Nanotechnologies: Technologies of the Future

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Abstract

At the nano scale, the physical, chemical, and biological properties of materials differ in fundamental, valuable ways from the properties of individual atoms, molecules, or bulk matter. The paper presents a short history, the progresses realized, the scientific challenges, the reliability, the stakes, the priorities in research and development; they have already entered our everyday life.

Keywords: nano technologies, nano sciences, progresses realized, reliability, ethics

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Introduction

From a very general point of view, nanotechnologies refer to nanomaterials, nanocomponents, nanosystems, to manufacturing, manipulation, imaging, characterization, and modeling and simulation techniques and procedures using a scale of 1 nanometers and 10 nanometers.

The definition of nanotechnology and nanoscience departs from a scale of length, the nanometer, which is one billionth of a meter. To understand what this means, consider a hair. It will grow about one centimeter each month. We discover that hair grows at a rate of about four nm per second by doing a simple calculation. However, why does the nanometer play such an important role? In order to answer this question, we must return to the very constituent elements of matter. The elements around us are made up of atoms, which can be represented in the form of small spheres with diameters of several tens of nanometers or molecules; they are closely linked to assemblies of atoms measuring only a few nanometers in diameter. In other words, the smallest amount of substance that we can discuss really refers to this scale of length. Atoms are so small that, in our everyday life, we are unlikely to ever feel that we are made up of such elements.

Even what we consider to be microscopic involves a very large number of atoms. For example, a rod-shaped bacterium with a length of 3000 nm contains one hundred billion atoms, enough to build complex machines that allow this bacterium to live. More simple than bacteria, viruses measure about one hundred nanometers and contain tens of millions of atoms. Also, microscopic systems, sometimes complex, such as microprocessors produced today in the industry, now have features of only a few dozen nanometers. This is the nanoworld, referred to by Richard Feynman, Nobel Prize-winner for Physics in 1965, in the title of a communication on nanoscience he presented in 1959: "There is plenty of room at the bottom".

Throughout the 20th century, advances in physics, chemistry, biology have yielded a detailed understanding of the structure and properties of both the living and inert matter at the nanoscale, that is, having a length of one billionth of a meter. By the end of 1950, rigorous tools were developed to observe, manipulate and assemble matter and devices at this scale. The convergence of all this knowledge has paved the way for spectacular applications, but in the 1990s nanotechnology really installed itself in its own fields.

The most visible application was undoubtedly nanoelectronics, today present in a growing number of products that are about to change our lives. Nanotechnology is being put to work in many other sectors, such as materials, sensors, energy and medical applications. Today thousands of products contain ingredients on a nano scale; taking into account the scope of these developments, concerns have been expressed, in particular regarding the possible toxicity of nanoparticles and a current inadequate control of industrial applications. Since its inception, nanotechnology has been closely associated with the notion of economic growth; its maturity will also depend on the understanding of the associated risks and its contribution to resolving future crucial questions on sustainable development.

The development of nanotechnologies began in the 1990s following the invention of the *scanning* *tunnelling microscope* (STM) in 1981 - by German Gerd Binning and the Swiss Heinrich Rohrer (the invention for which they received the Nobel Prize in 1986) - the first instrument has allowed the observation of objects at this nanometric scale. It delivers three-dimensional images with a very high resolution of less than one tenth of a nanometer, allowing simultaneous manipulation of atoms - which has opened the way for new nanometric experiments. By their nature, nanotechnologies are transversal and use disciplines like physics, chemistry, biology, making the boundaries between traditional scientific and technological disciplines permeable.

The *Atomic Force Microscope* (AFM) is a derivative of the STM microscope that serves to visualize the surface topology of a non-conducting sample, as it measures a contact force instead of an electric current.

Perspectives of nanotechnologies:
- Metrology
- Biology
- Instruments
- Materials
- Physics
- Electronics
- Informatics
- Chemistry
- Medicine

Figure 1 Fields of research in the nanotechnology study

The nano science study focuses mainly on perspectives, instruments, physics, chemistry, and biology science (Figure 1). It provides the basis for future developments in the field, also taking a look at the future, but also a perspective on some important factors outside the research lab - for example, social issues.

Over the last decade, our world has changed significantly. Most universities now encourage involvement in large and small business environments, as well as international collaboration at unprecedented levels. That's why it's good to help prepare students for the future. All industrial production - in general - is based on technologies and standards, and nano is no exception. Nano challenges are formidable. Metrology itself goes through its own revolution; a new class of standards based on universal constants and quantum mechanics is about to have a particular impact on metrology [27]. As lower critical dimensions are reached and overcome, research, development, and the entire nanotechnology industry needs to adapt quickly to keep pace with global developments.

Short history

The idea that the world is made of atoms is not a recent one.

It is attributed to the Greek philosopher Leucip and his Democritus disciple (circa 400 BC).

However, only in the nineteenth century, advances in science have transformed this idea into a serious hypothesis and then in reality, with implicit reference to the nanoscale scale.

Between the end of the nineteenth and mid-twentieth centuries, techniques for observing matter at this scale were developed. For example, in 1931, two German engineers Ernst Ruska and Max Knoll invented the electronic microscope.

The basic idea can be understood by comparison with the optical microscope, with the difference that light is replaced by electrons, and they can probe matter with much finer detail.

About ten years later, the electronic microscope could already achieve a resolution of 10 nm, and progress was still recorded even at the end of the 20th century. A resolution of 0.1 nm - the size of a single atom - was reached in the 1990s.

In a broad sense, nanosciences are critical facilitators that will allow humanity to exploit the ultimate technological capabilities of electronic, magnetic, mechanical and biological systems. Currently, the best examples of nanoscience are clearly associated with the information technology industry, but the potential of such devices is much wider. Nanosciences will ultimately have a tremendous impact on our ability to increase energy conversion efficiency, increasing pollution control, food production, improving human health and increasing longevity.

Due to their special properties at nanoscale, nanotechnology research raises important hopes that allow us to approach new, unimaginable new functions.

Scientific progress

Over the last decade, our ability to handle top-down matter, combined with advances and, in some cases, unexpected breakthroughs in the synthesis and assembly of nanoscale structures, has led to progress in a series of areas. Some examples worth noting include the following:

- Unexpected discovery, and thereafter, more controlled preparation of carbon nanotubes and the use of proximal probes and lithographic schemes to manufacture individual electronic devices from these materials [1, 3, 7, 8, 15, 26].
- Ability to start placing carefully designed individual molecules on appropriate electrical contacts and measure transport by molecules [2, 20].
- Explosion of the availability of proximal probe techniques and their use in material handling and nanostructures [4, 10, 21, 24].
- Introduction of biomolecules and supramolecular structures in the field of nanodispozitives [14].
- Developing chemical synthesis methods to prepare nanocrystals, and methods to assemble - further - these nanocrystals into a variety of larger organized structures [18].

- Isolation of biological motors and their incorporation into non-biological environments [19, 23].

A number of examples of devices in the microelectronics and telecommunication industries are based on nanometric phenomena for their operation. These devices are, in a sense, one-dimensional nanotechnologies because they are thin-film micrometer objects with nanometer-sized thicknesses.

A success in this category is the gigantic magnetoresistance structure (*giant magnetoresistance* GMR). These structures can operate sensors with extremely sensitive magnetic fields. The GMR structures used for this purpose are made up of layers of magnetic and non-magnetic metal sheets. The critical layers of the structure have nanometer-sized thicknesses.

The transport of polarized spin electrons that occur between magnetic layers on a scale of nanometric lengths is responsible for the structure's ability to sense magnetic fields such as magnetic bits stored on computer disks. GMR structures have revolutionized the magnetic storage industry of hard disks (Figure 2).

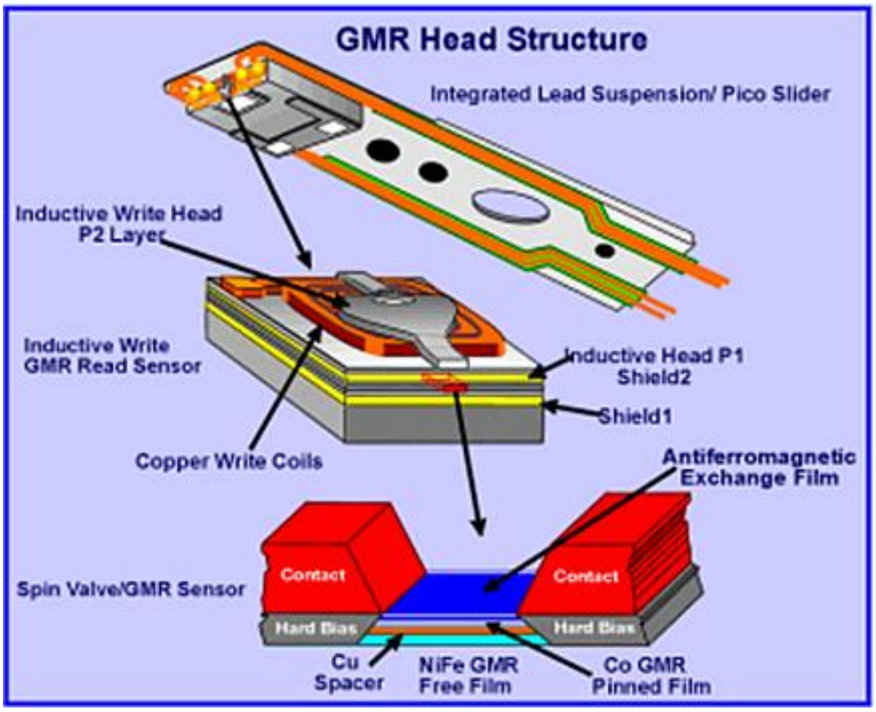

Figure 2. Commercial IBM giant magnetoresistance read head [9]

The ability to control single-dimensional materials to build nanometer scale structures with atomic precision is due to a decade of basic and applied research on surface and interface growth on thin films.

Extending from a nanodimension to two or three is not simple, but the results can be extremely important. Innovations in trying to produce three-dimensional nanodisplays include the following:

- Introduction of biomolecules and supramolecular structures in the field of nanodispozitives [14].
- Demonstration of the Coulomb block, quantum effect and single electron memory, and logic elements operating at room temperature [5, 11, 16].
- Introduction of biomolecules and supramolecular structures in the field of nanodispozitives [14].
- Integration of the scanning probe into resizable matrices for lithographic and mechanical information storage applications [12, 17].
- Manufacture of photonic structures with tape holes [22].
- Integration of nanoparticles into sensible gas sensors [5].

Exploring and manufacturing nanosciences requires access to sophisticated and sometimes costly tools. Better and broader access to such equipment is needed, as well as facilities for rapid prototyping. It is also important to recognize that the success of nanosciences will be explored in a wide range of traditional disciplines. It is, therefore, imperative that programs be set up to facilitate and strengthen cross-fertilization between different disciplines and allow the swift adoption of new methods beyond the usual borders.

Nanodisplays are very complicated nanotechnology systems. They require understanding of fundamental phenomena, the synthesis of appropriate materials, the use of these materials for the manufacture of devices that can work, and the integration of these devices into work systems. For this reason, success will require a substantial level of funding over a long period of time and structured support for interdisciplinary teams.

Scientific challenges

The fabrication, observation and manipulation of nano-objects, the study and understanding of their properties and their interactions with the environment, modelling and simulation, their integration into interconnecting systems - these are the major scientific challenges that will need to be solved in order to develop numerous and very important applications in a perfectly controlled and well-managed manner.

Nanotechnology applications are increasingly important in each of us, for industry and commerce, for health and society. Today, R & D is a real explosion in nanotechnology applications in the fields of energy, chemistry, captors, materials, information, telecommunication, biology, medicine, and the environment.

A key element: Reliability

The key element that must be taken into account in the development of nanotechnologies is that they will be used together with other mature technologies in a market where reliability is predominant. There is, therefore, a long gap between the technological breakthrough and the demonstration of the high reliability of the new nanodisplays. The study of their reliability is imperative for validating the progress of their performance. It should be taken into account both in the upstream - when choosing and developing new processes, in the process of being carried out - but also downstream, in the industrial phase of qualification of nanocomponents. A complete renewal of construction and demonstration of reliability will be required. The basis for high reliability lies at the level of conception, technological choices, process mastery, physical modelling of failure mechanisms; one of the objectives to ensure is that the distribution of failures is as concentrated as possible towards the end of the life of nanodevices.

The aging of components is the result of a set of physical-chemical processes that are manifested by the derivation of the functional, or not, characteristics. These unavoidable degradations are part of the component as a technical achievement, but also depend strongly on its use, its environment, its nature and its kinetics.

In time, progressive or faster damage leads to a loss of system functionality (definition of a failure criterion) and therefore to failure.

For top-down nanoparticles, we have a knowledge base of the major failure mechanisms of microelectronics. This is not the case for the "bottom-up" nanodevices for which the introduction of new materials, new processes, exploitation of unused properties will inevitably lead to new behaviours.

Nanotechnology stakes

The development of atomic scale manipulation is a revolution with passionate, but sometimes worrying prospects. Their analysis highlights a tension between the two aspirations, seemingly contradictory: the desire to control and the desire to manifest itself. The fictional aura that accompanies them must be taken seriously: the need for ethical and social vigilance towards the "nano" approach - genuinely generic technology that will affect all the production sectors.

Several factors will have to be taken into account:
(a) the scientific context;
(b) nano-bio-info-cognitive convergence;
(c) the political context;
(d) globalization and competition;
(e) the social context;
(f) a demanding audience.

Ethical and social issues have evolved in several European countries:

- the Netherlands (Constructive Technology Assessment);
- United Kingdom (Public Engagement in Science);
- Germany and France (Pour une symbiose entre science et culture).

The basics of ethics applied to nanoscience and naotechnologies are fair practices; risk prevention; precaution against uncertainties; reflection on values and goals.

In the career of researchers, ethical research will have to be done at several levels: initial training, evaluation, formulation of research projects, drawing attention to the ethical risks of research, arbitration of conflicts of interest in relations with industry, ensuring the transparency of sources financing, taking into account ethical risks, not just being limited to economic and industrial stakes, keeping the dialogue with the public.

Nanotechnologies have already entered our daily lives

- Non-abrasion glasses due to coating with a nanostructured layer; they are easier to clean and scratch harder than ordinary glasses.
- Certain glasses are colored due to the presence of metallic nanoparticles.
- Some natural or artificial materials (cement, wood, clay) owe their properties thanks to the presence of nanoscale particles in their structure.
- Some textiles with waterproof nanostructures are protected from water and stains.

- Solar creams with TiO_2 nanoparticles provide better protection.
- Tennis racquets are lighter and stronger due to the integration of carbon nanotubes.
- Tennis balls are stronger due to a nanostructured internal layer.
- Due to nanoelectronics, electronic circuits are increasingly miniaturized, thus allowing for increased data densities.
- Photonics research has allowed solar cell yields to increase [26].
- Nanoscale membranes can better filter air and water, depolarize and desalinate better.

Risks

- Health risks.
- Legal vacuum with regard to the use of technologies; is not yet in official regulations.
- The public has an unfavourable picture of nanotechnologies.

R & D priorities

- Developing new systems and architectures for given functions.
- Interface study and integration of nanostructures into devices and systems.
- Multiscale: modelling of multi-phenomena and simulation of complex systems.

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Authors' Biography

Titu I. BĂJENESCU was born in Câmpina (Romania) on April 2, 1933.

He received his engineering training at the Polytechnic Institute Bucharest.

He served for the first five years in the *Romanian Army Research Institute*, including tours on radio and telecom maintenance, and in the reliability, safety and maintainability office of the Ministry of Defence (main base ground facilities).

R&D *Experience*: design and manufacture of experimental equipment for Romanian Army Research Institute and for air defence system.

He joined *Brown Boveri* (today: *Asea Brown Boveri*) Baden (Switzerland) in 1969, as research and development engineer.

R&D *Experience*: design and manufacture of new industrial equipment for telecommunications.

In 1974, he joined *Hasler Limited* (today: *Ascom*) Berne as Reliability Manager (recruitment by competitive examination).

Experience: Set up QRA and R&M teams. Developed policies, procedures and training. Managed QRA and R&M programmes. As QRA Manager monitoring and reporting on production quality and in-service reliability.

As Switzerland official, contributed to development of new ITU and IEC standards.

In 1981, he joined *Messtechnik und Optoelektronik* (Neuchâtel, Switzerland, and Haar, West Germany), a subsidiary of Messerschmitt-Bölkow-Blohm (MBB) Munich, as Quality and Reliability Manager (recruitment by competitive examination).

Experience: Product Assurance Manager of "intelligent cables". Managed applied research on reliability (electronic components, system analysis methods, test methods, etc.).

Since 1985, he has worked as an *independent consultant and international expert* on engineering management, telecommunications, reliability, quality and safety.

Mr. Băjenescu is the author of many technical books — published in English, French, German and Romanian.

He is emeritus university professor and has written many papers and contributions on modern telecommunications, and on quality and reliability engineering and management.

He lectures as invited professor, visiting lecturer or speaker at European universities and other venues on these subjects.

Since 1991, he won many Awards and Distinctions, presented by the Romanian Academy, Romanian Society for Quality, Romanian Engineers Association, etc. for his contribution to reliability science and technology.

Recently, he received the honorific titles of *Doctor Honoris Causa* from the *Romanian Military Academy* and from *Technical University of the Republic of Moldavia*.

In 2013, he obtained, together with prof. Marius Bâzu (head of reliability laboratory of Romanian Research Institute for Micro and Nano-technologies – IMT) the *Romanian Academy "Tudor Tănăsescu" prize* for the book *Failure Analysis*, published by John Wiley & Sons.

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