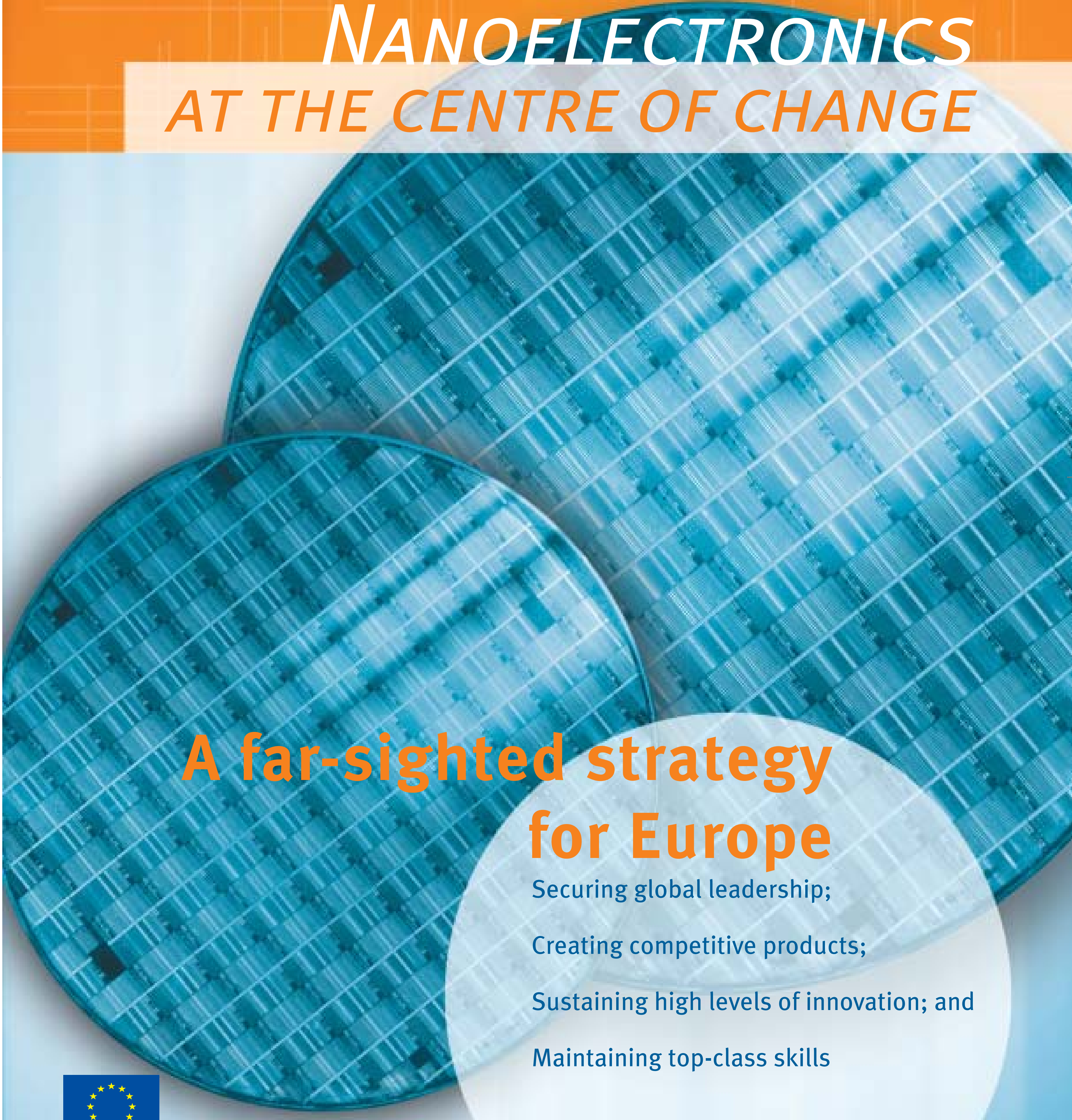
VISION 2020

NANOELECTRONICS

AT THE CENTRE OF CHANGE



A far-sighted strategy for Europe

Securing global leadership;

Creating competitive products;

Sustaining high levels of innovation; and

Maintaining top-class skills

European Commission

REPORT OF THE HIGH LEVEL GROUP - JUNE 2004

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Foreword

In the 17th century, Blaise Pascal claimed that the infinitely small is made of an infinity of universes, in which each has its own firmament, planets and earth, in the same proportion as the visible world, and expanding into the infinitely big. His vision, in our days of nano-scale technologies, is proving increasingly right.

In the 20th century, we gradually built up such an expertise. By manipulating some of those infinitely small universes, we were able to develop a very large industrial sector, now at the heart of the Information Society: that is microelectronics and its related technologies. And today, when we talk about nanoelectronics, we are considering devices that are 1000 times smaller than this. Research is constantly pushing back the physical limits of electronics technology at an amazingly steady pace.

The growing success of the European players in micro- and nanoelectronics is well known. European collaborative research programmes have contributed consistently to the development of this industry over the past 20 years. This success is boosting our determination to improve European competitiveness even further in the field. The positive climate resulting from European beacons such as the Lisbon and Barcelona objectives of the European Council, the *e*Europe action plan and the Initiative for Growth is setting the political impetus for further ambitious action in this fascinating domain.

In view of the tremendous challenges ahead – technological, economic and cultural – we are very pleased to present the first building block of a new European initiative for nanoelectronics: a vision of what the next 15 years will bring in this key technological field, and the increasing leverage such developments will have on other sectors of the economy.

We strongly support the views expressed here by members of a representative group of industrial and research organisations who have each shown strong interest and commitment to join in and actively contribute to such an initiative. The objective for the coming year is to spell out a strategic research agenda for Europe's nanoelectronics sector. This 2020 vision could thus become the main roadmap for all parties involved from private and public sector alike, to realise a true European research and innovation area in nanoelectronics.

We would like to thank all the members of the group for the time and attention they have devoted to this exercise. And if Pascal was right when he wrote: "It requires no less capacity to reach nothingness as it takes to reach everything", then we are certainly taking measure of the magnitude of the task now ahead of us.

Philippe Busquin
Commissioner for Research

Erkki Liikanen
Commissioner for Information
Society and Enterprise

Commissioners Busquin and Liikanen at High Level Group workshop

1. Executive summary

Microelectronics has become a foremost driver of social and economic progress worldwide. With an average annual growth of 15% a year for the past three decades, its industry has made massive investments and is heavily rooted in Europe, creating thousands of jobs. The move to nano-scale devices, called nanoelectronics, will further revolutionise applications while demanding increasingly heavy investment in research and production to remain competitive.

Opening up new opportunities

Microelectronics underpins almost every single industrial sector. Its value chain currently represents 1% of global gross domestic product. More generally, the electronics sector receives 30% of industrial investment in the developed world and results in a global annual market of nearly €800 billion. Taking into account the many other industries that depend on electronics, the global value leverages some €5 000 billion. Electronics also generates highly skilled employment.

The main trends for the future nanoelectronics are spelt out in the International Technology Roadmap for Semiconductors (ITRS). It is crucial for European industry and research organisations to keep up with and orient this global industry-led roadmap. World-wide competition is fierce and state support widespread. The USA and Asian countries are investing huge amounts of public funds in research and manufacturing.

So, Europe must increase its efforts to stay in the race in terms of research, design, applications and manufacturing needs. Nanoelectronics requires a multidisciplinary approach, sophisticated research and production facilities and, above all, much greater coordination of pre-competitive industry-oriented research and public support at regional, Member State and EU level.

Advanced production process research is a driving force behind Europe's significant scientific and manufacturing economies. Demands on systems design will also increase with the growing complexity of devices. It will result in a wider range of easier-to-use products – from sophisticated home entertainment and mobile communications to faster and more complete medical diagnostics and treatment systems.

The integration of different devices and new functionalities requires the development and co-existence of many technical approaches. Long-term nanoscience research will play a key role by offering alternatives such as spin electronics, molecular electronics and quantum computing.

Creating more effective partnerships

The nanoelectronics industry has a vital role in meeting the Lisbon challenge for a knowledge-based economy. Maintaining leadership in areas such as communications, medical and automotive electronics requires access to key intellectual property and leading-edge technologies implying an efficient knowledge transfer between R&D and manufacturing centres. Without this, Europe is left vulnerable – not only in chip manufacturing itself but also in the systems industries that rely on the components.

Synergy between industrial strategies, scientific objectives and funding priorities must be optimised to meet goals for industrial exploitation and public benefit. Public-private partnerships at European level are crucial to avoid duplication and dispersion of effort and to catalyse a critical mass of coherent investments. The development of a Technology Platform for nanoelectronics would enable industry, research centres, universities, financial organisations, regional and Member State authorities, and the EU to interact to provide the resources required within a visionary programme to foster collaboration and make best use of European talent and infrastructures. The framework must remain flexible to accommodate technology disruption, business evolution and societal changes. It must also take into account initiatives outside Europe.

Large-scale funding for strategic priorities should permit even more unified collaborative R&D than today. It is estimated that financial resources need to be doubled over the next five years for the development of nanoelectronics technologies. Substantial and coherent public (EU, national and regional) funding will be needed to leverage the required level of private investment.

Meeting immediate challenges

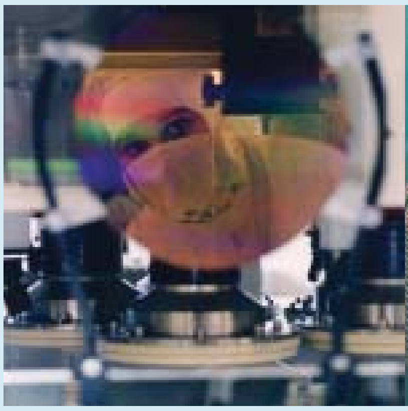
The group of top-level management executives from European industry and research institutes who have framed and endorsed the present vision recommends that a Technology Platform should be put in place urgently to ensure nanoelectronics success in Europe and to harvest the expected benefits in terms of job and wealth creation. Such a Platform would strengthen collaborative research, create a more favourable regulatory and financial environment, and offer a course of action to back winners in this key sector. There is also a need for an adequate supply of skilled human resources through a suitable education system.

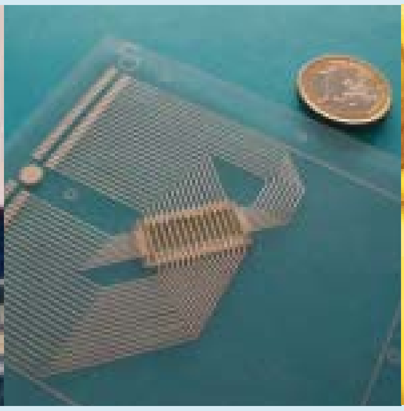
An ambitious programme of action is entirely achievable. It would put Europe in a pre-eminent technological position, with consequent economic and societal benefits. Major semiconductor and electronics companies, as well as research institutes across Europe, are already indicating their broad support for this initiative and would look forward to taking an active role in it.

2020 vision for Europe

For Europe to achieve world leadership in R&D and maintain high value-added, next-generation production processes, it must provide:

- A competitive supply chain with no major missing links;
- A research environment and infrastructures capable of supporting visionary and industrially relevant research activities;
- Strategic public-private partnerships in which strong user industries share their long-term visions with research partners and mobilise a critical mass of resources;
- A favourable legal and financial environment; and
- An education system delivering a skilled, multidisciplinary research, design and production workforce.





2. NANOELECTRONICS – KEY ASSET FOR THE FUTURE OF EUROPE

Electronics has been a foremost driver of the scientific and technological progress that has made a major contribution to social and economic growth worldwide since the middle of the 20th century. Notable recent success stories – mobile telephones, digital media, computing and networking (especially the Internet), safer and more efficient vehicles with less-polluting engines, and medical systems – illustrate the crucial innovative role that microelectronics has played. And the move from micro- to nanoelectronics can only increase this key position.

2.1. Nanoelectronics: a strategic industrial sector

Nanoelectronics can be defined as electronics on the deep submicron level – that is with circuit dimensions of less than 0.1 micron. The term covers both the manufacturing of ever-smaller and hence higher performance of existing semiconductor devices and advances in molecular electronics that involve exploiting single atoms or molecules. Semiconductor chips with submicron dimensions are already in production. And new nanotechnology materials – from carbon nanotubes to organic polymers – are being investigated for a range of applications that include smaller, flexible displays and more powerful storage devices.

Such recent advances in nano-scale technologies can be exploited not only to lead to new mass markets for electronics but also to provide the high-technology experience and low-cost manufacturing expertise required to develop other nanotechnology industries.

Acting as strategic enabler

With an annual growth rate of some 15% over the past three decades, the microelectronics industry has become a central strategic enabler for the entire global economy, surrounding us in our daily lives as an essential constituent of a huge range of products and services: cars, phones, medical systems, multimedia applications, to name but a few since computing power is embedded in most products today. The industry also fosters sustainable development by contributing to savings in energy and natural resources, for example through fuel consumption management in cars and heating systems, or through more efficient and input-saving manufacturing. And, as the construction kit of the Information Society, it stimulates innovation – which in turn contributes to wealth creation and employment growth both directly and indirectly.

Strategic sector

Bird on a wire

Airbus rewrote the rule book in 1988 when it used fly-by-wire technology to replace mechanical linkages on the Airbus A320 – a first for a commercial jetliner. Electronic flight control uses computers and electrical cables to operate the plane. The result is reduced weight, so cutting fuel consumption, lowering operating costs and reducing exhaust gases. Other advantages include enhanced safety with fully monitored control, and development of a family of aircraft with similar cockpit designs and handling characteristics. Electronic control has now become an aviation industry standard – which has extended to other transport with development in Europe of 'drive-by-wire' systems for cars. Fail-safe computer networks enable the car to steer and brake.

Courtesy: Airbus

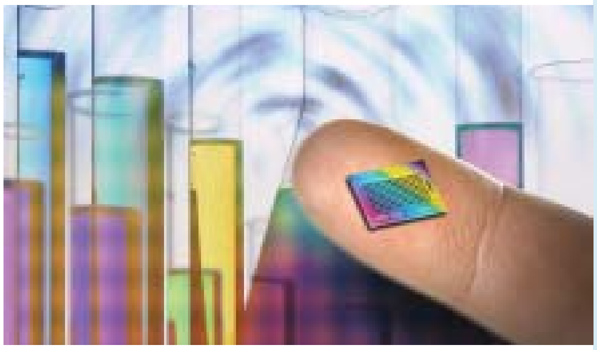
Spot-on navigation

The idea of an easily portable system that would provide your exact location anywhere on the globe seemed unimaginable a generation ago. Now a range of easy-to-use navigation systems has developed and such devices are to be found increasingly in even mid-range cars. And increasing miniaturisation means that global positioning system (GPS) devices can now be built into mobile phones – simplifying personal location and fast dispatch of assistance.

Courtesy: Thales

Safer transplants

The use of nanoelectronics and nanosciences for the detection of biomolecules has resulted in a range of biochips for routine biomedical diagnosis and mass screening of patients. A typical use is in transplant surgery, where organs run the risk of being rejected by the patient's immune system. This risk can be characterised by DNA testing. The new biochips will allow faster, cheaper and more complete testing of organs and recipients to get a better match in a time-critical situation.

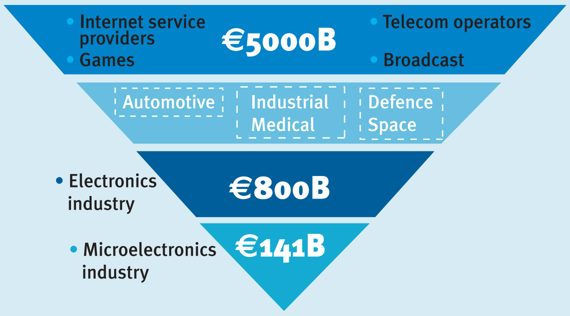


Courtesy: Infineon

Current investment in electronics accounts for some 30% of overall industrial investment in the developed world. The microelectronics value chain – from the semiconductor chip manufacturers together with their equipment and materials suppliers to the large set of related industries, such as design houses, systems builders and integrators – represent nearly 1% of global gross domestic product (GDP). Moreover, in Europe alone, some 40% of the annual sales of the semiconductor manufacturers are reinvested in R&D and improved production processes.

As a direct result, the worldwide annual market for electronics at just under €800 billion is now bigger even than the global automotive market. When the many other industries that depend on electronics – from telecommunications, Internet services and consumer products to the defence and aerospace industries – are included, the global value leverages some €5 000 billion.

Nanoelectronics as key enabler



Worldwide production of transistors reached $1x10^{18}$ or a million, million, million 'gates' in 2003. By 2015, it is forecast that industry will need capabilities to manufacture the equivalent of 10 million silicon transistors per human being per day in the developed world. For example, estimates for 2007 already indicate an increase over 2003 in demand for DVDs by 50 to 55%, digital televisions by 30 to 40%, mobile phones by 45 to 50% and personal computers by 35 to 40%. This in itself will lead to a much greater need for nanoelectronics design and manufacturing capabilities, and increased opportunities.

While US company Intel is leading the worldwide chip market, the three major European semiconductor manufacturers (STMicroelectronics, Infineon and Philips Semiconductors) have figured among the global top ten for the past ten years. On the process equipment side, ASM Lithography has become a true European success story by gaining world leadership in the lithography market – the most essential equipment for semiconductor fabrication.

Source of highly skilled employment

The electronics industry generates the type of highly skilled employment that is essential for the future social and economic well-being of Europe, with vast spill over into virtually all other production sectors. The major European chipmakers are important employers: STMicroelectronics has 40 000 people, Infineon 34 000, and Philips Semiconductors 32 000 – and lithography equipment manufacturer ASML has 5 000 employees.

This compares well with Intel which today has around 80 000 employees worldwide, and AMD with 14 000 – many in Europe. Other international companies – including IBM and Motorola – with headquarters outside Europe have created tens of thousands of jobs in the EU. However, China is fast becoming the major global electronics producer, particularly of consumer products.

Nanoelectronics offers the European electronics sector the opportunity of becoming an even more significant generator of jobs for highly qualified personnel. On a broader scale, the information and communications technology (ICT) and associated services sectors employ around a million people in Europe. This figure is also sure to increase, given the importance of these sectors to our future economic growth.

It is imperative to note that the increasing complexity of the technology requires significant multidisciplinary education and training programmes. Demand is already outstripping the supply of talent. The way to educate and retain future technology leaders is to ensure that state-of-the-art education and research infrastructures are available and that most of the high-value-creating industrial activities of the total value chain are located within Europe.

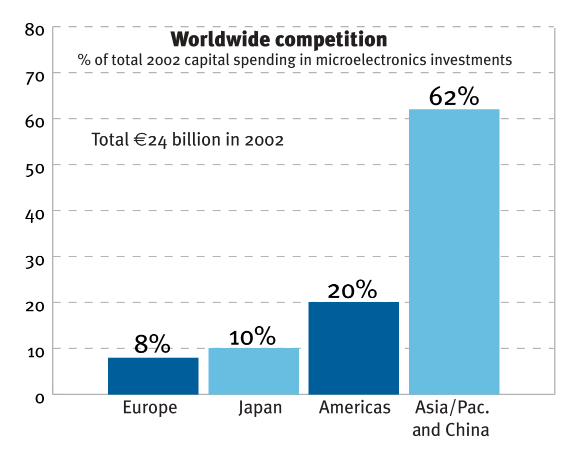
Courtesy: Infineon

Concentration and consolidation

Global competition is fierce and state support widespread. Asian countries such as Taiwan and, particularly, mainland China are investing huge amounts of public funds in new production facilities and design capabilities. The USA is also investing massively in electronics, especially through defence projects – both directly through support for R&D and through government purchase of the resulting products.

Each new technological generation requires a steep increase in the level of investment needed to conduct research and build production plants – the European electronics industry currently spends 20% of turnover on research and a typical fabrication facility today costs around €2.5 billion.

There are clear indications that further industrial concentration and clustering will take place in the coming years. Europe's ambition should be to anchor more of these major clusters on European soil, and to tie in the associated systems industry that is increasingly enmeshed with them. Besides the consolidation of the nanoelectronics industry, the research environment will also have to evolve due to the increasing complexity and costs. This will require a critical mass of resources and internationally recognised research platforms in order to keep talent, knowledge and industrial activities in Europe.



Courtesy: Nokia

Keeping knowledge in Europe

Maintaining leadership requires early insight into, ownership of, and/or access to, key intellectual property and leading-edge technologies. It is essential for the future of European industry that development of the intellectual property is carried out here in order to ensure access to it.

If the basic semiconductor technology is not available here, Europe is left vulnerable – not only in the chip manufacturing area itself but also in the systems industries that rely on the components – from consumer electronics and telecommunications to medical and automotive equipment. All need early access to the latest technology.

If research, design and manufacturing were to leave Europe as global nanoelectronics companies are drawn by more attractive conditions on other continents, it would be very difficult for European industry to stay at the forefront of electronics applications. And the loss to the associated equipment and materials industries would come at a high price. An industry based exclusively on the supply of services will not be sustainable. Europe must encourage entrepreneurship in order to take advantage of the new industrial developments that will result from the nanoelectronics opportunities.

Only by retaining and fostering a high value domestic manufacturing capability on this continent can this be guaranteed. The significant spin-off benefits of having semiconductor manufacturers in Europe –

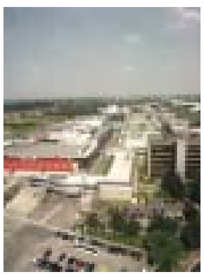
the so-called ‘Silicon Valley’ effect – are apparent from experiences in microelectronic eco-zones such as Dresden in Germany, Grenoble in France, Nijmegen-Eindhoven-Veldhoven-Leuven in The Netherlands and Belgium, and Agrate-Cornaredo in Italy. These eco-zones offer local employment directly to more than 33 000 people and indirectly to at least as many in their suppliers (the multiplier effect), and ensure secure ‘local’ sourcing in Europe for systems suppliers. They have also triggered the establishment of local branches of non-European high-tech industries (for example the Du Pont mask shop in Dresden and the DNP one in Agrate). Finally, they contribute significantly to European high-tech exports.

Major European electronics eco-zones

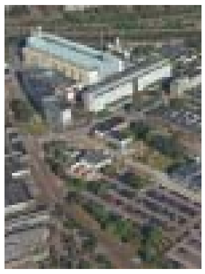
A decade of clustering in high-technology hotspots has generated jobs, economic growth and leadership in innovation as demonstrated by major microelectronic eco-zones in Germany, France, Italy, The Netherlands and Belgium:

Dresden
- Created 15 000 permanent jobs at semiconductor plants
- Attracted more than 30 international equipment and service suppliers
- Achieved break-even in tax revenues/social security contributions in 2003 (from 1994)

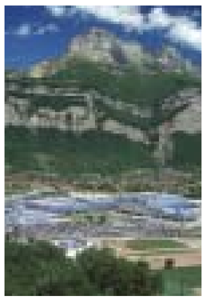
Catania
- Created 10 000 direct jobs
- State-of-the-art production plants for memory products
- Strong-standing collaboration with surrounding universities



Agrate – Cornaredo
- Created 5 500 direct jobs at production and design sites
- Established the first Dai Nippon Printing (DNP) mask shop in Europe
- On-site laboratory of National Institute for Matter Physics and co-operation with local universities



Nijmegen – Eindhoven – Veldhoven – Leuven
- 4 500 direct jobs at Nijmegen production site, and 10 000 + jobs with local suppliers
- Eindhoven High-Tech Campus/MiPlaza open innovation growing to 8 000 jobs by 2008
- World-leading lithography equipment supplier ASML headquartered in Veldhoven
- On-site collaboration with IMEC in Leuven



Grenoble (Crolles)
- Within a decade, generated over 6 000 direct jobs; adding indirect and associated activities, over 20 000 total jobs linked to microelectronics
- Extensive collaboration with CEA-LETI in Grenoble
- Attracted more than 30 international equipment, material and service suppliers

Specialist electronics centres have also developed, such as around the IMEC research centre in Leuven with its close relationship to Flemish universities, local wafer fabrication facilities and systems manufacturers as well as to Philips in Eindhoven and ASML in Veldhoven.

Similarly, the Grenoble-Isère area hosting MINATEC, a centre for innovation in micro- and nanotechnology established by CEA-LETI and Institut National Polytechnique de Grenoble with the participation of CNRS, offers a pool of 17 000 jobs in scientific and academic research, and 13 350 workers in the local microelectronics industry.

Moreover, industry can benefit from a diversity of specialised and high-profile academic groups throughout Europe to contribute and progress specific research challenges.

Need for global standards

Setting standards is very important for mass-manufactured products. Breakthrough technologies require global standards to stimulate the commercial electronics market, as has been clearly demonstrated in multimedia equipment – such as CDs and DVDs – and telecommunications. Industries that can set the standards can be winners – so EU industry needs to be active and aware of standardisation matters as well as being effective in getting its standards accepted in the markets.

New levels of co-operation and convergence in product standardisation will be essential. Historically, Europe has been particularly effective in this area – such as with GSM and now universal mobile telecommunications system (UMTS) third-generation technology for ambient intelligence. World competition for new markets will place stringent demands on legislators to arrive quickly at agreed standards. For example, China is now becoming more aggressive by starting to set its own standards to protect its national industry and to avoid having to license Western technologies.

Example of investment in R&D infrastructure

New IMEC facility in Leuven

In early 2004, Belgian/Flemish electronics research centre IMEC opened a new nanoelectronics research facility at its Leuven base that will enable it to maintain its world-leading role in research in nano-scaled technologies. This facility required an investment of €84 million alone for the building – €37.2 million a grant from the local government, and the remaining €46.8 million as a loan, financially supported by the European Investment Bank (EIB). Equipping the facilities and carrying out the work programme for the next five years will bring this cost to some €800 million, to be financed with help from public funding and core industrial partners on three continents. IMEC state-of-the-art facilities include a clean room for sub-45nm, 300-mm wafer fabrication. IMEC has a staff of more than 1 300, with nearly 400 industrial residents and guest researchers. And it has already set up more than 20 spin-off companies.

Example of joint R&D facilities

MINATEC, Grenoble

In April 2004, CEA-LETI extended its nanoelectronics facilities in Grenoble to conduct the NANOTEC300, a joint programme established together with the three partners of the Crolles II Alliance: Freescale Technology, Philips and STMicroelectronics. An investment of €15 million was directly supported by CEA-LETI for the development of the infrastructure. At the end of 2005, MINATEC will also open new facilities. The total investment of €169 million for the buildings is supported by public authorities and CEA (€128 million), and private investments (€41 million). Those new facilities will gather an education platform driven by INPG (1 000 students, 200 professors), a research platform driven by CEA-LETI (1 600 permanent researchers and over 300 PhDs), and an industrial platform driven by MINATEC Enterprises that will lend dedicated on-site facilities to industry (1 000 industrial researchers are expected).

2.2. Competitive global products: vision of the nano future

Predicting 'killer' applications as far ahead as 2020 is unrealistic given the high pace of innovation. However, a technology roadmap and a long-term vision can be proposed, based on current European strengths in telecommunications, medical and automotive electronics.

We are already enjoying enhanced life experience, comfort and well-being derived from micro- and nanoelectronics. This trend will be reinforced over the next decade as the price of even the most highly sophisticated systems will continue to fall. And nanoelectronics will undoubtedly play an important social role by making complex equipment much simpler to operate.

Wireless communications, networking and power-saving nanotechnologies will bring entirely new, affordable and easy-to-use services that will be both highly reliable and widely accessible. They will stimulate researchers, innovators and entrepreneurs in unforeseen ways, leading to as-yet unimagined applications. Success in new markets will depend on strong interaction between the market specialists and the product designers on the one hand, and the nanoelectronics manufacturers on the other. Creativity, rather than the technology itself, is likely to be the limiting factor.

By 2020, new end-user products and systems employing nanoelectronics devices can be envisaged in the following categories:

• **Ambient intelligence**
Moving from micro- to nanometer dimensions allows chips to become so small and cheap that they can be integrated almost anywhere and interact with each other, making everyday activities systematically smarter and more reactive. This concept of ambient intelligence could result in our living environment in the home, car and office becoming sensitive and responsive to our presence. Appliances such as computers, multimedia equipment and communications devices would be integrated into that environment – allowing continuous and much simpler interaction with information to enhance quality of life, improve working conditions and increase productivity. Typical applications could centre on personal health, entertainment and leisure delivered through networked multi-functional appliances. Examples could include flexible mobile phones able to act at the same time as personal digital assistants (PDA), electronic purses and interactive media providers at an affordable cost – or combined mobile communications and global location units enabling the dispatch of assistance quickly to elderly or handicapped people in trouble. Another major trend is intelligent tagging and tracing of products such as medicines throughout the supply chain.

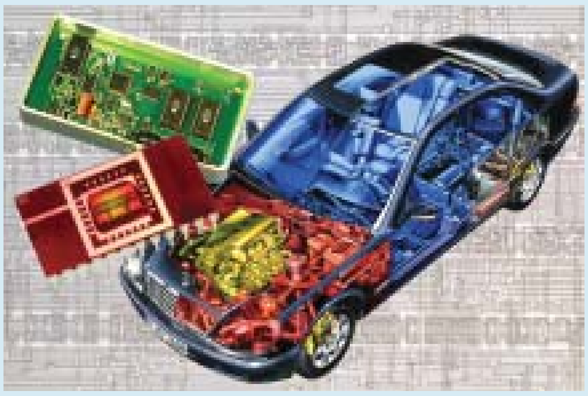
Ambient intelligence – Philips HomeLab

• Nano-scale medical diagnostics and treatment


Courtesy: MIC

Nanoelectronics-based biosensors will speed and simplify measurements at molecular level. This will allow us to design and fabricate ultra-sensitive sensors for the detection of extremely low concentrations of cell structures, antibodies or proteins, creating new insights into our health as well as offering better diagnostics and treatments. Nanobiosensors will also encourage the development of smart implants, micro-laboratories and non-invasive health control. Moreover, combining such biosensors with intelligent tagging will improve food safety – providing continuous control of quality, and speeding detection and tracing of sources of infection and disease.

• Cleaner, safer and more comfortable transport


Courtesy: Infineon

Highly reliable, smart and interactive low-cost devices will be created, able to withstand harsh environments, for example for application in cars and other forms of transport, where intelligent engine management could reduce fuel consumption (contributing to the 1 litre/100 km car dream), and cut pollution. Safety will be improved thanks to collision-avoidance devices, adaptive navigation systems, control of personal access to vehicles, setting of driver preferences, and control of the in-car environment and entertainment systems. All would become more affordable and effective with nanoelectronics.

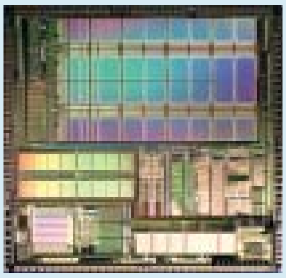
• Anti-terrorism and security applications

International terrorism has stimulated massive investment in nanotechnology research for security systems, strongly boosting nanotechnology-based industries. Nanoelectronics applications range from surveillance (observation, alarms, etc.) to personal identification – using biometrics – and access control.

Courtesy: Siemens

3. Facing up to the changing world of electronics

The rate of development of electronic semiconductor technology since the introduction of the first integrated circuits in the 1960s has been breathtaking. The radical revolution that has taken place is clearly illustrated by the fact that the dimensions of individual components, such as transistors on a semiconductor chip, have shrunk by a factor of 10 000 since the early 1960s and that hundreds of millions of transistors can now be integrated in a single electronic component such as a microprocessor, computer memory or application-specific integrated circuit (ASIC). The price of 1 gigabit of memory has decreased by a staggering 1.5 million times while tens of thousands of transatlantic telephone conversations can now be carried over a single optical fibre!



Experts predict similar rates of improvement can be expected in the coming years, following the well-known 'Moore's Law'. Obviously, this will still give rise to another revolutionary increase in the applications of electronics.

3.1. Continuous miniaturisation

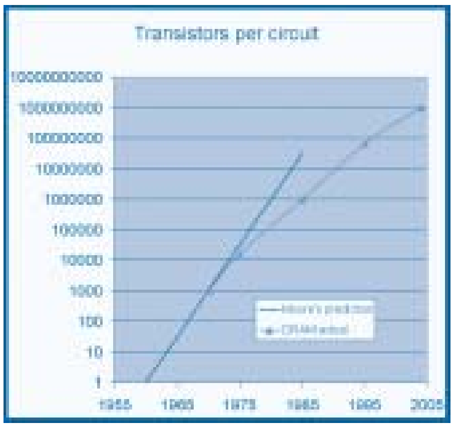
Until recently, the size of the smallest electronic circuit element was expressed in microns, but continuous evolution in technology over the years has shrunk circuits so much that these dimensions are now less than 100 nanometer or 1/10th of a micron. The term 'nanoelectronics' is therefore used instead of 'microelectronics'.

At this scale, some of the classical laws of physics no longer apply and give way to properties defined by quantum physics – the so-called 'quantum effect'. A dramatic improvement in chip performance can still be achieved by taking these effects into account and making use of these properties.

The majority of electronic devices now consist of complementary metal oxide semiconductor (CMOS) circuits on silicon wafers, and tremendous manufacturing experience has been built up in their low-cost production. Due to its advantageous characteristics and future development potential, experts predict that CMOS will remain the mainstream technology for many years and improvements will continue until at least 2016.

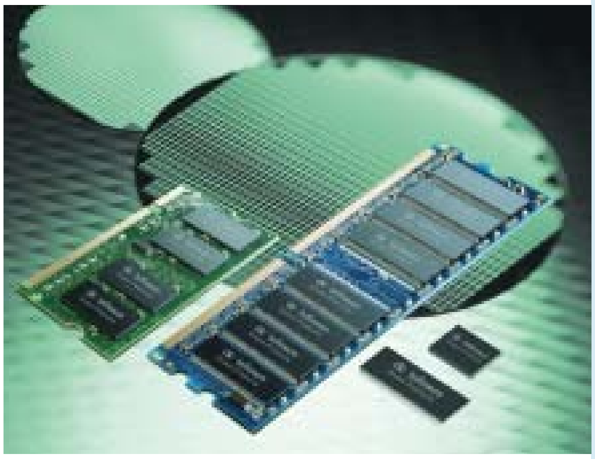
Moore's Law

It was back in 1965, just four years after the first integrated circuits were introduced, that Gordon Moore, co-founder of Intel, made his famous observation that the number of transistors on a given area of a semiconductor chip will double every year – a rough measure also of computer processing power. The press called this 'Moore's Law', and both the name and the law have stuck. Moore revised his law in 1975 – increasing the period of doubling to two years, which, in practice, is still the case today.



Why CMOS?

Complementary metal oxide semiconductor (CMOS) technology dominates manufacture of integrated circuits today. Its energy efficiency makes it possible to integrate many more CMOS gates on a chip than those made with alternative technologies, so offering much higher functionality. As a result, CMOS is currently the mainstream technology for microprocessors, memory and logic circuits.



Courtesy: Infineon

While the size of the electronic elements in integrated circuits is shrinking and complexity is strongly increasing to combine more functions on a single chip, there is also a powerful trend to develop new families of integrated circuit technologies for special applications. These include operation with ultra-high clock speeds, ultra-low electric power consumption and functioning in very harsh environments. This leads to diversification of the standard (CMOS) technology into sub-families.

Furthermore, there is a strong drive towards further product miniaturisation. This is even leading to full integration in single 'system-on-chip' (SoC) components that can include wireless communication modules, sensors – for example: image sensors for photo and video equipment, mechanical, chemical and biosensors – and actuators such as micro-lasers, micro-switches or micro-pumps. One strong industry requirement is that the production processes be compatible with silicon wafer technologies to allow a smooth transfer in manufacturing.

System in a package (Courtesy: Philips)

Alternatives or complements to CMOS, such as spin-electronics, molecular electronics and quantum computing, also exist and are in the early stages of research and development. They are promising directions to find new device concepts.

3.2. Sustaining the flow of technology and skills

To allow the semiconductor industry to develop technology at a fast pace, strict planning of industry developments is absolutely essential. Requirements for the semiconductor industry are spelt out in the International Technology Roadmap for Semiconductors (ITRS), which follows Moore's Law. It is crucial for European industry and research organisations to orient this roadmap and keep up with, if not be ahead of the ITRS. This means investment in skilled personnel and sophisticated facilities.

In this race, a series of research and development challenges need to be faced. These challenges are situated at the level of advancing design and testing technologies, manufacturing process technology, the development of breakthrough novel nano-materials and the integration of nanoelectronics with other functions, such as sensors or actuators.

Manufacturing process technology

Advanced research into manufacturing process technology is a driving force behind Europe's significant scientific and manufacturing economies. Going to smaller circuit feature sizes in the nanometer range down to 22nm or even lower, the process technology for nano-lithography, as well as for the deposition and etching of device layers, also needs to be improved. Certain of the device layers will have a thickness of only one or a few atomic layers and their deposition process needs to be very well controlled and take place in an ultra-clean environment. Obtaining the fundamental insights that will lead to acceptable manufacturing yields for the resulting billion-transistor devices will be extremely demanding.

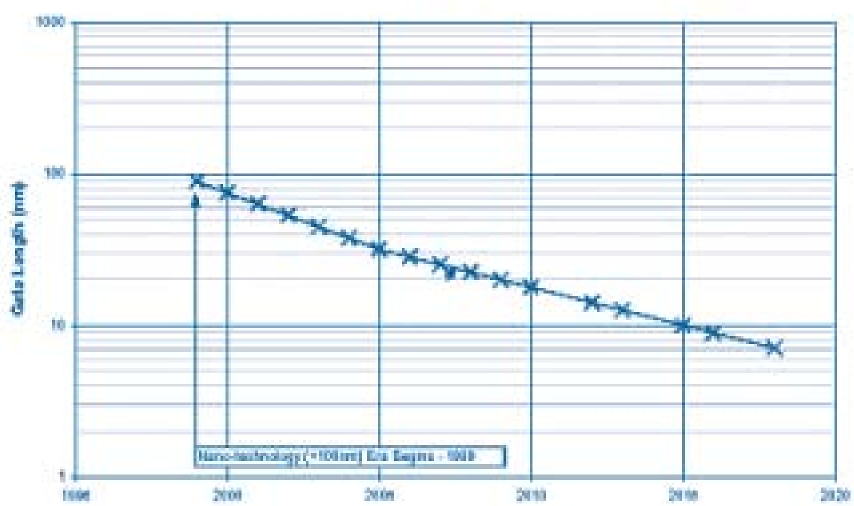
Additional difficulties will have to be overcome in device packaging, on- and off-chip interconnection schemes, and combining different technologies on a single chip.

Testing of the resulting complex products also poses a tremendous challenge. Very efficient new testing methodologies and tools will have to be developed to meet the requirements for ultra-high reliability, especially since safety and security are at stake for many applications.

International Technology Roadmap for Semiconductors (ITRS)

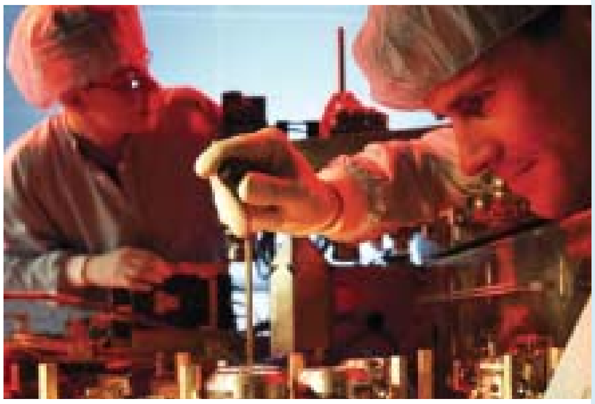
The objective of the ITRS is to identify the technological challenges facing the global semiconductor industry over the next 15 years. It is a worldwide co-operative effort of electronic circuit manufacturers and their manufacturing equipment and materials suppliers, research centres, universities and end-user companies for the various applications. The process of updating the ITRS encourages discussion and debate throughout the global semiconductor community to obtain consensus on industry drivers, requirements and timelines for new technology introduction. Over 4 000 industrial experts worldwide are involved in some 14 Technology Working Groups (TWGs) that build the individual roadmaps; they assess the state of technology and identify areas that may provide solutions as well as indicating needs for new research and innovation. The ITRS is updated annually based on the latest developments. It defines industry requirements for future generations of semiconductor chips, indicated by terms such as the 'minimum gate length': 150nm, 130nm, 110nm, 90nm, 65nm, 45nm, 35nm, 22nm, etc. Each new generation has much improved performance compared with the previous generation and allows more functions to be integrated. While initially focused on high performance CMOS technology, this roadmap now extends towards diversified embedded technologies and emerging nano-devices. A so-called 'red brick wall' in the roadmap signifies as yet unsolved technological problems that stand in the way of introducing future products; considerable research is therefore needed to find a solution.

2003 ITRS Technology Trends - Gate Length



Europe leading way in nano-lithography

Development of new generations of ultra-sophisticated nano-lithography equipment is of crucial importance. This makes it possible to 'print' the complex patterns on the circuits using a patterned mask and a so-called 'wafer stepper'. Nano-lithography is a highly capital-intensive field of research where the Dutch equipment supplier ASML is the world leader. ASML works in very close collaboration with the German company Zeiss for the lens supply and the Belgian research organisation IMEC for process development.



Courtesy: ASML

European success in materials through innovation

Courtesy: SOITEC

New devices ask for the introduction of new materials. The strong knowledge of Europe in materials science and chemistry allowed many European equipment and materials suppliers to take a significant share in the worldwide competition. As an example, SOITEC became world leader in Silicon-on-Insulator substrates with its Smart Cut™ process by relying on a strong innovative spirit developed in collaboration with CEA-LETI's scientists.

The ITRS 'red brick wall' barrier on process technology roadmaps signifies the set of unsolved problems that lies beyond the 45nm design node. Resolving these implies huge R&D costs and a new research infrastructure that must be in place to maintain ITRS progress to around 22nm technology in 2016.

At that point, the physical limits of downscaling CMOS technology may be reached. Even then, CMOS will continue for decades as a mainstream processing technology, although the importance of integration with alternative substrates and processing approaches will increase at a steady pace. Beyond 2016, the ITRS is still largely undefined but it is expected that new scenarios will be developed, based on inputs from basic research, for introduction of new technology options.

An eventual move from today's 300 to 450 mm diameter silicon wafers – scheduled by the ITRS for 2012 – will require huge efforts in industrial development, especially from manufacturing equipment suppliers.

The need for technologies supporting ubiquitous ambient intelligence is also likely to shift the focus from computational power to ultra-low-cost fabrication.

Breakthrough in design technology

Demands on systems design will increase with the adoption of new nanoelectronics technologies and the resultant increase in complexity of the devices and heavily integrated applications. Each new generation of components has the potential to offer more

Electronic design automation is crucial functionality, more added-value. Breakthroughs in electronic design automation technology are required to close the ever-widening gap between what is realisable in nanoelectronics hardware and what can be economically and efficiently designed and tested.

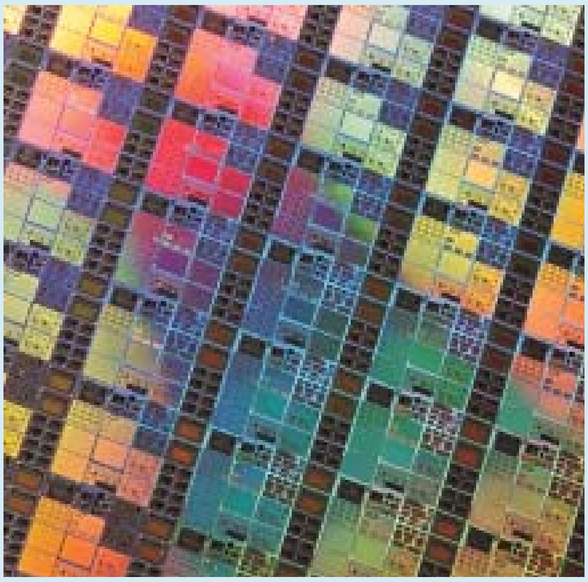
There will be a need for new design approaches that make it possible to reuse designs easily when new generations or families of products appear. These approaches should be coupled with automatic translation of the resulting high-level designs into device manufacture.

Identifying research targets for improving design productivity

- Developing cross-disciplinary design capabilities, methods and tools; and educating system architects and multidisciplinary experts to cross current conventional boundaries between design and process technology;
- Designing with tools for more automation of circuit implementation on chip, taking into account new trends, such as 3D and Silicon-in-Package integration;
- Improving functional analysis to simplify the transfer of product designs between differing implementation technologies and architectures;
- Using new technologies to develop redundant, reconfigurable or even self-adaptive systems, decreasing the need for sophisticated application-specific design work;
- Developing standard interfaces to deal efficiently with the convergence of many application domains;
- Exploiting new materials and design approaches to manage energy and heat dissipation at the nano level; and
- Improving testing and verification of systems and components resulting from new process technologies, system design methods and the resultant massively more complex networked systems. This is essential to ensure the ultra-high reliability required by system providers and the always-on availability demanded by users.

3.3. Key role for long-term nanoscience and materials research

Long-term nanoscience research in universities and research centres plays a key role by offering a range of novel approaches to the realisation of high-performance nanoelectronics devices as well as for developing novel sensors, actuators, visual display technologies, etc. At the scale of nanoelectronics, the individual electronic and other functions are performed by components with sizes that are in the order of hundreds of atoms or often less. At this scale, it is difficult to maintain the classical concept that we have of a material. Nanosciences and nano-materials science then become strongly interlinked and it would not make sense to treat them separately.



Courtesy: Infineon

Of particular importance here is that the scale compatibility between nanoelectronics and molecular biology introduces the possibility of producing hybrid devices interfacing electronic and biological components – opening a wide range of medical and biological applications with benefits for health and well-being.

Nanosciences and nano-materials offer breakthrough applications

- **Nanomagnetism** – very fast, very low power nano-transistors based on 'spin electronics' can be the source of new storage technologies with tremendous capacities;

- **Biomimetics** – allowing man-made structures to emulate nature by reproducing such mechanisms as molecular motors, machines and structural components;

- **Displays** – novel organic light-emitting semiconductor materials will be used to manufacture very thin and flexible visual displays with much improved performance;

- **Nanophotonics** – will still increase the speed and lower the cost of data transmission, and also have important applications in sensors technology;

- **Molecular electronics** – where functions such as transistors can be embodied in a single molecule. It has become a very active basic research field and, in the long term, may offer new possibilities for even higher performance computing and other applications;

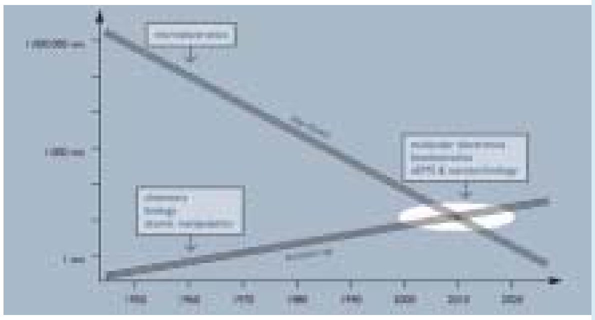
- **Nano-mechanical tools** – these could include nano-fluid management systems, nano-filters, nano-rods and nano-tweezers, and molecular-scale balances. Nano-mechanical tools will also play an important role in research and production of future nanoelectronics devices; and

- **Nano-sensors and nano-actuators** – more sensitive and selective sensors and actuators will accommodate voice, vision, tactile senses and stimulation, as well as offering new applications such as biometrics and environmental monitoring.

Taking different approaches

The present route to the manufacturing of electronic devices is called 'top-down', but nanoscientists are now also developing a new approach based on self-assembly of atoms and molecules and this is called 'bottom-up' – see BOX. Progress along both of these avenues will entail massive expenditure of research effort and investment in resources. The success of Europe in this area requires broad-scale collaboration and the assembly of critical mass in projects and networks capable of achieving the necessary breakthrough results.

Two paths to progress

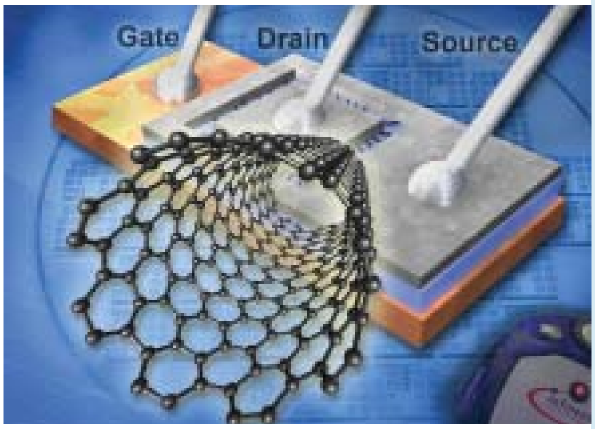


- The 'top-down' path continues miniaturisation of electronic components by the development of strongly improved production processes and materials, starting from current practice. This approach enables developers to profit from the low-cost mass manufacturing expertise already acquired with silicon-based systems. It is the path prescribed by the ITRS for the industrial development of mainstream nanoelectronics technology, producing commercially marketable results quickly.

- 'Bottom-up' synthesis takes nature as a model and tries to assemble complex structures from the starting point of atoms and molecules. Self-assembly is a phenomenon that is widespread in the natural world, from the growth of crystals to the formation of complex functional biotechnological systems – including the cells of the human body. Yet the mechanisms of these processes are little understood and their research represents a formidable challenge. Introduction of production processes based on self-assembly methods in electronics manufacture is a long-term objective.

The experts think that eventually the 'top-down' and 'bottom-up' approaches can both be combined into a single nanoelectronics manufacturing process, where certain manufacturing steps can then be carried out using the top-down approach and others using the bottom-up approach. Such a hybrid method has the potential to lead to a more economical nanomanufacturing process.

Carbon nanotubes



Courtesy: Infineon

Interesting classes of new materials are becoming available for nanoelectronics – such as the development of highly stable carbon 'nanotubes'. Many times stronger and lighter than steel, and able to act as conductors or semiconductors, carbon nanotubes will open the door to a huge range of novel applications once methods have been developed to control their properties and to manufacture them inexpensively in industrial quantities.

3.4. Need for multidisciplinary approach

It is clear that, for the development of highly integrated miniaturised products, very strong interdisciplinary co-operation is needed from the earliest development phases between the marketers, developers, designers and manufacturers of the electronic circuitry, software developers and specialists for the sensors, actuators, displays, and especially the product specialists who define the requirements of the applications.

All this underlines the need for a large R&D effort, from basic science and long-term studies into future and emerging technologies, to product development, system design and implementation. To manage these aspects, it will be necessary to devise appropriate collaboration schemes and business models. This is an area in which European-level programmes can be of major assistance.

The technology research programmes also require educated multidisciplinary staff as well as system architects, giving rise to a need for curricula delivering new profiles of expertise to avoid bottlenecks in development. These should be introduced into undergraduate and graduate courses as soon as possible, so that qualified people are available to undertake research and development enabling new products and applications to be designed and manufactured in the 2015 to 2020 time frame.

3.5. Impact on society

There are environmental considerations to be taken into account. The electronics industry is continuing to develop hugely. The quantity of products is increasing, consumption patterns are changing and both environmental science and technology are continuing to evolve. The regulatory framework therefore needs to be adapted continuously in close consultation with industry, society and policy-makers.

Europe is leading the way with legislation already in place to address and appropriately manage environmental risks arising from production, use and disposal of electronic products – from the collection and recycling of electrical and electronic waste to the development of lead-free solders. However, the regulatory framework balancing the needs of industry and consumers will have to be further developed, provided that the rules can be accepted in an international forum.

The impact of nanoelectronics on personal security and privacy will also have to be taken into account. New technology will offer low-cost and user-friendly embedded security but this will pose privacy questions as nanotechnologies allow tagging, tracing and data collection on a large scale. Massively available computing power can also lead to new possibilities for breaking security systems. All this demands research on new technical, regulatory and ethical solutions, with input from other relevant disciplines and application sectors.

Europe will be in a position to impose its societal values for the benefit of its citizens through balanced regulations if it is able to maintain technology leadership and high-value manufacturing.

Personal privacy

Courtesy: VISA

The electronics industry has made considerable progress in the development of 'smart cards' incorporating chips to store an extensive amount of information. Such cards are now leading to faster and better medical treatment by speeding access to personal details. But it is the health services and policy-makers that must take responsibility for integrating such devices into well-thought-through systems that protect patient privacy.

4. The way forward: creating ever more effective public-private partnerships for research and innovation

The European Councils of Lisbon, Gothenburg and Barcelona clearly set the objective for the Union to become the most dynamic and competitive knowledge-based economy by 2010. At the same time, the eEurope programme set out to develop modern public services and a dynamic environment for e-business through widespread availability of broadband access at competitive prices and a secure information infrastructure.

The nanoelectronics industry is already making a vital contribution to meeting these challenges, as the speed of innovation and the rapid uptake of new technologies are major attributes of the sector. Research is crucial to help companies stay in the race – and the major European electronics companies already reinvest 20% of their turnover in research.

Electronics research (Courtesy: Philips)

For a decade, EU and EUREKA research programmes have successfully supported large-scale efforts to bring micro-/nanoelectronics research in Europe on a par with that of competitors worldwide. They have embraced research into systems, design, manufacturing and related materials science and equipment.

Europe now needs to maintain and further develop its high-technology know-how, both to control access to technological solutions in strategic areas and to sustain its industrial base. Given the steep rise in costs involved and the scarcity of funds available, strongly increased coordination between industrial, national and European levels of investment is therefore essential.

4.1. Need for coordinated action

Europe is at present a world leader in telecommunications, medical and automotive electronics. However, globalisation, and the ever-escalating costs of R&D in this sector to meet the staggering technology demands and the very high capital investment demands of new production facilities, mean that individual companies and even individual countries can no longer meet the challenges alone.

Public-private partnership catalysed at a supranational level is the only answer to avoid duplication and dispersion of effort. Semiconductor chipmakers, their equipment and materials suppliers, the system designers and manufacturers, research centres and universities are already involved in such partnerships with the EU, Member State governments and regional authorities.

Coordinated and heavily government-supported initiatives also exist in the USA and in Japan. In the USA, there are the International Sematech semiconductor manufacturing technology programme and state initiatives such as those in Texas and New York. Japan supports the microelectronics industry through the Semiconductor Leading Edge Technologies (Selete) organisation.

Europe cannot afford to lag behind. A much scaled-up collaborative approach uniting the various actors would enable European industries and research partners to remain at the forefront, provided necessary financial resources are forthcoming. This will require focus and critical mass.

European pre-eminence in the research, development and deployment of nanoelectronics into dominant future product areas depends upon:

- The establishment of a European Strategic Research Agenda with a 2020 horizon, in co-operation with the EU, Member States, industry and academia to establish research priorities, avoid duplication and reach a critical mass of coherent effort;

- Stronger coordination of the work plans of the EU Framework Programmes, the pan-European EUREKA MEDEA+ programme for advanced co-operative microelectronics R&D, and national programmes; and

- The availability of a well-trained multidisciplinary workforce.

4.2. Developing a Technology Platform

To meet these many combined challenges, all interested stakeholders in Europe should pursue the development of a pre-competitive Technology Platform for nanoelectronics. This would enable industry, research institutions, university researchers, governmental authorities (EU, regional and national) and financial organisations to interact over a long time frame, bringing to bear all the required resources within a multi-dimensional framework of funding and visionary programmes, with a view to fostering collaboration and the best use of talent and infrastructures.

What is expected from Technology Platforms?

Technology Platforms bring together all relevant European stakeholders – including industry, research centres, academia and policy-makers – to realise a long-term vision for the development of key scientific and technological areas while addressing major social, economic and environmental challenges. Such Platforms are intended to develop and implement a strategic research agenda and create the action plans needed to realise the vision. They rely on strong co-operation between EU and national level policy-makers to implement such plans and to create public-private partnerships to mobilise the necessary resources.

Benefits of collaboration

The framework for the Technology Platform must remain highly flexible to accommodate technology disruption, business evolution and societal changes. It must also take into account new and important science and technology initiatives being taken outside Europe. Researchers, companies and regions/nations working in isolation will not possess the resources, knowledge or means to meet a challenge of this magnitude.

Pre-competitive collaboration is needed to underpin and move towards advanced nanoelectronics-based production plants for 2020. This can take place at many levels with plants and development centres concentrating on their core competences. It is crucial that the optimal combinations of market and applications knowledge are brought together with access to relevant intellectual property and production resources.

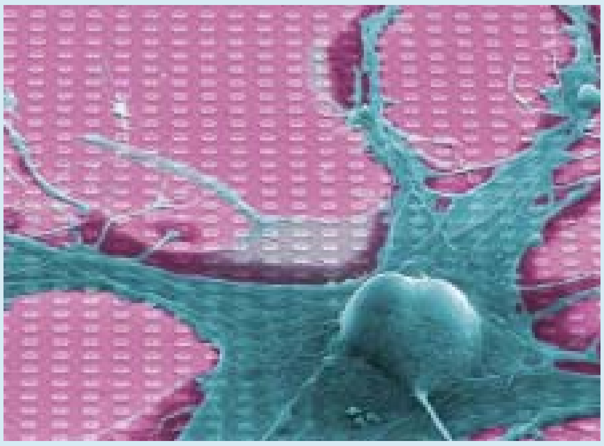
Experience shows the way

Production technologies for microelectronics – now becoming nanoelectronics – are perceived as core competences in Europe. This situation owes much to the advanced process research and manufacturing expertise that has developed over the past two decades, assisted by coordinated European research actions such as EU Framework Programmes and EUREKA initiatives.

Global dimension

At the same time, requirements for broader co-operation – as highlighted by the ITRS – will make it necessary for the European programme to work in relationships with Asian and US partners. In addition, every effort should be put into making Europe more attractive to manufacturing, keeping existing companies and encouraging others to come here.

Any new collaborative programme of sufficient size must also be integrated throughout the nanoelectronics community. There is a need for technology transfer between all players, including the different sectors of the industrial community: equipment and materials manufacturers, product designers, assemblers, packagers, designers and the research community.



Neurochip (Courtesy: Infineon)

Owing to the strong interdependencies between research and production, R&D will have to be conducted in connection with an active semiconductor wafer fabrication unit and a network of supply industries that must work in close support or in strongly organised networks of industrial partners. Although these may not necessarily be located in the same place, they must be flexible in attitude and willing to share costs.

Measuring success

The success of the Technology Platform should be measured according to a number of indicators, such as:

- Increasing overall employment and productivity levels;
- Improving Europe's global position in terms of the number of manufacturing plants, market share for equipment supply, and trade in high-value products such as mobile multimedia, automotive electronics and broadband access;
- Increasing public and private investment in research and production;
- Augmenting innovative sales and the number of spin-off companies;
- Increasing the number of students in nanoelectronics-related fields with attractive employment opportunities in Europe, thereby achieving a critical mass of full-time nanoelectronics-related researchers; and
- Increasing the number of patents and the number of EU scientific publications, as well as their impact.

4.3. Promoting public awareness

A key aspect of collaborative research programmes in this field must be to raise awareness of nanoelectronics industries and products among politicians and the public at large. Both policy-makers and the public need to appreciate the needs of the nanoelectronics industry in terms of favourable regulatory, environmental and educational conditions.

To improve understanding of the depth, size and opportunities offered by nanoelectronics, the industry, the research community and governments must all strive to explain and demonstrate effectively its benefits to Europe's citizens. It appears that technology is much better appreciated in some Asian countries and the USA than in Europe.

A renewed agenda should also be set to encourage more general recognition of science and engineering, with an emphasis on education and graduate recruitment. Coverage should also be promoted in the more general media and not just the specialist press.

4.4. Financing the vision

Any European collaborative programme targeting nanoelectronics for 2020 must be visionary and holistic enough to offer a platform of technologies ranging across and combining equipment and materials, new fabrication methods, system design methods and tools, and adapted contents leading to appealing new products. It should also produce a competitive environment and offer attractive working conditions.

Investment in the achievement of critical mass will create knowledge, attractive employment and economic growth throughout Europe. Nanoelectronics will form a sound basis for a key industry, which must be encouraged financially, to give a level playing field with competitors on the other continents. The strategy must afford sufficient support in the early stages, without becoming interventionist. Public funds help provide the strength to avoid an economic discontinuity in Europe's own nanoelectronics activities.

Large-scale funding

Large-scale funding for strategic priorities should permit collaborative R&D to be conducted in a more unified way, taking into account the specific role of each actor in the technology life cycle and avoiding the inconsistencies and overlap between current national programmes.

The overall R&D effort required in Europe to develop nanoelectronics technologies over the next five-year period (2004 to 2008) is estimated to need a doubling of financial resources from the current level of €3 billion a year. The required annual investment of around €6 billion would comprise €2 billion a year to support upstream research and infrastructures, plus €4 billion a year for downstream industrial R&D.

Substantial public funds will be needed to leverage the required level of private investment. This can involve Member States contributing directly through their intergovernmental (e.g. EUREKA), national and regional programmes (including funding education and training), and European funds such as the Framework Programme and Structural Funds.

There is also a need for a technology-aware banking sector with financial institutions – banks, venture capital funds, etc. – able to identify, accept and balance out risk to support funding for new R&D projects and financing of research and production facilities.

4.5. Taking urgent action

All concerned European stakeholders should endeavour to urgently put in place a Technology Platform to ensure nanoelectronics success in Europe and to harvest the expected benefits in terms of job and wealth creation.

Such a programme of action is entirely achievable. It would put Europe in a pre-eminent technological position, with consequent economic and sociological benefits. Major semiconductor and electronics companies, as well as research institutes across Europe, are already indicating their broad support for this activity and look forward to participating in it.

A 2020 vision for the European nanoelectronics sector

The ambition is to achieve world leadership in R&D and manufacture, and maintain high-value added next-generation production processes in Europe. This requires:

- **A competitive supply chain** with no major missing links, extending from strong major actors to SME suppliers capable of exploiting all of the available expertise – thereby turning new technologies into competitive products;

- **A research environment and adequate infrastructure** capable of supporting visionary and industrially relevant advanced pre-production research activities, including validation processes (such as pilot lines), that facilitate the rapid introduction of innovative technologies into manufacturing systems, products and services to deliver world-class results in a timely manner;

- **Strategic public-private partnerships** in which strong user industries share their long-term visions with research partners, mobilise a critical mass of resources in the most coherent possible way, and establish mechanisms for exploitation of the effort spent;

- **An education system** capable of delivering the required diversity and multidisciplinarity in a skilled research, design and production workforce; and

- **A favourable legal and financial environment**, including fast-responding regulatory support, for the huge and ever-increasing investments required from the major actors of the critical value chains to speed up participation in the competitive globalised market.

A Technology Platform involving all major stakeholders should play a central role in defining a strategic research agenda and creating the action plans to implement the vision.

Glossary

ambient intelligence	Combines ubiquitous computing and intelligent systems in a long-term vision of a future where people are surrounded by sensitive and responsive electronic environments
biosensor	Powerful analytical tool combining biological and electronic technologies
CD	Compact disc -– optical disc used for storing digital data
CMOS	Complementary metal oxide semiconductor – principal technology used currently for chip manufacture
DVD	Digital versatile disc – optical disc storage medium
eEurope	European Council-backed strategy to develop modern public services and a dynamic environment for e-business through widespread availability of broadband access at competitive prices and a secure information infrastructure
EUREKA	Pan-European network of 33 countries and the European Commission for market-oriented, industrial R&D
GPS	Global positioning system
GSM	Global system for mobile communications – the European-led standard for mobile phones
ICT	Information and communications technology
International Sematech	Subsidiary of Sematech (see below), formed in 1998 to include non-US companies
IP	Intellectual property
IST	Information Society technologies – thematic priority under EU Sixth Framework Programme (FP6)
ITRS	International technology roadmap for semiconductors
JESSI	Joint European submicron silicon initiative – EUREKA programme from 1989 to 1996 that primarily focused on closing the technology gap with the USA and Japan
MEDEA	Microelectronic development for European applications – the continuation of JESSI, from 1997 to 2000, strengthening co-operation among system suppliers and semiconductor companies
MEDEA+	Continuation of MEDEA, from 2001 to 2008, with the objective of helping Europe to become a leader in system innovation on silicon
nanotube	High-strength cylindrical fullerene graphite structure with attractive physical and chemical properties
PDA	Personal digital assistant
quantum computing	Storing and processing data in ‘qubits’ rather than binary digits (bits) to obtain exponential improvement in computing power
R&D	Research and development
Selete	Semiconductor Leading Edge Technologies – Japanese semiconductor industry consortium working on future technologies
Sematech	Semiconductor manufacturing technology – consortium of US semiconductor manufacturers
SoC	System-on-Chip
spin electronics	Devices making use of ‘spin’ states in semiconductor materials
UMTS	Universal mobile telecommunications system – third-generation (3G) mobile phone technology

European Commission

Vision 2020 - nanoelectronics at the centre of change

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The growing success of the European players in nanoelectronics is well known. However, in view of the tremendous technological, economic and social challenges ahead, this document presents the first building block of a new European initiative for this sector. It results from consultations with a representative group of industrial and research organisations. The objective is to spell out a strategic research agenda for nanoelectronics based on the 2020 vision that would become the main roadmap for all stakeholders involved.

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