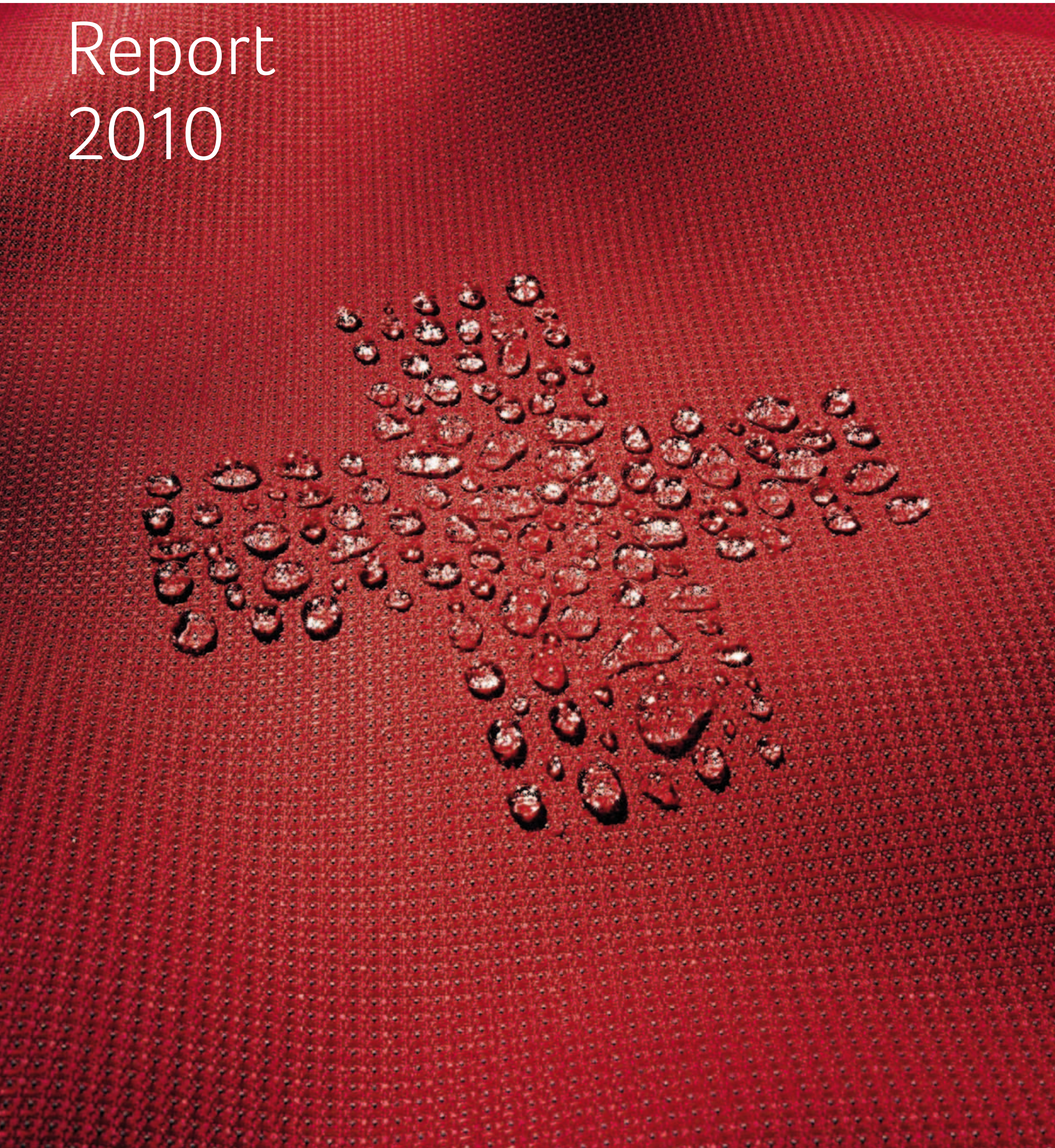
# Swiss Nanotech Report 2010

Tiny but important things



# Contents

# Nanotechnology, a key to sustainability

Nanotechnology is considered as one of the key technologies of this century. Some talk of a nano-revolution, some see it more as an evolution. Nanotechnology is still mostly seen as an extension of what is done and achieved on the micrometer scale. As such, it plays a central role in modern electronics, where the smallest features are only some 20 nm in size, as well as in new concepts for electronics, such as spintronics or quantum computing.

Nanotechnology, however, is much more than just smaller: It is a fundamentally new domain of nearly unlimited diversity, be it in novel material properties enabling new functionalities and components or in novel concepts to tackle problems of an increasing complexity – you name it. Take, as an example, some applications of simple nano-particles. Thanks to the nano-roughness induced by nano-particles, surfaces repel water and dirt. In clinical nano-medicine, nano-particles serve as "intelligent" vehicles for drug delivery or as local heaters in cancer therapy. Different sizes of nano-particles absorb light of different wavelengths. They are likewise expected to play an important role in catalytic processes and in regeneration schemes.

For Nano, the sky is the limit – and so are the expectations and challenges. Ideas, not only futuristic ones like nano-robots controlling or even replacing bacteria, are abundant. But the obstacles to overcome are high. For example, to name just two of them: i) nano is mostly not scalable, i.e., functionality is not retained when sizes shrink, and ii) nano will, to an appreciable part, be a wireless world, and supplying energy to and communicating with autonomous nanosystems of sensors, actuators, and processors are a quite formidable tasks.

The nano-domain links the macroscopic world of condensed matter to the world of the atoms and molecules. We understand and can handle either side pretty well, but the "in-between" is new grounds for both science and technology, and progress in one depends critically on the achievements in the other. And whoever, be it an institution, an industrial enterprise, or a country, wants to be top in nano-technology needs a thorough understanding of nano-science as well. Science and technology on the nanometer scale in general are very demanding on all professional levels. And Switzerland, with its expertise in both fields, is very well prepared to meet the challenges of the nano-domain successfully.

Last but not least, sustainability will be a key merit of nano. Small in size intrinsically translates to sustainable in terms of material use, energy consumption, and excellence of performance. Microelectronics was an unintentional, but huge and extremely successful step towards a sustainable world. Nano-systems, which will replace many computer-controlled macro-systems or perform new tasks in a new way, are expected to add also new dimensions to sustainability. However, when talking about sustainability we should always keep in mind that it is not just a matter of solving a single task most efficiently and effectively, but that it is the sum of all the tasks that counts. In computing, for example, the energy consumption per arithmetic operation has decreased a trillion times over the past 60 years. But in the same time span, the total energy consumption of computing has increased by orders of magnitude.

**Heinrich Rohrer**

**Portrait**
IBM Fellow Emeritus, Nobel Prize in Physics 1986, jointly with Gerd Binnig, for the design of the scanning tunneling microscope.

# The nano dimension – a tiny world with huge impact

**Nanotechnology is beginning to shape our world. Materials, textiles, pharmaceuticals, cosmetics, computer chips – the list of potential applications seems unlimited. As one of the pioneers in this field, Switzerland plays an important role as a location for performing outstanding research and creating successful nanotechnology applications.**

### The nano cosmos: Big things from a tiny world

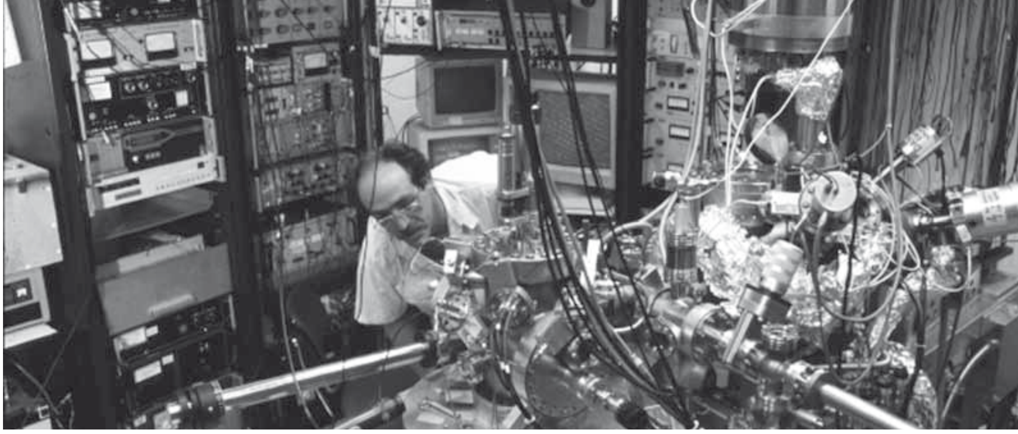
The world is becoming more instrumented, interconnected and intelligent, or, in one word, smarter. By 2011, there will be more than a billion transistors per human, instrumenting everything – from cars, roadways, pipelines, appliances to pharmaceuticals and even livestock. Sophisticated nanotechnology processes are needed to fabricate these transistors, the basic building blocks of computer chips, that help interconnect our world. The benefits of nanotechnology, however, extend to much more than just electronic devices. Nanoscale systems may lead to a more efficient use of solar energy, new ways of purifying or desalinating water, and faster and more accurate healthcare diagnostic tools. Thus, it is no surprise that nanotechnology is attracting increasing attention from researchers, public authorities, and companies all over the world.

Switzerland as one of the world's leading industrial nations has recognized the importance and commercial potential of nanotechnology early on. The country has a long tradition in the construction of precision instruments and exquisite products, such as intricate watches. Moreover, just as Swiss craftsmen have been driving the progress and innovation in the area of measuring instruments for a long time, Swiss scientists and engineers were and are pioneers in the miniaturization of processes and structures.

Above all, the development of scanning tunneling microscopy by G. Binnig and H. Rohrer was very influential for nanotechnology. This imaging technique, which only shortly after its invention was recognized with the Nobel Prize, fuelled the imagination of scientists and made them think in bold terms of conquering the new frontier at the nanoscale: Seeing individual atoms and fabricating structures atom by atom paved the ground for a vast upswing of research on the nanoscale in all fields. Today, nanoscience and nanotechnology are indispensable in and for research and industry, and the innovative projects they foster are increasingly also impacting the world of business.

### How tiny is tiny?

What is nanotechnology? Some view it as the result of just another miniaturization step, others stress the fact that at the scale of the nanometer completely new functionality comes into play. Broadly speaking can nanotechnology be defined as research and technology developments at the atomic or molecular level, that is, on a length scale smaller than 100 nanometers – one ten thousandth of a millimeter. Particles and structures of this size differ from their counterparts in the macroscopic world in two fundamental aspects: the relative surface area of such structures increases enormously, and quantum effects occur. This can result in significant modifications of the physical and chemical properties, often leading to improved characteristics – a typical example being the porosity of a catalyst or the water-repellent surface of a fabric.



However, it is not only the exceptional properties of materials that make nanotechnology special. The second exciting aspect is that the nanotechnology field is highly interdisciplinary. Physicists, chemists, biologists, and engineers cooperate to find new and innovative solutions to long-standing problems, for example to obtain clean and affordable energy, construct better materials, or develop devices and drugs that can treat diseases better and have fewer side effects.

There are two different approaches to fabricate nanoscale structures: So-called top-down techniques build very small structures by starting from larger pieces of material and extending existing fabrication technologies to the nanoscale (see p. 8). In contrast, so-called bottom-up techniques aim to build structures atom by atom or molecule by molecule. Here, self-assembly or steered assembly are the methods of choice to force atoms or molecules into the desired arrangement (see p. 10). Although these latter techniques currently seem to have only a relatively small impact on real applications, they are expected to gain importance in the future.

## Education and appealing research conditions: Prerequisites for excellence

There is widespread agreement that excellent higher education and favourable business conditions are key enablers for outstanding nanotechnology research and development. Education, research and innovation have traditionally played an important role in the policy of the Swiss authorities, a role that is expected to grow in the future (see p. 12). Switzerland has an excellent range of academic institutions that offer technical and scientific education with close links to research institutions and industry. The research sector and companies benefit from the large number of both well-trained and educated professionals and skilled and innovative researchers.

In addition to the favourable general framework for education and research, nanotechnology projects also benefit from being encouraged and promoted by public funding. Swiss funding agencies launched several programmes that target the entire range of nanotechnology, from exploring basic research to developing product prototypes. Special emphasis is put on collaboration with non-academic partners and on know-how and technology transfer (see p. 14).

## From research to business

In many fields, research results have already found their way into industry and spawned new applications. To render this knowledge transfer successful and efficient, public research institutions are closely linked to and cooperate with industry and business. Promising developments in the nanotechnology field are effectively being commercialized by both new and established companies. These companies benefit not only from Switzerland's prominent role in nanotechnology but also from lead-time advantages (see p. 16). The large number of institutions of higher education, the proximity of research institutes and companies, and the well-established collaboration between public authorities and private parties have resulted in several "nanotechnology hubs" in Switzerland, where outstanding research in nanotechnology is done and seminal products are created (see p. 20).

In addition to the good conditions in research and development, nanotechnology in Switzerland benefits from an excellent administrative framework and financing options which help to commercialize innovative nanotechnology processes and products (see p. 22, 24).

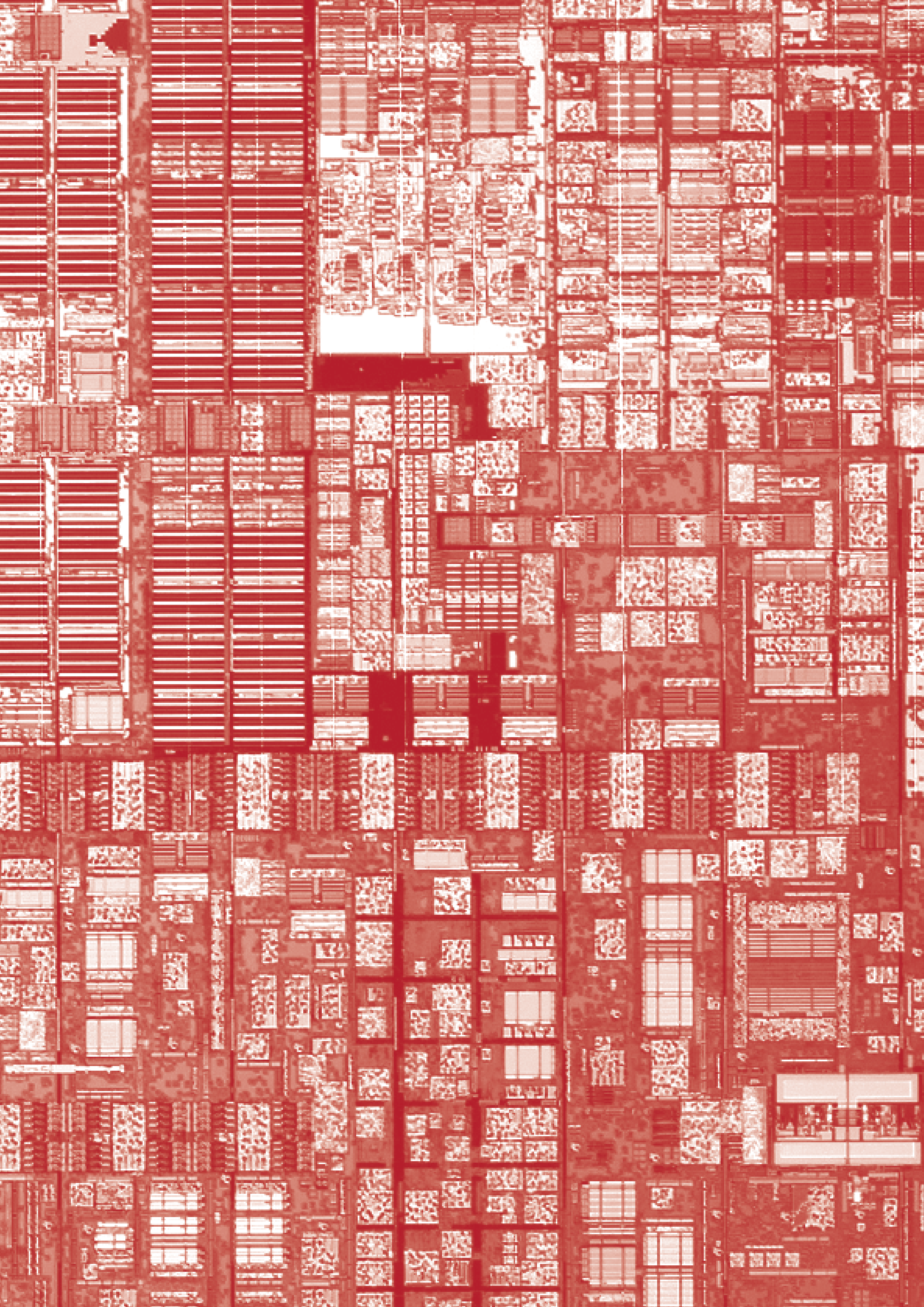
**Responsible use of nanotechnology**

In parallel to recognizing the importance and economic significance of nanotechnology, Switzerland has early on identified potential risks of this new technology to health and the environment. It is crucial to investigate these risks and to deal with these issues to play for safety from the outset. In this way, Switzerland has made relevant contributions to a responsible use of nanotechnology and to the high degree of acceptance these innovations enjoy in the Swiss population (see p. 25).

From the perspective of fundamental science, nano is a venture into unchartered territory, full of exciting surprises. From the perspective of applications and products, nano offers not only novel technical solutions because of its miniaturization but also exciting possibilities and opportunities for both economic growth and sustainability. So come and join us on a tour of the world of nanotechnology in Switzerland.

**Rolf Allenspach**
**IBM Research - Zurich**

**Christian Soltmann**
**Swiss Federal Institute of Intellectual Property**



# The top-down approach: Scaling to atomic limits, or novel functionality beyond Moore's law

**The tremendous success of the microelectronics industry in the past decades, which was largely enabled by the creative effort of electrical engineers and physicists, has resulted in today's low-power mobile-computing and personal telecommunication devices. These devices, which exploit the unique performance of nano-scaled circuits, have a huge societal impact and significantly contribute to improving our quality of life.**

The past 50 years, ever since Moore stated his law, have seen the miniaturization of devices to ever smaller dimensions. Nowadays, feature sizes on chips are below 50 nm, and they are poised to shrink even further. By observing certain design rules on how to scale the transistors to ever smaller sizes, the engineers follow a "top-down" approach: Starting from the macroscopic scale, they use lithography techniques to pattern nanoscale features onto silicon wafers.

To meet the challenges related to ecology and the aging society, environment-friendly technologies, more energy-efficient electrical systems, and personalised electronic devices will be required. For building them, the further miniaturization of existing electronic structures and devices will play a key role.

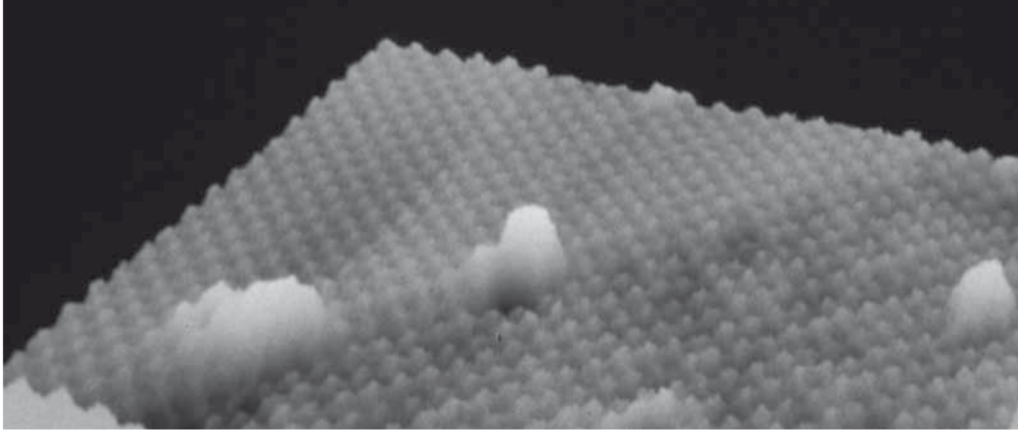
Swiss know-how in the field of nanotechnology and nanoelectronic engineering can make a significant contribution to realising the appropriate technologies and applications, such as ultra-low-power and energy-efficient systems, and to creating new functionalities by means of heterogeneously integrated miniaturized devices. Essential efforts in this direction are being made, for example, by the Swiss Federal Institutes of Technology in Lausanne (EPFL) and Zurich (ETH Zurich), which are supported by the Swiss Nanotera initiative.

### A paradigm change in the electronics field

Until very recently, business needs and scalability aspects have determined the evolution of silicon complementary metal oxide semiconductors (CMOS) as the technology with the highest added value of the final product as compared with the raw material cost.

Today, Swiss research is giving high priority to the investigation of so-called beyond-CMOS devices and systems that apply alternative, disruptive technology and device principles. For example, traditional charge-based transistors will be replaced or complemented by other elements that exploit not only the charge but also the spin of the electrons, or possibly even use photons. The existing semiconductor technology can be regarded as the base for future unique ultra-low-power logic and memory functions relying on novel molecular- or even atomic-scale technologies.

A second approach focuses on the so-called More than Moore domain in electronics, where complex systems are being developed in which 3D heterogeneous integration techniques are employed to combine various electronic and non-electronic technologies. Such systems aim at meeting the challenging specifications of advanced applications, such as wearable or implantable devices. Another interesting field of research is environmental monitoring based on wireless sensor networks and so-called ambient intelligence applications in which nanoelectronic circuits are so well integrated into the environment that they become virtually invisible.



Research at EPFL, for instance, pays particular attention to micro- and nano-electro-mechanical systems and novel sensor technologies that are interfaced with silicon-based information and communication technologies. Together with the steady progress in the "beyond-CMOS" area, this research is expected to bring together technology and design communities, and lead to stronger cooperation between Swiss research facilities and industry, both in Switzerland and abroad.

Swiss research in the field of electrical engineering and micro-/nano-engineering enjoys an excellent reputation in the international technical community: Researchers from EPFL and other institutions are regularly invited to contribute ideas and insight to nano-electronics initiatives around the globe, such as the semiconductor roadmap ITRS and the European nanotechnology platform ENIAC, and to European consortia in the field of nanoelectronics, in which all key players from industry participate.

**Adrian Ionescu, NANOLAB/EPFL**

# The bottom-up approach to nanostructures

**Nanomaterials can be made by means of an extremely diverse range of synthesis and processing schemes. Most of these fabrication approaches can be classified as either "top-down" or "bottom-up": Top-down processes start from a bulk material and nanoscale structures are created by patterning methods, whereas bottom-up schemes rely on the self- or directed assembly of smaller building blocks into such nanoscale structures. The simplicity of bottom-up concepts is intriguing and bodes well for their broad technological exploitation.**

### Self-assembly: Let nature do the work

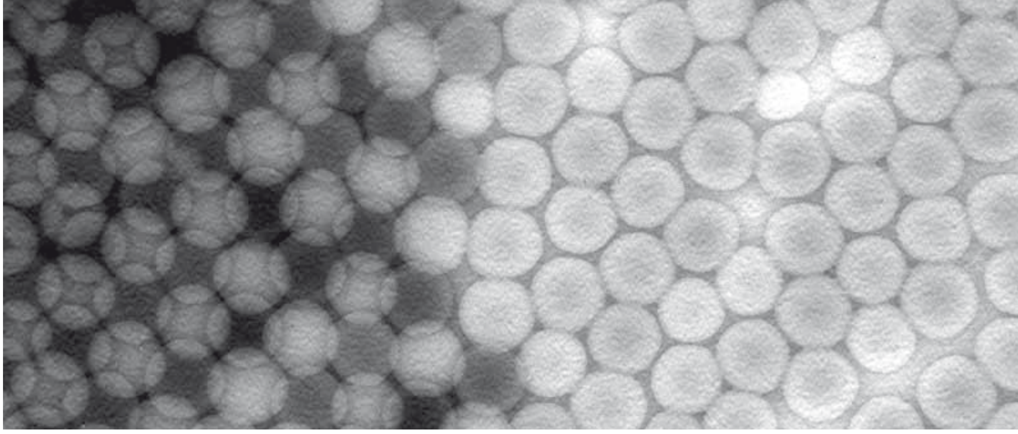
The idea of creating nanostructured materials through self-assembly of small molecules, macromolecules or nanoparticles is attractive because of its simplicity: Mix the components, and let the forces of nature assemble them into the desired structure. Indeed, this concept has proved to be an attractive route for the fabrication of two- and three-dimensional nanostructures. The general approach has become an exciting path to construct a rapidly increasing number of materials and devices ranging from the molecular to the macroscopic scale and from artificial opals to self-assembled electronic circuits.

### Chemistry meets processing

Many areas in bottom-up nanotechnology are only enabled by the growing variety of functional nanoparticles with well-defined properties that chemists are capable of producing. With nanoscience maturing into an independent field of research, many synthetic techniques that are known, for example, from areas such as colloidal chemistry and polymer science were adapted and refined to meet the needs of this emerging discipline. In addition, a large variety of specific methods were developed that allow the direct synthesis of new types of nanoparticles. The intriguing feature of direct synthesis approaches is that a large number of particles can be produced in parallel. Moreover, these methods can often be scaled up to production volumes in a straightforward manner.

### Mimicking biology: Creating nano-scale materials from the bottom up

Regarding the assembly process, much inspiration can be taken from nature. The dimensions of artificial nanomaterials are comparable to those of the smallest structures created and used by nature in living organisms. Bio-nanostructures are all formed exclusively by self-assembly processes. Molecular recognition effects play a key role in these bottom-up schemes. Nature uses a range of different supramolecular motifs, which can exert minute structural control, ranging from the conformation of individual molecules to the assembly of complex hierarchical structures.



## From model atoms to functional materials

In the past few years, several Swiss research groups have adapted concepts from biology in their research activities in nanosciences. At the University of Fribourg, for instance, several groups use bio-inspired self-assembly schemes to create complex nanomaterials. Researchers at the Adolphe Merkle Institute (AMI) create mesoscopic structures with well-defined local order that can be either liquid-like or crystalline. When these concepts are combined with particles having different functionalities, macroscopic materials with novel, tailored physical and chemical properties can be designed and built. Such functionalities range from magnetic to optical properties, including also specific responses to external parameters such as temperature, ionic strength or acidity. The latter group of functionalities is of particular interest because it allows the creation of advanced materials with switchable properties.

## Directed or template-assisted self-assembly: Combining the best of both worlds

Whereas simple self-assembly of nanoparticles represents an easy and inexpensive way to build nanostructured materials, it results in a limited number of accessible structures, which in general are randomly oriented and prone to defects. These issues can largely be overcome by template-assisted self-assembly, which incorporates features of the bottom-up and the top-down approach. Similarly, the use of external magnetic and electrical fields combined with magnetic or charged nanoparticles allows directed self-assembly. Such approaches are considered to combine the best of both worlds in that complex structures can rapidly and reliably be assembled on a large scale.

## Self-assembly of complex dynamic structures

The structure of natural materials is significantly more complex than that of artificial nanostructures produced by self-assembly. However, the architecture of biological structures can often be simplified to create bio-inspired artificial materials with interesting functionalities. AMI researchers have recently created a new family of bio-inspired adaptive materials with chemically controllable stiffness. The design of these materials mimics the structural concepts at work in the dermis of sea cucumbers. These creatures have the fascinating ability to change the stiffness of their skin rapidly and reversibly if they are threatened. This mechanical adaptability is achieved by means of a nanocomposite architecture, in which rigid nanofibers reinforce a viscoelastic matrix. Adding or removing specific chemicals allows one to control and drastically change the mechanical properties of these materials.

## The path forward: Teaching the building blocks new tricks

Scientists have come a long way in creating useful nanostructures by self-assembly, even if the most sophisticated examples are still quite simplistic compared with, for instance, a living cell, which also is formed entirely by self-assembly. Thus, for scientists to be able to truly mimic structures of the complexity found in nature, they will have to teach their building blocks many more tricks – before they can sit back and watch them assemble.

**Peter Schurtenberger and Christoph Weder, Adolphe Merkle Institute**

# Education, research and innovation as an essential mission in Switzerland

**Education, research and innovation are key to Switzerland's development and economic prosperity. Their support is an important element of Switzerland's long term strategy, as evidenced by the increased funding for these activities in recent years.**

People living, studying or working in Switzerland are well aware of the value of knowledge for both their individual and societal development. Even in economically difficult times, education, research and innovation remain very high on the agenda and are not subject to short-term reductions, as political actions, company policies, and opinion polls regularly show.

Sustained by continuous investments, this attitude has led to a well functioning and highly performing academic and economic system: Switzerland ranks first in the latest Global Competitiveness Report for 2009–2010. Incentive systems as well as processes and structures are designed to promote bottom up activities as much as possible. Sound entrepreneurship together with favourable framework conditions lead to a vibrant and robust economic environment, which is attractive for domestic as well as foreign people and firms.

## People are key

The backbone of Swiss success is smart, responsible and autonomous people of all ages, making the quality of education vital in the long run. Decision makers on all levels share this view, cooperate to provide coherent education throughout an individual's life, from primary and secondary school up to tertiary education, supplemented with a rich palette of continuing education possibilities. The Swiss education system is characterized by its high quality, a meaningful diversity, and a sound balance between vocational and academic training. The higher education sector, for example, comprises various public universities, among them the world-renowned Swiss Federal Institutes of Technology in Zurich and Lausanne, and several universities of applied sciences.

## Switzerland as a hub for top research

Some 3% of the Swiss GDP is used for domestic R&D. Two thirds of this amount is spent by companies, in particular in the pharmaceutical, chemical, ICT, machinery and the food industry, that is in fields with an already existing or a potential link to nanotechnology. Even though the bulk is spent by large companies, research-intensive SMEs are essential for a vital and dynamic innovation system.

Research in the public sector is the domain of universities and research institutions, which enjoy substantial autonomy and often high international reputation. Apart from their base funding, universities and research institutions compete for research funding from either the Swiss National Science Foundation, the Innovation Promotion Agency, or other national and international sources.

## International networking to promote "brain exchange"

Active networking is crucial to keep pace with international developments, and is done by a multitude of players from both industry and academia. To facilitate this networking and promote Switzerland as a location of choice for higher education, research and innovation, Swiss houses for scientific and technological exchange have been established in Boston, San Francisco, Singapore and Shanghai. This network of so-called swissnex offices is complemented by science and technology counselors at selected Swiss embassies around the world.


Location of swissnex offices and science and technology counselors

Switzerland is largely internationalized: 25% of its workforce and 40% of the university professors in Switzerland are foreigners. This is also reflected in the fact that in its multicultural context with four national languages, English is gaining importance as the language of communication in business, research and teaching. Another crucial factor in the economic development of a small country like Switzerland is openness: Businesses located in Switzerland are highly innovative and participate in global value chains, extending the "Swiss" innovation system to the European and world economy.

## An integrated and lean support policy

In Switzerland, the measures to support education, research and innovation form an integrated policy domain, and are specified, assessed and adapted in a four years cycle. They consistently rank high on the political agenda, and enjoy concomitant funding. Annually, almost one tenth of the federal budget is spent on higher education and research.

To foster business activities and innovation, Switzerland has created an excellent business environment based on an attractive taxation scheme, a well educated workforce, an open labor market, and a high quality of life. Public support not only includes base funding and increasingly competitive R&D funding for public organizations, but also processes to build national synergies and participation in international research organizations and programs.

Although Switzerland is very well positioned at the moment, its current system is continually being challenged: How will changes in international competition impact on the Swiss innovation system? What is the best balance between the various education and research programs? Can Switzerland sustain its focus on knowledge activities, even in economically tougher times? Regularly assessed, these questions help the decision makers implement any adjustments needed to keep abreast of international developments. There is widespread agreement that Switzerland can rely on its strengths and that its model for education, research and innovation will provide an excellent basis for meeting the challenges of tomorrow, and beyond.

**Patrick Vock, State Secretariat for Education and Research**

# Switzerland – a hub of expertise

**Excellent research is a prerequisite for economic competitiveness at the international level. Switzerland safeguards its position as a leading location for outstanding research through funding institutions, which promote individual researchers as well as research facilities and companies. This concept fosters technical expertise in research, allowing companies to easily access know-how and a body of highly qualified researchers and engineers.**

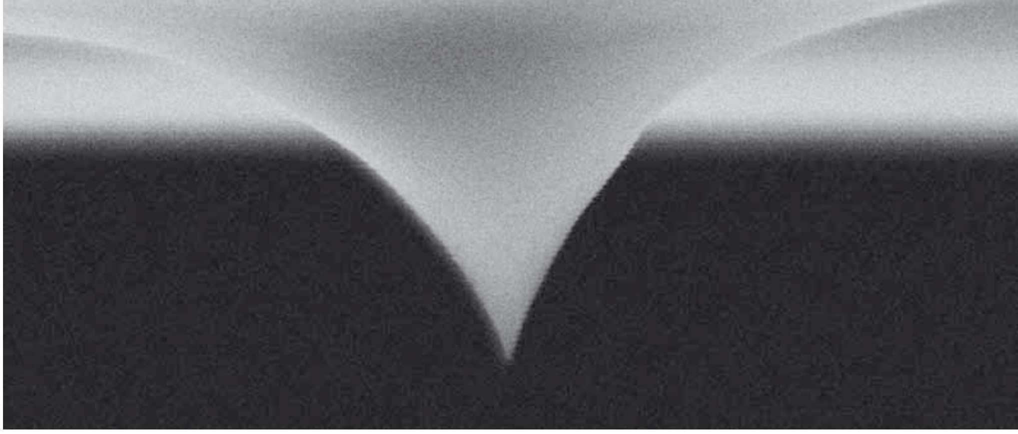
Important goals of public research funding in Switzerland are the strengthening of research, innovation and cooperation at the national and the international level. The main funding agencies are the innovation promotion agency (CTI) and the Swiss National Science Foundation (SNSF).

CTI is the most relevant institution at the federal level for application-oriented research. It provides funding for market-oriented joint R&D projects of companies and academic institutions, for the creation and expansion of companies which pursue new scientific and technological concepts, and for the knowledge and technology transfer by means of specific platforms and networks.

The SNSF is the most important institution for the promotion of scientific research in Switzerland. It is very active in funding areas that hold promise for the future, such as nanoscience. In doing so, it creates a fertile environment for innovation and economic power. To stay ahead in international competition, it is vital that research is focused and sets priorities. The state-funded SNSF therefore not only finances individual projects, but in cooperation with universities also supports research centres, i.e., the National Centres of Competence in Research (NCCRs).

The NCCRs strengthen Switzerland's position in strategically important areas and help establish research structures that will be important in the future. In the nano-technology field, two NCCRs are of particular importance: *Materials with novel electronic properties (MaNEP)* in Geneva and *Nanoscale Science* in Basel. Whereas MaNEP focuses on new materials with complex electronic structures, the NCCR *Nanoscale Science* links up nanobiology, functional materials, and molecular electronics. Both programmes are each funded over a period of twelve years.

The two NCCRs are a success story. Today, Switzerland ranks among the world leaders in nanobiology, an achievement largely due to the NCCR *Nanoscale Science,* which enabled interdisciplinary research by physicists and biologists.



## From basic research to practical application

NCCRs are devoted not only to cutting-edge research but also to taking specific steps towards promoting technical know-how and technology transfer. This strategy is very successful: The activities of the NCCR *Nanoscale Science* alone led to 23 patents and 7 start-up companies. To date, commercial cooperation with over 20 companies has been established. Thanks to this kind of cooperation, companies can keep up with research trends and share the latest findings and technologies, establish informal contacts and benefit from the exchange of information and training possibilities.

## New programmes launched

Switzerland has identified nanotechnology as one of the key technologies of the 21$^{st}$ century. The country already holds a pole position in nanotechnology and aims at safeguarding its position with the help of innovative, interdisciplinary research. For this reason, the SNSF launched the two National Research Programmes *Smart Materials* and *Opportunities and Risks of Nanomaterials* in 2009, which will run over a period of five years. In addition, the Swiss nano-tera.ch programme was started in 2008, which aims to improve the health and protect both humans and the environment by means of engineering and information technology.

**Helen Jaisli, Swiss National Science Foundation**

# Technology transfer: Turning tiny science into big business

**Even though nanotechnology has already spawned numerous applications and is entering industries and markets at an ever-accelerating speed, much of its potential is still untapped. Therefore, a successful transfer from research to business is critical to fully exploit its innovative and economic impact.**

Technology transfer has become a focal point for academic institutions worldwide, for obvious reasons: Research results and technologies developed at publicly funded universities and institutes have to feed back into the national economy that finances said institutions. Traditionally, technology transfer has been viewed mainly as the patenting and licensing of inventions or the creation of start-up companies.

It is, however, much more than this. Building a solid transfer bridge "from science to business and society", for example, to convert scientific results in nanotechnology into technological advances, requires a number of things: a focus on applied research, close links to industry, an integrated strategy with various complementary routes to turn research results into business ideas, the "right" people and – last but not least – sufficient resources to fund all those activities.

### An integrated approach to technology transfer

The first product of any scientific endeavor is knowledge. The instruments by which knowledge is transferred to industry are manifold: joint research projects, licensing agreements or the transfer of patents, the founding of new companies or the establishing of new partnerships as well as information exchange and continuing education. And not to forget the exchange of people, the "brain transfer": Scientists who move from the academic realm into the corporate world or researchers from industry who opt for a sabbatical. All appropriate routes have to be pursued vigorously to make technology transfer successful.

A prerequisite is, of course, the will to commercialize, a mindset that allows you to cash in on your assets – in this case, scientific or technological know-how. Switzerland is home to a number of highly reputed scientific institutions with a long history of applied research where scientists are given incentives to protect their findings, e.g. through shared licensing revenue and award schemes. Research results are commercialized by technology transfer offices in close collaboration with the researchers. Inventions are evaluated on the basis of various criteria, and an optimal exploitation strategy applied to the specific situation is defined. Intellectual property is frequently protected by means of a patent application, filed by the research institution alone or in collaboration with an industry partner.

Although many companies in Switzerland, especially larger ones, already foster good relationships with academic research institutions, it is still a challenge for the latter to establish initial contact, especially with small and medium-size enterprises. The Swiss Federal Laboratories for Materials Testing and Research (Empa), for instance, have established a "Portal" acting as single point of entry for potential partners and actively try to lower the threshold for companies that could (and should) get to know Empa's R&D portfolio. Besides that, there are numerous organizations and consortia that try to expand the cooperation between academia and business through events, liaison offices, networking, etc.

## Joint research – the mainstay of technology transfer in nanotechnology

Currently, the majority of joint research projects in nanotechnology is supported either by national or international public funding (Swiss innovation promotion agency CTI, Swiss National Science Foundation, European Union), which is indispensable to enable an efficient technology transfer between academia and industry. Of the 250 CTI-funded R&D-projects, 17% are in the field of micro- and nanotechnology. Successful project-based cooperations have the potential to turn into long-term strategic partnerships, competence centers or public-private partnerships.

Both joint research projects and the subsequent exploitation of results need to be negotiated and defined in written agreements and contracts – the core business of the technology transfer offices at Swiss research institutions. In close cooperation with the researchers involved, these offices help to define the strategy for protecting and exploiting the intellectual property. Moreover, they help to define the conditions and parameters for such agreements, thus relieving researchers from the burden of contract negotiations, and actively promote novel technologies to partners from industry.

## Nanotechnology start-ups face challenges

To a lesser extent the commercialization of nanotechnology accrues from spin-offs. The reasons are twofold. As an enabling technology, nanotechnology finds its biggest added value in applications. High processing costs as well as challenges in the scalability from laboratory to industrial production make this field less suitable for emerging companies, in contrast to, for instance, the software sector.

Another widely reported barrier is the scarcity of financial resources. Through various start-up initiatives and the network of Swiss Science and Technoparks, young entrepreneurs can benefit from a wide range of infrastructure, networking and coaching offers. However, bridging the financial gap between existing start-up funds and venture capital poses a serious obstacle on the path to sustained commercial success.

Facilitating access to funding sources, such as foundations, banks, and business angels, is a growing task for business incubators like Empa's *glaTec* and *tebo* technology centers. The Swiss Center for Electronics and Microtechnology (CSEM) has created *Jade Invest*, a Swiss venture capital company with the aim of identifying and sustaining leading-edge technologies for today's and future emerging markets. Their goal is to support start-up companies with a strong growth potential by granting them the essential capital and providing strategic guidance.

Some of the challenges faced by start-ups are exacerbated by the fact that many potential applications still are at an early state of development. Moreover, the complexity of the technologies required to realize these applications adds to the challenges.

However, many of the challenges in the nanotechnology field, such as high infrastructure investments, largely correspond to those already observed in other fields, e.g. in biotechnology. Experts expect that these obstacles will be overcome in the near future. Correspondingly, nanotechnology is considered a technology that will open up new fields of activity and opportunities for traditional Swiss industries, such as manufacturing, electronics, or the textile industry.

**Gabriele Dobenecker, Empa**

# Protecting intellectual property in the nanotechnology field

**After information technology and biotechnology, nanotechnology is expected to become the next area of the knowledge-based economy set to boom at the beginning of the third millennium. Significant investments in nanotechnology R&D call for the protection of the innovative new approaches developed.**

The protection of inventions and innovations in the high-technology domain is generally achieved by the patent system. Correspondingly, patent portfolios are widely considered an essential asset for high-technology companies.

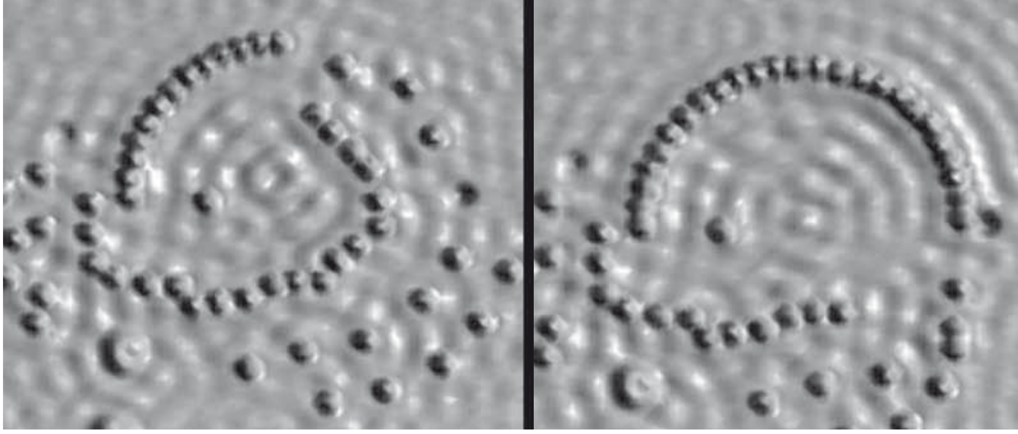
A rapid increase in nanotechnology patent applications has been observed at all patent offices worldwide. For example, the number of nanotech patent applications at the European Patent Office has increased approximately twentyfold between 2000 and 2006, whereas the total number of patent applications only doubled in the same period. Likewise, despite the worldwide economic crisis, the number of nanotechnology patent applications at the World Intellectual Property Organization in 2008 grew by almost 20% , although the total number of applications increased by only about 2%.

## Switzerland's assets

Although these figures are impressive, the number of patents issued for nanotechnology inventions still is only a small fraction of all patents (approx. 1% at the European Patent Office). There are several reasons for this. For one, many of these technologies represent emerging science. Accordingly, the number of patent applications is still small, but a significant increase is expected in the next few years. Secondly, the interdisciplinary nature of nanotechnology often makes it difficult for patent examiners to assign certain inventions to this particular field of technology. Nevertheless, the ever increasing patenting activity clearly reflects the fast emergence of this new field of technology in all leading high-technology countries.

Compared with other countries, the pace and quality of high-technology research are outstanding in Switzerland. Its excellent dual education system and the close cooperation between the private sector and academic institutions attract researchers and companies alike from all over the world. In particular, the transfer rate of innovative ideas into high-technology products in Switzerland is impressive. The eighth edition of the European Innovation Scoreboard, published in January 2009, showed that the innovation performance of Switzerland is well above that of the EU-27 and all other European countries examined.

Switzerland has been at the forefront of high-technology developments for many decades. Historically, Switzerland has a long tradition of producing small-scale objects. Starting with the watch makers' ability to work with tiny tools and objects, microtechnology has developed into a large industry in the past decades. In addition, some of the key scientific breakthroughs towards even smaller scales were achieved in Switzerland. For example, Gerd Binnig and Heinrich Rohrer developed a tool to display individual atoms, the scanning tunneling microscope. The first in a long series of patent applications for this groundbreaking instrument was filed already in 1979. For their invention, Binnig and Rohrer were conferred the Nobel Prize in Physics in 1986.



## Filling the knowledge gap

Researchers at universities and in industry alike are challenged by the fast pace of development in nanotechnology. In particular in the academic environment, researchers generally have a thorough knowledge of the developments disclosed in scientific and technical journals. But they struggle with technical information made available in patent documents because they have not been trained in reliably finding specific information in the more than 70 million such documents that exist. It is estimated that in certain technical fields up to 80% of all technical know-how can be found only in patent documents.

For this reason, being able to tap this enormous pool of knowledge can be critical for researchers in companies and academic institutions to secure a competitive advantage. Moreover, patent information can help make informed decisions when creating strategies for doing research or developing new products. Information disclosed in patent documents allows one to find solutions for technical problems, ideas for research and development, details of the state of the art and trends in a specific technical field, information about R&D activities of business competitors, and potential licensing partners.

Accordingly, patent information is vital to a broad range of professionals, from scientists and engineers to patent attorneys, accountants and business strategy managers. In this context, the Swiss Federal Institute of Intellectual Property is mandated to help academia and industry filling the knowledge gap by offering professional patent information services that are tailored to meet the demands of these target groups.

**Heinz Müller, Swiss Federal Institute of Intellectual Property**

**The Swiss Federal Institute of Intellectual Property is commissioned to inform scientists and engineers as well as companies about the various aspects of intellectual property. In this context, the institute offers the following services:**

- training and special courses for academia and for companies
  **www.ige.ch/en/training/training.html**

- so-called assisted patent searches for scientists and engineers in both industry and academia
  **www.ige.ch/en/searches/patents/assisted-patent-search.html**

- tailored searches for companies, professionals in the intellectual property domain and individuals
  **www.ip-search.ch**

# Swiss nanotechnology landscape

**Many potential nanotechnology applications are at the crossroads regarding their future success. Especially for companies, time has come to analyze the conditions at which nanotechnology can be integrated into their products and processes. One of the criteria hereby is an appropriate choice of location for the company, potentially a critical factor for future success.**

Research and development in the nanotechnology field generally require substantial investments into the technical infrastructure as well as close cooperation between different areas of research and engineering. Moreover, a smooth interplay between research facilities, local and regional actors, and commerce is another important prerequisite for a successful commercialization of new applications. In this context, the proximity of excellent research facilities, innovative companies that may utilize these applications in their processes and products, and progressive public authorities are a clear advantage.

### A fertile ground for R&D and nanotechnology

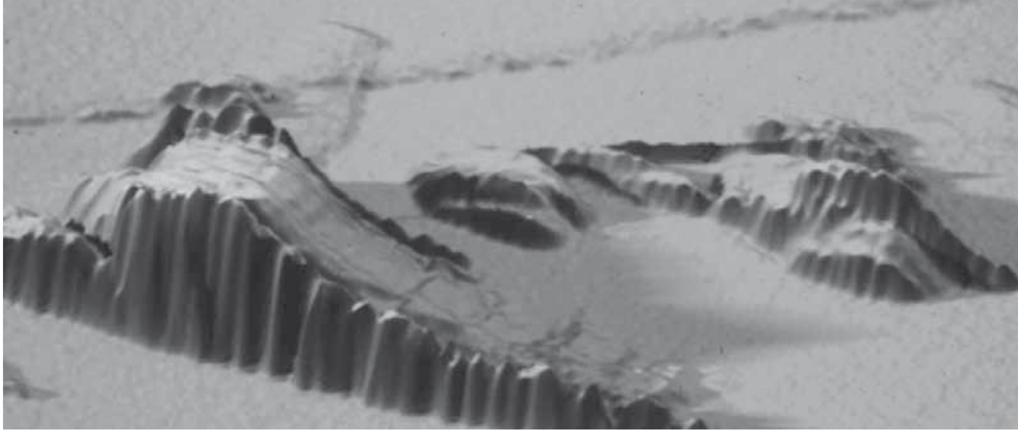
Switzerland as a location for nanotechnology strongly benefits from its high density of research facilities. Numerous nanotechnology applications have originated in these facilities run both by academic institutions as well as by private companies. Significant efforts made to develop new technologies and applications in the nanotechnology field have led to an increasing number of potential applications that are now leaving the laboratories and are being transformed into new products by companies.

In this context, Switzerland's long-standing tradition of investing in R&D is a clear asset. Currently about 3% of Switzerland's GDP are spent on R&D annually by public institutions and by companies, which is one of the highest R&D expenditures per capita and allows Switzerland to assert its position as one of the leading high-technology locations.

Around two thirds of the investments in R&D are made by private companies in Switzerland, a high number when compared with most other countries. These companies are convinced that R&D is a key value driver and spend up to 20% of their turn-over on research-based activities. As a result of this major investment, Switzerland has become the leading country in Europe regarding innovation, according to the European Innovation Scoreboard. This positive attitude towards R&D in Switzerland also prevails in the nanotechnology field.

### Nanotechnology hubs in Switzerland

In the public sector, both university laboratories and research institutes are active in the nanotechnology domain. In the private sector, an increasing number of start-ups focuses on nanotechnology, in addition to the significant number of large high-technology enterprises that are active in this field. These laboratories and companies are located throughout Switzerland, from the eastern border to the west, with three larger clusters in the greater Zurich area, around Basel, and in the western part of Switzerland.



The Basel area is a prominent example for the advantages offered by the proximity and cooperation between academic institutions, companies, and public authorities: R&D in nanotechnology plays an important role in companies and in public laboratories, such as the NCCR *Nanoscale Science* at the University of Basel, which is currently being integrated into the new Swiss Nanoscience Institute. While public institutions are very active in nanoscience, most of the nanotechnology R&D investment in the Basel area is made by companies, ranging from global players in the life sciences field, such as Actelion, Novartis and Roche, to those in the chemistry sector, e.g., BASF, Clariant and Lonza. In addition, many small and medium-sized enterprises, such as Rolic or Straumann, as well as an increasing number of start-ups, such as Nanosurf, add to the vitality of the Basel area in this field.

In the western part of Switzerland, R&D activities in nanotechnology are focused in public institution at the lake of Geneva, in Fribourg and in Neuchâtel: The EPFL, for instance, with its Center of Micronanotechnology traditionally is very active in technology transfer to commercialize the results of their research activities. In Fribourg, nanoscience efforts were recently boosted by the creation of the Adolf Merkle Institute at the University of Fribourg. At the Swiss Center for Electronics and Microtechnology in Neuchâtel, which specializes in micro- and nanotechnology, numerous activities aim at technology transfer projects with companies. Several companies have been set up in the vicinity of these research facilities, such as Solaronix and Lyncée Tec.

In the greater Zurich area, the ETH Zurich, Empa, the Paul Scherrer Institute and IBM Research – Zurich play a prominent role in the nanotechnology field. In this environment, numerous successful spin-offs and startups, such as Sensirion or Nanonis, have been created. An additional stimulus is expected from the recently created strategic public-private partnership between the ETH and IBM, which will lead to the construction of the so-called Nanoscale Exploratory Technology Laboratory (see p. 28).

**Wolf Zinkl, i-net BASEL**

# An international marketplace for nanotechnology companies

**Nanotechnology is a highly interdisciplinary field. Chemists, physicists and engineers from academia as well as from various industries, such as biotechnology, medical, pharmaceutical and others, cooperate in the development of novel applications. Switzerland with its long tradition in the engineering of precision instruments, in life sciences and in microtechnology has been able to position itself as an excellent hub for companies which are active in the domain of nanotechnology. Over the years, a favorable business environment has been created, in which also the financial industry has been involved quite early on.**

### Switzerland's focus on nanotechnology

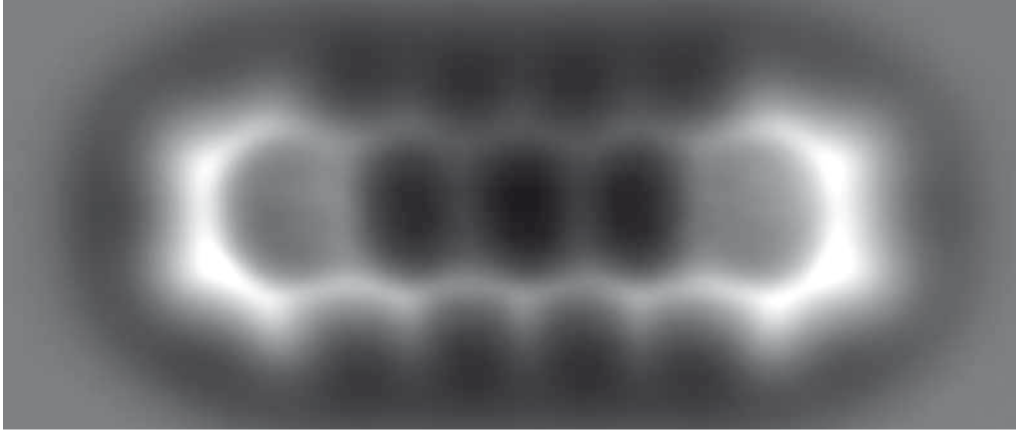
Companies that are active in nanotechnology benefit from Switzerland's longstanding and fruitful interaction between the well-established Swiss pharmaceutical, biotechnology and medical industries, the microtechnology sector, and the country's financial institutions.

Considering this background, it is natural that nanotechnology companies attract the interest of well-informed public and private investors, who over the years have acquired expertise in valuing these stocks.

Private as well as publicly listed companies benefit from the strong marketplace and liquidity offered by the Swiss financial hub. The latter is indeed attractive for domestic and foreign companies seeking capital: It is compact, closely networked, internationally oriented, and the local banks have strong financing and placing power.

**The Swiss financial marketplace in numbers:**

- international investor base and leading position in crossborder private banking worldwide
- global market share of crossborder private banking: 28%[1]
- total amount of assets in deposits: ca. CHF 4.208 bn[2]
  - foreign clients: 56.4%[2]
  - institutional investors: 64%[2]
  - invested in stocks and funds: 74.6%[2]
- a leading financial hub for equity-investing institutions



## The location of choice

As companies active in nanotechnology normally have a strong scientific and technical background, Switzerland with its highly skilled workforce and willingness to invest in research offers an ideal location fostering the growth and prosperity of such companies. Switzerland consistently ranks among the leaders in terms of global competitiveness: It holds the leading position in company spending on R&D[3], is first in the Global Competitiveness Index 2009–2010[4] and third in terms of innovation capacity[3].

Decisive factors for Switzerland's attractiveness include the country's outstanding educational system and the long tradition of Swiss scientists and engineers in the miniaturization of processes and structures, and their know-how in the manipulation of matter at the microscopic or even the nanoscopic level. Furthermore, Switzerland is ideal for international business because of the high quality and reliability of its infrastructure, its political and legal stability, innovation-driven economy, market-consistent regulatory standards, and liberal labor laws. Last but not least, also the country's competitive tax levels, its quality of living, and its openness toward the rest of the world all contribute to Switzerland's excellent reputation as an ideal high-technology location.

## Nanotechnology companies are a focal point for investors, analysts, and the media

For Swiss and foreign companies, SIX Swiss Exchange is the gateway to the international and domestic capital markets. A public offering and the listing of securities on SIX Swiss Exchange grant a company access to a highly experienced and financially potent circle of international investors. In view of the overseeable number of initial public offerings per year, which are effected in favorable market conditions, the attractive small number of transactions and the relatively compact universe of listed companies, any firm listed on SIX Swiss Exchange enjoys, and benefits from, a high degree of visibility and recognition among global investors, analysts, and the media. Moreover, Swiss investors have many years of experience in crossborder, sector-specific investment strategies and have focused on and competently understand the field of nanotechnology.

## Regulation: In line with international standards, but also in touch with the market

Another factor that facilitates the raising of capital in Switzerland is the close-to-the-market nature of SIX Swiss Exchange's regulatory provisions. Under the Swiss federal securities exchange legislation, SIX Swiss Exchange is empowered with self-regulatory authority and therefore has optimal leeway to combine a high level of investor protection with regulatory conditions that are more than acceptable from an issuer's point of view.

**Andrea Isler, SIX Swiss Exchange**

[1] Boston Consulting Group, Global Wealth Report, 2009
[2] Swiss National Bank, Monthly Statistics Bulletin, October 2009
[3] World Economic Forum, Executive Opinion Survey 2008, 2009
[4] The Global Competitiveness Report 2009–2010

# Economic and location promotion in Switzerland

More detailed information, online publications and the agenda of events are accessible at **www.osec.ch**

**Economic and location promotion form an integral part of Switzerland's economic policy. Various measures implemented at the local, regional and national level support companies in their economic activities and help foreign companies extend their activities to Switzerland.**

The political and economic environment is becoming an increasingly important factor in attracting international businesses. Hereby two aspects play a key role. First, the general political and economic framework needs to support and foster entrepreneurial activities. Second, decision makers in companies need to be sensitized to the quality and advantages of the location.

At the federal level, the Swiss State Secretariat for Economic Affairs has mandated Osec to take the operative responsibility for location and export promotion. Osec cooperates with public and private organizations around the world as well as manages the Business Network Switzerland. In Switzerland and in Liechtenstein, this network consists of the chambers of commerce and industry, trade and economic associations as well as the regional economic development offices. In addition, Osec partners with trade and professional associations, and with private specialists both in Switzerland and abroad.

### Assisting potential investors

Within the programme "Switzerland. Trade & Investment Promotion", Osec organizes and coordinates activities for promoting foreign investment in Switzerland. The programme opens the door to Switzerland and its authorities, and offers foreign companies administrative support during the location process. It comprises the "Location Step-by-Step" service which offers foreign investors in a three-step procedure:

- Initial information: The goal is to disseminate relevant, up-to-date information about Switzerland as a business location, be it in the form of documents, via the internet, the investor hotline, through media tours, or in person at information events.

- Basic consultation: This service helps answer very specific questions from foreign investors, and is offered in close collaboration with experts from the private sector and the network of regional economic development offices.

- Detailed consultation: In this step, Osec helps companies in finding access to ex perts that provide detailed, in-depth consulting, professional analyses, and de pendable contacts.

**Hans Jörg Jegge, Osec**

# Responsible risk management to allow sustainable growth

**A large number of consumer products and processes using nanotechnology have appeared in our everyday life in the past few years. So the question arises, which of these applications are unquestionably safe, and when or where do we have to exercise caution? A strategy based on risk evaluation and specific preventive measures will allow the development of sustainable applications of nanotechnology whilst ensuring public and political acceptance.**

The appearance of new materials or technologies on the market often leads to questions about health and environmental issues. Switzerland has a long tradition of assuring the safety and reliability of new materials. This is evidently also true in a field such as nanotechnology, where Switzerland has been able to create the basis for a responsible policy through the early promotion of specific research. A very important aspect of this strategy is the protection against work-related risks.

### Protecting workers from health problems

Technological progress increases the number of substances used in production processes. Nanoparticles are a typical example. For this reason, the Swiss government has decided to create a national action plan for the systematic protection of workers exposed to such new substances. Organizations like the Swiss National Accident Insurance Fund (Suva) are already very active in this field, thoroughly investigating potential risks to prevent possible harmful impacts on health and safety in the long term.

In April 2008, Switzerland adopted the "Action Plan on Synthetic Nanomaterials", which calls for a responsible development in the field of synthetic nanomaterials, taking into account economic, medical, and environmental aspects and concerns. This action plan has four principal objectives:

i) Creating favorable conditions for responsible manufacturing, handling, and disposal of synthetic nanoparticles, e.g. by establishing directives for industry and research,

ii) Promoting research on possible harmful effects of synthetic nanomaterials or nanotechnology products on the health and the environment, and elaborating international, standardized evaluation methods,

iii) Fostering a broad public dialogue about the promises and risks of nanotechnology, to avoid emotional debates such as those triggered by the appearance of genetically modified crops,

iv) Intensifying the partnership between industry and academia for the development and market launch of sustainable nanotechnology applications.

## Studies on possible toxic effects of nanoparticles

It is important to examine and understand the interaction between nanoparticles and organisms. One of the entry points of ultrafine particles into the organism is the respiratory system, with nanoparticles ultimately reaching the lung. Nanometer-sized particles can pass through biological barriers and deteriorate the organism. It has been realized that, in general, the toxicity of nanoparticles cannot be inferred from that of bigger particles of the same chemical composition. For instance, nanoparticles and ultrafine particles tend to agglomerate, which can make them lose their intended functionality. In a risk assessment, it is generally not the mass but the surface area and/or the number of nanoparticles that need to be considered to estimate potential exposure limits.

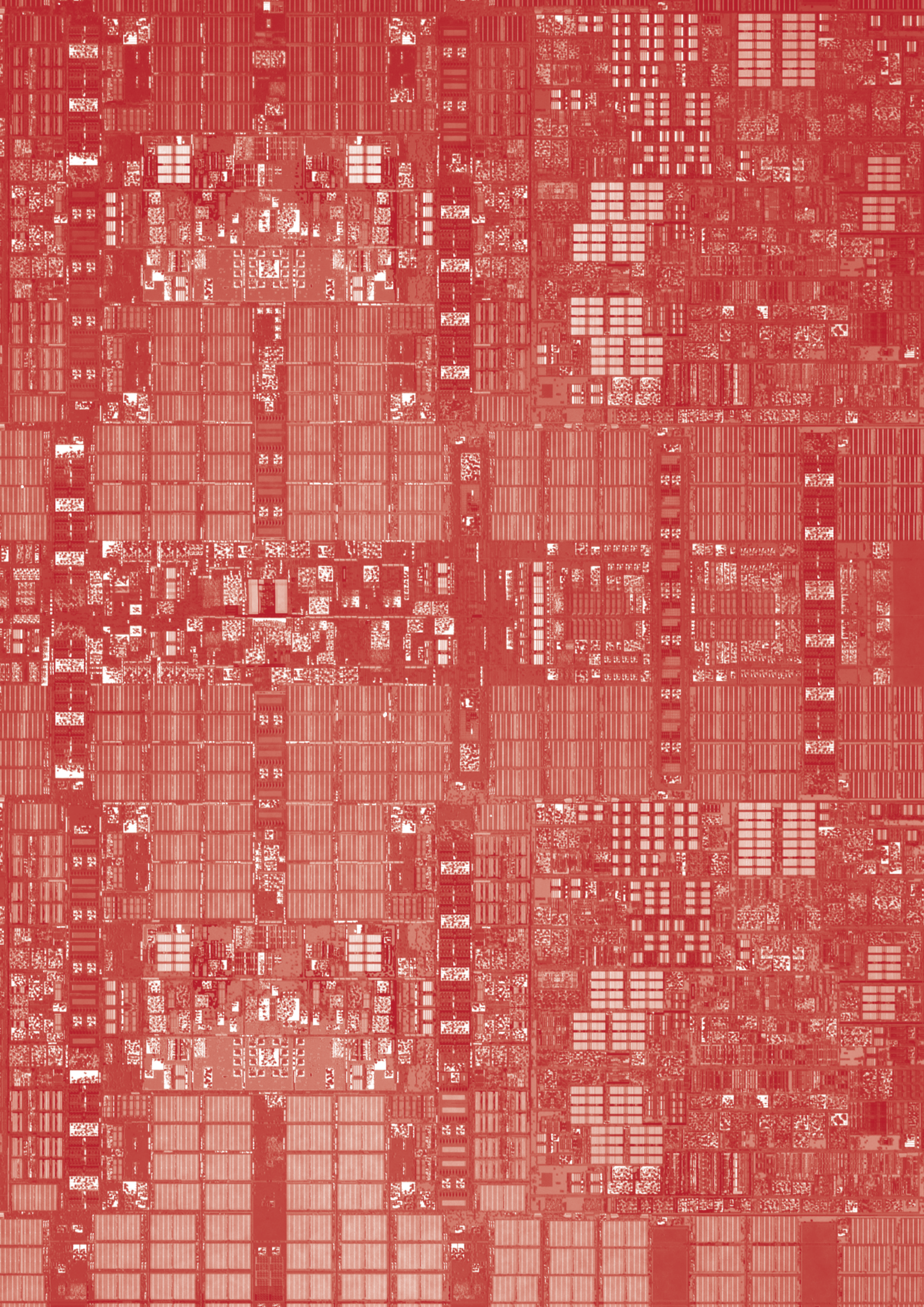
Suva as well as other Swiss institutions support several research projects in the nanotechnology field, such as a survey conducted by the Institute for Work and Health in Lausanne which assesses the use of nanoparticles in Swiss industry. In addition, Suva aims at establishing a nano-inventory. This inventory will provide the authorities with relevant information about the application of nanoparticles in the various industrial sectors, which in turn enables the development and establishment of adequate protection measures for people working with such particles.

## Worker protection in the future

In 2006, Switzerland was among the first countries in Europe to publish concrete recommendations related to nanoparticle exposure at work. Swiss institutions collaborate actively in international commissions, such as the NanoImpactNet program, to study the current state of nanotechnology and the most recent scientific developments relating to the effects of nanoparticles.

Technical and organizational protective measures will help to reduce the exposure risks of nanoparticles for each individual to an acceptable level and ensure the growth of the nanotechnology field. Manufacturers and suppliers of products that contain nanoparticles have to be made aware of the risks and of possible solutions. Information on technical or organizational measures, such as the use of sealed systems or the reduction of exposure levels and number of workers exposed, are already available on the Suva Internet platform.

**Marc Truffer, Suva**



# Open collaboration and innovation in the nano world

**Can a tiny structure, 10,000 times thinner than a human hair, provide us with the answers to some of the world's greatest challenges? Scientists at IBM Research – Zurich and the ETH Zurich think the answer is yes, but they know they cannot explore the vast world of nanoscience alone – partnerships and collaboration are essential.**

Former IBM chairman Thomas J. Watson Jr. said it best: "Advances in the various fields of human endeavor are due, to a large extent, to the cooperation of the best brains and best talents available everywhere." Collaborating with partners is not a new concept, but innovating with partners under the same roof in a shared laboratory is literally groundbreaking. In fact, IBM and the ETH Zurich broke ground in 2009 for a new $90-million collaborative laboratory on the IBM campus in Rüschlikon to jointly explore nanoscience and nanotechnology.

### In the vanguard of research centers

Appropriately named, the new Nanoscale Exploratory Technology Laboratory raises the bar for collaborative research in nanoscience. Starting operations in 2011, the laboratory will provide nearly 1000 $m^2$ of cleanroom space, the most advanced tools, and specially shielded laboratories for conducting highly sensitive experiments, which provide isolation from mechanical vibrations, temperature variations and electromagnetic interference. More than 100 scientists will make use of the facility, with room to grow, as IBM continues to look for additional qualified partners.

Under the multi-year collaboration, scientists and engineers from the two institutions will join forces to conduct research into new atomic- and molecular-scale structures and devices to enhance information technologies, as well as to discover and understand their scientific foundations. More specifically, research topics will include nanowires, organic and molecular electronics, nano-photonics, spintronics, nanosensors, nano-electromechanical systems, and nanobiology. The new laboratory will enable research on new device concepts exploiting quantum-mechanical effects for computing and sensing, and contribute to resolving upcoming challenges in manufacturing through approaches such as directed self-assembly of nanostructures, the use of functional materials and 3D integration.

While the partners are free to independently pursue their own research agendas, collaboration means that some inventions will inevitably be shared, in which case both institutions will be able to exploit the joint intellectual property independently.

The new laboratory is expected to continue the success story of IBM Research – Zurich, the birthplace of nanoscience where the study of nanoscience was brought to reality when Gerd Binnig and Heinrich Rohrer developed the pioneering scanning tunneling microscope, which enabled the first look at surfaces at the atomic level. Ever since, IBM researchers have been pushing the frontiers of scientific knowledge and manipulating matter down to the level of individual atoms – most recently announcing the ability to measure the charge states of atoms and, for the first time, resolving the chemical structure of a molecule with atomic resolution.

# On the pulse of the nano world

**The region of Basel is one of the renowned research locations in the nano-domain. It owes its reputation to a multitude of research groups that work across various disciplines at a high level. The scientists Christian Schönenberger and Helma Wennemers work at the University of Basel and give some insights into the challenges and opportunities of working in the field of nanoscience.**

**Prof. Wennemers, Prof. Schönenberger: in your opinion, what characterises research in the field of nanoscience?**

H.W.: Nanoscience brings together scientists and engineers from a host of different disciplines. This is a natural consequence of the questions that are addressed in this field, which can only be tackled if scientists with different backgrounds collaborate. As a result, discussions and an exchange of views beyond the boundaries of one's own scientific discipline take place regularly. This is exciting, and great fun, but of course also requires a certain open-mindedness and ability to talk and interact with colleagues from other fields.

C.S.: In my opinion, another characteristic of the nano-domain is the great potential that this area offers technologically. Today, we are able to examine and influence structures at both the atomic and the molecular level. This offers extensive possibilities for developing applications that were not even conceivable until now. An important prerequisite for this is the advances in analysis and imaging methods – particularly scanning probe microscopy – which to a large extent was made possible by research groups in Switzerland.

**Research in the field of nanoscience has existed for some time. In the past few years, however, a marked increase in the attention paid by the public to developments in this field has been observed. Are you surprised by this?**

C.S.: No. In my opinion, the attention is justified because developments in the nano-domain have an enormous potential with regards to applications as has been demonstrated in the past few years. We should try to use the opportunities that are offered by the nano-domain for research and commercial applications. However, we should not forget that not all problems can be solved with the help of nanotechnology. In this context, it is important that the current attention and enthusiasm for the nano-domain will not turn into disappointment or even antipathy in the future when it becomes clear that not all hopes can be fulfilled, as has already happened with other technologies such as biotechnology.

**Quite early on, Switzerland began to investigate the potential effects of nanotechnology on humans and the environment in order to prevent possible risks as well as fears in the general public. Some examples are technological impact assessment and analyses of safety at work when dealing with nanomaterials. Do you find the handling of nanotechnology in Switzerland adequate?**

C.S.: Possible dangers exist in all technologies. The population of Switzerland is, however, able to differentiate between dangers that could be inherent in nanotechnology as such and those that may result from an incorrect handling of useful applications and that could be avoided through appropriate precautionary measures. In this context, I am satisfied with the precautionary measures that Switzerland has taken to minimize the risks associated with dealing with nanotechnology. It is good that possible problems are discussed openly and the concerns of the population are taken seriously. In this respect, the National Research Programme on the opportunities and risks of nanomaterials can certainly make an important contribution.

H.W.: I also think that risks in connection with nanotechnology cannot be completely eliminated. As for any other technology, we must identify where the dangers of nanotechnology applications could lie and take appropriate measures. In addition to implementing safety precautions, we are responsible for entering into an open dialogue with all stakeholders, including the public.

**How do you find the research environment and the funding possibilities for your work in Switzerland?**

C.S.: I have been working in the field of nanoscience for many years and appreciate the positive research environment in Switzerland. The excellent facilities at the research institutions make it possible to work very successfully. In addition, the reliable and research-friendly conditions are helpful. Another important reason for the good research climate is the research and funding programmes, which allow researchers to concentrate on their research work and to develop new fields. In this context, by establishing the National Centres of Competence in Research and the National Research Programmes the Swiss National Science Foundation has created vehicles that facilitate the setting of focal points in research, the creation of networks for particular research fields and also promote the cooperation between individual researchers. An example of this targeted funding and structural support is the NCCR *Nanoscale Science* in Basel, which combines the research of various Swiss research institutes in the field of nanoscience.

H.W.: In my opinion, the research funding in Switzerland is one of the best worldwide. The national funding institutions show a lot of good judgement with regards to the needs of researchers. Most notably, the mistake is not made that has been made in many other countries, namely, that the funding of individual researchers is increasingly being eliminated. Individual funding is particularly important so that a researcher can gain expertise in a scientific area and later work together with others in joint projects.

**Did these advantages help you to decide to come to Switzerland after your research career abroad?**

H.W.: I had various offers in other countries, and I decided to come to Basel because I discovered a very open-minded scientific environment in which excellent research is carried out and in which researchers interact with each other in a very friendly and supportive way. One aspect of Switzerland as a research location in general that I also appreciate is the comparatively low level of bureaucracy as well as the possibility of being able to use research funding flexibly. I do not regret the decision to come to Switzerland and to Basel.

**Portrait**

Christian Schönenberger is a full professor for experimental physics at the University of Basel and directs the NCCR *Nanoscale Science* and the Swiss Nanoscience Institute. His research group focuses on charge transport in nanoscale devices.

Helma Wennemers is an associate professor for organic chemistry at the University of Basel. She heads a group that specialises in peptides and their application, ranging from asymmetric catalysis and supramolecular assemblies to silver nanoparticles.

# The CSEM concept: Smoothing the way from the laboratory to real-world applications

To address the challenges of micro- and nanotechnology transfer, the CSEM has formed the Heterogeneous Technology Alliance (HTA) with the French Commission for Atomic Energy, the German Fraunhofer Society and the VTT Technical Research Centre of Finland. The HTA aims to carry out joint research projects and to develop innovative solutions and products for industry. Cooperation in the HTA in general is organised in joint focal areas of research and through joint projects. The alliance pools the expertise of the respective institutions to cover the entire value chain from applied research to development and engineering at the system level and finally production. The HTA also created 4-LABS in Geneva, a service company that provides a single entry point to the HTA and actively promotes the members' capabilities, expertise and technologies to foster the dissemination of innovative technologies from HTA members to corporate clients.

**Harry Heinzelmann heads the nanotechnology division at CSEM, a non-profit-making company for applied research that has been active in the field of micro- and nanotechnology for many years. In the following interview, he gives a brief overview of the working methods and characteristics of this institution.**

**Mr. Heinzelmann, what differentiates your approach with regard to research and development in the field of nanotechnology from that of other research institutions and universities?**

Universities have a very clear mission to teach and carry out research, mostly concerning basic research. We, however, carry out applied rather than basic research. With this is mind, it is primarily the practical use – or rather the market – that judges the quality of our work. This practical approach, as opposed to an evaluation by other researchers - as is common in the academic field – is rather attractive, in my personal view.

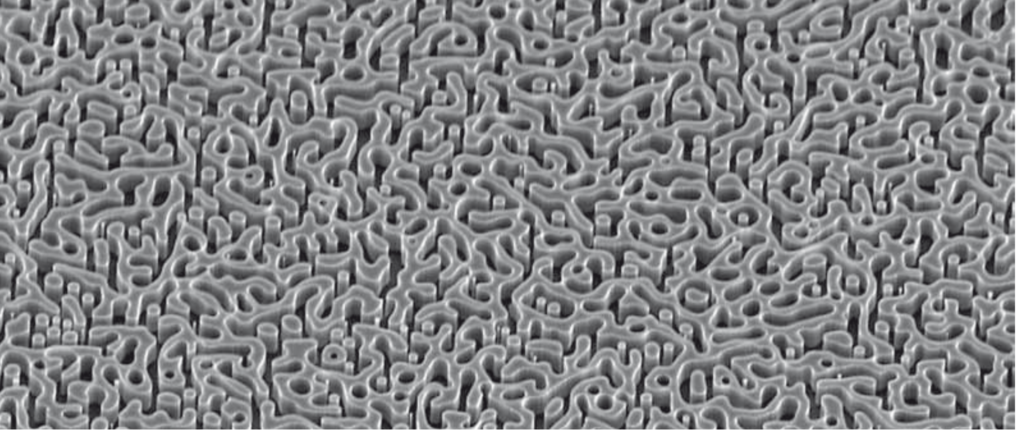
We investigate topics that have the potential to be practically applied in the economy. As a rule, we only take something up once a phenomenon has been scientifically examined. We then improve the parameters in order to optimize and develop practical technologies. Since we are a company, we can communicate as equals with industry partners and, thanks to our lean decision-making process, we are in a position to react relatively fast to newly emerging trends.

**It seems that there is another important difference in comparison to other research institutions. Your institute is actively trying to introduce new technologies to the market.**

Yes, although usually with partners and very rarely on our own. We try to make an educated guess regarding which technologies will become important in the future and then use this to define the technologies relevant for us. Then, based on the strategy we defined, we launch our research projects, and often already seeking active cooperations with partners from basic science or industry early on in the process. Development projects with industry partners usually follow later on so that we can develop concrete solutions and pass these on to our partners. Should this not be possible for a particular technology we consider worth developing, we may set up a start-up company ourselves.

**Your approach seems to supplement other research and commercialization approaches that exist in Switzerland.**

That is exactly our line of thought. We do not want to compete with others, but rather supplement existing efforts and fill a gap. Industry often does not want or cannot afford to pursue basic research, whereas universities cannot pursue a business opportunity to full maturity without negative impact on their mission of education and basic research. Therefore, there needs to be someone who covers the application-orientated area.



**Can you give an example of your work in the field of nanotechnology?**
One interesting focus of our work at CSEM is self-organisation, i.e. the fact that under certain circumstances, molecular systems will form a characteristic structure by themselves. For example, so-called block copolymers in solution can be placed on a surface on which they will then assemble themselves into a characteristic structure that is about 50 nanometres in size. It would be extremely difficult and time-consuming to manufacture this structure using other methods. In addition, it is possible to influence the shape of this structure, say, make it bigger or smaller, denser or taller. Such a self-organising structure forms a unique pattern. Therefore, this can be used as a tamper-proof security feature for valuable objects, for example, or as authentication on pharmaceutical products to protect consumers from dangerous counterfeits.

**How do you proceed in taking an idea from the laboratory to finding potential applications? Do you sit together with your team and think about possible applications, or are there other stimuli to fuel this transition?**
For us, both the exchange of ideas within our team and the cooperation with other CSEM departments are important. In the case of the self-organising structures, for example, we collaborated with departments that had already worked in optical pattern recognition. This kind of horizontal cooperation is an integral part of CSEM's concept, and an important part of our research budget is used for it. Nanotechnology is very much an interdisciplinary technology, and thus our concept fits very well.

**How do you judge the importance of nanotechnology for other fields of research?**
Nanotechnology is already an important research area and will continue to gain in importance. Switzerland understood early on that nanoscience should be promoted. Today, there is an active nanoscience research community, and almost all universities are working in this field.

In comparison with other countries, Switzerland is in a very good position, and is also very broadly positioned with regard to applications. Commercially successful materials today are primarily those that contain nano-components. Instruments are another success area, particularly scanning probe microscopy. There are also applications that were established a long time ago, but now are being attributed to nanotechnology, such as, for example, the circuits in electronic components. Other areas still are largely "work in progress", such as applications in the field of medical technology. I believe that we will clearly see more nanotechnology applications in five years' time.

**Would you say that nanotechnology derives its economic importance more from the creation of new applications than from the improvement of existing products?**
Nanotechnology will definitely play a key role in improving existing products and processes; here interesting developments are already happening today. Accordingly, an important part of nanotechnology developments will take place in companies already in existence. But we will also see truly novel and revolutionary applications, if not tomorrow, then the day after.

**Portrait**
Harry Heinzelmann is Vice President and Head of the Division Nanotechnology and Life Sciences at CSEM in Neuchâtel. CSEM – the Swiss Center for Electronics and Microtechnology – is a Swiss research and development centre managed like an enterprise, and owned by Swiss domestic companies as well as government bodies. Researchers and developers from a wide variety of fields work on projects in the areas of micro- and nanotechnology, micro-electronics, system engineering and communication technologies, amongst others.

# Small particles – huge possibilities: Nanotechnology as an innovation pool for large and small companies

**It has often been claimed that in industrial countries the textile industry hardly has a future. However, Schoeller Textil AG has proven that a family business can be successful through specialisation and innovative concepts. Hans-Jürgen Hübner and Hans U. Kohn describe what the basis of the success of Schoeller Textil is.**

**In your opinion, what differentiates Schoeller Textil from other companies in the textile industry?**

H.-J.H.: Our advantage is the fact that Schoeller Textil is an open and innovative family business, in which the pathways between employees are short, whereas in large companies, processes can often be very static and cumbersome.

In addition, research and development play a very large role at Schoeller Textil. However, we can only afford this very cost-intensive area, if we succeed in commercializing the technologies developed as optimally as possible. We do so in the form of licences or within a joint venture so that we can recover our costs and develop new markets or products to which we would otherwise have no easy access. Hereby, our subsidiary company, Schoeller Technologies, plays a very important role, especially in commercialising our new developments.

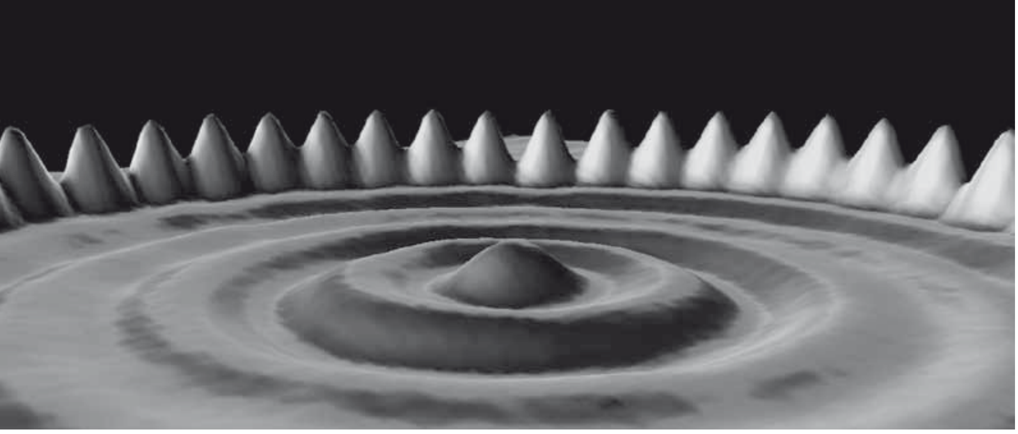
Ever since the reorientation of our company, which was initiated in the early 80s, long term perspective processes have been playing an important role. For instance, ten years ago, nanotechnology has allowed us to be successful in an increasingly difficult environment. In the reorientation phase, we bore in mind that as a Swiss company, we can only survive if we are innovative. An important role hereby played the bluesign® standard, which means a commitment to sustainability throughout all production processes and what we have embraced as our company philosophy. In this context, we investigated possibilities beyond the water- and dirt-repellent materials available at the time, and used nanotechnology to improve our textiles. This step proved to be very successful, and led to the discovery of various other applications and also triggered developments in other areas.

**Where do you see the future of the textile industry in a country with high wages like Switzerland?**

H.-J.H.: In my opinion, health will be the topic of the future. Every person wears approximately 3m$^2$ of textiles on their skin, with which we can do a lot. For example, we are in the midst of developing textiles equipped with nanocontainers that can be filled with and discharge substances. These substances can then be gradually transferred to the skin to improve health and wellbeing. Such materials can be used in special-purpose as well as everyday clothing. We have high expectations for this and similar developments.

**There are at least two concepts with which SMEs can compete in research- and capital-intensive industries: they look for a bigger partner in order to be able to continue working or they focus on research and development, then licence and thus spread the technology. Which concept has Schoeller Textil chosen?**

H.U.K.: Many SMEs decide to go for one large partner. However, we decided to look instead for several partners, and in fact, in each case we look for the partners most suitable for a specific Schoeller technology. Our licensing business is therefore global. Thus we need partners of a certain size to commercialise the technologies worldwide and to deliver the products, service and the training for these technologies. In addition, it is important to guarantee the quality control locally. In the marketing of NanoSphere®, our first nanotechnology-based development, we found an ideal partner with Clariant.



In development questions, in contrast, we act very flexibly at the beginning. Often it is small, flexible and specialized partners or universities that help us develop a marketable product in cooperation with our employees and bring it up to market-readiness.
H.-J.H.: In addition, there are CTI projects in Switzerland that help SMEs with the transition from research to a market-ready or licensable product. Cooperation takes place with numerous research institutions, some of which are in quite close proximity. For example, locally there is Empa in St Gallen, which has vast experience in the textile industry and has been active in the field of nanotechnology for many years. The geographical proximity to such institutions plays a major role for us, and was one of the reasons why we decided in the reorientation phase of our company that Switzerland should remain the location of our headquarters.

**You made a careful and deliberate decision to protect technologies and to commercialise them via Schoeller Technologies as optimally as possible by means of licensing. What exactly motivated you to choose this approach?**
H.U.K.: Basically, what we are talking about is a highly structured sharing of know-how. The licensing must be handled in a controlled way, as otherwise the advantage for the licensor would be very small or could even be risky. Therefore, we need to manage our intellectual property well, which also encompasses implementing a deliberate and mature trademark and patent strategy. This includes developing, maintaining and also enforcing proprietary rights. There are also areas in which we deliberately decide against using a proprietary right if the context demands it or if it makes more sense for us. In general, we have to weigh the expected financial benefits against the potential costs of protecting and enforcing our rights.

Therefore, we look at each new development individually to see whether it should be protected as proprietary. Of course, an important aspect is whether it is something that will be used in a cooperation with others or internally in our own company.

Another and very important part of our strategy is marketing, which has to be very well thought through, especially for an SME with limited marketing possibilities. So, for example, when we introduce a new technology, it is much more important for us to work together with high-profile partners than high-volume partners so that we generate a high awareness of the new development as quickly as possible. Once this has been achieved, the market volume will largely grow automatically. In this way, we are able to remain innovative and successful despite the limitation of being an SME.


**Portrait**
Schoeller Textil AG is a globally-active, high-technology company in the textile industry that specialises in the development and manufacturing of sophisticated functional fabrics and innovative textile technologies for the clothing industry. Schoeller Textil introduced nanotechnology quite early on to develop textiles with new and innovative properties, such as the well-known NanoSphere® fabrics.

Hans-Jürgen Hübner is CEO of Schoeller Textil. Hans U. Kohn is COO of the licensing company Schoeller Technologies, which is responsible for the exploitation of Schoeller Textil technologies.

For further information about Schoeller Textil AG please visit:
**www.schoeller-textiles.com**

# Nanotechnology to improve the score

**Nanotechnology is often considered to be a technology that can only be employed by highly specialised companies with extensive expertise in the field. Composites Busch SA has shown that nanotechnology can be successfully integrated into existing processes to improve products and strengthen competitiveness. Ahmet Muderris, Managing Director at Composites Busch SA, explains.**

**Mr. Muderris, what brought Composites Busch SA, a medium-sized company, to use nanotechnology for its products?**
Our company was established in 1988 and initially produced composite-based vanes for our parent company, Busch Vacuum International, headquartered in Germany. Only later did we decide to diversify our portfolio of composite-based products, which today ranges from products for the aerospace sector to medical devices, mechanical applications, luxury goods, and sports equipment.

It is for the sports equipment sector that we first investigated the use of nanotechnology. Busch Composites SA was the first company to apply composite technology for hockey sticks. Even though our market position is still unique in that we produce one-piece sticks having superior performance over multi-part sticks, we decided to improve our product. To benefit from new ideas and a fresh approach, we initiated a collaboration with the ETH Zurich. The two years project resulted in new construction designs for hockey sticks. Partners in this project were also suppliers of raw materials, such as Huntsman Advanced Materials in Basel. They suggested us using their nanoparticle-enhanced Araldite® NanoTech Composite system instead of standard resin. This approach proved to be very successful because it improves the impact resistance and the vibration behavior of the stick. Needless to say, the nanoparticle-enhanced solution was integrated into our production line.

**Does the production of the new nanotechnology-based stick require your company to adjust your manufacturing processes or to meet specific safety requirements?**
No. Huntsman Advanced Materials supplies us with a ready-to-use system which can be easily integrated into the production process. The nanoparticles are securely bound into the resin so that no extra precautionary measures have to be taken. In fact, we continue to work using exactly the same methods and infrastructure as before, which is a critical success factor.

**Composites Busch was established in Switzerland and remains loyal to the country as a manufacturing and business location. What are the advantages for a company in the high-technology field to be in Switzerland?**
There is a number of reasons for a high-technology-based company to opt for Switzerland. From my point of view, two important assets of this country are the business-friendly attitude of the public authorities and the highly qualified and dedicated workforce.

Switzerland is not only a rather small country with excellent general infrastructure and highly skilled employees, but also a country whose regional authorities understand your problems, and are service- and solution-oriented – something that can hardly be found elsewhere in the world. For example, the minister of economic affairs of our regional authorities does not hesitate to visit companies to discuss the challenges they face and their options. In other words: the regional authorities are close to the people and companies.

Secondly, Switzerland has a long-standing tradition of precision and quality workmanship. This attitude is extremely valuable for technology-based companies, where high quality is a prerequisite for success and considerable efforts are made to achieve and maintain highest standards in processes and products. This traditional focus on the importance of quality helps companies in Switzerland to maintain an excellent standard of quality and gives them a valuable edge on the highly competitive world market.

Huntsman Advanced Materials has a long tradition of developing polymer systems that help customers to overcome specific challenges in their areas of expertise. Amongst the various fields of activities, the company tailors polymer systems for the emerging nanotechnology market for more than a decade now, turning knowledge from research into industrially applicable solutions. With its ample technical expertise in the field of nanotechnology, Huntsman enables customers to integrate its ready-to-use resins directly into the manufacturing process. The development of the hockey stick with Composites Busch SA is a good example for the successful application of a nanoparticle-enhanced resin system, demonstrating its outstanding properties in terms of toughening and damping performance.

For more information, see
**www.huntsman.com/advanced_materials**

**Portrait**
Ahmet Muderris is Managing Director at Composites Busch SA, which is part of Busch Vacuum International. Composites Busch SA specialises in the processing of composite materials. Focal areas are products for medical devices and the machinery and watch industries, as well as sports equipment. In addition, the company is active in the Direct Laser Sintering field, with special emphasis on the prototyping and production of small series or limited editions without mechanical tools and geometric constraints. Composites Busch SA has been headquartered in Porrentruy since 1988.

For further information about Composites Busch SA please visit:
**www.compositesbusch.ch**

# List of illustrations

# List of contributors

**Rolf Allenspach** manages IBM Research - Zurich's research efforts related to the physics of nanoscale systems, and **Paul Seidler** is responsible for nanotechnology business and partnership opportunities for the new nanotechnology center. IBM Research – Zurich is the European branch of IBM Research. The spectrum of activities at the Zurich laboratory ranges from exploratory research to the development of computer systems and software to the designing of novel business models and services.
**www.zurich.ibm.com**

**Gabriele Dobenecker** is head of the Marketing, Knowledge and Technology Transfer Section at Empa. Empa is an interdisciplinary research and service institution for material sciences and technology development within the ETH domain. The aim of Empa's activities is to transform research results and scientific knowledge into marketable innovations. Nanotechnology is one of its main fields of activity.
**www.empa.ch**

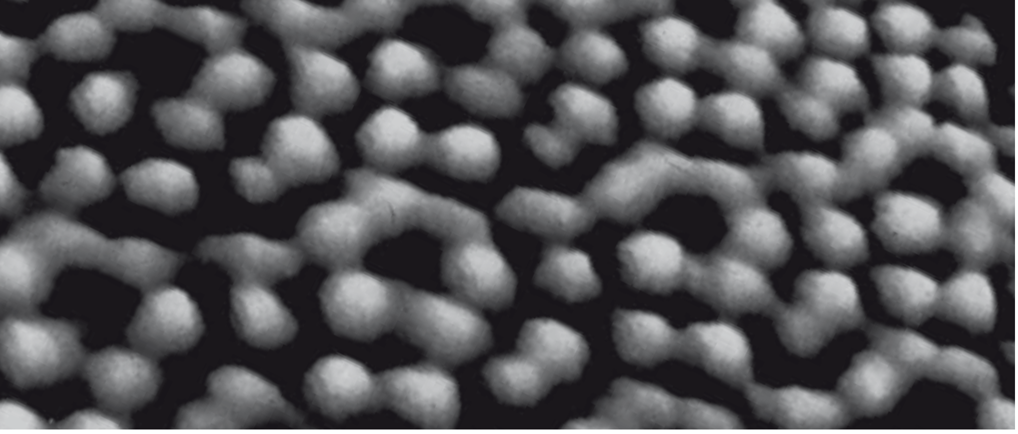
**Adrian Ionescu** is an associate professor at the Swiss Federal Institute of Technology, Lausanne (EPFL). He heads the Nanoelectronic Devices group (NANOLAB), which is active in the field of micro/nanoelectronics with special emphasis on the technology, design and modelling of nanoscale solid-state devices, radio-frequency microelectromechanical devices, and optoelectronic devices. The group explores new materials, novel fabrication techniques, and novel device concepts for future nanoelectronic systems.
**www.epfl.ch**

**Andrea Isler** is Relationship Manager of Issuer Relations at SIX Swiss Exchange, which is Switzerland's principal stock exchange. Switzerland's leading position in crossborder private banking, the remarkable placing power of its banks, and the general attractiveness of Switzerland as a financial marketplace make the SIX Swiss Exchange attractive for both domestic and foreign companies.
**www.six-swiss-exchange.com**

**Helen Jaisli** is Scientific Officer at the Swiss National Science Foundation (SNSF). The SNSF is the largest Swiss agency for promoting scientific research. Mandated by the Swiss Federal government, it supports all scientific disciplines, ranging from philosophy and biology to nanoscience and medicine.
**www.snf.ch**

**Hans Jörg Jegge** is head of location promotion at Osec, which is Switzerland's umbrella organisation for the promotion of exports, imports and investments, as well as for the promotion of Switzerland as a business location.
**www.osec.ch**

**Heinz Müller** and **Christian Soltmann** are patent experts at the Swiss Federal Institute of Intellectual Property (IPI). The IPI is the Swiss federal government's premier centre of competence for all issues concerning patents, trademarks, certificates of origin, design protection and copyright.
**www.ige.ch**



**Peter Schurtenberger** and **Christoph Weder** are full professors at the Adolphe Merkle Institute (AMI) which is devoted to pure and applied nanoscience. It is associated with the University of Fribourg and financed by the private Adolphe Merkle Foundation. The institute's research specializes in the creation, study, and application of soft nanomaterials using bottom-up concepts such as self-assembly and other "fabless" strategies.
**www.am-institute.ch**

**Marc Truffer** is head of the division "Sécurité au travail pour la Suisse romande" at Suva. As a financially independent body incorporated under Swiss public law, Suva insures some 110,000 companies and two million employees and unemployed people against the consequences of accidents and occupational diseases. Its services cover prevention, insurance, and rehabilitation. Suva's social partners – employers and employees – are represented in its Board of Directors, as is the Swiss federal government.
**www.suva.ch**

**Patrick Vock** works at the State Secretariat for Education and Research (SER) within the Federal Department of Home Affairs. The SER is the federal government's specialised agency for national and international matters concerning general and university education, research and space.
**www.sbf.admin.ch**

**Wolf Zinkl** is CEO at COGIT AG and involved with i-net BASEL, which aims to promote innovation in the Basel region. It supports and brings forward promising developments in specific fields of technology. i-net BASEL has started i-net BASEL Nano which is a public-private-partnership in Northwestern Switzerland (Aargau, Basel, Jura) bringing together suppliers, customers and research institutions in the nanotechnology field. i-net BASEL Nano aims to foster collaborative innovation and to accelerate value creation in industry in selected fields of technology, such as nanotechnology.
**www.inet-basel.ch**

# Facts and figures

Figure 1: Number of nanotechnology-related inventions which were filed for patent protection, per capita [1]

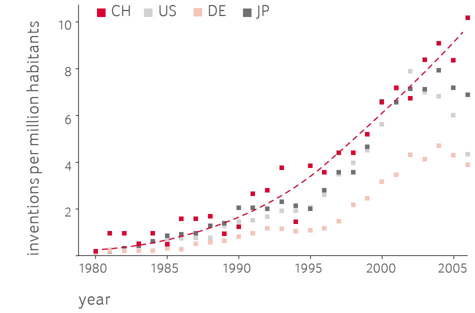



Figure 2: Number of nanotechnology-related inventions which were filed for patent protection, GDP normalised (current prices, purchasing power parity)

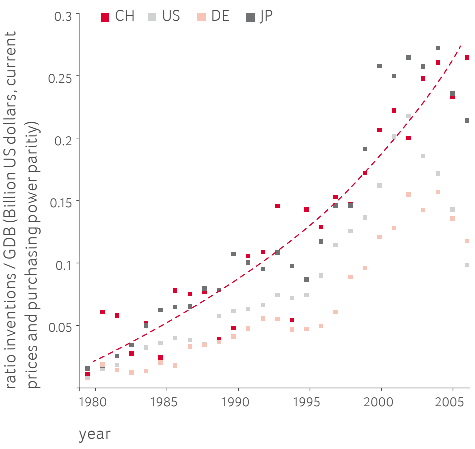
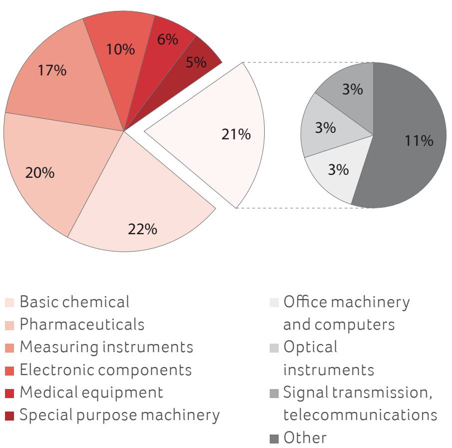



Figure 3: Sector distribution of Swiss patent applicants in the nanotechnology field [2]




## The Swiss nanotechnology sector is constantly growing

Nanotechnology is widely considered a rapidly developing and, from an economic point of view, increasingly important field of technology. Switzerland, with its long tradition in the construction of precision instruments and exquisite products, has recognized the importance and commercial potential of nanotechnology early on. Swiss scientists and engineers were and are pioneers in the miniaturisation of processes and structures, which shows in the early upswing of nanotechnology-related patent applications from Swiss inventors and applicants. The country consistently ranks among the leaders in terms of innovation activity, as evidenced by the high number of patent applications per capita (figure 1).

## Swiss nanotechnology landscape

ETH Zurich has started a study on nanotechnology with the objective of improving the economic data on the nanotechnology field in Switzerland and of developing a systematic approach to technology exploration while at the same time providing an overview of how nanotechnology is used in Swiss companies. The project is a cooperation of the ETH Zurich, the KOF Swiss Economic Institute, and the Swiss Federal Institute of Intellectual Property. Results of the study will help to address the field of nanotechnology in future innovation surveys of the KOF Swiss Economic Institute.

The study revealed a first picture of nanotechnology developments in Switzerland. Although groundbreaking manipulation techniques, such as the scanning tunneling microscope and the atomic force microscope, were developed in Switzerland, nanotechnology activities have clearly extended into the other segments. New products and improving existing products are the most common motifs for pursuing nanotechnology. The majority of firms stated that nanotechnology did not significantly influence their manufacturing costs.

[1] The estimation was based on patent documents which were identified by the European Patent Office as nanotechnology-related. The documents were pooled by means of World Patent Index data and normalised. Data for 2007–2009 was disregarded due to potential artefacts owing to the patent prosecution process and data handling.
[2] Source: A. McGibbon, Determining the Swiss nanotechnology landscape: A systematic approach to technology exploration, ETH Zurich, 2009

EMPA Materials Science & Technology

IBM

Eidgenössisches Institut für Geistiges Eigentum
Institut Fédéral de la Propriété Intellectuelle
Istituto Federale della Proprietà Intellettuale
Swiss Federal Institute of Intellectual Property

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA
State Secretariat for Education and Research SER

SIX SWISS EXCHANGE

suva

adolphe merkle institute
excellence in pure and applied nanoscience

BaselArea

csem

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

i-net BASEL

osec Business Network Switzerland

FNSNF Swiss National Science Foundation


## Impressum

**Steering committee**
Rolf Allenspach (IBM-Research Zurich)
Florence Amez-Droz (CSEM)
Gabriele Dobenecker (Empa)
Harry Heinzelmann (CSEM)
Adrian Ionescu (NANOLAB/Swiss Federal Institute of Technology Lausanne)
Andrea Isler (SIX Swiss Exchange)
Helen Jaisli (Swiss National Science Foundation)
Hans Jörg Jegge (Osec)
Christof Klöpper (Office of Economy and Labour of Basel-Stadt)
Heinz Müller (Swiss Federal Institute of Intellectual Property)
Peter Schurtenberger (Adolphe Merkle Institute)
Christian Soltmann (Swiss Federal Institute of Intellectual Property)
Marc Truffer (Suva)
Patrick Vock (State Secretariat for Education and Research)
Christoph Weder (Adolphe Merkle Institute)
Wolf Zinkl (i-net BASEL)

**Project management**
Christian Soltmann

**Editorial staff**
Rolf Allenspach, Heinz Müller,
Christian Soltmann, Wolf Zinkl

**Editorial assistance**
Charlotte Bolliger

**Concept, layout and design**
Frey Communications SA
TGG Hafen Senn Stieger

**Print**
Cavelti AG

**Illustrations courtesy of**
Adolphe Merkle Institute (page 11)
CSEM (page 32)
IBM-Research Zurich (pages 5, 7, 9, 15, 17, 19, 21, 23, 27, 30, 34, 38)
Schoeller Textil AG (title page)
State Secretariat for Education and Research (page 13)