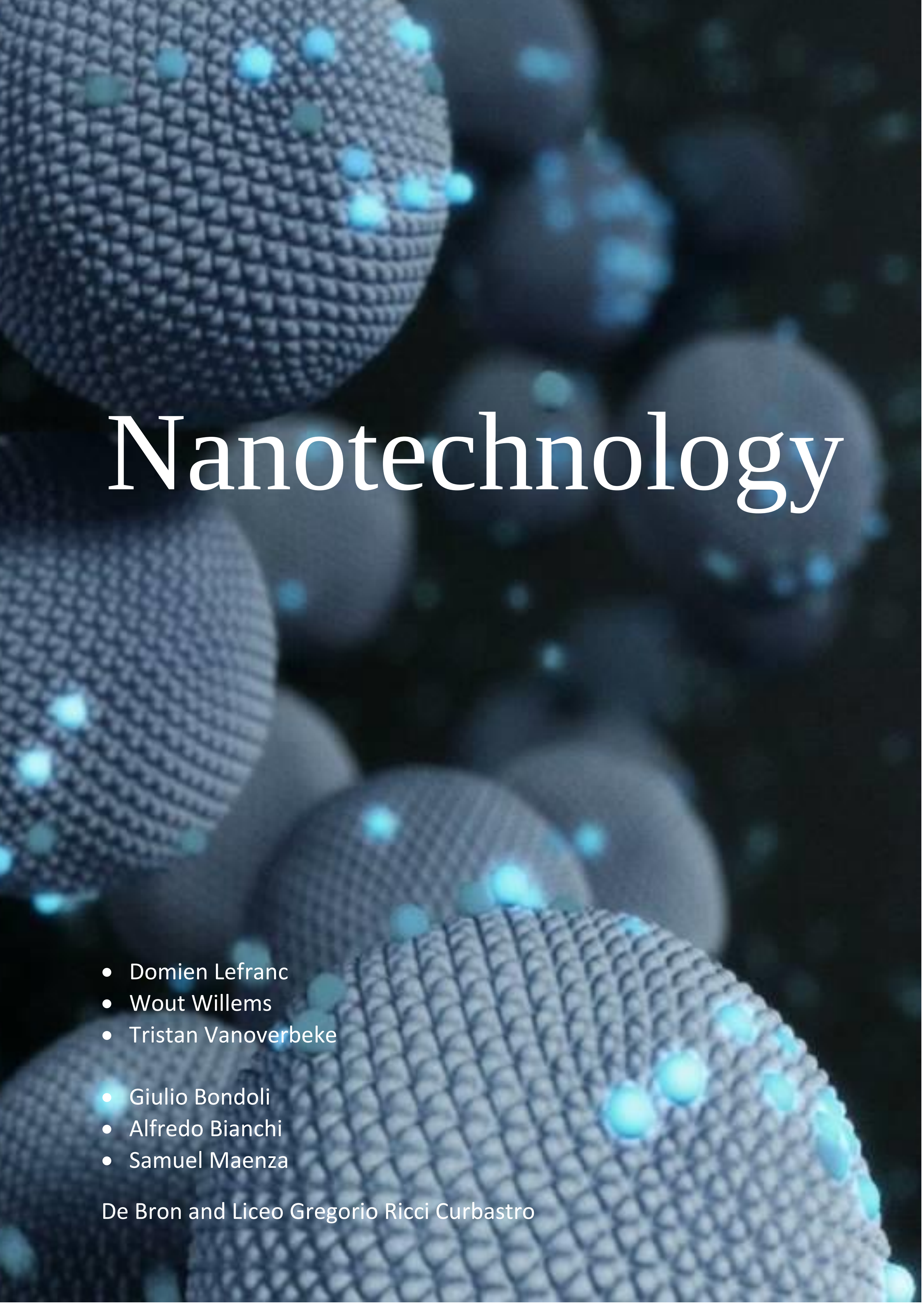


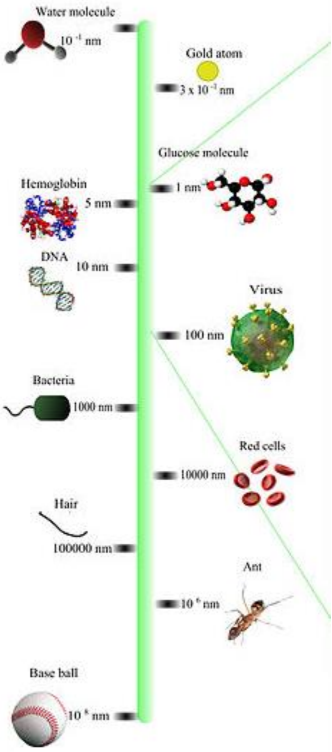
Nanotechnology

- Domien Lefranc
- Wout Willems
- Tristan Vanoverbeke

- Giulio Bondoli
- Alfredo Bianchi
- Samuel Maenza

De Bron and Liceo Gregorio Ricci Curbastro

Introduction



A few objects compared to the nanoscale

You may not be aware of it yet, but nanotechnology is the most innovative, advancing and promising field in modern physics. During the next twenty years, everyone will feel the positive impact on their lives and at some point we will not even be able to live without it. Revolutionizing medicine, solving the energy problem, reversing climate change, pushing our technology beyond current limits,... to name just a few aspects. Nanotechnology will definitely change our world in the imminent future, or maybe even today?

Now you're probably wondering, "What is nanotechnology?". Nanotechnology is the science of designing, producing and using structures and devices by manipulating matter on an atomic, molecular or supramolecular scale. In other words, it's the technology of producing and applying incredibly small devices, with dimensions between one and one hundred nanometres (one nanometre equals 10^{-9} m or one billionth of a metre). In practice, nanotechnology consists of a broad spectrum of other science domains, such as organic chemistry, molecular biology, semiconductor physics, engineering, microfabrication, atomic physics and the study of energy,… How the field emerged, which principles it uses, how nanoparticles are made and what the (possible) applications are, will be explained in the next paragraphs.

A brief history

The American physicist and Nobel Prize laureate Richard Feynman introduced the concept of nanotechnology in 1959 – but didn't use the term itself – during a talk at CalTech, in which he described a technique to manipulate individual atoms and molecules. Fifteen years later, a Japanese professor called Norio Taniguchi coined the term 'nano-technology' and defined it as a science that mainly consists of the processing of separation, consolidation and deformation of materials by one atom or one molecule. Unfortunately, the new domain of science didn't spread like wildfire and remained quite unknown until the American scientist K. Eric Drexler wrote a book on the subject. Inspired by Feynman, he – too – used the term 'nanotechnology' and proposed the idea of a nanosized assembler which would build a tiny copy of itself, down to the smallest scale. The theoretical work Drexler delivered, made it possible for field to emerge during the 1980s as a conceptual framework. During the same period, two major breakthroughs in physics and chemistry sparked the growth of nanotechnology and marked the beginning of a new era.

Richard Feynman, the conceptual father of nanotechnology

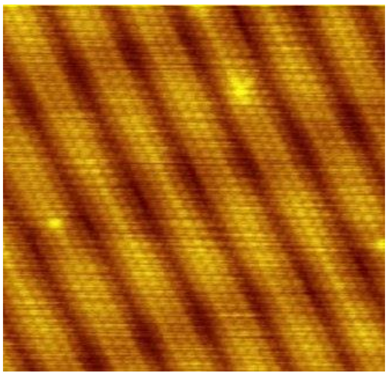
First, there was the invention of the scanning tunnelling microscope in 1981, which provided unprecedented visualization of individual atoms and bonds. The new technique enabled scientists to manipulate individual atoms and created possibilities for the first practical applications. Second, fullerenes were discovered in 1985. These are a special type of molecules, only consisting of carbon atoms and adapting complex geometrical structures, like hollow spheres, ellipsoids and tubes.

An extreme member of this group, called graphene, exists of a single layer of carbon atoms and rolled up, it can form so-called ‘carbon nanotubes’ of ‘Bucky tubes’. Because of their physical and chemical properties, these tubes are the perfect conductors for nanoscale electronics and devices. This meant the birth of the nanotechnology we know today.

Principles of nanotechnology

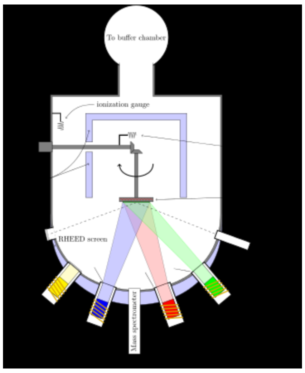
At the nanoscale, not all rules of physics and chemistry still apply to everything. Brand-new areas of physics - such as nanoelectronics, nanomechanics, nanophotonics and nanoionics - have evolved during the last few decades to provide a basic scientific foundation of nanotechnology. There’s a branch of physics that studies the behaviour of electrons and other particles on the smallest scale: quantum physics. At this level, particles can behave like a particle or as a wave, which sometimes causes unpredictable consequences; the quantum effects. These effects become significant when the nanometre size range is reached, the very scale of the nanotechnological devices. Some people call this the quantum realm. Additionally, some physical (mechanical, electrical, optical, etc.) properties change when compared to macroscopic systems. This enables unique applications that weren’t possible a few decades ago. A few examples are: opaque substances can become transparent (copper), stable materials can turn combustible (aluminium) or insoluble materials may become soluble (gold).

Since the emergence of the field, two approaches have been developed covering the different possibilities for the synthesis of nanostructures. These ways of manufacturing fall under two categories: top-down and bottom-up, which differ in degrees of quality, speed and cost.



Individual gold atoms, viewed with a scanning tunnelling microscope

The “top-down” approach is essentially the breaking down of bulk material to get nano-sized particles, this means that the nanodevices must be built step by step in different stages, much as other manufactured items are made. This can be achieved by using a broad set of advanced techniques. To characterize and synthesize the nanomaterials, scientists use scanning probe microscopy, in which they scan the surface of an object at the atomic level by using a special type of needle (the ‘tip’). Atomic force microscopes and scanning tunnelling microscopes can be used to examine the surface more closely and to move the atoms around. By changing the tips, structures can be carved out and self-assembling systems can be made. This method of etching and carving belongs to a group of techniques called nanolithography. Along with the science of precision engineering, nanolithography – especially the variety in which light is used, called photolithography - forms the heart of today’s microelectronics industry.



Setup of the MBE technique

In the "bottom-up" approach, materials and devices are built up from the bottom: larger structures are assembled atom by atom or molecule by molecule, based on different chemical and physical principles and techniques, such as chemical synthesis, self-assembly and positional assembly. The concept of molecular recognition is especially important: molecules can be designed so that a specific arrangement of atoms is favoured due to intermolecular forces – attractive and repulsive forces between separate molecules. Most of the time, the wanted molecular structures require too complex arrangements and are thermodynamically unstable because of unfavourable energy distributions throughout the molecule. Nevertheless, we do find such structures in nature, for example the Watson–Crick base pairing in DNA (two organic bases held together by hydrogen bonds, enabling the double helix structure) and the enzyme-substrate interactions in our bodies (spontaneous and specific binding between enzymes and the biomolecules they influence). In the bottom-up approach, scientists try to design new systems in addition to these natural ones. An analytical method called dual-polarisation interferometry is used to check if the atoms in the self-assembled layers obtain the correct position. Another handy tool is the MBE technique (molecular beam epitaxy), which allows scientists to lay down precise layers of atoms on one another so they could build up complex structures. This is practically the most complex technique we can use today.

Current applications of nanotechnology

Over the past few decades, nanotechnology has increasingly revolutionized many sectors. It has caused the start of a new industrial revolution, in agriculture, food processing, electronics, etc.

Current applications of nanomaterials do not involve atomic control of matter. Some examples include:

- using silver nanoparticles as an antibacterial agent
- nanoparticle-based transparent sunscreens
- carbon fiber strengthening using silica nanoparticles
- carbon nanotubes for stain-resistant textiles

The usage of nanotechnology in textiles

Most applications only use the “first generation" passive nanomaterials, some examples are:

- titanium dioxide in sunscreen, cosmetics, surface coatings
- carbon allotropes used to produce gecko tape
- silver in food packaging, clothing, disinfectants, and household appliances
- cerium oxide as a fuel catalyst
- bandages infused with silver nanoparticles to heal cuts faster

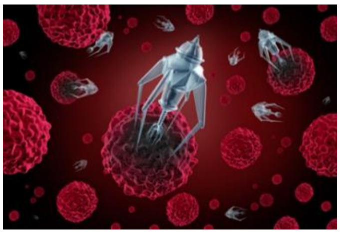
Some of the existing or emerging uses of nanomaterials in electronics include:

- the use of carbon nanotubes in semiconductor chips
- potential use of carbon nanotubes and other nanomaterials in fuel cells and by the solar industry for use in photovoltaics.

Nanotechnology has already been used and commercialised by the production of electronic chips for mobile phones and computers. IBM has even developed carbon nanotube transistors. They are working towards the development of chips using nanotubes and have announced in 2006 that they had succeeded in building a complete electronic integrated circuit around a single carbon nanotube molecule. Since then, IBM has kept on developing more efficient circuits and many other companies have joined the race. Nantero, for example, is today's leader in carbon nanotube memory chips. It should be clear that the most interesting and revolutionizing applications haven't been realized yet!

How nanotechnology will change your life

One of the most interesting things to talk about when we're discussing nanotechnology is, of course, the future. In many ways, it could affect our everyday life so much that, one day, we couldn't live without it.



One of the most useful applications could be in medicine, like wearable fitness technology, implants, sensors, ... By scaling down this technology even further, we could make it possible to implant or inject tiny sensors inside our bodies. This means that gathering data from within the body and administering treatments in real-time could move from science fiction to the real world. As targeted drug delivery becomes more feasible, it could be possible to administer treatment to an infected area at the first sign of infection. We could start to monitor our health and collect enormous amounts of information about vital functions in the body that were unreachable in the past. The possibilities of medical imaging are endless, ranging from monitoring inflammation and post-surgery recovery to more exotic applications whereby electronic devices interfere with our body's signals for controlling organ function.

Another application of this technology could be all kinds of sensors in structures and buildings. By putting these at lots of points over critical infrastructure, this opens up the possibility to constantly check that everything is running correctly. Bridges, aircraft and even nuclear power plants could benefit. If cracks do appear then nanotechnology could play a further role. Changing the structure of materials at the nanoscale can give them some amazing properties, by giving them a texture that repels water, for example. In the future, nanotechnology coatings or additives will even have the potential to allow materials to "heal" when damaged or worn.

Also, in the fight against climate change, nanotechnology could play a crucial role. One of the biggest problems is that we need to find new ways to generate and use electricity, and man-made microrobots have already helped us to create batteries that can store more energy for electric cars and enabled solar panels to convert more sunlight into electricity. In the future, nanotechnology could also enable objects to harvest energy from their environment, from movement and sunlight to temperature changes and glucose.

Conclusion

Nanotechnology is a recent field, but the possibilities are already endless. Within a few years, we won't be able to live without it. The future of physics will be here soon!

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