fig.3c high aspect ratio photonic bandgap (Courtesy of D. Lippens, IEMN)

In addition, our ability to manipulate matter at nanoscales combined with advances in the synthesis and directed or self-assembly of nanostructures has resulted in advances in a number of scientific areas.

- Preparation of carbon nanotubes and fabrication of electronic devices from these materials [6]
- Demonstration of transport measurement of individual molecules carefully placed onto electrical contacts [7]
- Explosion in the availability of near field microscope and their use to fabricate nanostructures [8]
- Introduction of biomolecules and supermolecular structures into the field of nanodevices [9]

Associated with these developments, nanostructures offer a new paradigm for materials manufacture by submicron-scale self-organization and self-assembly to create entities from the "bottom up" rather than the "top down" method. However, we are just beginning to understand some of the principles to use to create "by design" nanostructures and how to economically fabricate nanodevices and systems. Each significant advance in understanding the physical/chemical/biological properties and fabrication principles, as well as in development of predictive methods to control them, is likely to lead to major advances in our ability to design, fabricate and assemble the nanostructures and nanodevices into a working system. "Bottom up" approaches, closely linked as they are to the field of molecular electronics are elegant, cheap, and possibly enormously powerful techniques for future mass replication, but their applicability remains limited until total control over the emerging structures in terms of wiring and interconnections can be obtained. It is clear that new architectures are required for such bottom up fabrication approaches [10]. The specific quantum mechanical properties of many nanodevices require radically novel architectures approaches. Such approaches are now starting to be introduced by the architecture experts. Concepts like fault tolerant architecture, parallel processing, neural nets are directly translatable into conventional (Si) hardware, whereas more advanced concepts like non dissipative and quantum computing, DNA-based computing will certainly required the implementation of novel nanodevices

4. INDUSTRIAL ASPECTS OF NANOTECHNOLOGY

Several industrial domains have been identified as essential for future applications of nanotechnologies:

- Nanostructured materials: how to design and to fabricate stronger, lighter, harder, self-repairing and safer materials. Nanocomposites and nanoparticule reinforces polymers could for instance be used for automotive applications.

-Nanoelectronics, optoelectronics ans magnetics: It is foreseeable that nanometer structures will foster a revolution in information technology hardware rivaling the microelectronics revolution 30 years ago.

- Advances healthcare, therapeutics and diagnostics: nanotechnology will contribute to significant advances through the development of biosensors and improved imaging technologies. Drugs production and delivery are expected to be drastically change in the next decade.

-Environment and Energy: Nanotechnology has the potential to significantly impact energy storage, efficiency and production. The use of Through Capacitor technology could be use for water desalinization with better efficiency and energy dissipation that conventional reverse osmosis.

5. CONCLUSION

Nanometer structures will foster a revolution in information technology hardware rivaling the microelectronics revolution begun about 30 years ago that displaced vacuum tube electronics. Minuscule transistors and memory chips will improve computer speed and efficiency by factors of millions, expand mass storage electronics to multi-terabit memory capacity that will increase the memory storage per unit surface a thousand-fold and make data available on a pinhead, and reduce power consumption tens of thousands of times. Communication paradigms will change by increasing bandwidth a hundred times — which will reduce business travel and commuting — and by developing foldable panel displays that are also ten times brighter. Merging biological and non-biological objects into interacting systems will create new generations of sensors, processors, and nanodevices. Rapid development of nanotechnology will require changes in the laboratory and human resource infrastructure in universities, and in the education of nanotechnology professionals.

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