

Foreword

The nanoworld: from the laboratory to the field



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Who hasn't heard of nanotechnologies? In the space of less than fifteen years, nanotechnology has carved out a significant share of the research sector in both pure and applied sciences. It draws investment, and attention, from the decision-makers. That said, it is not easy to give a concise description of this new scientific field. Put briefly, we can start out by stating that the subject of nanotechnology covers any technique of extreme miniaturization that makes it possible to produce objects, components or systems at dimensions below 100 nanometres, where 1 nanometre is one billionth of a metre ($1 \text{ nm} = 10^{-9} \text{ m}$). The nanosciences themselves draw on all of the scientific disciplines able to improve our understanding and control of the new properties created by this "top-down" ultra-miniaturization.

The term "nanotechnologies" has proved a highly successful formula. It has even spawned a range of offspring, including the word "nanoworld", a key feature throughout this issue of *Clefs CEA*. It all started with the development of microelectronics, backbone and driving force behind these techniques. Electronic circuits are fitted with transistors interlinked by wire conductors in order to perform advanced functions. The first transistors created in 1947 were built at a millimetre scale into relatively huge electronic circuits. As technology advanced, progressively more complex assemblies of transistors and conductors were built directly onto a single silicon wafer. Driven by the desire to cram more and more onto a chip of about 1 cm^2 , engineers managed

to progressively reduce the already tight transistor dimensions down to only 1 micron in the 1980s, and then to tenths of a micron (a few hundred nm) in the late 1990s. The dawn of the 21st century has already seen integrated circuits produced at a feature-size of below 100 nm. By 2010, we'll be down to 20 nm! In parallel, it has become possible to produce microprocessor chips on one single silicon wafer with only a 2 cm^2 surface area that contain several hundred million transistors, and soon a billion! Factories able to produce them cost several billion euros each, while the price of each component produced is spiralling downwards.

After five decades of technological progress, microelectronics has risen from nowhere to become the flagship industry of complexity, miniaturization and massive investment. Is the story set to continue, spreading into other technological fields? Will the information and communication technologies (ICT) revolution spread further? The answer to these questions is to be found in the recent history of microelectronics, from which half a dozen lessons can be drawn.

Lesson 1: "smaller, faster, cheaper". Switching individual production engineering to shared techniques makes it possible to realize major production runs, significantly cutting costs.

Lesson 2: miniaturize everything and anything. At any point in a production, quantification or analytical process where intangible or very small objects are handled, think miniaturization. Data transfer by electron or photon packets provides a particularly illustrative example. Miniaturization has revolutionized computation and modelling as well as communication, in all its forms. It is expected to do the same in other sectors, from measurement of physical parameters to chemical or biochemical analysis, through to labelling, screening and synthesis - again, chemical or biochemical - of small quantities of products.

Lesson 3: we need to learn how to handle and miniaturize new supports and new environments. Magnetic materials, for example, to pioneer new

kinds of RAM, new hard disks. Or fluids, pioneering new sciences such as microfluidics or indeed nanofluidics, to be set to work in labs-on-chips or DNA chips. Molecules that we need to learn to harness and selectively bind.

Lesson 4: pure sciences and applied engineering need to lend each other a helping hand.

The nanotechnology revolution is neither pure science nor pure engineering, and so requires not only new tools (microscopes, production machinery, etc.) but also new design concepts (what is the transistor of the future? How do fluids behave at nanometre scale?). Ignoring this aspect of modern scientific advances is a sure-fire way of failing from the outset. Is it still possible to persist with such a bipolar view of pure and applied science? Aren't they even more interdependent than ever before?

“Combining pure science and applied technologies and creating new applications while respecting individual freedom of choice.”

Lesson 5: the various branches of science need to team up and pull together. Physics, chemistry, biology, medicine, mechanical engineering, etc., have all emerged from a body of knowledge borne by the “*honnête homme*”. As they became more complex, they split into autonomous and occasionally rival fields. The pure volume of knowledge required means that it is impossible to master them all, but rather than competing in separate spheres, they have to learn to work together and synergize. Indeed, at nanometric scale, dealing with atoms and molecules, the traditional distinctions no longer hold sway. And the enormous potential advances to be made from combining computing and biology, or medicine and microsystems, to name just two examples, makes it doubly obvious that we need to get straight down to working on cross-disciplinary fertilization.

Lesson 6: as it continues to open up perspectives, the nanotechnology revolution also generates fears. By moving to transform our social environment (further extending the reign of computers, freedom of information, access to data, etc.), nanotechnologies are opening up a world of uncertainty. Is nanotechnology converging with biotechnology and cognitive science in a drive towards “*upgrading humans*”, as some protagonists have suggested? Science today is generally treated with a certain amount of mistrust. How can we weed out the realistic and usefully advantageous perspectives from the vague and often unfounded speculation? Make room for the Pasteurs and close out the Dr Strangeloves? This is a lesson that has to remain a series of questions. Questions for specialists, true. But more importantly, issues brought before society as a whole: what kind of world do we want to live in? What technology are we ready to accept?

This issue of *Clefs CEA* aims to provide an overview of a wide range of nanotechnology fields where CEA researchers have been actively involved for many

years now, often leading the way forward. Readers will find the same questions and issues as described above: how to combine pure science and applied technologies, make physicists, electronics engineers and biologists work together, develop pioneering new means of analysis and production, and how to create new applications while respecting individual freedom of choice.

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