Towards a Bright Future for Europe

Strategic Research Agenda in Photonics

PHOTONICS21

Photonics21 • Towards a Bright Future for Europe • Strategic Research Agenda in Photonics

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Photonics21 European Technology Platform

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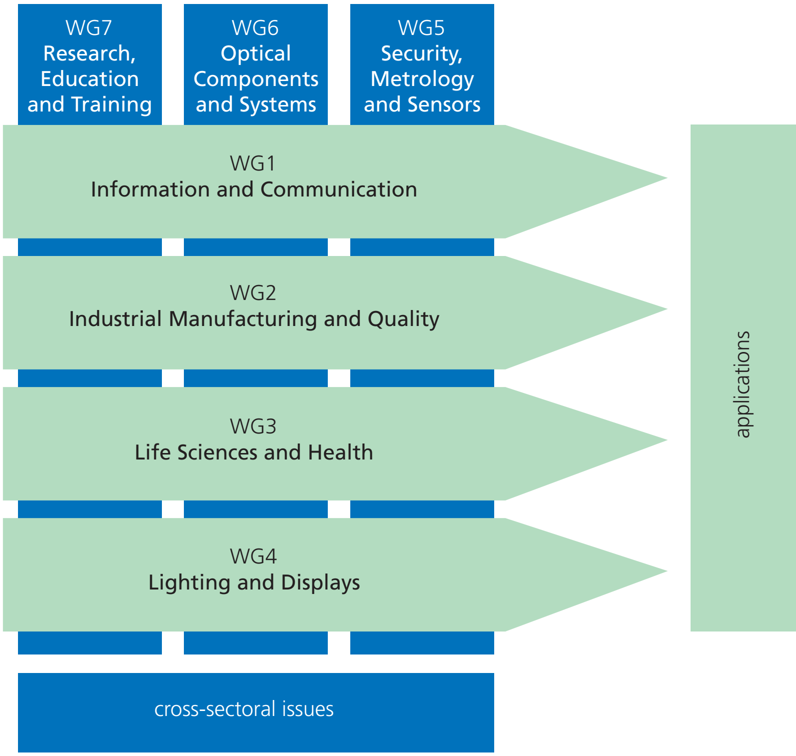
1 Executive Summary

Technology Platform Photonics21

The European Technology Platform Photonics21 has been founded in December 2005, based on an industry-led initiative. Comprising more than 350 members from 27 countries, Photonics21 unites the majority of the leading Photonics industries and relevant R&D stakeholders along the whole economic value chain throughout Europe. Presently, Photonics21 comprises seven work groups (WG):



In spite of the diversity of the disciplines involved and the fields of application addressed, there is an urgent need for a common approach for photonics R&D in Europe:

– leading-edge research and innovation requires involvement and cooperation along the whole economic value chain - from the exploration of the underlying techniques to the development of marketable products;
– cross-sectoral issues need to be linked with application-oriented issues;
– synergies between different fields of application have to be utilised;
– finally, substantial attention should be given to the fact that photonics communities and coalitions emerge in many parts of the world (e.g. in the US, Japan and Australia) and develop common strategies while photonics in Europe is still widely fragmented.

Thus, the members of Photonics21 aim at jointly paving the way for Europe's scientific, technological and economic leadership in photonics and, in the long term, making Europe the number one knowledge-based economic area in the world.

Societal and economic impact of Photonics

At this stage, photons are found at work all around us in obvious as well as subtle ways, helping to improve our quality of life. Although only a small fraction of their ultimate performance has been realised, yet, photonic technologies contribute significantly to vital societal objectives, such as achieving information society, improving health care and prevention, saving energy, providing safety and security for the citizens and, last but not least, creating employment and growth:

– Photonics is a driver for technological innovation and one of the most important key technologies for markets in the 21st century. It has a tremendous leverage for creating products in a broad range of industrial sectors that multiply the value of initial photonic components and technologies many times over.
– The innovative and competitive capability of many important European industries, such as ICT, lighting, health care and life-sciences, space and defence as well as the transport and automotive sector largely rely on progress and development in photonics. Without strong European leadership in photonic technologies, these industries will be left vulnerable to strong competition from the USA and from Asia.

But even the primary markets for photonic components, systems and optical consumer goods show impressive figures, considering that photonics is a technology sector widely dominated by SMEs which employ about two thirds of the photonics workforce:

– According to rather conservative estimations, the photonics world market in 2005 amounted to more than EUR 150 billion of which about 40% related to information and communication technologies.
– The annual growth rates of the optics and photonics industries far exceed those of the economy (e. g. laser sector greater than 14% for the past 10 years; optics and photonics in life sciences exceeding 38%) and also the future prospects are promising (e.g. for OLEDs = organic light-emitting diodes an annual growth rate of about 40% is expected over the next 5 years). The total photonics world market is expected to at least triple within the next 10 years!
– There are at least two areas where European photonics industry leads the world today: solid-state lighting, where European companies now account for more than 30% of the world lighting market; and laser-assisted manufacturing, where Europe dominates world-wide manufacturing and sales with about 50% of the total world-wide market.

Recent developments prove that economic growth does not necessarily cause an increase in employment. However, achieving and defending Europe's technological leadership in photonics is suited to have a beneficial impact on employment in threefold ways:

1. Photonics industry is widely based on SMEs where the correlation of growth and employment is higher-than-average.
2. Photonic technologies help securing the competitiveness of existing industries and thus safeguarding jobs in manufacturing which are threatened by shifting to low-wage countries outside the EU.
3. In the medium- and long-term, gaining technological lead in photonics will enable the creation of new jobs in industrial manufacturing of novel consumer products in sectors where Europe presently lags behind, such as displays, multimedia devices and entertainment electronics.

Today, about 200.000 people are directly employed in the photonics sector. In addition, the jobs of more than 2 million employees solely in the manufacturing sector in the European Union depend directly on photonic products.

Implementation of the Photonics21 strategy

It will take inspiration, brilliance, diligence and a lot of hard work to turn the ideas into design prototypes and then into useful products. But first of all, concerted efforts are required in order to enable industry and research to uphold their outstanding initiatives to explore the nearly limitless future applications of light. Taking into account the strong global competition, from talented and well-educated scientists in Asia and the US, it seems crucial for the optics and photonics community in Europe to strengthen its leadership position.

During and in particular subsequent to the initial workshop in Brussels in December 2005, Photonics21 members worked out the following recommendations for actions to be taken.

Key recommendations of Photonics21:

1. European photonics industry and science need to join forces under a strong European umbrella.
2. An increased public and private investment in photonics is needed.
3. Clear responsibility for photonics within the European Commission is needed.
4. A mirror group involving the relevant public authorities and funding bodies throughout Europe needs to be installed.
5. The present gap between photonics science and industry in Europe needs to be bridged through enhanced collaborative research and respective public funding.
6. Transnational and multilateral collaborative research projects should be stimulated through additional funding from the European Commission (e. g. through an incentive scheme).
7. The areas where R&D will lead to marketable products in ten years need to be identified in a systematic manner in order to derive specific roadmaps and strategies.
8. Detailed technical recommendations of the Strategic Research Agenda need to be updated annually by the Photonics21 members.
9. Photonics21 needs to seek cooperation with complementary Technology Platforms.

Backing on the part of politics will be crucial in order to foster cohesion and co-ordination between the fragmented endeavours and lay the foundations for concerted action. Political support will particularly be needed in providing the necessary research environment capable of accelerating photonics research, enhancing cooperation, increasing public and private R&D investments and ensuring the mobilisation of the critical mass of resources.

R&D investment requirements

In view of the massive efforts taken in the USA and in Asia, providing for sufficient European R&D investment in photonics will be an indispensable prerequisite for the future success of the European photonics economy and its competitiveness.

Today, private R&D investment by the European photonics industry amounts to EUR 3.3 Billion p.a. which represents about 9% of the overall annual turnover. On the other hand, the public investment in photonics lags far behind: the current ratio of public to private investment in collaborative photonics R&D is about 1:15 which is extremely low compared to other sectors.

Thus, two main objectives have to be tackled jointly by public authorities and industry:

1. The overall investment in collaborative photonics R&D needs to be increased in order to keep up with the global competitors and to achieve the 3% Lisbon goal.
2. The public/private investment ratio in photonics R&D needs to be adjusted which requires a disproportionately high increase of the public funding.

Private investment (agreed commitment from European photonics industry):

– European photonics industry is willing and prepared to increase today's annually EUR 3.3 billion R&D investment by 10% p.a.

Public investment (required commitment from public authorities):

– Public funding of collaborative photonics research from the European Commission needs to be doubled compared to FP6.
– Overall national public funding of collaborative photonics research from the Member States should be doubled over the next five years.

The members of Photonics21 are convinced that jointly implementing the recommendations given and significantly increasing the R&D investment in Photonics will have a major impact on meeting the goals of the European Lisbon Strategy and will lead to sustainable growth. A powerful and concerted European approach is the route to ensure our continued success and to ensure that we can benefit from the thrilling innovations that lie just ahead.

2 Introduction

The document in hand is the first Strategic Research Agenda (SRA) of the European Technology Platform Photonics21. It has been jointly developed and adopted by the members of Photonics21 between December 2005 and March 2006.

PHOTONICS21

Photonics21 was founded in December 2005, based on an industry-led initiative encouraged by the European Commission in 2004.
Today, Photonics21 comprises more than 350 members from 27 countries, among these 21 EU Member States. Almost 50 % of the members come from industry (manufacturers as well as users of optical technologies) and about three quarters of these industrial members represent SMEs. The second half of the members mainly consists of industrial and scientific associations and of research institutions, particularly those working at the industrial-scientific interface. Thus, Photonics21 unites the majority of the leading photonics industries and relevant R&D stakeholders along the whole economic value chain throughout Europe.

2.1 Objectives of the SRA

By setting up and implementing this SRA, the members of Photonics21 aim at paving the way for Europe's scientific, technological and economic leadership in photonics and, in the long term, making Europe the number one knowledge-based economic area in the world.
To this end, the following objectives will be pursued:

- Establish strategic links among mainly SME based photonics industries as well as towards key user industries and to align common R&D efforts accordingly;
- Ensure that knowledge generated through research is transformed into leading-edge technologies and processes, and ultimately into marketable products and services which are competitive on a global scale;
- Define medium to long-term research and technological development objectives and lay down markers for achieving them;
- Provide for the necessary research environment capable of accelerating photonics research, enhancing cooperation, increasing public and private R&D investments and ensuring the mobilisation of the critical mass of resources.

2.2 Photonics – a key technology based on multidisciplinarity

It is only 40 years ago since a new field of study and enterprise was created: photonics. It emerged as a synthesis of a number of disciplines all involved in the mastery of the photon: optics, material science, electrical engineering, nanotechnology, physics and chemistry. Meanwhile, the sophisticated combination of light and electricity has created synergies that nobody could have ever foreseen in 1967 when the term photonics was coined by Pierre Aigrain, a French scientist:

*"Photonics is the science of the harnessing of light.
Photonics encompasses the generation of light,
the detection of light, the management of light
through guidance, manipulation, and amplification,
and most importantly, its utilisation for the benefit
of mankind."*

In 2005, we celebrated the centennial of Einstein's discovery that light does not flow like a continuous fluid, but consists of indivisible elementary units that we now call photons. A century after this discovery, European scientists and engineers are prepared to take the mastery of light to a new dimension, bringing a quantum leap in spurring growth and competitiveness in economic areas of the highest importance.

History teaches that a major technology principle may trigger the creation of new and revolutionary industries for decades following its discovery. The transistor was immediately appreciated as a new kind of electronic amplifier when it was invented in 1948, but no one could conceive of the revolutionary change that this device would create in all walks of life. The transistor paved the way for the microelectronics industry, and the computer age, both of which are now major drivers of the world-wide economy. The laser was invented only a few years later, but there was no idea at the time that this would lead to a revolution in the recorded music, printing, and manufacturing industries.

Right now we just passed a milestone in the age of photonics with the knowledge and the technology in hand to stimulate the photonic revolution: achieve a new level of mastery in the generation, the control and the use of harnessed light, custom-tailored for many and varied applications. Due to ground-breaking progress in photonics and the related disciplines, a new generation of photonic tools is within reach. Now we have the means and the insight to create photonic systems that will fully exploit the unique powers and potentials inherent to light.

Just as the technological breakthroughs of the 20th century were enabled by the utilisation of the electron, the 21st century will very likely prove to be the century of the photon.

2.3 Europe's economic growth – boosted by photonics

Photonics is a driver for technological innovation and one of the most important key technologies for markets in the 21st century. The economic impact of Photonics outreaches by far the mere output of the photonics industry in terms of photonic components, systems and optical consumer goods.

On the one hand, photonic technologies boost competitiveness and technological leadership in a broad range of industrial sectors. For example, the application of laser systems for material processing causes significant impacts on the efficiency and the quality in user industries, such as automotive, microelectronics, aeronautics, etc. Thus, a sound and comprehensive survey of the overall economic and technological relevance of photonics should consider at least estimations of these indirect impacts, which are difficult to quantify.

On the other hand, a major part of the photonic components produced is applied to larger, sophisticated products and systems. For example, a laser is the core of any CD or DVD device. The proceeds of the sales of these lasers are minor compared to the revenues generated by the sales of the final product. Yet, DVD devices – and many other high-tech mass products - are principally enabled by photonic technology.

This is why photonics has a tremendous leverage for creating products that multiply the value of the initial photonic components and technologies many times over.

However, even the primary market figures are impressive, considering that photonics is a technology sector widely dominated by SMEs, which employ about two thirds of the photonics workforce. According to rather conservative estimations, the (direct) photonics world market in 2005 amounted to about EUR 150 billion of which about 40% related to information and communication technologies.

With regard to the primary sectors, there are at least two areas where European industry leads the world: solid-state lighting, where European companies now account for more than 30% of the world lighting market and are innovation leaders in the development of LEDs for lighting; and laser-assisted manufacturing, where Europe dominates world-wide manufacturing and sales with about 50% of the total world-wide market.
Moreover, the economic growth rates for optics and photonics industries far exceed those of the economy. The laser sector, where European industry has the majority share, enjoys an annual growth rate greater than 14% for the past 10 years. The annual growth rate for optics and photonics in life sciences exceeds 38%. The market for organic light-emitting diodes (OLED) is expected to have an annual growth rate of about 40% over the next 5 years – just like the solar cell market that has had an average annual growth of 37% since 1997[1].

It is obvious that not only the photonics sector but also many other important European industries, from chip manufacturing and lighting, health care and life sciences, to space, defence and the transport and automotive sector rely on the same fundamental mastery of light. Without strong European leadership in photonic technologies, these industries will be left vulnerable to strong competition from the USA and from Asia.

1 Photovoltaics, in the broader sense a photonic technology, too, are covered by the European Photovoltaic Technology Platform (http://www.eupvplatform.org). Provision is made for cooperation and exchange with this and other related ETPs.

2.4 Light – an extremely versatile tool

Several technological achievements of the present could not have been realised without significant contributions of photonics. At this stage, photons are found at work all around us in obvious as well as subtle ways, helping to improve our quality of life.
Here are some present and future prospects:

- Photonics enables the processing, the storage, the transport and the visualisation of the huge masses of data needed to make the information society become reality; information flow and data streams are rapidly increasing; in the future optical systems will provide bandwidth 1000 times greater than today's offering and enable broadband for all.
- Novel displays (e. g. interactive, flexible, large-area, transparent, 3-D) will enable ubiquitous data access within the vision of ambient intelligence and new consumer as well as professional applications which are capable of revolutionising professional life and creating new lifestyles.
- In manufacturing (laser-)light is used as a fast and precise tool for many purposes, materials and objects, in the fabrication of huge ocean-going tankers as well as in the generation of structures on a nano-scale. Photonics-based production provides the route for maintaining and developing cost-effective manufacturing in Europe in the future.
- Innovative lighting systems create convenient surroundings and save energy; if light-emitting diodes are introduced aggressively, at least 2 billion barrels of oil can be saved per year by 2010.
- Various photonic applications provide safety and security for Europe's citizens in diverse societal spheres, such as road traffic and public transport, trade and communications, environmental monitoring and industrial production.
- Modern health care has been revolutionised by the use of optical applications in examination, diagnosis, therapy and surgery; further innovations and breakthroughs appear to be within reach, such as e. g. micro-probes and remote diagnosis. In the near future, sophisticated but inexpensive (since mass-produced) devices might even be available for use in the workplace, in supermarkets, and in homes, enabling simple and reliable early detection and prevention of today's unpleasant and costly treatments.
- Finally, light is the key to the microcosmos of life in biotechnology, pharmaceutics and genetics. For example, photonic tools are capable of not only manipulating molecules but also living cells without causing harm to them. Deeper insights in the pathogenesis will be available and thus enable revolutionary ways of prevention. Moreover, photonics will significantly contribute to make life-saving drug development faster, more effective and affordable.

However, this is just the beginning. Present-day tools, sources, systems and applications allow us to realise only a small fraction of the ultimate performance of photonic systems. There can be no doubt that photonics and optical technologies will be among the most influential drivers of innovation in the 21st century:

- Photonics offers new and unique solutions where today's conventional technologies increasingly reach their limits in terms of velocity, capacity and accuracy.
- Future progress in key areas of industry and technology, such as life science and health, information and communication, energy and production, will to a large extend depend on photonics.
- Photonics offers vital contributions to a number of fundamental societal challenges with regard to the information society, public health care, sustainable growth, etc.
- Photonics is a growth sector capable of strengthening and advancing the competitiveness of European industry and economy.

It will take inspiration, brilliance, diligence and a lot of hard work to turn the ideas into design prototypes and then into useful products. But first of all, our entry into the "photon century" requires concerted efforts in order to enable industry and research to uphold their outstanding initiatives to explore the nearly limitless future applications of light and to reap the expected benefits in terms of creating both jobs and wealth for Europe.

2.5 Photonics – a common challenge for Europe

Although involving a number of disciplines, photonics is clearly a stand-alone scientific and technological field. Its common denominator is the mastery of the photon. Since the "Harnessing Light" study (National Research Council, 1998) was published in the US in the late nineties, photonics communities emerge in many parts of the world (e. g. in the US, in Japan and in Australia), build national photonics coalitions and develop common strategies.
In Europe, corresponding activities have been started at regional and national level. But at European level photonics research is still widely fragmented and scattered. Currently, the development of new photonic technologies and products faces two complicating factors:

1. National R&D activities and programs in the Member States are not yet effectively linked and coordinated.
2. At the European level, R&D programs involving optics and photonics are dispersed among various application areas. Projects are carried out widely isolated from each other in a number of different thematic priorities.

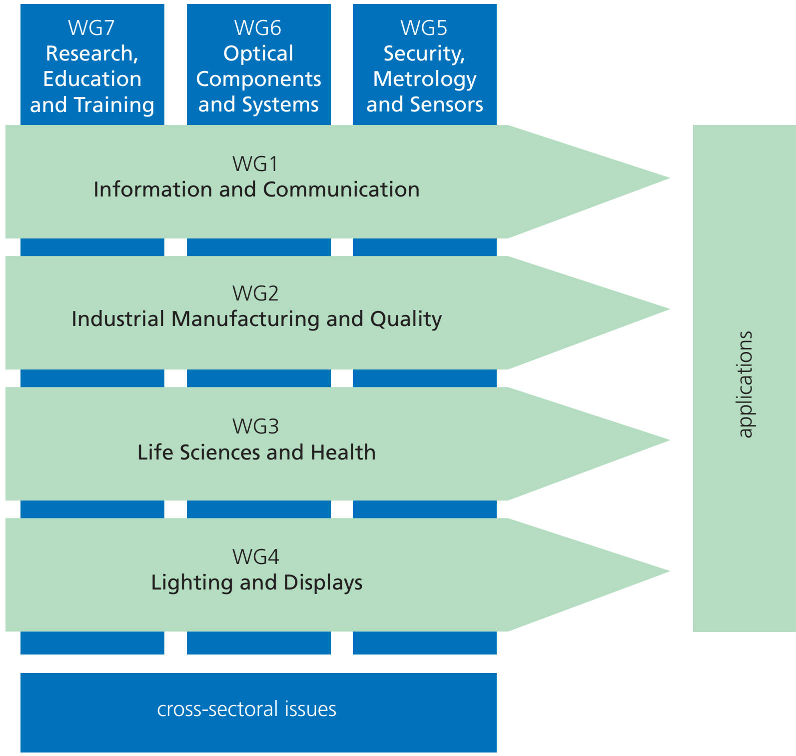
It will take prompt and forceful common European efforts in order to resolve this two-fold fragmentation, in order to stay competitive and to tap the full potential of photonics for the benefit of our citizens. The absence of co-ordination is a brake that impedes the progress and competitiveness of optics and photonics industries in Europe.

Backing on the part of politics will be crucial in order to foster cohesion and co-ordination between the fragmented endeavours and lay the foundations for concerted action plans among all stakeholders and for the implementation of joint strategies in terms of:

– Strengthening and the structuring European photonics research, mainly within the scope of the forthcoming Framework Programmes;
– Enhancing pre-competitive collaboration and standardisation;
– Providing for protection and exploitation of European intellectual property;
– Adapting and improving the educational and scientific basis;
– Raising public awareness and communicating research results to the wider public.

Political support will particularly be needed in providing the necessary research environment capable of accelerating photonics research, enhancing cooperation, increasing public and private R&D investments and ensuring the mobilisation of the critical mass of resources. Primarily, it is vital:

1. To give political support to the bottom-up endeavours of Photonics21 in terms of paving the way for public-private partnerships at all levels;
2. To consider the strategy, the recommendations and the priority research topics stated in the following chapters and to allow for them when shaping the objectives of future research and innovation programmes, if so.



Taking into account the strong global competition, from talented and well-educated scientists in Asia and the US, it is crucial for the optics and photonics community in Europe to build on its leadership position. A powerful and concerted European approach is the route to ensure our continued success and to ensure that Europe can benefit from the thrilling innovations that lie just ahead.

In order to meet the challenges described, the Technology Platform Photonics21 has been formed by a large number of leading actors in European optics and photonics R&D coming from industry, university, research institutes and relevant associations. They have joined their efforts in order to develop and implement a common strategy and provide support for the important political process that is needed to implement a coordinated action plan among all the stakeholders.
Presently, Photonics21 comprises seven work groups (WG). Four of those are focussing on different fields of application and three on cross-sectoral issues. Their findings, recommendations and strategic as well as technical objectives will be described in detail in the subsequent chapters.

3 Research Priorities for Europe

3.1 Information and Communication

Evolution of Communications: the electronics intermezzo
In ancient times, the fastest method of long distance data transport was provided by smoke signals. This "optical" approach was enhanced over the centuries to a complex network of relay stations and beacons, where semaphore arms were lifted and lowered, visible over long distances. The speed of data transport was acceptable, but capacity was low. During the last century this problem was solved by switching to electronic data transport, which connected people around the world. This approach changed our lives, but about twenty years ago this technology reached its limits, while our need for an even higher communication capacity has not.

Photonics – booster for information and communication
The major highways of communication and information flow are optical. The data rates of the Internet are scaling with advances in lasers, optical fibres and optical coding technologies. Bringing the benefits of broadband communications to European citizens presents both the challenges and the rewards for the next generation of photonic systems. We need components and architectures that support bandwidth growth to 100-1000 times that of today's "broadband" services. Through a leadership position Europe can drive standards rather than react to them and leverage European solutions into the global market.

Fig. 3.1.1
Optical communication works at the heart of our knowledge society: Worldwide operating Telecom Control Center
© Telekom

Optical networks have opened the way to almost unlimited digital communication, building the very foundations of our Information Society. Information and knowledge are becoming our most valuable commodities – unlimited access to which is becoming arguably the most significant driver of productivity and competitiveness. It is optical transmission networks that are enabling all of this, giving data accessibility to anyone, anywhere. For Europe, this is central to our future prosperity.

Your computer, telephone or workstation may be connected via cable or wireless to the network, but a short distance away the signals will certainly be optical. In the near future many of the 'short' distances will become 'zero' distances, with optical networks embedded into our homes and places of work as well as our equipment. We are all now dependent on this infrastructure for our communication, enterprise and entertainment and await the next stages of its evolution, be these in new services, enhanced connectivity, lower cost or infotainment. This evolution is **mandatory for our sustainable future** – ubiquitous truly broadband communications will continue to revolutionise all aspects of society, relieving pressures on areas as diverse as energy and transport particularly as communication and visualisation technologies break down geographic barriers and distances.

Next in league with information and communication is data storage. Data storage systems are intrinsically embedded in our knowledge society, with an enormous impact on economic and creative endeavours.

The change from vinyl to CD and video tape to DVD, again, represent major paradigm shifts. Abstracting away the obvious advantages of these scalable technologies, it is important to point out what made it happen: The CD displaced vinyl when infrared laser diodes became 'one-euro' articles; the DVD replaced the video cassette recorder (VCR) when visible red diodes also reached this price level. The imminent arrival of the blue ray disc is exactly correlated with the affordability of blue laser diodes, made possible only by the development of device technologies for shorter and shorter wavelengths. Further developments are underway, ranging from 'non-spinning' optical discs, discs with near-field optics and discs with holographic media. Whether future optical TeraByte discs come from Europe or abroad is just a question of who is first.

A third major area addressed in this chapter is the realization of scalable networks by means of **optical signal processing.** As network capacities and switching speeds extend to factors of 100 to 1000 times beyond current technology, it is very likely that the power of optics to switch and transform signals will be used to enhance and in many cases replace conventional electronic signal processing. The major advantages will be in network connectivity and capacity, with important gains in other physical attributes such as reduced power consumption, node footprint and network reliability. Many aspects of optical signal processing are currently intensive research topics, with many powerful demonstrations of functions such as all optical regeneration, optical (time division) multiplexing/ demultiplexing and wavelength translation. As bit rates increase, these techniques will become increasingly important and cost effective. It will be several years before deployment in mainstream networks, as areas of cost, simplicity of operation, standards and technology require significant investment. The tremendous potential of the area dictates that significant effort should be included in Framework 7, providing an excellent opportunity to enhance the European capacity for innovation and competitiveness in this global research arena.

There are many challenges to be faced in all of the above areas. To progress in telecommunications, it must be understood that current optoelectronic physical layer technologies will not sustain the demands. **Europe needs to develop technologies and a technology roadmap that will enable our industry to deliver year on year radical 'cost per bit' cost reduction and bandwidth enhancement.** This will drive and enable new ways of working, new industries, new applications. We cannot let the information flow in our Information Society become a bottleneck. Bandwidth and data storage demands will grow inexorably over the next century and we must enable the technologies and industry to deliver this. This is not only about transmission – routing, switching reconfiguration, protection and storage are all part of the future network.

Industrial Structure
The Telecom Photonics Industry has suffered severe trauma from the 'dotcom' bubble and its subsequent collapse. The (optical) communications and component industries are in a process of consolidation and cost reduction, to enable survival and growth in a market correcting itself from short term over-investment and over-capacity. Much of the pain has been absorbed, enabling consolidated strong industries and vibrant, innovative start ups to emerge, addressing world markets – often with global facilities and operations. This process will continue, building on the European capability for invention. We need to foster the climate of innovation and enable leverage of the extensive European infrastructure and investment – both Academic and Industrial – through collaborative programmes and direct industrial development.

Fig. 3.1.2
Modern facilities enable efficient production of optoelectronic devices for Information and Communication Industry
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The challenges need to be seen and addressed at network and service levels. This is not technology push; it is rather the identification and realisation of new technologies that will lead to component breakthroughs to enable cost effective, manageable networks capable of supporting next generation broadband services. We must strive to lead, rather than follow, giving our industries the opportunity to define and set standards rather than having to comply with them.

The global telecom market is expected to continue its double-digit growth from 2004 to reach over $2 trillion by 2008, according to the Telecommunications Industry Association (TIA). High-speed broadband access will be a principal driver of equipment revenue in the forthcoming years. As the broadband market expands, the need for infrastructure to support the traffic will further revitalize the network infrastructure equipment market. TIA expects equipment spending to increase at an annual growth rate of 8.1%, rising from $238 billion in 2004 to $325 billion in 2008.

The Telecom Photonics Industry is ready to gain an increasing share of the communication equipment market. According to the Optoelectronic Industry Development Association (OIDA), the optoelectronic communication market grew 9% in 2004 to $22 billion. Being part of this activity, and the services it supports, is core to European industry.

Optical storage is a multi-billion dollar market. According to the BBC Research Group the global market for magnetic and optical storage materials, which is estimated at $19.8 billion in 2005, is expected to grow to $39.9 billion in 2010. The optical storage media market is expected to grow much faster than the market for magnetic storage over the next five years, i.e., at an annual growth rate of 19.8% vs. 4.8%. At these growth rates, optical storage media are expected to increase their share of the data storage market from 58% in 2004 to 77% in 2010. Up to year 2015 new optical storage media such as holographic and near-field storage could become

significant factors, as they offer opportunities for managing higher orders of complexity and abstraction than has been possible so far, and thereby offer the potential to create new products and new applications in wide fields of the knowledge economy. Research activities initiated now and in the short term will enable European Industry to take a leadership role in the development of new emerging storage technologies.

3.1.1 TRANSMISSION

3.1.1.1 Current and future challenges

Significant Network evolution will provide leadership for a development of optical components and manufacturing technologies. Industry has moved beyond the hand-crafted, precision aligned, modules of the last decade, where performance counted well above cost. The commercial push coming from the data comms. sector is in driving modularity. This is leading to simplification of performance and functionality, with basic chips being designed for the 'hot pluggable' easy to use standards. This emergence has led to many lessons being learnt. The responsibility for managing and understanding complex optics has been advanced firmly to the component/ transponder/ subsystem supplier. The system integrator and supplier needs to know what the optics can do and how to use this for system advantage, taking much more of a 'black box' approach. Part of the challenge now is to achieve cost, size, integration and performance levels well beyond even today's telecom grade components into datacom footprints and cost range, and making these simple to use for the system integrator. Part of this will be to build more intelligence into the components, so that they can configure themselves – for instance, in wavelength, bit rate and dispersion.

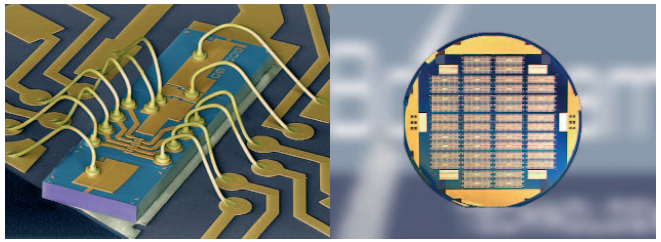

Fig. 3.1.3
Monolithic full band tunable laser fabricated in InP. The chip includes a multi element grating switch which digitally selects the waveband the device emits. The additional contacts provide the gain and fine tuning currents
© Bookham

New components – based on novel or emergent technologies – will be required for parts of the network which will become increasingly transparent – perhaps the 'holy grail' of optical network cost reduction. Optical switches, routers, wavelength switches, wavelength translators and all optical regenerators are likely to be differentiating components.

Optoelectronic integration both at the monolithic and hybrid level will be essential to deliver the functionality and cost; new self aligned assembly methods are required. The key added value in components will then be retained close to the European centres of design and fabrication excellence, with little added value in offshore assembly. High levels of automation in assembly and test will be standard. Low cost optical – electronic – optical (o-e-o) conversion and electronic switching/ demultiplexing is already finding application in certain areas of the network. Increasing reach and per-subscriber capacity in the access network will be a priority, reducing power demands, infrastructure and costs whilst enhancing service capability.

The component and subsystem costs are an important but relatively small part of the value-added-pyramid in the telecommunications system industry. However, innovation at the physical layer – both at component and subsystem levels – is essential to enable innovation and differentiation at the system level and hence enable the value added pyramid to flourish –the framework must be provided for our industries to work strategically together, from material, through component and system to application user.

The boundaries between components and subsystems will continue to evolve, driven partly by standards, partly by the enhancements offered by electronic processing of the optical signals, through coding or electronic mitigation of dispersion. Already techniques are being demonstrated giving several thousand kilometres of transmission distance at 10Gbps with no optical dispersion compensation. Methods of co-packaging, heat management and testing of subsystems comprising optoelectronic, optical and electronic components, possibly in multichannel configurations, must be developed.

Heat generation is a key generic limiting factor in today's components, limiting packaging density, architectures and cost. The industry must move increasingly towards components which function without internal coolers and require minimal drive currents. Packaging will be simplified, costs will reduce and our system designers can squeeze more and more interfaces onto a card, reducing real estate, power and costs. Low power is mandatory for subscriber interfaces, where extensive battery provision must be avoided on both environmental and cost grounds. Non-hermeticity may become a necessity in some end-user applications and the consequences of this need to be evaluated; for example lifetime reduction, failure rates and standards.

Many of the advances in photonics technology have been driven by the telecoms markets; many of the comments above relate to broadband network applications. In recent years, however, new application markets such as Aerospace and Security have developed and the photonics technology requirements of these new applications are as demanding as telecoms. It is vital therefore that the EU supports these emerging applications, which will undoubtedly lead to the formation of new industries and application areas.

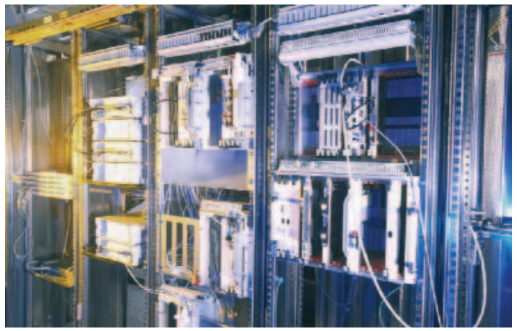

Fig. 3.1.4
Optical networks: Compact Add Drop Multiplexer and Mini Cross Connect for city networks/test and integration
© Alcatel

3.1.1.2 Predictions until 2015: Upcoming technologies and applications

Information networks are moving toward ubiquitous presence, connecting traditional telecommunication terminals, household appliances, computers and any other electronic equipment, whether mobile or fixed, in any environment, whether at home, at work or in any building, in the street, in public transportation or in private cars. This evolution will drive the continuous growth of bandwidth throughout the network from Access all the way to transcontinental links. As a result, photonics will continue to diffuse from the heart of the networks to the edges, and confirm its unique and unrivalled ability to convey tremendous volumes of data. According to a recent OIDA report:

- 2015 network bit rates will be dominated by 40Gbps in the core and 10Gbps in metro areas, with higher rates seeing some penetration.
- Total transmission capacity per carrier by 2015 will be in the 100 Tbps range.
- The rise of high bandwidth applications, such as internet protocol and high definition television, will drive fiber deeper into the network, i.e. to the residence and premise (FTTx).

At home, we know that European citizens will have access to **1Gbps per user** via optical fibre access, potentially using multi-mode (MM) polymer optical fibres (POF). Hence, within major cities (metropolitan networks) and between them (backbone networks), networks must be upgraded. With more than 100% growth of data traffic in 2005 (source Telegeography), some busy fibre routes are already fully provisioned today or will be in the next few years, despite their large capacities (circa 320Gbps per fibre). Hence, the consequences of the over-investment in backbone infrastructure in the years 2000-2002 will rapidly self correct, placing demand on a steep and sustainable curve. The capacity limit of current equipment will be reached and cost effective growth will be severely restricted, unless new photonic technologies and system designs are identified and turned into cost effective solutions.

Increasingly, data will be exchanged in a convenient way for the user, e.g. through unified, network-agnostic interfaces. On the service provider side, this suggests migration toward simplified, all-in-one (most likely all-IP) networks, merging (or "converging") all the networks than can be merged. This will require European researchers to identify innovative architectures and engineering rules to make the merger possible despite the heterogeneity of existing networks. At the same time, the photonic network will become more flexible, with enhanced possibilities of remote dynamic (re)configuration. Only limited features of this kind (such as ROADMs) are proposed today, even though operators are already very interested because they view them as a way of reducing their operational cost, by reducing the possibilities of mishandling, the major cause of system failure at present. Dynamic reconfigurability of networks has other longer-term applications of great economic potential. Operators will achieve better usage of the available capacity by reallocating bandwidth resources depending on the varying requests from the customers as well as creating new business opportunities (e.g. broadband access for the home users during the day, remote data storage for enterprises at night over a shared fibre infrastructure). In the longer run, further progress can be expected when photonic technologies for network reconfiguration are fast enough, with the provision of resources somehow following real-time variations of traffic. It should be noted that the trends to a greater reconfigurability are likely to go along with a trend toward **transparency** or at least islands of transparency. Transparency in a photonic network implies that any point of the network can be connected to any other point without regeneration in nodes, generally in a meshed configuration. An all-transparent view is generally too optimistic and a hybrid solution between opaque (all regeneration) and transparent looks more realistic. In such a hybrid solution, true dynamic reconfiguration requires that the control software of the photonic network be aware whether any optical path is feasible before establishing it or if regeneration is required. Hence, the trend toward transparency will require improved control software linked to accurate performance estimation / modeling. They also need to propose and to validate innovative photonic components, and innovative link designs, so as to bridge distances longer than those that today's systems are capable of (larger than 5000 km) in a cost effective way. More functional optical components that include tunability, optoelectronic integrated circuits (OEICs), analog/digital signal processing, and rate/protocol agile transceivers will be needed.

This must be achieved whilst keeping account of all the other changes in the network (e.g. introduction of new components along the links and in nodes, change of the bit-rate from 10Gbps to 40Gbps). These considerations also apply to metropolitan networks where some ultra-long haul technologies are currently prohibited on cost grounds (but where longer distances without regeneration are also becoming required).

This evolution will only occur if research efforts to drive the cost of photonic networks down are prioritized, focussed and co-ordinated in Europe. Europe must develop technologies that deliver radical cost per bit reduction. To meet this goal we recognize an urgent need for co-optimization of advanced high speed electronics (EDC, FEC, A/D etc) together with optical components and functional lightwave sub-systems. Furthermore, intense research activities must be performed to develop reconfigurable all-optical network components for high efficiency dynamic networking including ROADMs, wavelength converters etc.

Transmission technologies should not become the cost bottleneck in the next generation of our networked information society. The trend toward transparency (longer distance without regeneration, and hence by reducing the number of transponders) is headed in this direction where costs are driven down. However, beside this trend, any innovative photonic component or innovative system design aiming at reducing the capital or the operational expenditure of the network is of high value today and will remain so, especially as the focus towards photonics access grows. Continuous research efforts are needed in the fields of terminals, efficient modulation format/coding, amplification, new optical fibres, mitigation of impairment (dispersion compensation, PMD compensation, nonlinearity compensation), and equalisation.

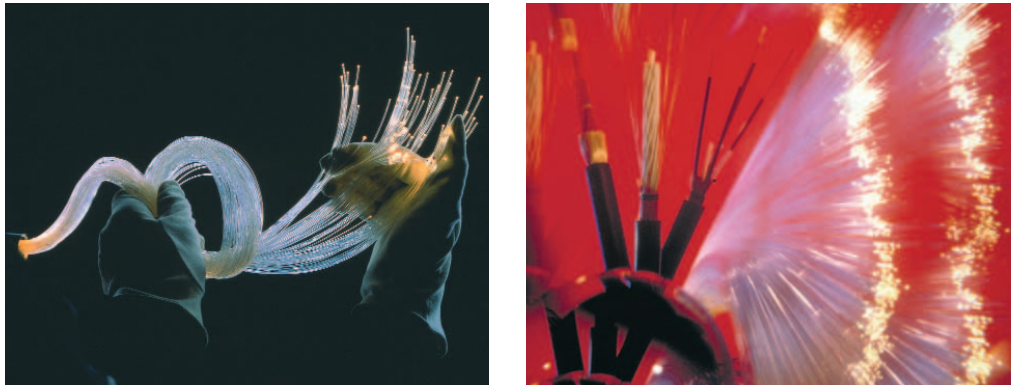

Fig. 3.1.5 Light transmission through optical fibres will enable transmission capacities per carrier in the 100 Tbps range by 2015 © left: Telekom; right: France Telecom

3.1.2 OPTICAL DATA STORAGE

3.1.2.1 Current and future challenges

Another area which is highly strategic and largely complementary to data transmission is that of optical data storage. The use of optical storage grows at a tremendous pace, driven by the flexibility and affordability the technology offers. Writable optical, when compared to other random access removable media storage solutions, offers the highest capacity available, the lowest cost per megabyte, and the longest archive life of any media.

Today, optical storage is a multi-billion dollar market. By the end of 2005 approximately 900 million drives and more than 15 billion discs had been sold worldwide. The economic activity associated with optical data storage is increasing continuously. The DVD market has exploded in only four years, surplanting the older VHS technology almost completely. The third generation of optical discs (Blu-Ray, HD-DVD) will be available to the customer in 2006 in the US and in Europe. The pre-recorded version will be used to distribute HD movies and promises a future as brilliant as DVD. The recordable version will probably become the medium of choice for recording user-authored content up to year 2010.

In spite of the impressive progress that optical storage technologies have already made at the heart of our information society, storage systems and devices are still in an early stage of their development. There continues to be rapid evolution of data storage systems and devices. Material processing and device design developments will cover photochromic polymers, optical illumination and 3-D imaging systems, micro-mechanical optical actuator chips, and micro-optical packaging techniques, to name a few.

On the market of optical data storage, the EU position is very strong, including major multinational industrial companies, many optical component, material and technology providers as well as world leading mastering, replication and high end equipment providers. This is backed up by an extensive and vibrant academic community, helping to fuel innovation in this dynamic environment. Our academic and industrial communities must continue to work together, building on this extensive experience, to develop the future generations of optical storage technologies and applications.

3.1.2.2 Predictions until 2015: Upcoming technologies and applications

The primary technical challenges are in further increasing storage density and data transfer rates to enable new applications such as digital storage for mobile digital devices (e.g. still picture cameras, camcorders, multi-functional mobile phones, mp3 players, handheld computers, PDA, game consoles), super high quality video (beyond HD-TV) distribution and economic long-term data archiving. Fourth generation technologies will target a capacity between 250 and 500 GB on a CD sized disc.

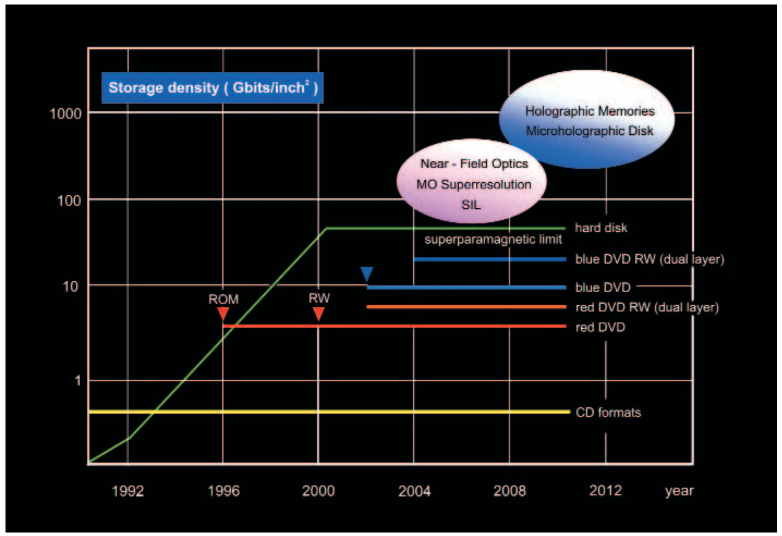

Fig. 3.1.6 Roadmap for optical storage technologies © Technical University Berlin

To reach such a high storage capacity, several technologies will be competing and working together. On the one hand, solutions may entail further increasing the real density by combating the diffraction limits of optics, using, for example, near-field optics and SuperRENS (Super Resolution Near-field Structure). On the other hand, solutions may take advantage of additional available dimensions such as proposed for various 3-D optical storage concepts which could dramatically change how we use microelectronics.

– **Near field optics** allows a further increase of the numerical aperture of the focusing objective lens by using the evanescent waves coming out of a solid immersion lens (SIL) on the basis of which the light is focused. The use of those evanescent waves is possible if the distance between the solid immersion lens and the disc is a fraction of the wavelength. Philips and Sony have succeeded in finding a servo system for the control of the air gap thickness. Sony is also developing mastering technologies to make the pre-recorded disc. **SIL** is providing a capacity at the bottom limit of what can be hoped for this generation. It is expected that the SIL technology will be combined with another one in order to increase both capacity and data rates. This technology could be the TWODOS technology that was developed by Philips in the frame of a European research program. In any case, mastering technologies have to be improved in order to avoid the use of electron beam mastering and advanced bit detection techniques will also have to be developed.

– **Holography** allows for encoding bits in a light-sensitive material as the three-dimensional interference pattern of lasers. Unlike CDs and DVDs, which store data bit by bit on their surfaces, holographic discs store data a page at a time in three dimensions, enabling huge leaps in capacity and access speed. Holography has a long history but is now coming to reality through the efforts of several European companies, enabled by breakthroughs in areas such as holographic recording polymers and novel backwards compatible recording and reading systems. Professional holographic recording devices and discs are already promised for 2006. Holograpic technology has to prove itself economically - can the cost of the drive and of the disc can be reduced to mass market prices? (i.e. from 15000$ to 150$ for the drive and from 150$ to 15$ for the disc). New system concepts are required in combination with, for instance, new single-frequency high-power laser diodes and high-speed spatial light modulators. Holographic material research is urgently needed since no rewritable material is foreseen up to now and only two non-European companies are providing convenient recordable materials. A replication system has also to be developed.

– **SuperRENS** is a novel method proposed to introduce the near-field optics into the disc layer stack itself by using nonlinear properties of a specific thin films. By doing so the disc remains removable and the distance between the disc and the objective lens remains comparable to Blu-Ray. This technology area requires significant further research and development on materials, layer stacks and channel coding technology. This is needed in combination with cross-talk-cancellation techniques in order to use conventional land and groove writing technology.

– **UV laser diodes** are also expected to be interesting for increasing the data storage capacity. Their exploitation will require a complete development of the optics and materials to be developed for use in the drive and in the discs themselves.

Another research frontier in optical storage is **slow light.** Recently researchers at IBM demonstrated a silicon chip that combined miniature heaters with photonic crystal technology to control the speed of light pulses and reduce the group velocity of light by a factor of up to 300. Up to year 2015 the ability to more closely control this slow light could make the technology useful for building optical storage systems.

European industry and research facilities are well positioned in these technologies. Optical data storage is providing substantial revenues to the patent owners and format founders in Europe. Europe has also major industries in the field of production or test equipment and in the field of materials. This position is supported by a top-level academic research activity in many related areas.

The strength of the production and R&D effort in Japanese and Korean companies is undeniable. Collaboration and vision are essential for European Industry to gain strength in this global market. Encouragement of innovation and collaboration through Framework 7 is an essential part of this approach.

3.1.3 Processing

3.1.3.1 Current and future challenges

Optical signal processing has the potential to realize high-speed and high-capacity processing at speeds which are 100 to 1000 times faster than that achievable with conventional electronic signal processing. This is a key enabling technology for ultra high speed networks, into the multi-terabit per second regime.

There are two complementary areas of optical signal processing – the realization of ‘optical in, optical out’ network elements such as regenerators of repeaters and the more futuristic of optical computing, which could apply to a wide range of applications including real-time digital signal processing for military and security, real-time video compression, as well as network functions such as header processing and error correction.

3.1.3.2 Predictions until 2015: Upcoming technologies and applications

One of the core challenge for the realization of all optical networks is the cost effective all optical regenerator, with the capability of regeneration, reshaping and retiming (3R). Breakthrough designs and technologies for achieving this in a multi-wavelength configuration will have a major impact.

All-optical processing can be viewed as the key enabling technology for very high bit rates (beyond 160 Gbps), where electronic solutions will become impractical. Many functional elements are required for such processing circuits, including switches, amplifiers, interferometers, polarization control elements as well as more complex elements for the DWDM aspects, such as Arrayed Wave Guides (AWGs) and integrated elements for photon control, wavelength/dispersion management and ultimately photon storage. Improvements in switching technologies must also be included, both in the spatial and wavelength domains. Realisation of photonic memory may also play a critical role here, with significant developments being made in the field of ‘slow light’ and PBG (Photonic Band Gap) technologies.

One goal is to make available optical devices that switch 100 Gbps optical channels with rapid switching times (under 1 ns) and that are amenable to switching small data granularity (at the sub-wavelength level). Nonlinear components are necessary to realize such functions and new materials have to be studied, such as photonic band gap structures, to increase nonlinearities.

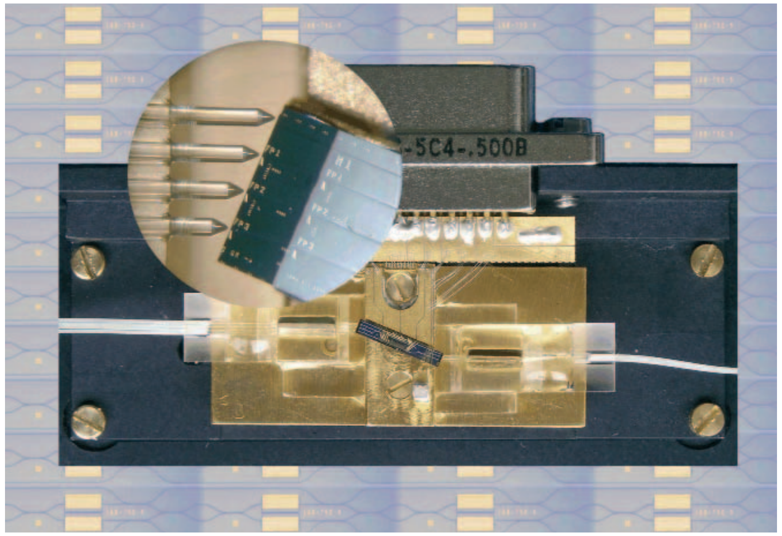

Fig. 3.1.7
Next Generation Networks will apply optical switching and routing in the nodes in order to adapt the net dynamically and cost effectively to variable traffic demands
© Fraunhofer HHI

Photonic integration, using hybrid or monolithic combinations of materials will be central to realizing these functions cost effectively.

The target areas where optical processing will gain early acceptance are those applications where the promise for integration is also beneficial from a manufacturing cost perspective. The ability to manufacture high volumes at acceptable cost, unprecedented performance and good reliability will potentially drive volumes for all-optical chips and optical interconnects.

The research strategy should always seek the best combination of electronic and optical technologies working together. The advent of silicon photonics may be a way of addressing some of the manufacturability aspects at high integration density, with the monolithic integration of photonics and electronics in one manufacturing process providing the route to low cost. III-V and other conventional optical technologies have not in any way reached limits of development, with technologies such as Photonic Band Gap (PBG) and Quantum Dots still in their infancy. This may be best exploited through hybrid strategies, leading to a System In a Package (SIP). Many enabling technologies are needed here, including optical interconnect and packaging, to reduce losses for multiple in-out and chip to chip optical interfaces.

A different and complementary research frontier in optical signal processing is in quantum technologies - quantum cryptography and quantum computing.

Quantum cryptography is the basis for quantum-key distribution networks which use single photons for storing and transferring information with impenetrable encryption. Developing such a quantum-key distribution network requires intense research in order to reliably generate single photons with the desired spin together with single photon detectors and a way to combine these into a network using very low loss switching techniques. To accelerate the introduction of these types of highly innovative new functionalities, international partnering is necessary.

Quantum computing is an area of basic research, but with enormous possible benefit. Quantum computers operate on quantum data and allow for performing highly parallel computations using compound bits called qubits. Qubits can be thought of as having multiple values at the same time, stored in quantum states. Understanding how to efficiently generate and process qubits will require tremendous research efforts.

Activities in the rapidly expanding global area of quantum cryptography and quantum communications are expected to open new avenues of research in photonics and nanotechnology creating great advances, of both scientific and economic value.

Socio-economic challenges / impact	Research topic	Technical objectives	Economic relevance
Short term (1-3 years)			
Broadband as a driving force behind the evolution of our knowledge society, major impact on areas such as health, transport and learning.	Regional and backbone transport networks: to face the huge IP-related demand for bandwidth in the transport network along with an effective business model	40 Gbps system design in the core, ROADM, efficient modulation formats, agile semiconductor and fiber technologies (nanotechnologies, photonic crystal)	Next generation broadband networks and services as a principal driver of the global telecom and the network infrastructure equipment market
Limitations of electrical links (power consumption, signal integrity, density) and need for optical solutions	CAPEX/OPEX reduction of the network through a full utilization of network resources owing to transparent reconfigurable networks.	In the field assessment of transmission quality, network monitoring, transparent transmission	
Common access to high bandwidth applications providing substantial gains in business efficiency and helping the quality of life of our citizens (e.g. tele-medicine, distance learning, tele-work)	Metro access networks: To ensure the migration of the metro access network to full IP packet networks	10 Gbps system design in metro areas, IP packet access optical network, Control plane, system design of optical packet networks Burst compliant technologies (amplifiers, process, ...)	Increasing importance of the metro market, promoting new business fields
New applications such as HDTV, VoIP, advanced 3D multiplayer on-line video games, streaming PC audio/video and internet telephony	Enabling ultra high speed network access for the user	1Gbps system design when entering the home, FTTx, broadband photonic home networks using MM fibres and POF	Strongly growing market for end-user broadband services
Increasing storage density and data transfer rates to enable new applications, as e.g. digital storage for mobile digital devices, super high quality video (beyond HDTV) distribution and economic long-term data archiving, impact on areas as diverse as entertainment, learning and preservation of cultural heritage	Driving capacity towards 250 to 500 GB on a CD sized disc by increasing the areal density or by developing 3-D optical storage concepts.	Laser diodes with shorter wavelength (UV), single frequency, higher power Optical components like high-speed spatial light modulators, aspheric glass lenses with high NA, etc. High-speed, low-noise, short wavelength enhanced single element and array detectors Holographic replication equipment (for providing mass-produced pre-recorded holographic disc)	Largely growing use of optical storage systems due to flexibility and affordability Optical storage media´s share of the data storage market expected to be 80% in 2010.
Mid term (4-7 years)			
Next-generation information networks connecting traditional telecom networks, household appliances etc.	Regional and backbone transport networks: Ensure future up-grade of the transport network following convergence of mobile and fixed technologies	Fully automatized and self regenerating optical networks, almost non-linearity free optical link fibers, full integrated optical technologies (transmitter, amplifiers, regenerators)	Photonics as a booster for telecom industry due to continuous growth of bandwidth throughout the network from access all the way to trans-continental links
Next-generation information networks connecting traditional telecom networks, household appliances etc.	Regional and backbone transport networks: Merging of optical and processing technologies	Optical IP packet switching and based processors requiring high line rate channel, buffering capabilities, processing, factor of 10 reduction in cost per transmitted and switched bit	Photonics as a primary force in the global telecom market for components and equipment.

Socio-economic challenges / impact	Research topic	Technical objectives	Economic relevance
Providing a basis for ultra high speed data processing beyond the limits of conventional electronic signal processing	Compact integratable functional systems for optical data processing	New active optical components for integration in planar nano-photonics (Si laser, modulators, switches, interconnects inside the chip, chip-to-chip back-planes etc.)	New technologies and functionalities are aimed to dramatically reduce cost per bit in ultra high speed photonic networks
Fabrication of nanoscale photonic devices at industrial level enabling ultra high speed photonic networks	Cheap compact integratable functional systems for optical data processing with low power consumption and maintenance cost	Validation of new materials that meet requirements for new functions to be used in planar photonics (e.g. optically active polymers, electro-optical and magneto-optical materials, and the compatibility with CMOS process)	Volume manufacturing of small components with huge functionality
Data storage systems as the backbone of a new era, with academic and economic output being dependent on knowledge-based activities and on powerful tools to create, access, and manage information Emerging optical storage systems enabling huge leaps in capacity and access speed	Ultrafast readout optical storage systems with capacities in the TeraByte range on a CD sized disc	High density optical mastering (minimum bit length 50 nm), advanced bit detection and channel coding techniques for near-field optics and SuperRENS ROM, Recordable and rewritable SuperRENS materials for the masking and the storage layer Stable inorganic low cost recordable disc (for reliable archiving and legal storage) Holographic rewritable materials	Continuously growing global storage market due to mobile digital devices and broadband services

Long term (8-10 years)			
Ubiquitous information networks, access at work or in any building, in the street, in public transportation or in private cars, creating new opportunities to address major societal challenges in areas such as health, transport and learning	Merging optical and electrical functionality in monolithic manufacturing process	Nanophotonic integration (III-IV-V) of components to provide VLSI photonics beyond 100 Gbps transmission speeds, to address the field where electronics fails (> 40 Gbps), photonics IC	New technical solutions challenge cost structures of established technologies
Potential for scaleable photonic networks, quantum cryptography and quantum computing with enormous possible benefit and societal impact	Identify new physical phenomena and qualify and evaluate to determine an new enabling optical functionality or functional element	Bose Einstein Condensates, single photon sources / detectors and low loss switching techniques for quantum cryptography, slow light, efficient generation and processing of qubits for quantum computing	New technical solutions challenge cost structures of established technologies

3.2 Industrial Production / Manufacturing and Quality

Light is the tool of the future. Today Europe is in the leading position in the world market for photonics in industrial production. Continuous research and development has been one of the cornerstones for success of European companies, which led to superior products with high quality and cutting edge technology. European companies, however, are now facing stronger competition and need innovation to further defend their position and to adopt novel technologies to keep up with the world-wide development. It is becoming increasingly difficult for Europe to stay competitive in such areas where labour cost accounts for a significant part of the overall manufacturing cost. An improvement in efficiency and the establishment of processes suitable for the manufacturing of high-end and high-quality products is therefore frequently the primary aim in order to sustain competitiveness.

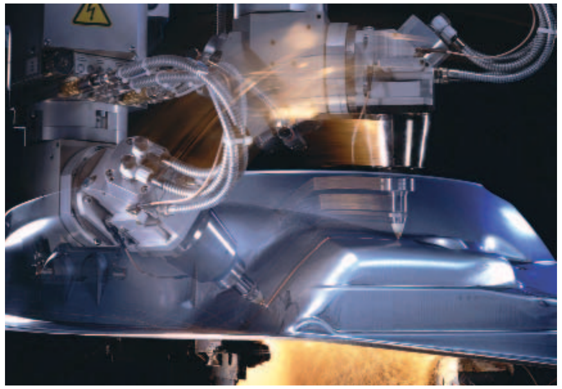

Fig. 3.2.1
Laser processing system for cutting and welding
© Trumpf

A quantum-leap has taken place by the introduction of photonic technologies in production processes on macro-, micro- and nanoscale in the past decades. Several European key economic fields were changed profoundly and the production process has been improved tremendously in terms of flexibility, precision, quality, cost structure and productivity.
Various examples can be found. For instance, in the automotive industry, the welding of car bodies and cutting of stamped parts has fundamentally improved both productivity and quality. Other examples can be found in the consumer industry with applications such as the manufacturing of sheet metal frame components, or in the semiconductor industry, where photonics again acts as a key enabling technology. For over thirty years the storage capacity of circuits has doubled every eighteen months and is driven by photonics. This rise is well known as Moore´s Law. The size of the current manufactured structures is below 100 nm. Furthermore, inspection and qualification of manufactured parts is also a vast application field for photonics.
Although enormous success has been achieved in these fields, an even larger potential for photonics technologies in production can still be developed and exploited. Many novel technologies and R&D results found at universities and public institutes have yet to be transferred to industrial production processes. Strong scientific centres and an efficient technology-transfer network will play an ever-increasing role in expanding and consolidating the competitiveness of Europe's economy. At the same time, the production demands are only partially satisfied by today's production tools.

All of the above clearly leads to the need for a large R&D offensive in the field of photonics in industrial production and manufacturing in both basic and applied research, as well as on product development including the build-up of a broad knowledge base and skilled workforce for the application of photonic processes.

3.2.1 ECONOMICAL CONSIDERATIONS

Photonics is a typical enabling technology with considerable impact on virtually all economical fields, not least in the field of production and manufacturing. The prediction of what share photonic technologies have on the overall economic growth is therefore difficult to specify. Here the very beneficial impact of photonics on the industrial innovation shall be illustrated with the example of laser systems for material processing. The development from a small niche market in the beginning of the 80s to a market of 4.75 billion Euros in 2005 is typical for a sector driven by photonic technologies (see Fig. 3.2.3). Also the very persistent and significant growth of the market of laser sources for material processing which exhibited an extraordinary increase of annually 14% averaged over the past decade points up the considerable economic potential of photonics in Europe. In the machine vision market a system sales grow of 14% is expected for the next years. The market volume increases from EUR 1.6 billion in 2004 to EUR 3.2 billion in 2009. Such a persistent and stable growth can hardly be found with other technologies and can only be compared to the performance of the micro-electronics industry – in which photonics again is the key enabling technology.

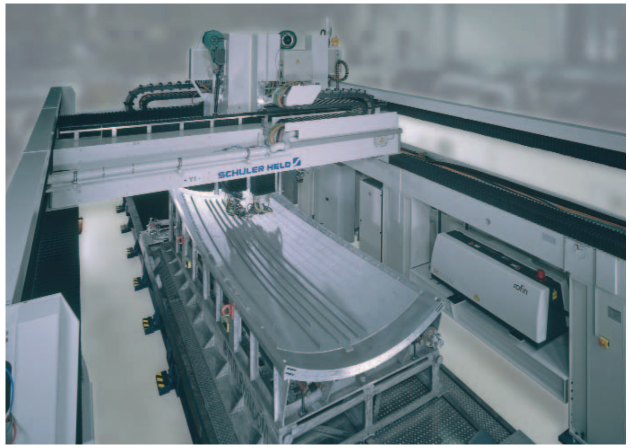

Fig 3.2.2
Welding of stringer profiles in aircraft construction
© Schuler Held Lasertechnik

Europe currently holds the biggest share in the world marked of laser material processing thanks to the successful development of superior laser beam sources and outstanding manufacturing systems at research institutions and world-leading European companies. But the present developments show that further scientific efforts and technology-transfer are required to defend this position and to extend the leadership to further industrial sectors that rely on photonics as an enabling technology.

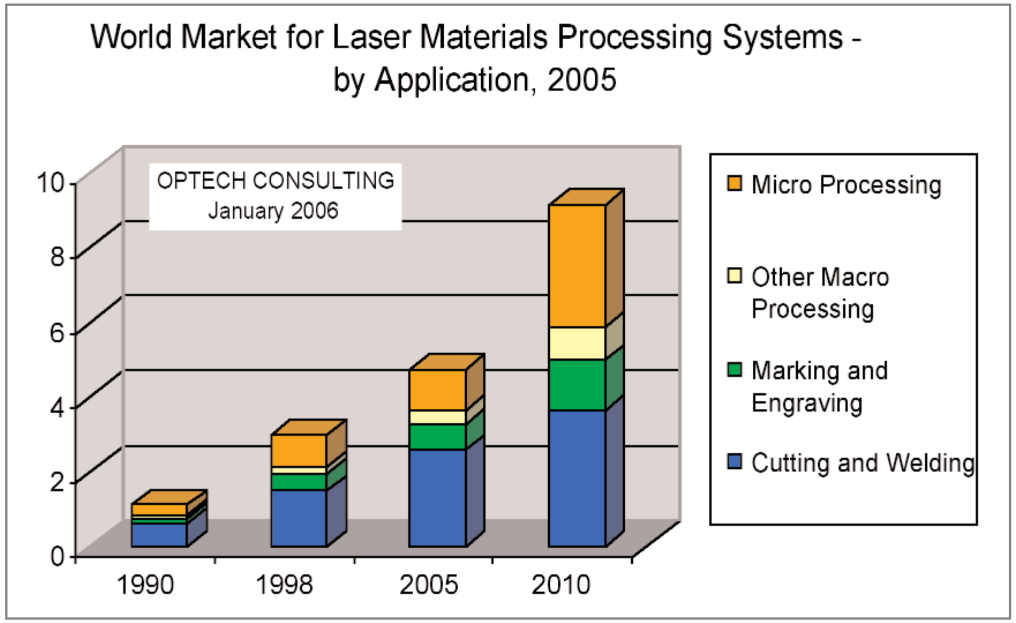

Fig. 3.2.3 Market for laser material processing systems. All numbers are in billion EUR. © Optech Consulting

It should be emphasized that this market has been developed by subsequent R&D-activities at both industry and universities over many years and it points out the benefit and the necessity for a sustainable R&D funding.

The development of lasers for material processing is but an example that illustrates the importance of photonics for production and manufacturing in Europe. From the vast demand for such systems it can be concluded that photonic technologies have significant advantages for the manufacturing industries. As one prominent example, better cars are today being built with higher productivity thanks to photonic technologies developed in Europe. The most important examples for the manufacturing processes with lasers are cutting and welding of car body panels, hydroforming units, tailored blanks and power train parts, welding of plastics, brazing of roof seams and hatches, laser structuring of cylinder walls and laser drilling of fuel filters and injection nozzles. But similar success stories can be found in many other European manufacturing sectors. In fact the abovementioned lasers for material processing constitute just about less than one third of the whole world-wide market for laser sources. Another third is found in the manufacturing of consumer electronics.

Therefore, it is of great interest for both, economical and social reasons to fully exploit potential of the photon for manufacturing processes. Photonics in production is of great importance. Its strategic value arises from the unique properties of the photon. Photons are precise and reliable and can be tailored to the needs of the manufacturing process. A faster, better and cheaper production is possible by the employment of photonic technologies. In addition, energy can be saved when compared with traditional manufacturing processes. Thus, these technologies offer a high potential for the European economy. The European competitiveness can be strengthened and employment can be sustained. New and bigger markets will emerge through the unique features of the photon. Therefore, it is of great interest for both, economical and social reasons to fully exploit potential of the photon for manufacturing processes.

3.2.2 CURRENT STRUCTURE OF INDUSTRY AND RESEARCH IN EUROPE

Generally, Europe benefits from a high average level of education on a broad basis provided by a dense net of universities, research institutes and other educational facilities that cover all aspects of practical and theoretical skills while providing an adequate educational system for differently talented people.
Especially in the field of photonics, several high level masterminds were born in Europe who established excellent research facilities with different key aspects of activity and now form a unique basis for transferring know-how into industry. On the industrial side large efforts have been made to support these structures, in addition to expenditure on their own R&D activities in photonic technologies. Whereas large R&D activities are today naturally limited to larger companies, smaller companies have always been innovative and would profit tremendously from a reinforced photonic initiative.

3.2.3 CURRENT AND FUTURE CHALLENGES

Research and Science
Wherever and however light is utilized, its manifold benefits are manifested solely through the interaction with matter. Whether as energy source or as information carrier, the light is generated, manipulated and detected in material components. The underlying physical fundamentals of the phenomenon light – Maxwell's equations and basic quantum optics – are well understood and describe the generation, propagation, and interaction of photons in and with matter. With this present knowledge we have already learnt to make use of photons in science, engineering, and industry in manifold manners and exploit photonics as a pace making technology. Nevertheless, scientists and engineers continuously struggle with significant obstacles when striving towards new photonic technologies for the societal and economic benefit. These difficulties are not rooted in the basic physical laws but emanate from technical shortcomings of current optical components and systems. Here, science meets material-specific physical and technical limits of optical components as well as system-inherent deficiencies of the process capability. EUV-lithography is an example. The high intensity of the EUV beam sources leads to degradation of the components which decreases their lifetime and the poor reflectivity of others limits the potential of the processes.

Overcoming such limitations requires a combination of competences on much diverse scientific disciplines. Material science, quantum optics, thermodynamics and solid-state physics are required to conquer the fundamental limits of current optical elements. The physical and technical limitations of optics components can only be resolved with interdisciplinary research efforts in the fields of manufacturing technologies, micro-system engineering, nano-technology, telecommunications and optics. The improvement of the system integration of the components and processes resulting form these efforts finally acts as the innovation driver in science, technical engineering and industry.

With the aim to further strengthen the pervasion of basic research and applied sciences the formation of clusters of excellence for industrial production is a suitable approach to strengthen Europe's leading position in the photonic technologies. Current fundamental limits must be overcome with basic research on the light-matter interaction processes and on novel materials and structures with revolutionary photonic properties. This will open up the way to groundbreaking new optical components and the corresponding technologies for their fabrication. In turn this will lead to novel photonic processes in manufacturing. Based on these efforts the technology transfer culminates in the investigation and the implementation of optical systems and photonic processes in manufacturing with novel flexibility, functionalities, and productivity to strengthen the present leading European position on the world market of photonic technologies and mechanical engineering and sustain this position in the future.

Industry
Many companies already employ photonic technologies and many more are currently investigating the capabilities which arise from the application of photonic tools in production. A European initiative to further strengthen photonic technologies will therefore have a significant impact and help the economy to take up a novel technology with a persistent and innovative drive.

A majority of the involved companies believe that manufacturing processes in their individual business environment will soon enter the era of photonics and claim that they are just at the stage to identify the potential of photonics for the manufacturing processes. It is estimated that completely new manufacturing solutions are possible by complete redesign of the underlying processes. The challenge for the industry lies in the development and the successful implementation of the novel possibilities provided by photonics in its manufacturing processes. To illustrate this the laser welding process currently used in the automotive industry can be considered. This process is undergoing a dramatic change now. Compared with the usual laser welding, remote welding can reduce the non-productive time from some ten percent to nearly zero. The need for specific solutions requires a strong collaboration with leading scientific institutions and will on the other hand give new input and goals for the European research.

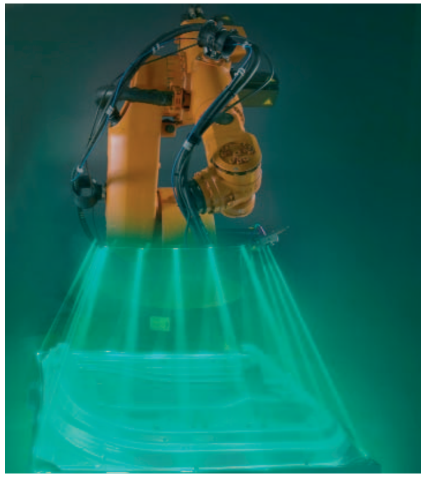

Fig. 3.2.4
Laser remote welding
© Kuka

The companies participating in Photonics 21 believe that the driving forces for product innovation arise from applications of photonic technologies. Two aspects can be identified thereby: Firstly, as already discussed, photonics is an enabling technology for new solutions and new products and secondly, existing manufacturing processes can be improved or even substituted with photon-based technologies.

3.2.4 UPCOMING TECHNOLOGIES UNTIL 2015

Within the next 10 to 15 years the photon will be used in many fields of production, part of which being already known and a majority being new applications. The reasons for the success of the Photon in manufacturing are the unique properties of the photon:
– Due to the very small energy of a single photon the ´dose´ can be tailored precisely to the process needs leading to unprecedented precision.
– Due to the nearly vanishing momentum ´contactless´ processes are possible opening up the way to completely novel production processes.
– Variable parameters like wavelength, spatial and temporal radiation characteristics make it a very flexible tool, which can be controlled very precisely and automated to a large extent.

Already known and emerging large application fields of the Photon in manufacturing are
– Optical macro processing
– Lithography
– Optical quality control
– Optical test and measurement

These markets and applications will grow with the increasing capabilities of the photonic tools. Future research must concentrate on improving the existing technologies, see e.g. general remarks below.

Large future industrial fields of photonics in manufacturing will be
– Optical micro and nano processing
– Machine Vision
– Biotechnology (tweezers, laser microscope, optical tracers ; see also chapter 3. “Photonics for life sciences and health care”)
– Processing of new and artificial materials
– Medical applications (see also chapter 3. “Photonics for life sciences and health care”)

The field of optical micro processing is already emerging and is predicted to have a very bright future by using high brilliance lasers like cw, Q-switch, femosecond, NIR green, and UV. The reason is that our daily life objects are becoming ever smaller and smarter and the above mentioned properties of the Photon are adapted very meaningfully to the production processes of these goods.

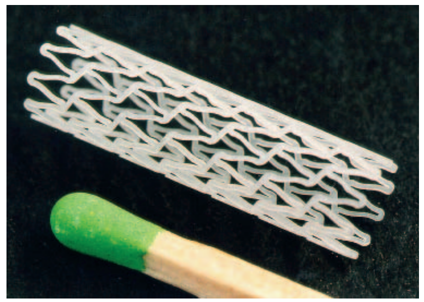

Fig. 3.2.5
Lasercutted biocompatible and resorbable polymerstent
© Laser Zentrum Hannover

Machine Vision has become a synonym for competitive manufacturing and for novel, innovative processes and products covering virtually all industrial sectors and areas of modern life. As the "eye of the machine" it gives machines and devices the sense of visual perception: Cameras are used to generate images of objects (parts, products) and to derive information from these images. This information is used to verify processes, perform diagnostic tasks and take automated intelligent decisions – with absolute reliability and at extremely high speed. Although machine vision already plays a major role in the manufacturing industry it is estimated that only approximately 20% of the possible applications have been realized.

Therefore, a large potential remains to be tapped to further:
– increase productivity and competitiveness (with a view to keeping production and employment in Europe),
– increase product quality and lower manufacturing costs,
– raise quality to a 100%-level economically,
– enable innovative and novel "new generation" products and processes,
– raise the quality of life,
– avoid waste, reduce energy consumption and protect the environment,
– increase safety and security in people's daily lives and at the work place.

The pressure to relocate production not only of simple mass-produced goods but also of high-tech products to low-wage countries continues to increase. This endangers not only blue-collar jobs in Europe but will also have an impact on white-collar jobs in research, engineering and management. The only answer to this development is to dramatically increase production speeds, process efficiency, product quality and innovation.

3.2.5 RESEARCH PRIORITIES FOR EUROPE

The primary development goals arise from the technology evolution process which is necessary for successful product development. A strategy for successful product development has been proposed which covers all steps in the manufacturing process starting from basic research and development up to products and their market penetration. Understanding of the photonic manufacturing processes as a whole and in depth is necessary for sustaining market success.
The potential of photonics emerges both from currently known applications in which photonic tools are currently used, as well as from completely novel applications that are discovered as a result of the uniqueness of the tailored attributes of the photon.
Beam sources such as lasers play a major role in accessing these applications. Therefore, a further improvement of existing and the development of new beam sources as well as related technologies (e.g. beam delivery and beam manipulation) must be emphasized and pursued that will lead to systems of industrial grade for tomorrow's demands. This also includes further development of optical materials used in beam sources and optical systems.
Another focus must be on the process itself. The light-matter interaction defines its intrinsic properties. In order to get to improved or advanced processes, the interplay between laser beam, material and the surrounding atmosphere must be understood. Finally, diagnostics must be incorporated, and a quality assurance must be achieved for the process. Intensive development in the sensor technology is necessary to meet these demands.
A further issue is the integration and downscaling of today's solutions to broaden the applicability. In addition to classical metal processing, other materials such as ceramics and plastics are promising candidates for new applications.

A closed development cycle consisting of beam source, process and quality assurance has to be established which will lead to superior solutions for the manufacturing processes.

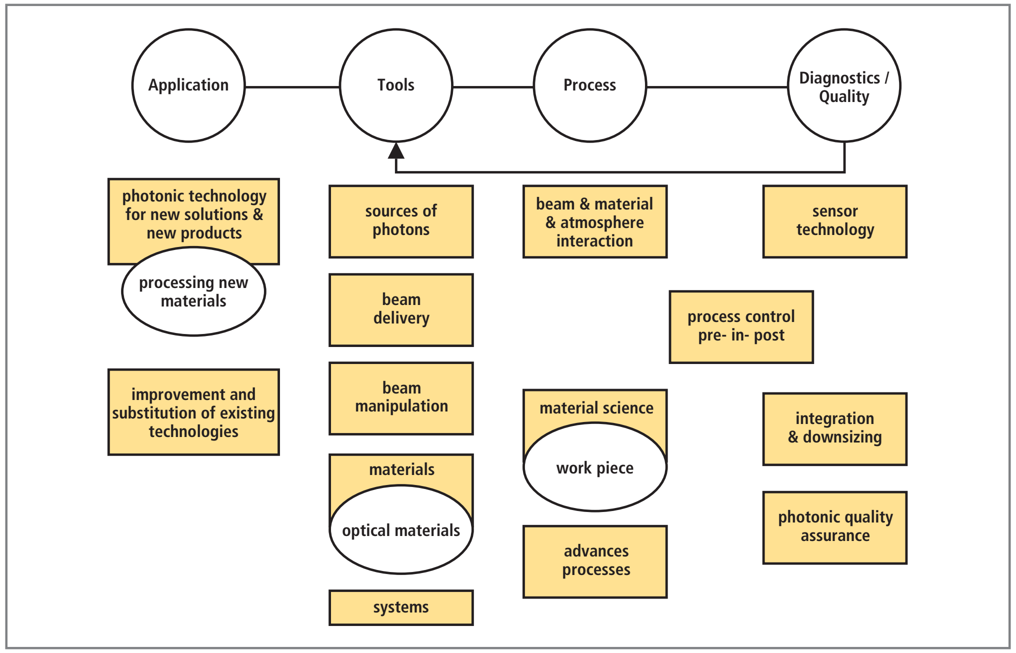

Fig. 3.2.6 Illustration of the strategy for the use of photons in industrial production

Besides successful product development, it is necessary to educate the manufacturing sector about the potential that laser-assisted fabrication can offer to a particular application. The demands are to strengthen already existing laser institutes and application centres and the interaction between them and the industry providing solutions for material processing. For example in Eastern Europe, there are only a few institutes which are capable of transferring knowledge of laser material processing to the local companies. This becomes apparent when considering that a lot of manufacturing steps in the automotive industry have already been or going to be shifted towards Eastern Europe.

Research priorities in the area of machine vision and photonic quality assurance are related to an extremely broad range of applications covering the entire field of industrial production, manufacturing and quality, such as assembly, robot vision, or metrology. Therefore a major potential for improvements in production technology needs to be tapped by developing more sophisticated machine vision components and systems than those that are available today. Great importance will have to be given to the development of new 3D imaging technologies. Current techniques still have technical restrictions and are relatively expensive. Therefore, 2D solutions are often used where 3D solutions would be clearly preferable. The development of new 3D techniques (such as „time-of-flight" based principles) would increase the technological leadership of the European machine vision industry and have a significant impact on the competitiveness of manufacturing. Multisensorial principles combining the imaging of different physical effects which are not visible to the human eye are another important research priority for the European machine vision industry. This will allow the measurement of a wide variety of parameters in the production process – including the analysis of the chemical composition of workpieces or substances. True colour measurement systems will further enhance innovation and competitiveness in manufacturing. In very general terms, machine vision systems will have to become faster, more compact, more precise, more robust and more easily applicable.

3.2.6 CLASSIFICATION OF RESEARCH TOPICS

For the specification of the research demands, it is necessary to take care about the following issues:

1. Different research demands exist.
2. The research demands are on a different time scale.
3. The technological dependencies must be considered.

Therefore, a classification of research demands in four main topics has been completed as explained below (see also tables 3.2.1 to 3.2.4 at the end of the chapter).

■ **Photonic applications**
This field will cover the applications of the photonic process. Existing photonic processes should be transferred to applications where photonics is not incorporated today. By usage of photonic technologies, the aim of the application could be better satisfied compared to existing manufacturing solutions e.g. the achievement of a higher productivity, quality, flexibility, and reliability.
In addition new applications can be found which are only possible by the usage of the unique properties of the photon.

■ **Photonic tools**
This field is attributed to the aspect of photonics being a universal tool for the manufacturing process. It covers the beam sources, the optical materials used therein, the optical properties of the beam, delivery of the beam to the part, and the control of the beam.

■ **Photonic process**
This topic covers the photonics based manufacturing process. The primary aim is to improve the process in terms of quality, reliability, and efficiency. In addition, new photonic processes should be established in order to substitute existing manufacturing chains or to create new applications.
For the improvement of the quality and reliability of the process, a profound knowledge of the light-matter interaction is necessary. Moreover, improved process control will help to increase its efficiency and reliability by monitoring the process and its function. As a result, quality and stability will improve. The understanding of the process, its emissions and the necessary sensor technology, the algorithms to evaluate process signals and the establishment of a process knowledge management are key fields to be addressed.

■ **Photonic diagnostic, quality control and machine vision**
In contrast to photonic process, this field covers also non-photonic manufacturing processes in addition to photonics processes. The photon is used for diagnostic purposes, such as control the quality, yield, input, and output parameters of the manufacturing process by imaging and sensing. Big efforts are required in new and more flexible machine vision systems capable of real time 3D and multispectral image analysis for big complex objects and processes control. Such imaging systems will make the European industrial products and processes more reliable, increasing its quality standards and strengthening the overall competitiveness.

Detailed description of short term research demand
From the above and the current technological issues in the implementation of photonics in industrial productions processes, some of the most urgent developments to be targeted with focused research activities are listed in the following.

■ **Photonic applications (see Tab. 3.2.1)**
New applications enabled by photonics
Photonic tools open up new applications both with respect to new materials as well to new structures that can be processed with photons. Examples include the manipulation of organic materials such as polymers and living cells. The photonic advantage of flexibility and precision will enable new approaches in these fields.

Replacement of existing technologies
Prerequisites for the replacement of existing technologies are significant reductions in the overall production cost, improvements in flexibility, and/or addition of flexibility and precision of photonic tools. Ideally programs directed at photonic applications should channel the know how of the full production chain, from the manufacturer of the photonic tool to the end user for whom photonics may be a surprisingly new approach.

Macro processing
The laser is already well established in macroscopic applications such as cutting and welding. A further improvement, however, may stem from hybrid approaches where the laser is either combined with other non-photonic techniques or with other photonic tools including laser beams with other parameters. Significant improvements can likely be expected in high speed and remote laser processing, enabled by higher laser powers and better beam delivery techniques, see below.

Micro processing
As stated above, the vast field of micromachining exhibits some of the most exciting growth figures in photonics. It covers the modification of surfaces, cutting of small or thin materials, as well as tiny functional modifications inside workpieces. Just as in macro processing, hybrid approaches can open up new applications or improve and replace existing technologies in micro processing. For instance, the workpiece can be prepared by a laser pulse to react in a certain way to the following, different laser pulse. The potential benefit of such schemes has been already investigated in laser chemistry for a number of years in the field of coherent control. Such reactions – just like non-coherent processes – can and should certainly be exploited in manufacturing. Interferometric processes offer the ultimate precision in photonics by using the wave character of light on nanometre and sub-nanometre scales, in particular if combined with nonlinear processes. Nonlinearities lead to the topic of multi-photon processing at high (focal) intensities, allowing for the modification of otherwise transparent materials including glasses, polymers and crystals. The processing of semiconductors for microelectronics obviously is a paradigm for micro processing and will exceedingly benefit from laser cutting and ablation, from single-chip to full scale wafer processing to large scale applications including, e.g., solar panels.

Photonic tools (see Tab. 3.2.2)

Advanced laser sources

The majority of the recent innovations that have successfully been implemented in the European industry were enabled by the sole availability of novel laser sources with superior properties such as higher power, better beam quality and higher wall-plug efficiency. In other sectors such as micro-machining the industry is ready to implement the photonic technologies but is still awaiting industry-poof laser systems. Generally the demand for ever improved advanced laser sources is very real. This covers all types of sources, from high-power continuous-wave lasers with better beam quality and customised beam properties, over more reliable (including ultrashort) pulsed systems for micro-machining, to high-power laser diodes for the excitation of the above lasers as well as for direct applications. Further improvements of the laser performance and a significant reduction of the costs (especially of diode-lasers) will be an important factor for a continued and fast proliferation of photonics in material processing. Shorter wavelengths in the UV and EUV are required for certain applications (e.g in the semi-conductor industry), longer infrared wavelengths (including eye safe wavelengths) for others (e.g. materials processing, measurement and spectroscopy) and should become accessible from truly industrial laser platforms of high reliability at reasonable cost. Within the last decade fibre lasers have emerged as highly brilliant sources of powerful beams. Further improvements of their reliability can be expected from novel fibres and fibre laser concepts. The power scaling of fundamental mode lasers will be based on improved thermal management and possibly adaptive components, see below.

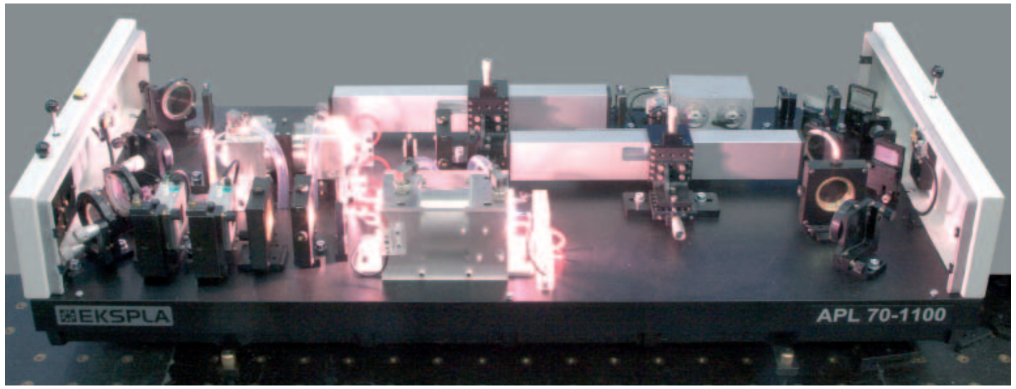

Fig. 3.2.7 High energy picosecond laser © EKSPLA

Advanced beam delivery

One of the major if not the most important reason for the fast growth of the solid-state laser market was the possibility to deliver the laser beam through state-of-the-art optical fibres. With the currently required improvements of the laser sources, high-performance beams can no longer be delivered with current fibre technologies. Hence, the development of advanced laser systems will also require research on novel approaches to beam guidance covering all aspects of fibre optics, high-power beam couplers and switches and high-performance focusing and beam-shaping optics. Such interconnects should allow for intelligent high-power laser networks, in particular if monolithic integration is to be achieved avoiding free-space coupling.

Beam manipulation

In order to fully exploit the ultimate precision and flexibility of laser processing, technologies for spatial and temporal beam control have to be improved and transferred to the application. The spatial profile of laser beams can already be modified by optical components including adaptive and/or diffractive elements. Also, several techniques exist today that allow for precise control of the temporal variation of the temporal shape of the laser output, which holds great promise for dynamic improvements of laser-material interaction. Such technologies should be extended to new regimes in terms of average laser power and pulse energy as well as improved with regards to dynamical response, simplicity and reliability.

Optical components

Along with the progresses in laser beam parameters the existing optical components have to be adapted. In particular, components for UV laser radiation currently still suffer from chemical destruction due to the high photon energies. Improvements may well require novel approaches for the design and production of the components, e.g., improved techniques for the production of aspherical lenses, including mould optics for mass production, new techniques for joining of optical components, as well as advanced thin film technologies. The relatively young field of photonic crystals is already exploding and should benefit from interdisciplinary European collaborations. New materials with tailored optical properties (absorption, saturation intensity, dynamic response, tailored reflection, scattering, dispersion…) are likely to affect all fields of photonics and research and their improvement should continue.

Modular photonic production concepts

Low investment costs for manufacturing equipment is part of the fundamental boundary conditions which must be satisfied in order to compete with classical manufacturing solutions. Laser safety turns out to be one of the cost drivers since safety policy asks for elaborate protection of laser installations. By application of sensor technology, modular production cells can be created which can reduce the additional costs for laser safety significantly by smart detection of scattered light making heavy steel construction obsolete. These modular production cells are highly flexible, easy to configure, and free of maintenance.

Photonic processes (see Tab.3.2.3)

Understanding laser material processing

As the photonic machining technologies are being implemented at a very fast growth rate into increasingly varied and more complex and critical industrial manufacturing processes the industrial call for absolutely reliable process monitoring and quality control is becoming very insistent. Scientifically this demand can only be satisfied with a fundamental and total understanding of the exceptionally complex dynamics of the laser-material interaction processes, as the current lack of understanding prevents an even more widespread and more efficient use of the otherwise so attractive photonic tools. Due to the multidimensional and high degree of complexity no comprehensive simulation models have been developed to date. But a total understanding and modelling capability of the interaction of the laser beam with the machined material in its solid, liquid, vapour and plasma states with the simultaneous consideration of the thermodynamic, hydrodynamic, aerodynamic, plasmadynamic, and electrodynamic processes in the micro- and macroscopic scale with down to femtosecond resolution is absolutely essential to determine the right monitoring strategies and lead the way to reliable quality control. The extension of the present understanding of the scientifically very complex laser material processing will also help to predict and open up novel application fields of this very competitive manufacturing photonic technology. Hence, apart the urgent need for a better understanding to solve current limitations of laser material processing a focused research effort on the fundamentals of laser-matter interaction will also be very beneficial for the future implementation of photonics in yet unforeseen applications.

Process diagnostics and process control
The abovementioned better understanding of the underlying photonic machining processes will also point the direction for effective process monitoring and process controlling strategies and open up the development of dedicated diagnostics and control of laser material processing with the aim of a zero-fault production. The complete understanding of the laser material machining processes will allow to identify which of the physical phenomena qualify as a signal for a reliable process diagnostics and consequently for a reliable close-loop process control system. Once these signals are identified, the task will be to develop compact and field-proof optical systems for the photonic process and quality control in mass production. An underestimation of the strategic partnership between production and quality control would cause economic disturbances such as currently experienced with the increasingly frequent call-backs in the automotive industry and consequently weaken the European position in the international competition.

■ **Photonic diagnostics and quality control (see Tab.3.2.4)**
Profound progress in production can be achieved by new sensor technologies. A combination of imaging sensors in different spectral regions can reveal undiscovered information about the process and its reliability (e.g. images below the surface of objects). Intelligent environmental sensing will also improve the interaction between humans and systems by intelligent environmental perception of the system and smart reactions. Along with the advancements in the precision of photonic tools, new sensing techniques also have to be implemented for the precise control of the manufacturing process in all dimensions, including for example online depth profiling of the workpiece.

General Remarks on the implementation of the research agenda

From a large number of contributions to the discussion in the workgroup it is obvious, that photonic applications, tools, processes and quality control have to obey the guidelines of

Cost-Down – Reliability Up – Safety-Ensured

if photonic manufacturing in Europe shall be competitive in the future. This must be one of the primary goals for all research projects. The following aspects should be considered within the implementation:

1. European companies typically achieve the cost reduction by an improvement in efficiency.
2. The large beneficial potential for the European economy will only be realized if the processes are cost-effective and robust.
3. Reliability-Up does not only mean the development of reliable and maintenance free tools but also robust processes in a sense, that the processes have a sufficiently large window of acceptance with respect to changes in process parameters. If this condition is fulfilled the processes can be run on machines and handling systems with moderate complexity by low- and medium skilled personnel and with sufficient yield. In case of applications where the unique features of the photon play an important role and the process window itself is small, a higher degree of complexity is necessary to obtain reliability.
4. Unsafe or environmental-harmful applications and processes will not be accepted by the European society.

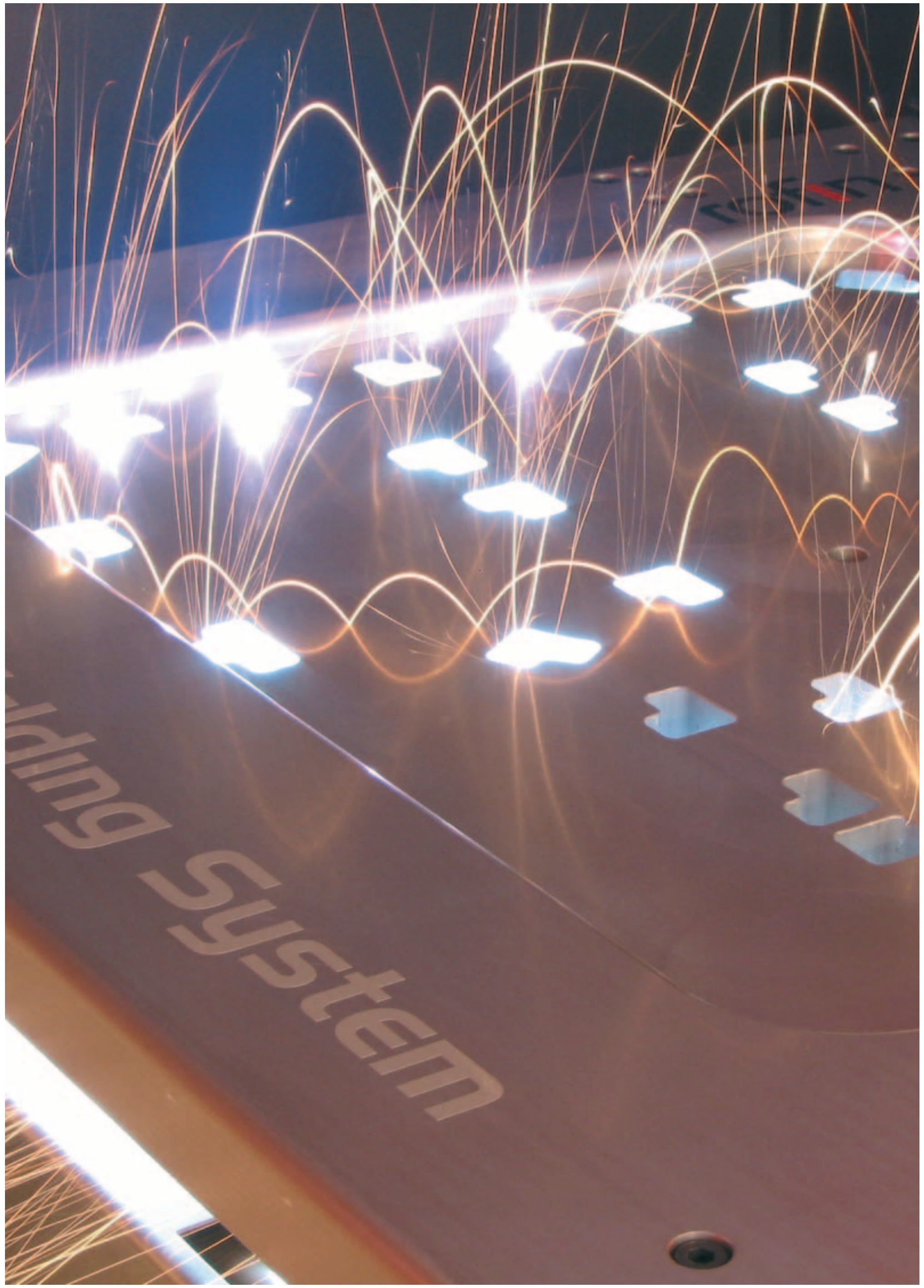

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Table 3.2.1: Photonic applications

Research area	Technological field	Technological objectives
Photonic technology for new solutions and products	Processing of new materials	
	Processing of new structures	
	Photonic systems for cell handling	
	Photonic processing of polymers and organic materials	
Improvement and substitution of existing technology	Lasers for built-up and repair using material additive processes	
	Rapid prototyping and rapid tooling	
Optical macro processing	Hybrid processes	
	High speed and remote laser processing	
Optical micro & nano processing	Hybrid processes for enhanced speed and quality of application	
	Applications using the wave character of light	Interferometric processes
		Holography
	Material deposition and removal on µm-scale for prototyping and serial production	
	Multi-photon processing	
	Advanced processing of semiconductors	Cutting, ablation, ...
		Wafer processing
		Moulded Interconnect Devices – MID technology with increased function integration and density
	Microstructuring of surfaces	Engraving
		Flexography
		Embossing
		Finishing

Table 3.2.2: Photonic tools

Research area	Technological field	Technological objectives
Sources of Photons	High power lasers	High power lasers with increased efficiency
		High power diode lasers with increased focusability
		Novel fibres and fibre laser concepts
		High power RGB sources for manufacturing & quality control
		Short wavelength lasers
		Eye safe lasers
		Superior thermal management systems
	Non-coherent radiation sources	Extended EUV sources
		LED emitters
	High brilliance lasers	Power scaling of fundamental mode laser systems
		Power scaling of ultrashort laser systems
		Novel fibres and fibre laser concepts
		Power scaling of low cost, brilliant diode lasers
		Reliable and versatile frequency conversion
		New wavelength lasers and tuneable lasers for improved process efficiency
		Fundamental mode lasers with improved spatial and temporal stability
		New assembling technologies
	Speckle free laser	Advanced test and measurement equipment
Beam delivery	Components	Free space and fibre-based beam delivery components
		Components based on Photonic crystal fibre
		Adaptive components
	Beam delivery networks	
	Monolithic integrated systems	
	Systems for the homogeneous exposure of extended areas	
Beam manipulation	Components and systems	Beam shaping & phase control
		Temporal and spatial tailored beams
		Beam control in real time using high modulation bandwidth e.g. AOM and EOM
		Highly dynamical focusing optics
		High resolution handling systems
Optical components	Lifetime	Extending the lifetime of optical materials, e.g. in high power applications and for ´aggressive´ wavelength

	Machines and software tools for design and production of optical components	Mould optics for mass production
		Aspherical production
		Joining of optical components
		Advanced thin film production
	Tailored photonic crystal materials	Microstructured optical materials
	Optical materials with tailored properties	Transparency-Absorption, Reflection, Scattering, Dispersion, Refractive index, …
Photonic systems	Photon factory	Versatile & adaptable lasers sources
		Laser on demand: with respect to laser parameters (wavelength, power, temporal characteristics, …)
		Process adaptive lasers and autonomous (self-adaptive) systems

Table 3.2.3 : Photonic processes

Research area	Technological field	Technological objectives
Process control (Pre-, In- and Post-Control)	Closed feedback loop for process control; Self tuning processes; Fault reduction	Sensing – Signal processing – Intelligent reaction
	In situ control of weld seams	
Process efficiency	Increased process efficiency	Lowering cost
		Energy saving
		Protecting environment
Beam and material and atmosphere interaction	Process understanding by theoretical modelling and simulations	Process stability
		Environmental aspects and safety
	Application research	With focus on micro- nano processing
Material science with special focus on work piece materials	Tailored materials for optimized light-matter interaction.	Ceramics, Glasses, Crystals
		Organic materials and polymers
		Others and new materials
Expert systems		

Table 3.2.4: Photonic diagnostics, quality control and machine vision

Research area	Technological field	Technological objectives
Sensor technology	New principles	
	Intelligent sensors	Robot-vision, visual servoing, eye-in-hand
	True color measurement systems	Reproducability, easy operation
	Multispectral imaging for process control	Integrated reliable multispectral sensors
		Enlarging the scope of machine vision technology to new fields and industries.
Improved 3D sensors and new 3D sensor principles	Time-of-Flight-based 3D imaging, integrated 3D color solutions, non-planar light stripe measurement	Better resolution x/y/z; speed; sensitivity; ambient light suppression, integration of structure and texture measurement, increased flexibility of production and versatility of 3D sensor use, shape discovery independent of surface properties.
Iconic processing	3D structure from motion	Brute force computing application
Integration and downsizing	Systems with easy operability	System on Chip for small size, low power and low cost. Small 3D sensor for robotics. Embedded configurable systems for on-machine integration.
		Expanation components in supervised learning systems
	Handheld systems	Robustness, small optics, small size, low power, network, image stability and low cost
Photonic quality assurance and Machine Vision	Integrated imaging systems	Higher dynamic range sensors for extreme image acquisition conditions.
Hybrid machine vision systems	2D / sparse 3D fusion	3D robot vision, adding more information to 3D measurement

3.3 Life Sciences and Health

Photons are unique enabling tools for health care and life sciences

Photonics has demonstrated a long tradition in the fields of life science and health care. The microscope has opened the view into the world of cells and bacteria and has evolved into a modern powerful tool for the basic biological research of cell processes.
Modern surgical microscopes have become key tools in neurosurgery, as well as in ophthalmology and ENT surgery. Image guided systems make use of computer tomography and MRI data in navigated surgery.
Laser diagnosis and treatments in ophthalmology, dermatology and other medical fields have evolved into standard procedures in the last two decades
Endoscopes have opened an easy access to the inner of the human body in minimal invasive surgery.

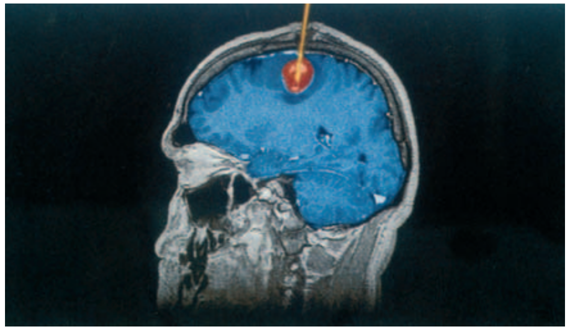


Fig. 3.3.1
Magnetic resonance imaging during interstitial laser irradiation of a brain tumor (color coded; blue: brain structures, red: tumor, yellow: light guide with schematic of emission profile)
© Dr. Schwarzmaier, Klinikum Krefeld

Optical methods for gene sequencing and biochips open new routes for diagnosis and treatment of cancer. Fluorescence methods have replaced radioactive methods in screening processes in drug development.

The role of photonics as key enabling factor in health care and life sciences will grow tremendously in the future. The key principal reasons are:

- The capability of photons to monitor biomaterial in real-time, non-contact and without affecting the life processes. In addition the use of light as a probe allows to look at a large variety of features simultaneously, and to study very complex processes like protein reactions in living cells. Even single molecules can be detected with these photonic tools.
- Probing of biomaterial from the level of single molecules over tissue samples and living organs up to whole bodies of animals or humans is possible
- In specific technical variants photons can be used as very gentle manipulation and modification tools in cell biological research and minimally invasive treatment.

No other 3D-imaging and manipulation technology for life sciences and health care, like Ultrasound, MRI or computer tomography, possesses similar capabilities in resolution, simultaneous parallel probing and sensitivity. The option for gentle manipulation is unique to the photons.

Paradigm shift in modern Diagnosis and Treatment in Health Care expected
Since the very early days of health care the treatment of diseases follows the general route

- Recognizing the symptoms
- Followed by a diagnosis and
- Subsequent treatment

Today diseases can only be treated after they have been manifested but not before. Treatment is mainly done on a trial and error basis.

The decoding of the complete genome of several organisms from bacteria up to the human genome has opened a perspective for a principally different route. Many diseases – among them cancer, cardiovascular and metabolic diseases – show a strong correlation with variances in the genome or defects in protein processes. Preventive screening could identify individuals with a predisposition for these diseases. Thus, there exists the opportunity for a major paradigm shift in the treatment of diseases, which is evident and will result in the following new route

- Preventive screening
- Identification of a gene or protein anomaly
- Repair of the anomaly or prophylaxis

In this way individuals with a predisposition for specific diseases can be identified and “treated” in advance prophylactically. This goal will clearly not be reached without photonics as all past advances in genome and protein research have been enabled by photonics.

In contrast to available technologies today, light has the potential to recognize the origin of diseases on a molecular level for applications in health care. This way, diseases can be prevented or healed in an early and gentle manner. Focused lasers can be used to isolate specific cells and preposition them for meaningful downstream analyses. Laser light based minimal invasive treatment devices will help to reduce side effects and costs of hospitalization. Furthermore, the ageing population and the high expectations for better quality of life accompanied by the changing lifestyle of the European society call for improved, more efficient and affordable health care.

3.3.1 IMPACT OF PHOTONICS IN SPECIFIC FIELDS

Thus, advances in the areas of life sciences and healthcare require innovative photonic technologies, which allow monitoring and manipulating cellular processes on the molecular level from single cells up to entire organs and organisms. New photonic devices and procedures will also allow identifying, preparing and treating living cells in a fast, three-dimensional way in order to cure diseases with major importance such as cancer and degenerative diseases.

Advances in photonics will have a huge impact in major application areas:
So far still the origins of 80% of diseases are unknown; therefore only symptoms can be treated. There is still no real cure for wide spread diseases like cancer, diabetes, Alzheimer’s and Parkinson’s disease, cardiovascular problems, inflammatory, neurodegenerative and infectious diseases.

Photonics could help to understand the molecular mechanism of defective cell metabolism and their effect on the human organism. Recognition of tumor cells in an early state and their selective treatment with the assistance of optical methods will help to cure cancer or optimize its treatment. The secure identification, capture and treatment of stem cells with optical technologies will enable safe stem cell therapy and organ design.

The Pharma industries could develop new patient tailored drugs based on analyses of the patient's body fluid or organ biopsies, thus providing more efficient medication and avoiding negative side effects.

Fig. 3.3.2
Example for an operating theater using minimal invasive set up with an endoscope for detecting early cancer
© Karl Storz

Today the development of new drugs takes a long time at very high costs. A shorter time-to-market for new and more effective drugs with less negative side effects would be a solution for affordable supply worldwide. Photonics will allow the development of specific active ingredients avoiding longtime screening and statistical experiments, due to fact, that the binding specificity could be monitored and optimized.

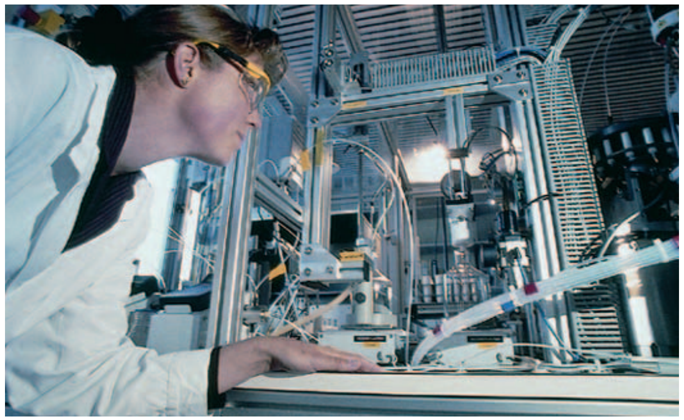


Fig. 3.3.3
Photonic technologies enable high throughput screening of potential pharmaceutical compounds
© Sanofi Aventis

3.3.1.1 Societal impact

Due to the demographic changes with an increasingly aging population health care costs are rising. Photonics can play a major role in containing or even reducing cost and at the same time improving the quality of health care as well as quality of life.

Health care can become more effective, cheaper and affordable because of the following reasons
– patient specific drug development
– Photonics based screening methods will enable early detection of diseases
– Non- or minimally invasive repair of bones and joints, or liver or kidney failure as well as neurodegenerative diseases, spinal cord injury or multiples sclerosis using "designed" cells will help to improve life style and mobility. Organ transplantation is not anymore dependent on the death of donors.

3.3.1.2 Economical impact

Advances in photonics will financially drive health care, pharma, and food industrie markets.

Health care costs in 2004 in USA was 1.8 trillion $US (US Dep. of Commerce), in Germany 250 billion $US (bpb, Bundesanstalt politische Bildung). Advanced photonic technology will enable early detection of diseases and the development of minimal-invasive treatment will lead to shorter hospitalization time. Patient specific drugs will be more effective and treat the origin of the diseases. These changes will reduce health care cost considerably. Some estimates expect a reduction of up to 20%. This would result in an overall reduction of up to 400 billion $US per annum worldwide.

The growth potential of the photonics market in Health Care might be illustrated with a few concrete examples on a lower level of aggregation.

The prognosis for the market of photonics in medtech expects growth from US$ 5.95 billion in 2002 to US$ 20,4 billion in 2010 to US$ 38,3 billion in 2015 (Optoelectronic Industry and Technology Development Association, Japan)

The global market for medical imaging equipment amounts to US$ 19.9 billion in 2003 and is expected to grow to US$ 26.3 billion in 2007. This market contains all ultrasound equipment, CT scans, MRI and x-ray imaging with a considerably small amount of optical equipment. The clear expectation is, that optical imaging will in many applications strongly compete with established technologies, because photonics offer a better resolution and much more specifity than ultrasound or x-ray. Optical Coherence Tomography with a typical penetration depth of a few millimeters as applied to the retina already shows great potential for endoscopy and cardiovascular applications. Imaging methods for diffuse media for optical mammography or blood volume imaging is another set of methods in the context, just to name a few (Frost and Sullivan).

Pharmaceutical drugs constitute a market of about US$ 400 billion per annum worldwide. 15% of this turnover is invested for new drug developments (EU Health Care Pharmaceutical and Medical Devices Market 1998 -2008 Frost and Sullivan base year 2004).This amount could be reduced by a factor of 2, which will result in an estimated cost reduction of 30 billion $US per annum using advanced photonics by shorter and cost effective drug development only.

The global market for biotech instrumentation (all technologies, including consumables) is expected to reach US$ 11.5 billion in 2006. The part of high-throughput drug screening on the basis of fluorescence and spectroscopic methods is approximately at US$ 1.8 billion.

A French survey in 2005 for "Biophotonics" estimated the market for optical devices to be 25 billion $US per annum. With the development of compact, easy to use personal checking and monitoring devices (mass market) there could be a much bigger increase.

3.3.2 CURRENT STRUCTURE OF INDUSTRY AND RESEARCH

The level of research activities in photonics for life sciences worldwide is highest in the USA. The National Research Council (NRC) suggested in their 1998 report, "Harnessing Light-Optical Science and Engineering for the 21st Century" to address the chances and needs of photonic research and optical technologies for life sciences and health care. The USA Government is supporting photonics in life science with high financial support for specific research projects as well as structural activities like new institutes pushing the future applications of photonics in heath care and life sciences.

A new study from Deloitte in 2005 shows the optical industry has an increased focus on photonics in life sciences (Biophotonics) worldwide. An industrial survey in Germany is expecting a strong growth of 20% in the next 3 years, which is also expected worldwide.
Research activities with support from government are beginning to start in France, Great Britain and have started 2003 in Germany. The industrial activities are most advanced in the USA.
In the EU, Great Britain and Germany are close to the US standards. Joint European research activities for photonics in Life Science and Health will boost the competitiveness and give Europe the chance of having the advantage of new tools which enable new products in the health care- and pharma-industries.

The development in photonics for life science markets in Asia, like Japan, China, Singapore and Taiwan is advancing rapidly, i.e. much faster than in USA or EU due to major investments. Major activities are necessary to keep Europe in a leading position.

3.3.3 PREDICTIONS UNTIL 2015

Photonics enable a paradigm shift in future life science and health care.

Life sciences
The understanding of cell processes, tissues and model organisms will be improved by the use of imaging and manipulation systems which allow 3D-real-time, in-vivo-visualization and manipulation of molecules and cell structures.
Bench-top size sequencers will allow patient stratification according to genomic data and thus reduce the number of patients, which have to be dismissed because of drug side effects. Potential patients with impending side effects can now be identified through genome analysis.

Benchtop size labelfree cell sorters will allow the selection of stem cell populations and thus speed up stem cell research.

Health care
Today treatment on the basis of the apparent disease symptoms is the practice. In the future, the origin of disease will be detected and cured before symptoms occur. Ideally, the formation of diseases will be prevented by early detection. Some examples of this personalized medicine will exist before the year 2015.
Screening the human secreted metabolites like breath, saliva, urine, perspiration or through spectral analysis of the retina could be a possible way of monitoring this status non invasively and automatically.

A small optical device could monitor health parameters and help to regulate automatic drug delivery for individuals. These could be products for mass markets.

It would also be possible to perform environmental monitoring optically for upcoming infections and allergens for early warning systems.

The availability of monitoring tools on molecular level will create new, more effective and minimal invasive therapy concepts in health care. For some diseases label free optical cell sorters will be used in the preparation process for cell therapies.

3.3.4 EXPECTED APPLICATIONS AND TECHNOLOGIES WITHIN NEXT 10 YEARS

Photonic devices will contribute significantly to more efficient diagnoses and 'personalized' therapies. New analytical methods such as nonlinear optical methods will give new insight in cell processes. Tools for cellular micromanipulation as well as the selective capture of single cells or tissue will be developed towards miniaturized chip-based technologies, allowing high-content measurements or therapy.
Photonics for faster and more detailed diagnosis in medical treatment such as intra-operative diagnostics and advanced in vivo imaging technologies will enter the operating room. New laser types such as e.g. fiber lasers will enable development of more advanced, safer, less expensive, faster and more reliable diagnostic and therapeutic methods. New computer controlled optical delivery systems will be developed for more precise, patient friendly and minimally invasive treatments.

Advances in health care and life sciences through photonics will most likely be driven in four major application fields with several topics (Fig. 3.3.4).

– Cell and molecular biology
– Advanced and early diagnosis
– Preventive medicine
– Minimally invasive and personalized therapies

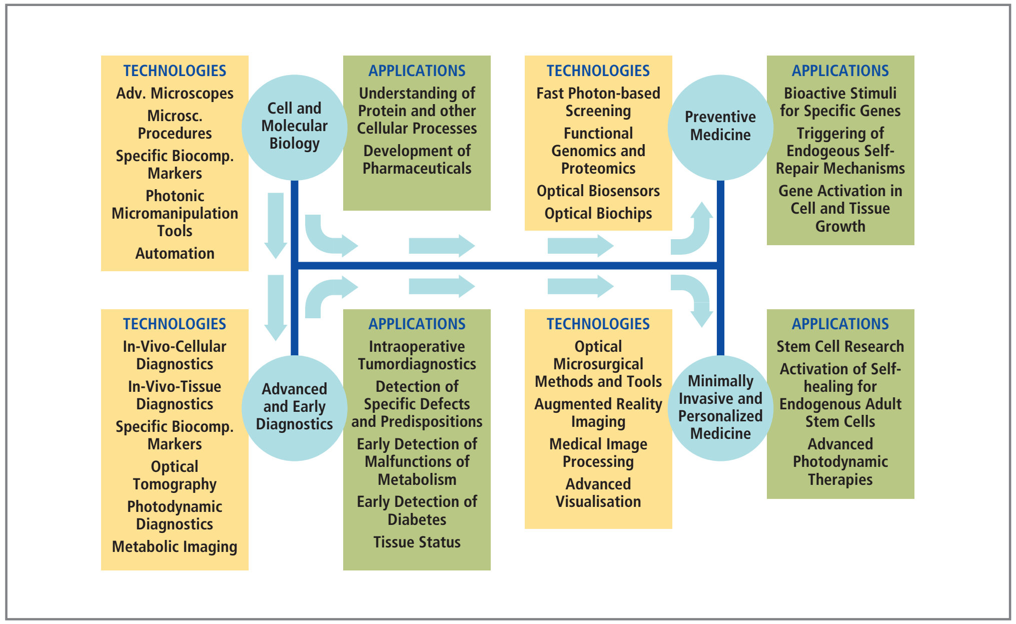


Fig. 3.3.4 Graphical overview of main future applications and technologies

Cell and molecular biology
Cell biological research builds the basis for the other three major fields mentioned above. Goals of this research are:
1. A detailed understanding of the biochemical processes in cells or tissue – ideally one would like to monitor in vivo the dynamics of the entire process from single genes and transcripts to entire proteins.
2. The selection or engineering of substances which could trigger cellular processes, cell differentiation or repair malfunctioning cells and could serve as constituents of drugs.

A number of microscope tools, i.e. 3D fluorescence microscopy, nonlinear methods like 2-photon microscopy and others, have already been developed for studying molecular processes within cells. The understanding of these processes forms the basis for early diagnosis and the identification of potential ways for treatments of diseases with highly selective therapies. Emphasize should also be on the development of devices which allow to monitor cellular processes without the need of markers. Holographic methods could be used for non-contact volume measurements and might be useful for online process controlling.

Tools for the manipulation of cells, i.e. optical tweezers, cell stretcher or photonic micro dissection tools, are already available on a laboratory level and are used to capture specific cells from tissues for further analysis or for injecting specific molecules into the cells.

One example for marking of proteins and light induced manipulation of cell processes is CALI (Chromophore-assisted laser inactivation). Cell processes are studied with this method by the inactivation of a specific protein. The advantage of this photonic method over genetic changes and specific inhibitors is that this protein function in a single cell even within an organism can be inactivated by use of a laser beam.
These tools have to be developed further for higher efficiency and effectiveness. Automation will be the key challenge in order to handle the vast number of specimen in routine research and clinical use.

Advanced and early diagnosis
Methods for advanced diagnostics will be developed for various applications:
1. In-vivo cellular diagnostics will help to identify individuals with specific defects and predisposition for diseases.
2. In-vivo histology and intra-operative tumor diagnostics will help doctors during surgery, i.e. with fluorescence markers for tumor tissue
3. Metabolic imaging will help to detect malfunctions in metabolism in an early stage
4. Optical tomography, which is well established in ophthalmology, will provide a 3D-image of tissues
5. Breath analysis with optical systems could give diagnostic insight
6. Photodynamic diagnostics requires specific markers to become a valuable tool
7. Fast and sensitive at-site pathogen detection and identification will help to fight diseases

Preventive Medicine
Individuals with genetic defects resulting in defective proteins or a predisposition for a specific disease could be treated before the disease manifests itself, i.e. early diagnostics of diabetes. Research in functional genomics and proteomics will help to identify the status of the disease and to find the best therapy. Photonic biochips and other biosensors will play an essential role.

Understanding the dynamic interactions of our immune system with internal or external (environmental) stimuli on a molecular level would help to prevent diseases.
A future goal to prevent cellular malfunction or aging is to use bioactive stimuli to activate genes as a preventive treatment; maintaining the health of tissues as they age.

Novel technologies have to be designed:
1. Enabling the development and monitoring of biomaterials for the sequential delivery of actives and/or chemo-attractants for the triggering of endogenous self-repair mechanisms;
2. Generating knowledge and products, that are centred on the nano scale interactions between different types of cells and their immediate environment;
3. Enabling monitoring tissue regeneration;
4. Triggering and monitoring precise gene activation as well as cell and tissue growth.

Minimally invasive and personalized therapies
1. Photodynamic therapy is widely studied up to now but has only found one reasonable application so far, the age related macular degeneration (AMD). A basic problem is the lack of specific photosensitizer. Those could be found in concert with the experience gained in cell biological research.

2. Photosensitive retinal implants for the treatment of specific eye diseases, e.g. Retinitis Pigmentosa, are currently in an experimental stage and could be developed into an important tool to help visually impaired people.
3. Optical methods will contribute significantly to minimally-invasive, site-specific cell therapy.
4. Microsurgical tools for specific endoscopic surgery, in-vivo-image guided manipulation and navigation are essential for improved minimally invasive surgery resulting in new robust, low cost and save surgical treatment.
5. Tissue engineering, tissue regeneration and organ confection is one major focus in the development of tissue and organ replacement.
6. The major focus of ongoing and future efforts in regenerative medicine will effectively exploit the enormous self-repair potential that has been observed in stem cells. The next generation therapies will need to build on the progress made with tissue engineering in understanding the huge potential for cell based therapies which involve undifferentiated cells.

Photonics in combination with nanotechnology will help in pursuing three main objectives:

1. Identifying signalling systems in order to leverage the self-healing potential of endogenous adult stem cells.
2. Developing efficient targeting systems for adult stem cell therapies.
3. Sorting and extraction of relevant cell populations which than are used in cell therapies.

3.3.5 RESEARCH PRIORITIES FOR EUROPE

All research activities in life sciences and health care have to be carried out in a strictly application oriented way in health care-, and pharma- industries. Cooperation between the future applicants, i.e. cell biologists or clinicians, and the research community in physics and chemistry as well as engineering is mandatory.

The advancement of the following research topics will provide the basis for the development of successful applications and develop the applications in parallel in the field of the life sciences and health care.

3.3.5.1 Photonic tools for cell and tissue manipulation

Non-contact photonic tools for cell manipulation can easily combined with specific diagnostic tools. These tools are applied for the isolation of cells from tissue, transport of cells and cell constituents and micro-dissection of cells.

Typical examples include new markers for spectral fingerprinting and identification of specific cell constituents. In addition marker-less methods such as Raman and CARS are of high importance.

Advanced optical tweezers to move, rotate, gently separate cells by optical forces, optical tools for measuring binding forces between cells and molecules, tools for the temporary opening of pores in cell membranes for the influx of signal molecules and CALI (Chromophore-assisted laser inactivation) represent examples for the large variety of photonic manipulation equipment needed in this field.

Essential requirements for the optical systems are robustness, ease of use, low cost and high potential to be used in automated systems. Systems have to be developed in cross functional teams together with the application.

3.3.5.2 In-vivo Cellular Diagnostics, In-vivo Histology, Pathology

Specific, biocompatible markers or new marker-less methods are needed for a 3D-diagnosis of tissue and cells.

The first important interest here is to study the dynamic behaviour of cells with the goal to understand the transformation process of cells from a normal behaviour into a tumor cell. In a second step approaches to prevent this transformation have to be looked for.

This requires to study the living cell in several dimensions simultaneously, i.e. 3 geometrical coordinates plus the spectral and time coordinate. Light sources and methods with better penetration into biological tissue are of importance. Non-linear methods like 2-Photon-, Raman- or CARS-imaging are interesting candidates for advanced technologies in this area.

But also coarse methods for the study of cell elasticity will give information of the cell status. For tissue imaging structured illumination and optical tomography have to be developed.

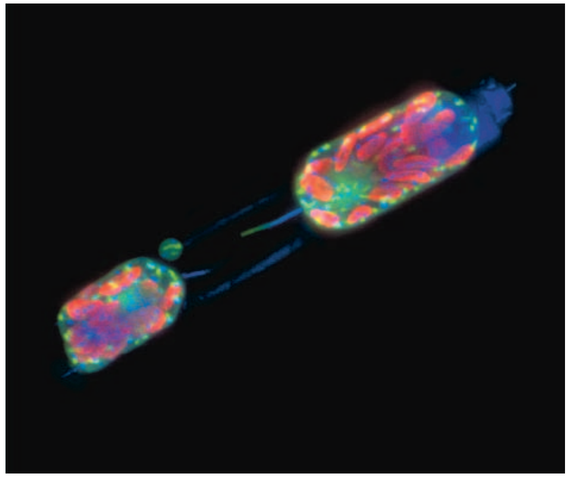


Fig. 3.3.5
Example for using life marker in a living cell. The auto fluorescence of photosynthetic pigments is marked in red, the cell cover (Reflection) in blue und Fluorceindiacetat (FDA) was used as a live marker.
© Dr. J. W. Rijstenbil, Netherlands Institute of Ecology

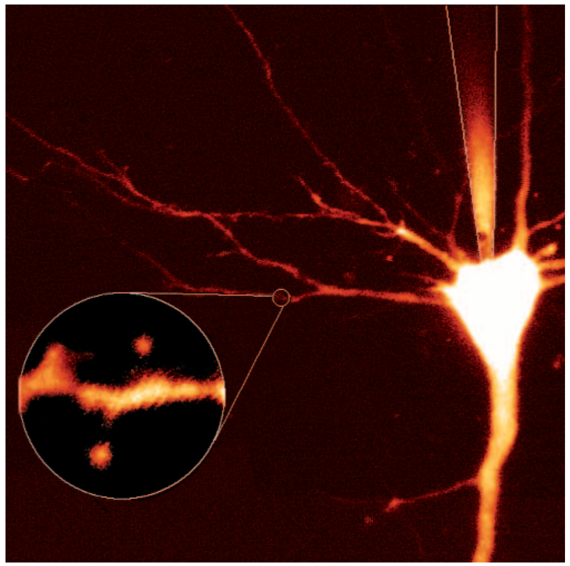


Fig 3.3.6
Example for measuring dynamical processes in living cells: Experiment on calcium gradient in dendrite nerves using two photon laser scanning microscopy
© Dr. Koester, MPI for Medical Research

New methods and procedures for the optical preparation and control of intracellular and intercellular processes have to be worked out. Automation of cell sorting and positioning with optical tweezers and similar instrumentation are examples for this area.

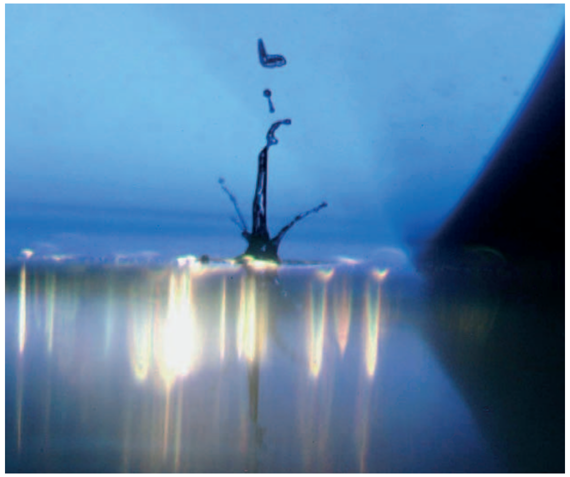


Fig. 3.3.7
Example for dynamic handling of cells, using laser pressure catapulting technology to take out a specific cell out of the tissue with no biological contamination
© PALM

The second important aspect here is to clearly identify cancerous tissue in-situ for example in a neurosurgical operating room. This is of extreme importance for the future quality of life of the patient. The above-mentioned technologies have to be prepared for the clinical use. That means development of the application together with the clinical users, improving reliability of the technology as well as bringing costs to an acceptable level. Optical biopsies would support medical treatment in many cases.

3.3.5.3 Microscopic Tomography, Microscopes

New approaches to microscopy supporting cellular diagnostics, histology and pathology have to be found. These approaches afford better geometrical and spectral resolution and extreme sensitivity at the same time. Instruments have to be applied in-situ without removing a tissue sample from an animal or a human individual. Again non-linear imaging methods as mentioned above are interesting candidates.

3.3.5.4 Ophthalmic Instruments

Non-invasive instruments combining diagnostic as well as treatment capabilities working online are needed in this field.
Optical Coherence Tomography has evolved into an interesting tool for ophthalmic diagnosis for the retina and for the cornea. The technology has gained a considerable market over the last 5 years. More work is needed to improve the acquisition speed and resolution of the instruments. Applications in non-ophthalmic field have to be explored. Fast, robust and low-cost adaptive optics for intrastromal corneal surgery are of high importance.
One interesting aspect is also the monitoring of non-ophthalmic diseases through the eye. Optical non-invasive glucose monitoring in diabetes would be highly attractive to patients and could at the same time reduce cost considerably.

3.3.5.5 Optical Biochips and Biosensors

Future research has to centre in increasing the efficiency of the chips through higher throughput, smaller chip sizes and parallel reading. Preparation of the chip surfaces has to be improved considerably. Standardisation and data management are needed to simplify interdisciplinary work. (For further information, see chapter 3.5)

3.3.5.6 Minimally – Invasive Therapies

Endoscopic instrumentation should be developed further regarding optical resolution and multispectral imaging for in vivo characterisation of tumors. In vivo image-guided microsurgical tools for manipulation and navigation will lead to robust, low-cost and safe surgical treatments. Specific photosensitizers for photodynamic therapies should be developed on the basis of experience of cell biological research.
All photonic technologies for cell and tissue characterisation and manipulation will drive the advance of minimally-invasive on site cell therapies as well as tissue engineering and regeneration activities.

3.3.6.7 Advanced Implants

In the promising field of retinal implants Europe has gained a leading role. The scope is to speed up pace for research in this field in order to defend this lead.

Research area	Technical objectives	Applications
Cell and molecular biology	Optical analysis of the biochemical processes in cells or tissue; Selection or engineering of photon sensitive substances which could trigger cellular processes, cell differentiation or repair malfunctioning cells and could serve as constituents of drugs	Understanding of these processes forms the basis for early diagnosis and treatments
Preventive Medicine	Enabling the development and monitoring of biomaterials for the sequential delivery of actives and/or chemo-attractants for the triggering of endogenous self-repair mechanisms; Generating knowledge and products, that are centred on the nano scale interactions between different types of cells and their immediate environment; Enabling monitoring tissue regeneration; Triggering and monitoring precise gene activation as well as cell and tissue growth	Disease could be treated before the disease manifests itself
Advanced and early diagnosis	In-vivo cellular diagnostics; In-vivo histology and intra-operative tumor diagnostics; Metabolic imaging will help to detect malfunctions in metabolism in an early stage; Breath analysis with optical systems; Specific markers for Photodynamic diagnostics; Fast and sensitive at-site pathogen detection and identification will help to fight diseases	Identify individuals with specific defects and predisposition for diseases
Minimally – Invasive and Personalized Therapies	Endoscopic instrumentation enabling enhanced optical resolution and multispectral imaging for in vivo characterisation of tumors; In vivo image-guided microsurgical tools for manipulation and navigation	Efficient (low-cost) and safe surgical treatments
	Development of specific photosensitizers for Photodynamic therapy; Photosensitive retinal implants for the treatment of specific eye diseases, e.g. Retinitis Pigmentosa, Optical methods for minimally-invasive, site-specific cell therapy; Microsurgical tools for specific endoscopic surgery, in-vivo-image guided manipulation and navigation; Tissue engineering, tissue regeneration and organ confection; Exploitation of the enormous self-repair potential that has been observed in stem cells.	
Photonic tools for cell and tissue manipulation	Advanced optical tweezers to move, rotate, gently separate cells by optical forces; New markers for spectral fingerprinting and identification of specific cell constituents	Molecular farming
In-vivo Cellular Diagnostics, In-vivo Histology, Pathology	Specific, biocompatible markers or new marker-less methods for 3D-diagnosis of tissue and cells	Analysis of transformation of tumor cells
Ophthalmic Instruments	Non-invasive instruments combining diagnostic as well as treatment capabilities working on-line; Monitoring of non-ophthalmic diseases through the eye	"Through-the-eye" diagnosis
Optical Biochips and Biosensors	Increasing the efficiency of the chips through higher throughput, smaller chip sizes and parallel reading	Real-time diagnosis
Microscopic Tomography, Microscopes	Enhanced geometrical and spectral resolution and extreme sensitivity at the same time	In-situ cellular diagnosis
Advanced Implants	Development of advanced retina implants	Heathcare

3.4 Lighting and Displays

Fig. 3.4.1 This image of Earth's city lights was created with data from the Defense Meteorological Satellite Program © NASA

3.4.1 INTRODUCTION

Lighting

For centuries mankind has essentially used burning or heated materials as light sources. The invention of the incandescent light bulb in the 19th century together with the introduction of the electric power grid paved the way for the first mass-produced light source that offered clean and reasonable bright illumination for the homes and factories of the industrial world. Since then, the conversion of electrical energy into visible light with higher efficiencies and brightness has been the aim of major research and development effort in academia and industry. Gas discharge lamps, invented in the middle of the 20th century, presented a first step in this direction, but cannot be fully customized in form, colour and appearance. In both conventional technologies, incandescent lamps and discharge lamps, European institutions and companies played a leading role from an early stage. As a result the major players in the lighting industry are still in Europe and have a European R&D base: This excellent position for Europe has to be secured by constant innovation.

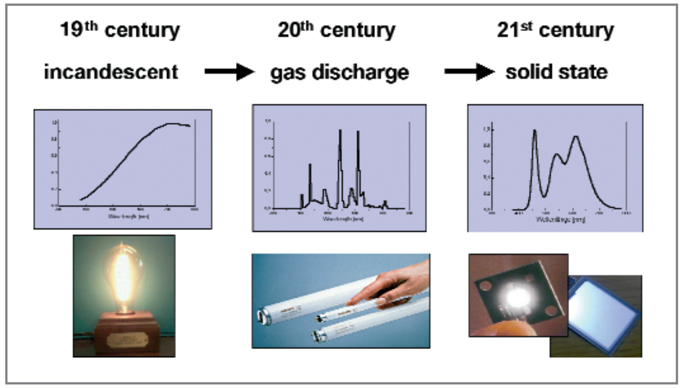


Fig. 3.4.2
The evolution of light sources.

Currently the next revolution in lighting is taking place: Solid State Lighting (SSL), Fig. 3.4.2. SSL has the potential of replacing conventional light sources the way integrated circuits replaced electron tubes fifty years ago. SSL offers an elegant way for direct conversion of electrical energy into visible light. It combines high conversion efficiencies that will reach the currently most efficient sources in general lighting applications as early as 2007 with freedom in shape offering new design and application opportunities as well as full tunability of brightness and colour. This will open new markets for light solutions.

Gas discharge lamps and in particular high intensity discharge (HID) lamps will continue to play an important role in lighting. These lamps are not only the light sources with the highest electro-optical efficiency as of today, but also find more and more applications outside of general lighting. Medical treatment with light and the use of UV light to disinfect water are two examples of such applications.

In the long term SSL, inorganic and organic light emitting diodes (LEDs) as well as lasers, will become the next generation light sources, even replacing the currently used incandescent and gas discharge lamps.

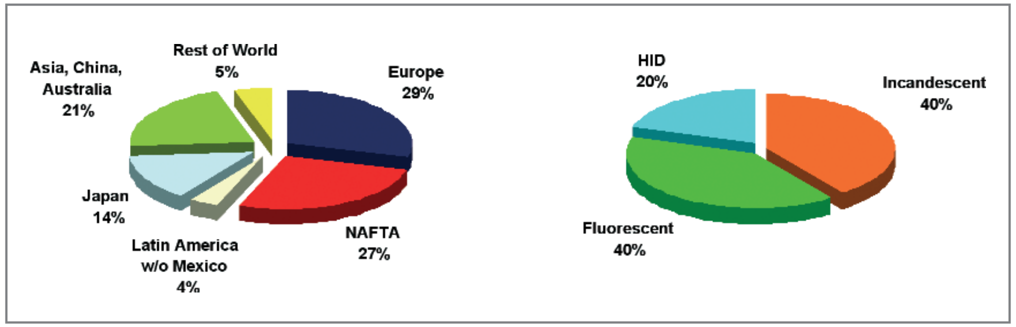


Fig. 3.4.3 Left: World market for lamps by region (without LEDs). Total market volume in 2004 was 12.6 billion EUR. Right: Technology breakdown (excluding special lighting applications). © Osram, Philips Lighting

The European lighting industry has established a strong position in the world lamp market (Fig. 3.4.3) which is expected to have an annual growth rate of 3%.

The market for high brightness LEDs reached 3.7 billion $ in 2004. In recent years, much of this growth has been driven by the increasing use of high brightness LEDs in mobile applications (e.g. mobile phones, digital cameras). Due to a saturation effect in this area, an annual growth of 10-15% is expected for the next five years (Source: High-Brightness LED market review and forecast, Strategies Unlimited 2005, Fig. 3.4.4).

We have to ensure that this leading position in the lighting market of the 20th century will extend to the 21st century. Now the basis for a sustainable growth business with an excellent environmental bill has to be built. It will take a joint EU sponsored and coordinated initiative, involving academia and industry laboratories, to maintain the leading European position in general illumination.

Application	2004	2005	2006	2007	2008	2009	CAGR
Signs/Displays	500	552	631	758	1,073	1,835	29.7%
Mobile Appliances	2,095	1,997	2,061	2,174	2,229	2,300	1.9%
Traffic Signals	63	74	87	98	94	90	7.5%
Automotive	472	519	650	766	905	1,019	16.6%
Illumination	174	252	360	494	661	857	37.6%
Electronic Equipment/Other	383	418	475	541	615	700	12.8%
Total	3,687	3,812	4,264	4,830	5,577	6,801	13.0%

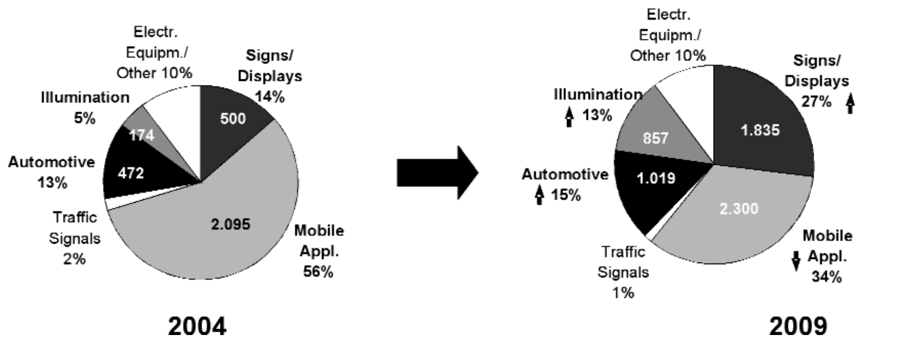


Fig. 3.4.4 The market for high brightness LEDs is expected to grow annually by 13% reaching 6.8 billion $ in 2009. Whereas a decrease in the market share of mobile applications is expected, a large increase in market share is foreseen for illumination, signs and displays. All numbers are in million $.
© Strategies Unlimited; High-Brightness LED market review and forecast, 2005

Displays

Even though it has been more than sixty years since the first Cathode Ray Tube (CRT) televisions appeared in the market, the electronic display is still a young emerging technology. The replacement of CRTs by Flat Panel Displays (FPDs) is just the first step towards fully immersive displays (see Fig. 3.4.5). Future displays together with flexible electronics will create an "intelligent environment" that will help the broad, intuitive and environmentally friendly use of electronics.

Display applications are already an economic heavyweight. Moving towards intelligent environments will push the display market to even higher levels. One visionary solution is the low-cost, flexible, large-area electronic display with integrated smart drivers. This technology forms a critical element of the "intelligent environment", and is just about to enter the market place with an outstanding potential for growth.

Standard display manufacturing with enormous production factories has left Europe to move to Asia. In this vein, Asia is spending a considerable amount of private and public money into research and technological development (RTD), but with a different emphasis than Europeans: They are continuously striving towards production cost reduction.[1] Research activities focus on the further development and refinement of their standard production-process technologies. In Europe research in the field of advanced displays is driven by the creation of novel applications. As a consequence research and development mainly targets the demonstration of the feasibility of new technologies. Similar as in Europe, RTD in the US is mainly looking at novel applications, however with special emphasis on military applications.[2]

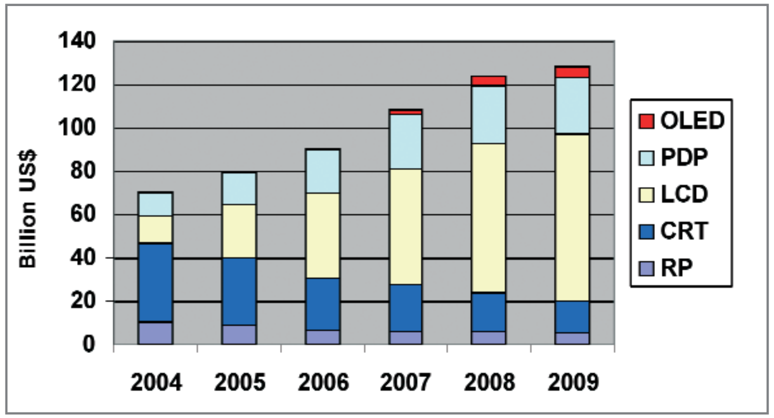


Fig. 3.4.5
The total display revenues are expected to rise with a decreasing market share in CRT and a steeply increasing market share in LCD.
Abbreviations:
OLED: organic light emitting diode,
PDP: plasma display panel,
LCD: liquid crystal display,
CRT: cathode ray tube,
RP: rear projection.
© DisplaySearch

Indeed, Europe is a global driver in displays research and displays innovation coupled with a strong supply industry. In fact, the standard Asian manufacturers are dependent on the European research and materials & equipment supplier base in the field of FPDs for its materials, components, equipment, and tools for the manufacture of FPDs. This can readily be explained by the fact that many basic inventions in the area of FPDs were made in Europe. However, the ability to maintain this position is in doubt since the EU is investing proportionately less than its main competitors into R&D and lacks world-class production as a main driver for innovation. Whereas Europe has not fully capitalized on the success of FPDs in the last decade, the evolution towards ambient intelligence (allowing the intuitive use of electronic systems everywhere for everybody) is a large step in product innovation and a new opportunity to regain economic strength in this market for Europe.

1 Taiwanese Industrial Economics & Knowledge Center, ITIS 2004 Taiwan Industrial Outlook; available at http://www.itis.org.tw/english/resource.htm
2 Special Technology Area Review on Displays, Report of Department of Defense, United States of America, Advisory Group on Electron Devices, Working Group C (Electro-Optics), March 2004; available at http://www.acq.osd.mil/aged/AGED_Displays_STAR.pdf

Display technologies are important for large parts of the European economy and therefore also for employment. The goal is to remain globally competitive, for suppliers and for end users. The displays industry (e.g. in Taiwan) has grown to one of the most dynamic and the most competitive worldwide in a single decade with production of 14.5 B$US and more than 110 companies in 2004. Compared to that, display production in Europe is tiny. However, novel displays, applications and small-scale, rapid prototyping and disruptive manufacturing techniques could contribute largely to sustainable growth in Europe and could grow to become a large, dynamic industry again. Indeed, networks of growing SMEs are already expanding in Europe at a furious rate.

For Europe, one must emphasize the advantages of securing a closed supply chain competence within the EU so that global instabilities do not severely impact on competitiveness or productivity. This will allow Europe to drive its competitive propositions led by scientific, technological and market evolutions. It gives the opportunity to re-invest in different sectors as circumstances change. If we do not remain active then we leave ourselves unable to engage in these sectors for decades.

The market is currently in considerable turmoil as many innovative technologies and applications are developing rapidly and many business propositions are being directed to meet radical new opportunities born out of the communications and technology revolutions of the last decade. Through leveraging of the innovation of these new, flexible technologies and applications in Europe in combination with rapid prototyping and low-cost manufacturing techniques, this currently offers the rare opportunity to re-invigorate a European industrial and research base in displays.

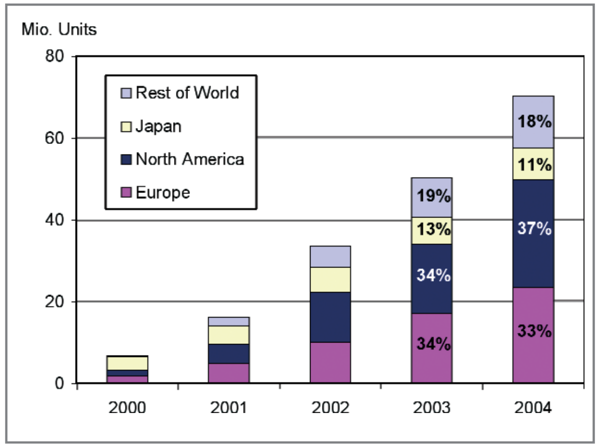


Fig. 3.4.6
On a global basis one third of all TFT-LCD desktop monitors are sold in Europe
© DisplaySearch, 2003

3.4.2 SOCIETAL NEEDS FOR LIGHTING AND DISPLAYS

3.4.2.1 Energy Savings, Resources and Sustainability

Lighting

Light production needs energy: more than 30 billion electrical lamps operate worldwide every day consuming more than 2,100 TWh per year (10-15% of the global energy production worldwide). An OECD estimation shows that in the near future the need for lighting will increase very rapidly (a factor of 2 is a realistic estimation within the next two decades).

The energy worldwide used for lighting per annum is valued at about 250 billion Euro (of which 25% amounts for Europe). However, light sources also find wide spread application in several important industrial domains. For example consider projection, reprography, entertainment, surface treatment, water and air purification, curing or process monitoring and control. If these additional applications are taken into account the total worldwide turnover of light source related technology is 2-3 times higher than the above figure. Europe has an important industrial stake in this major global industry.

The annual greenhouse gas (CO_2) due to the above energy production for illumination is estimated to be in the order of 900 million tons worldwide. Huge energy savings can be realized when replacing the current incandescent and discharge lamps by efficient SSL. If an efficiency of 150 lm/W is assumed (predicted for ca. 2015[3]) about 30% of the electrical energy used for general lighting purposes could be saved. That corresponds to 750 TWh energy savings per year as well as 300 million tons less greenhouse gas in the atmosphere. It is estimated[4] that by 2025 SSL could reduce the global amount of electricity used for lighting by 50%!

The reduction in CO_2 pollution is not the only environmental impact SSL will deliver. Common light sources contain small amounts of toxic and expensive raw materials, mercury and rare earths are common examples. As a consequence, at the end of life a considerable amount of "undesirable" waste is generated. SSL light sources are free of mercury and as a consequence are much easier to dispose of as for example gas discharge lamps. Furthermore, SSL will use LEDs that are expected to reach lifetimes exceeding 100,000 hours. This considerably reduces the waste issues related to rather short-lived incandescent light bulbs.

Displays

The societal impact of displays leveraged towards intelligent systems will be huge. Extraordinary product features of today's displays already contribute to human ease-of-use and quality of life, to environmental aspects and sustainability, GDP growth, employment, and competitiveness both for industry and for research. This will even be enhanced by future smart display-driven systems. Advanced research in smart displays will contribute to the worldwide perception of Europe's creativity and competitiveness. Displays are an indispensable key to every knowledge-based society.

The advancement of displays from bulky CRTs to flat panel displays in office applications already had a large effect on the environment: Less materials usage, less energy consumption for production and use, less radiation exposure and, after all, a lot less electronic waste. The advance-

3 Dr. N. Stath, Osram Opto Semiconductor Gmbh, DPG March 2004
4 OIDA Report, The Promise of Solid State Lighting for General Illumination, LEDs and OLEDs, 2002 Update

ment of FPDs in broader areas of life (e.g. into TV applications as seen now) will further increase that positive effect. With an evolution into smart displays we expect a comparable effect to even more environmentally friendly products and production. The concept of 'intelligent environments' will also lead to an increase of remote collaboration, leading to a significant reduction of travel.

3.4.2.2 Human Well-Being and Quality of Life

Lighting

Enhancing the experience of a space is an important lighting function. Technological developments in SSL open up new application areas. This will change how we use lighting to incorporate emotional benefits in addition to the more traditional functional benefits. The manipulation of the light spectrum, intensity, spatial and temporal distribution will become increasingly important in future lighting products for ambiance, health and well-being applications.

Targeted research on the influence of lighting parameters on people's perception of the lighting quality, productivity, perception of safety and comfort, well-being, mood and health is needed to fully exploit the possibilities offered by new lighting technologies. Efficient colour mixing technology for RGBa[5] and true colour rendering are important fields of investigation in this context. The gained knowledge will subsequently be built into advanced value added products based on a grounded knowledge of the human factors of lighting in different cultures.

Fig.3.4.7 LED lighting: The use of LEDs allows new opportunities for lighting and the creation of atmospheres. Left: multimedia library La Roche sur Yon, France, right: Restaurant Teatteri, Helsinki © Philips

This will eventually lead to the growth of completely new market areas such as atmosphere creation or light and health. As the functionality and complexity of these lighting systems increase it becomes important to develop intuitive and intelligent lighting management systems. Easy and efficient control of the complete lighting system must be enabled. It is anticipated that SSL components will physically merge with other elements in the space. Lighting and display devices

5 RGBa images can have a different transparency level for each individual pixel in the images. The appearance of each pixel in RGBa images is defined by four numbers: the three red (R), green (G) and blue (B) numbers that specify the colour and an alpha channel number (a) that specifies the transparency of that particular pixel.

Fig. 3.4.8
Chicago: Large outdoor displays based on LEDs in Crown Fountain Plaza, Chicago
© Barco

will become increasingly similar. Pixelated lamps will provide information content in addition to light. Home theater displays will have atmosphere-creating functions similar to today's lighting applications. Lighting controls will merge with other control systems, such as intelligent home control systems, thus impacting future standards. In short, a complete lighting architecture will play into the emerging themes of atmosphere lighting and integration in the total space.

Displays

Flat panel display technology has largely replaced the bulky tubes on our desks. It has been an enabler for "mobile information use". Therefore it has largely changed our working environment through "office mobility" with notebooks and mobile phones. Future display technologies will have a similar effect not only on the working environment, but on the quality of life in many other aspects.

The development of new display technologies and applications will provide citizens with information at any place and at any time upon request. For the rest of the time, the display is hidden and not providing constant information overload. This enables the citizen to move around freely enjoying a high quality of life, while still having full access to high-density information.

3.4.2.3 Ageing society, education and health

Lighting

So far the research and development pursued by the lamp industry has mainly focused on visual aspects of light like efficiency and colour rendering. Starting a few years ago with the identification of blue sensitive photoreceptors in the human eye a clearer understanding of the biological effects of light on human beings is emerging.

The lighting industry is now developing a new view on light quality including the biological effects. Biological effects like the suppression of the sleeping hormone melatonin are mainly dependent on the blue portion of the light spectrum. The positive biological effects of light are so far commonly acknowledged for health care applications like the treatment of Seasonal Affective Disorder. By optimizing the blue content of lamps for daily use in home, office and industrial applications it is expected to positively influence the circadian rhythm and well-being of people.

To achieve this goal, interdisciplinary studies on biological effects of real lamp spectra are necessary to determine the best colour temperature and spectral power distribution. Safety aspects of blue enhanced light sources have to be considered in these developments. Eye injuries can be caused by intensive radiation in the 400-500 nm range. Possibly glare is more critical for blue light. Investigations have to make sure that current standards and limitations for luminance in office lighting are still valid for blue enhanced light sources.

Light can also be useful for medical therapy, e.g. in the area of skin treatment, aesthetics, wellness, photo-dermatology or wound healing. Also in this area further investigations are needed to determine the optimal light spectra and intensity. A relevant trend observed in this area is the growing number of applications of light in the consumer market.

Displays

As the population ages, displays for e-books and e-newspapers with electronic capabilities to provide larger print, easier portability, and more intuitive human interfaces will extend the time in which elderly remain involved with the society.

Education will change through the use of electronic displays (portable, low-power and low-cost) for schoolbooks. Satchels of schoolchildren will get lighter, which is also an important health aspect. Interactive and enhanced electronic student-teacher learning with wireless e-textbooks will become an environmentally-sustainable reality. Furthermore, 3D imaging will make learning more effective.

The number of images used in the medical field is exploding, e.g. by periodic patient screenings or an increasing number of images per consultation. High resolution and 3D displays will make diagnoses much faster and more accurate. The enhancement of human vision (or as a cure for blindness) is a further topic of interest. Smart cards for medical histories, or systems including low-cost (organic) electronics and low information content displays, will bring small "disposable labs" for e.g. emergency diagnosis with reduced risk to the patient. The concept of an "intelligent environment" will enable that elderly can stay longer in their own home (by the possibility of monitoring and daily consultation with a doctor).

3.4.2.4 Safety and Information with Light

Personal mobility is a basic component of our modern society. Light does not only guide and control the traffic, but is also a crucial element for road safety. In future, traffic lights, signal lamps, street lamps as well as displays and luminaires in vehicles will be joined by further intelligent optical systems.

Fig. 3.4.9
Future automotive lighting systems will have more functionality
© Philips

Speed indicators and navigation systems will be projected via laser technology directly in the field of view of the driver. The view of the driver remains on the road and he can concentrate on driving. Installed infrared radiators and cameras will significantly improve vision at night or in fog. Intelligent assistance-systems relieve the driver of decisions so that he can concentrate on a few but important activities. In the next generation of automotives it is highly likely that head-up displays will provide not only telemetry of speed but also map and warning indicators in respect of a variety of intelligent systems.

Lighting systems will likely be used in future not only for illumination purposes, but at the same time as detector or communication tool. This will for example enable the communication of one vehicle with the other road users or a traffic management system.

Nearly 80% of fatal accidents, when related to the distance driven, happen during night or in adverse weather conditions. Increase of traffic safety at first instance therefore requires sufficient illumination of the road, ideally adapted to the actual traffic situation. Adaptive headlamps, equipped with high performance light sources and controlled by sensor information on speed, curvature of the road, weather condition and ambient illumination will lead to optimal illumination of the road under all traffic situations.

The spectrum of all new technologies and their applications includes intelligent lighting, optical measuring, information systems, sensoric, information and communication, dedication on long distance, object identification, signal and image processing, as well as visualization technologies.

3.4.3 PREDICTIONS UNTIL 2015: UPCOMING APPLICATIONS, TECHNOLOGIES AND MANUFACTURING

3.4.3.1 New Lighting Application Domains and System Integration

The lighting business is experiencing a number of dramatic changes that will require a different attitude towards lighting solutions. The system aspect will become much more important in future, it is not just the lamps that determine the lighting installation. Especially SSL offers new freedom of light design and atmosphere creation by a large number of individually controllable light sources. The application of LED lighting systems in general illumination requiring white light is expected to grow quickly in the coming years and to develop into a huge market that will be substantially larger than the current LED applications using monochrome light. Making white light by mixing the light of monochrome LEDs with different colours will serve a large part of this market since it will be the most efficient way of making white light and allowing for colour variation.

The visual experience is one of the top consumer considerations in purchasing lighting systems. True colour rendering will be important. To create white light or light of a certain colour, efficient ways for mixing multiple LEDs of different colour are needed. The most common way to mix light of different colours is either to couple the light into a waveguide or to place multiple LEDs into one collimator. Although this mixes light up to a certain extend, the mixing is not perfect. Furthermore etendue (the optical extent) is not conserved in those mixing devices. It can be important to have the smallest possible etendue for e.g. a spotlight or overhead office lighting. Therefore new ways to mix light and conserving the etendue are needed.

Next to the possibility to have fully adaptive lighting systems SSL offers ways to allow large area and flexible lighting systems. These lighting systems can even merge with displays, facilitating the use of the system depending on the personal needs. The convergence of functions such as illumination and visualization will change everyday life significantly.

Electronic supplies that enable basic intensity and colour control are readily available or under development. The challenge is their optimisation with respect to functionality, reliability, efficiency, cost and size, especially in relation to the colour stability and reproducibility and binning issues. They will have to meet stringent low audible noise limits. Innovative driver architectures and circuit solutions fulfilling these requirements will be an enabler for the successful introduction of new LED based lighting products.

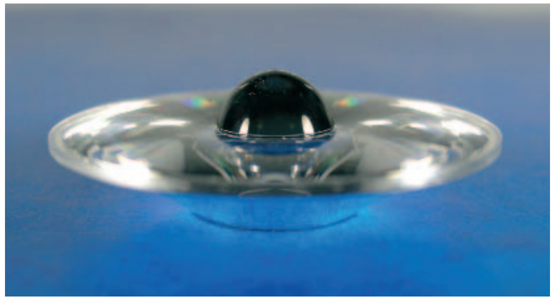


Fig. 3.4.10
Primary optics for LED-light-projector with homogeneous circular spot: diamond turned reflective-refractive concentrator
© Fraunhofer IOF

3.4.3.2 New Display Systems and Applications

Ambient intelligence represents a vision of the future where we will be surrounded by electronic environments, sensitive and responsive to people. It emphasizes greater user-friendliness, more efficient services support, user-empowerment, and support for human interactions. In this vision, people will be surrounded by intelligent and intuitive interfaces embedded in everyday objects around us. The environment will recognize and respond to the presence of individuals in an invisible way.

Ambient intelligence builds on three recent key technologies: ubiquitous computing, ubiquitous communication and intelligent user interfaces – some of these concepts are barely a decade old. Ubiquitous Computing means integration of microprocessors into everyday objects like furniture or clothing. Ubiquitous Communication enables these objects to communicate with each other and the user by means of displays, ad-hoc and wireless networking. An Intelligent User Interface enables the inhabitants of the environment to control and interact with the environment in a natural (voice, gestures) and personalised way (preferences, context), through the use of intelligent electronics.

3.4.3.3 Ambient intelligence needs flexible interfaces

Humans have always tried to make information content accessible in a way that appears to their senses in a manner as close as possible to their natural perception. What we call "virtual reality" would be the ideal: information you can "feel" with all your senses, i.e. an intelligent, interactive environment – "like a dream", in both senses of its meaning.

Intelligent integrated systems for ubiquitous computing will need appropriately adapted output devices: this will fuel display development enormously, since displays form the main route of high-information content to the citizen. We will therefore need displays that are flexible both physically (i.e. bendable, even rollable) as well as in production (easily customisable / small volume production by printing processes) and in their use (i.e. for multiple applications).

Fig. 3.4.11
Flexible active matrix e-paper SVGA display printed at Plastic Logic's Prototype Line in Cambridge, UK
© Plastic Logic Limited

An example would be a rollable display with a wireless interconnection for new content, such as e-newspaper displays.

The adoption of wireless technologies for display interfaces are a prerequisite for ubiquitous computing: This would allow computing devices to use whatever is the optimum display.

Novel 3D displays would bring us a lot closer to the "virtual reality" scenario described above. 3D is interesting not only for consumer applications but also for computer aided design and medical use.

Novel manufacturing techniques such as printing will enable very low cost displays that could be used even for packaging of goods. This could also enable "living" packages with small video sequences. With low cost display manufacturing, a high level of customisation can be obtained; the possibilities for applications are almost endless.

Displays will be integrated systems with embedded electronics and functionality to meet the needs of the citizen.

3.4.3.4 New Displays for novel means of information delivery

Flexible display technology, together with developments in plastic electronics, is an opportunity to leverage the cross fertilisation of several natural science disciplines that significantly plays upon the strength of European knowledge.

Fully transparent displays form a subset of several display technologies having many opportunities. These can leverage technology development in OLEDs, LCD, and other effects, and there are now propositions that can allow edge illuminated screens to operate.

3D displays have the potential of completely changing the way we handle information. "Real 3-D" would mean intuitive use without glasses and the display adapting to the user. This would open up new ways of learning and perceiving information.

For mass production of real 3D enabled displays new materials, new components, new standards and new technology will be needed. For 3D, there are also a number of implications in terms of data management, transmission and control protocols. These extend into the domains of pure mathematics and data management paradigms at the chip and system level. This may be an area where the EU's skill base in advanced architectures, especially in field programmable gate arrays and digital signal processing, may prove a strong leverage for technical and business leadership. In Europe, there are a number of companies – most of them are SMEs – and research institutes with very promising, innovative new technologies in the 3D field, that need to be developed further and advanced into mass production.

Smart displays, fully integrated with logic, sensors, antennae, power and the display itself on one backplane will provide the keystone to the intelligent environment. Together with the development of packaging and interconnects with embedded specific display and LED drivers and systems, a complete package can be developed effectively.

Finally, an overall system support for information content delivery to display devices, including infrastructure standards, and digital rights management must be researched and standardized to obtain a lock on the products based on the technology. Through improved human factors research, we can ultimately improve end-user interactivity, perception and design.

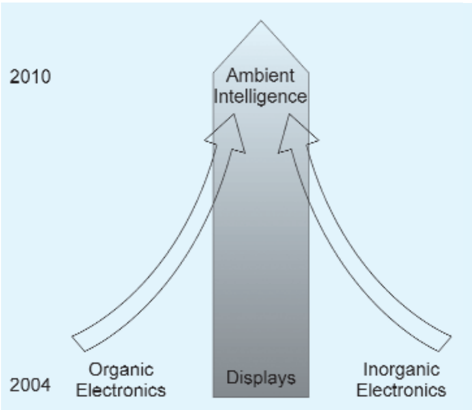


Fig. 3.4.12
Displays will get "smart" by embedding electronics, organic and inorganic. This will enable the ambient intelligence scenario on a timeframe until 2010.

3.4.4 ADVANCING TECHNOLOGY DOMAINS

3.4.4.1 Inorganic LEDs aiming to 150 lm/W

Inorganic LEDs went through an impressive improvement curve with a brightness increase of more than two orders of magnitude throughout the last three decades. No other light source offers such high efficiency improvement potentials as SSL sources today. Efficiencies up to 150 lm/W seem feasible within the next 1-2 decades. High research efforts are needed to reach this goal.

The efficiency of an LED light source includes the generation of light (internal efficiency), the extraction of light from the semiconductor (extraction efficiency), the colour conversion (conversion efficiency) and the light extraction from the packaged device. About 60% of the electrical power injected into an InGaN LED is converted into blue light and about 70% of this light is extracted out of the semiconductor chip. A phosphor converts the blue emission partly into yellow. Together with the remaining blue emission white light is created. Including all scattering losses, this process has an efficiency of about 50%. Finally, the white light has to be extracted from the device into air. For most lighting applications, all these efficiencies have to be increased significantly (internal >80%, extraction >80%, conversion > 80%, external: 150 lm/W).

In addition to a high efficiency, LED light sources must also be capable of providing sufficiently high quantities of light. Large-area, high-flux LEDs that are operated at high currents (>1 A) emit around 100 lm/device. The emitted power is limited thermally, but also by the pronounced, saturating power-current characteristic, which is typical for InGaN-based emitters. It will be possible to reduce this saturation by improving the material quality of the active layers. Besides the optimisation of the epitaxial growth itself, a huge opportunity lies in the use of alternative substrates such as GaN, AlN or ZnO. These materials are available only on a laboratory scale at extremely high costs, mostly from Asian sources. In parallel, attention has to be paid on alternative short wavelength emitting materials such as ZnO which is still in an early development stage. Here, European researchers are leading edge.

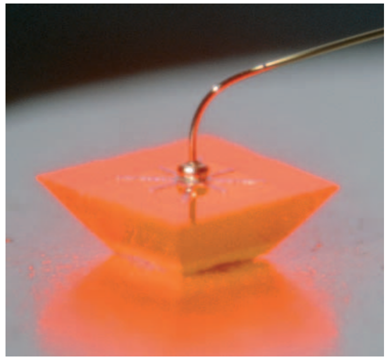


Fig. 3.4.13
Red high power LED
© Philips

Fig. 3.4.14 The new generation of the 6-lead MultiLED with black surface is much more powerful and lives five times longer than the previous version. © Osram

Even higher lumen packages of several thousand lumens can be generated with multi-chip power modules, either by blue-conversion or colour-mixing. Every single chip is driven at a current in the 1 A-range and the entire assembly produces a significant amount of excessive heat. In contrast to incandescent lamps, where the heat is simply dissipated by radiation, it is technologically very challenging to efficiently dissipate the heat from the small area of such modules. Transporting the heat away from the LEDs is of particular importance, because their efficiency suffers appreciably from temperature. With the increasing optical power densities great care has to be taken on the packaging materials. Research has to be addressed to moulding and casting materials which are UV-resistant, temperature stable and high reflective or high refractive. Novel interconnect materials with extremely low thermal resistance, low cost carriers with improved heat spreading properties such as carbon nanotubes composites and radiation stable optics are essential for high flux applications.

Multi-chip modules offer a number of advantages for lighting applications. It is possible to add red, orange or yellow emitting LEDs to the blue/phosphorous white in order to fill the gaps in the spectrum and to improve the colour rendering. Alternatively, the white can be generated by mixing the emission of red, blue and green LEDs. Since this approach does not require any colour conversion, it is inherently more effective. A particularly attractive feature of this solution is the possibility to control the colour mix by tuning the individual RGB drive currents.

In general, the light from LEDs can be used more efficiently, because the emission occurs only into one direction. The development of integrated optical elements will play an essential role in exploiting this advantage. For other, emerging applications such as automotive headlamps, backlighting of large LCD panels or even LED-based projectors, the combination of high-flux and directional emission is key. Applications, where the emission is imaged by an optical system, demand for much better directionality than the typical Lambertian emission profile. Technologies to facilitate this are e.g. the use of integrated photonic-bandgap surface structures or resonant device designs. However, this development is at the very beginning and viable technological solutions are not yet established. The total output and efficiency of RGB power modules today is limited by the comparably poor efficiency of the green devices. This is caused by the decreasing material quality as the In-fraction in the InGaN-alloy is increased. Ultimately, the performance gap of high-brightness LEDs in the green/yellow regime has to be improved considerably to reach the ambitious power and efficiency targets.

3.4.4.2 ORGANIC LIGHT EMITTING DIODES (OLEDS) WITH 120 LM/W

OLEDs bear the technological potential to achieve unprecedented efficiencies in energy to light conversion. This and the fact that OLEDs intrinsically have a broad range of options for design and appearance make OLEDs an interesting technology for SSL and display applications. However, much of this potential is to be uncovered and a strong and focused effort is necessary to fully harvest the advantages of OLEDs for applications in lighting, signage and display.

One of the foremost important topics in OLED R&D is the search for more stable, higher efficiency organic semiconductors. Unlike their inorganic counterpart, where the primary material set is rather fixed, OLED materials have virtually unlimited variation capability but very often suffer from limited stability, limited efficiency and lower robustness. Rational design of the molecules is hampered by the complexity of the interactions in organic structures. The relation between molecular design and performance in a device is an area yet to be developed.

Beyond the pure materials' design and synthesis, it is an important task to massively strengthen the insight into the device performance by rational device design and to strongly improve the reliability and defect tolerance of the thin film organic layers that constitute an OLED. In OLEDs the functional structure is based on a few hundred nanometre thin amorphous organic films. The understanding of the functionality of these layers and the interplay of the various materials in conjunction with light generation processes and light propagation in the device needs considerable improvement to achieve a stage of design capability that allows to accelerate product development and to improve efficiency beyond the 50 lm/W boundary. Similarly, these thin films are much too often prone to disruptions by dust particles, making processing of OLEDs a very expensive undertaking. Improving the defect tolerance of the device and the reliability in operation would enable capturing a much larger range of applications.

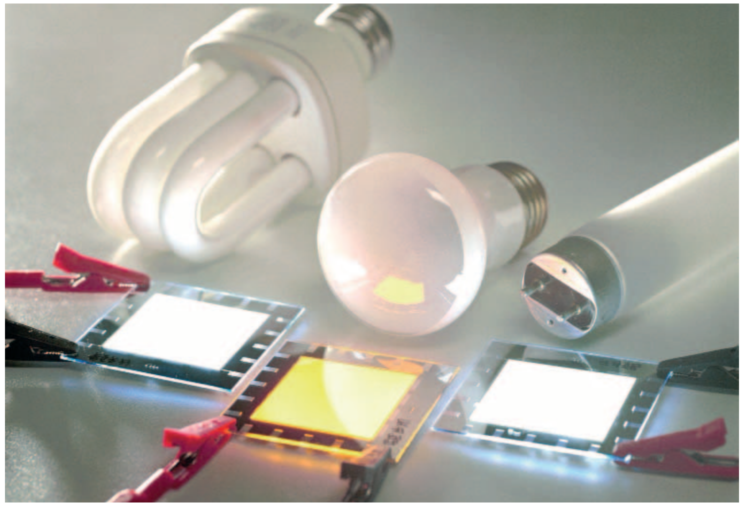


Fig. 3.4.15
OLED light sources have the potential to replace today's conventional light sources
© Philips

Under a system perspective, there is clearly need for intense R&D in new processing technologies as well as new encapsulation technologies, allowing a much faster and easier completion of the OLED device with the same protection and reliability of today's solutions. OLEDs offer the fascinating option of being processed on flexible substrates. This could enable manufacturing in a roll-to-roll mode, making OLEDs not only applicable in a multitude of new markets, but also lowering the cost of an OLED device dramatically. Roll-to-roll processing however, is a challenging task for OLED deposition, since two important components are not available: deposition techniques for fast and accurate definition of the organic films and thin film encapsulation. Both are urgently needed and viable results in these areas will result in a technological advantage. A flexible light source that is produced in a continuous process would certainly revolutionize the lighting and signage world. Complete freedom in design, shape and appearance like large area and flexible lighting systems, in combination with high efficiencies and long life would deeply alter the way of using light in our environment and would open up new application fields for the benefit of humans.

Finally, new options like colour variability, transparency, or patterned addressing need to be developed. Respective driving electronics as well as power supplies to operate the OLED lamps in the existing infrastructure need to be invented and optimized to enable an overall saving of energy, cost and to sustainably improve people's life through advanced light sources.

3.4.4.3 Laser Light Sources

The tremendous progress on laser light sources over the last decades paved the way for a variety of new applications. Illumination with laser light sources and the visualisation of information by laser displays are new applications with a very high market growing potential for the future.

In a long term perspective, laser illumination and laser display technology will converge. Lasers are ideal light sources to combine structured and dynamic illumination on free shaped surfaces with additional visualization of information like TV or home cinemas.

Illumination

IR illumination to improve night vision has the potential to reduce dramatically the rate of car accidents at night time. IR night vision needs very compact and low cost high power (~5 W) IR radiation sources with reliable operation up to temperatures of ~100°C. IR high power laser diodes have the potential to fulfill those demands. But strong effort is necessary in laser design capable for high operation temperatures and low cost packaging. Eye safety is a problem for the actually available wavelengths below ~1300 nm. R&D efforts are required in semiconductor material research and special laser design to shift the wavelength for IR high power laser sources into the eye safe range of ~1300-1500 nm.

Besides the illumination with IR laser sources, lighting with converted blue laser radiation may become important for some future applications (medical, head lamps). Fibre coupled blue laser light converted at the fibre end will result in an efficient white point source. Conversion of blue laser radiation also offers the possibility to realize lasers in the visible range by frequency conversion.

Backlighting of LCD screens with RGB laser sources as alternative to LEDs is expected to become a fast growing market as soon as low cost, high power RGB laser sources will become available. Ideal laser sources will be semiconductor laser bars in red, green and blue with optical output power in the Watt range. For the green colour, frequency converted solid state lasers, waveguide or semiconductor disk lasers will be an alternative.

Displays with laser light sources

Lasers are perfect light sources for information displays, with unmatched high brightness, low divergence, small bandwidth, high wall-plug efficiency, and the potential to provide extremely compact projection units. Such visible lasers enable a new class of projection displays, including embedded projection units for ubiquitous mobile devices and powerful 3D displays to fulfill the demand of the information society.

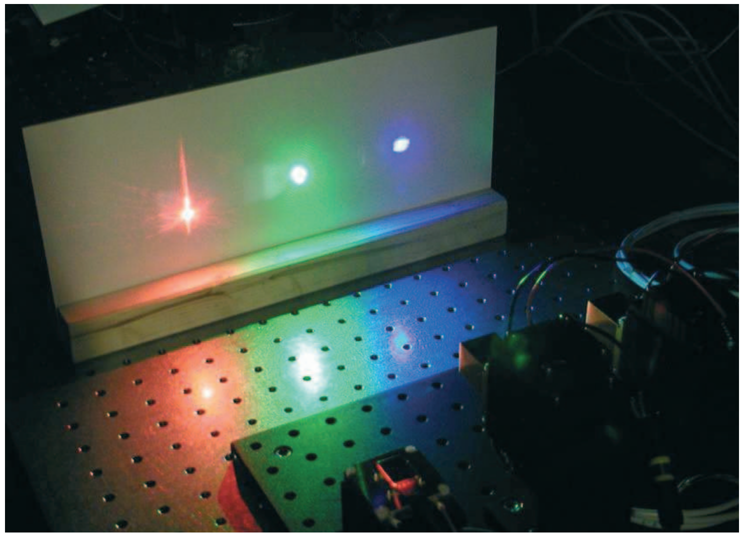


Fig. 3.4.16
Laser devices for projection applications
© Osram Opto Semiconductors

For these purposes, an entirely new core technology of powerful, efficient and compact laser sources in the visible range as well as novel system architectures are necessary.

Material development and device design of laser diodes and laser materials/crystals are key elements. Improving red and blue laser diodes in lifetime, brightness and extending the wavelength range towards 620 nm in red, and 470 nm for blue and even to green. New device structures based on edge-emitting and surface emitting laser, including external cavities with high modulation bandwidth and low coherence to suppress speckles are needed.

Since the advent of direct emitting green laser diodes is uncertain, frequency conversion of efficient IR/blue/UV lasers needs to be pursued. New device architecture and material development of frequency converting elements, including quasi-phase matching and up-/down-conversion materials should lead to 70% conversion efficiency in continuous operation.

Basic technological research topics include material development for heatsinks and heatspreaders with high thermal conductance, manufacturable in high volume, large panel sizes and dedicated surface finishing for solder processes, optical engines with highest possible compactness, including low cost and high-temperature resistant micro-optics and advanced mounting methods.

3.4.4.4 DISCHARGE LIGHT SOURCES

So-called high intensity discharge lamps (HIDs) emit light with a high quality spectrum comparable to natural light. HID lamps produce light by a high pressure gas discharge inside the lamp with high efficiency, making them much brighter than fluorescent or incandescent lamps, and ideal wherever ultra high brightness, high quality light is needed. Although HID lamps are already on an excellent level regarding their performance, there is still room and need for improvement, so that the European industry stays competitive. Nowadays HID lamps deliver up to 120 lm/W. That is 5 to 10 times more than conventional incandescent bulbs (including tungsten halogen) produce. But much more than 150 lm/W are feasible in future. Thus, the energy efficiency of discharge lamps makes them more environmentally friendly than any other light source. But HID lamps have a significant shortcoming: to optimize the discharge voltage they need mercury, a dangerous poison. That is why it is necessary to find mercury free alternatives with a long product lifetime and without decreasing the lamp efficiency. Such research is proceeding in Europe and there is great hope of a breakthrough with several promising developments. These systems for example require intelligent electronic control gears or microwave drivers and hence are dependent to some degree in companion technology developments elsewhere. The important goal is to transfer new fast starting HID lamps from their today's niche applications to the field of General Lighting to remarkably contribute to energy saving in lighting.

Fig. 3.4.17
Left: HID lamp for illumination of cinemas and theatres, right: excited molecules produce radiation for a better environment
© Osram

One way to produce light with potentially high efficiency is to use molecular emitters that aren't in gas phase at ambient temperature. The sulphur lamp was the first attractive concept solely based on a molecular filling demonstrating a luminous efficiency of more than 170 lm/W. Although commercially not successful, because requiring high wattage and generating a greenish light, this lamp stimulated research on other emitters. For instance, the use of "group IIIa and group IVa halides" or "group Vb oxides" have been demonstrated. Thus, it has been shown that diatomic molecules are potential alternative fillings for discharge lamps without using any environmentally unwanted substances. White light generation with high lamp efficacy, dimming and colour control appears to be feasible using such molecular radiators.

Another area where discharge lamps play an important role are special lighting applications using for instance the UV or VUV light generated in excimer lamps. Examples are the use for environmental topics as air and water purification or for surface treatment in semiconductor processing.

A further technological topic is “hybrid lamps” i.e. the combination of different light sources to one lamp that can be used especially for the purpose of adaptive illumination systems. Adaptive illumination systems give the chance for an individual design of the personal surrounding for office as well as for home and other applications. The personal mood can be enhanced and other aspects of the biological effects of light on human beings can be exploited. For example, HID lamps, which are already high quality and efficient light sources, the high efficiency can be combined with the possibility to adjust colour temperature and intensity as requested, by adding also high efficient LED light sources.

3.4.4.5 Flat Panel Display Device Structures

The focus on disruptive display development and manufacturing also implies that research on novel display principles must continue. The synergy between lighting and displays is evident here, since long-life materials for light-emission (OLED) and switching transistors (Organic thin film transistor) or transparent transistors for see-through lighting and displays are all important goals. Indeed, higher performance displays and lighting will require similar technological advances, in both flexible substrates, encapsulation, packaging, interconnects and more:

Materials with increased chemical and mechanical stability, lifetime and higher efficiency for
– OLED and liquid crystal (LC) displays,
– organic transistors for all-organic displays,
– transparent transistors.

Materials required for advancing technology in
– low-cost flexible substrates,
– thin film encapsulation for flexible displays (especially OLED),
– thin LC layers with high performance,
– hybrid organic/inorganic electronic devices
– improved light extraction from thin film devices.

New full-colour display effects including
– Electrowetting,
– Electrophoretic,
– Electrochromic,
– Novel ideas for display technologies with differentiating features.

In addition, we cannot afford to allow the EU to continue to treat packaging as an insignificant technology, The necessities of materials and process technologies in forming, handling and assembling displays represent a formidable challenge wherein the EU has allowed itself to fall far behind the Asian economies. The same statement applies to Quality Engineering and Testing.

3.4.5 MANUFACTURING AND COST

3.4.5.1 Reduction of initial and operational costs (total costs of ownership)

The breakthrough into the consumer market of new efficient technologies in lighting greatly depends on costs: initial purchasing costs and operational costs (total costs of ownership). Especially the initial purchasing costs currently present a considerable threshold for market penetration.

To improve system lifetime and decrease the total costs of ownership, the lifetime of electronics at elevated temperatures has to increase. Significant maintenance costs are caused by temporal optical performance variations. These can be reduced by smart sensing & control systems. Good cooling is necessary for both high efficiency and long lifetime of the devices. Therefore, advanced heat spreading systems and active cooling technologies will be needed for high flux LED light sources.

Smart beam shaping and power control can further help to increase the utilization efficiency of the light. Electro-optical control systems offer new opportunities here. Advanced communication and control electronics have to be developed to handle the new degrees of freedom and to offer a simple user interface.

The integration of advanced functionalities and technologies creates significant, and cost effective, added value that sets European LED lighting system solutions distinctly apart from competing potentially lower cost, but poor quality, LED systems.

Direct molding of multi-chip primary optics with micro-optical structures, that will enable higher packing density with high extraction efficiency, results in lower packaging costs. For efficient, high-quality light with dynamic colour point selection, low loss, low cost and space efficient colour mixing optics have to be developed.

Extended light sources are starting to be relevant, for which low cost mounting and encapsulating technologies need to be developed, including beam shaping (micro)optics. This offers the potential of roll-to-roll light source processing, low cost packaging and efficient, low temperature operation.

One of the cost increasing factors is the spread in LED characteristics. Colour converters with well controlled optical properties promise more robust systems concerning temperature dependence and reduced driver & control costs, while enabling accurate colour point selection, tunable lighting systems, and increased source brightness.

3.4.5.2 Rapid prototyping of displays and custom design fabrication

Display end-user industries differentiate their products more and more through design features. Displays play a very important role here. Moreover, their applications require special features like temperature resistance, brightness for use in sun- and daylight, shock- and vibration resistance (if you think e.g. about a car or mobile phone display). There is a growing demand for mission-critical applications. All of this requires the rapid development and use of customized displays. Indeed, standard modules from Asia usually cannot meet these special requirements, and European manufacturers are specialized in understanding and meeting the customer's specific needs.
The graph shows the need for such customized displays for Europe and the US (both share these markets approximately equally). Customization is therefore a market opportunity that will drive innovations in the abovementioned sectors. This is true both for customized modules and custom substrate design. This means shifting away from a "bigger is cheaper" display manufacturing mentality, into rapid prototyping and custom design fabrication.

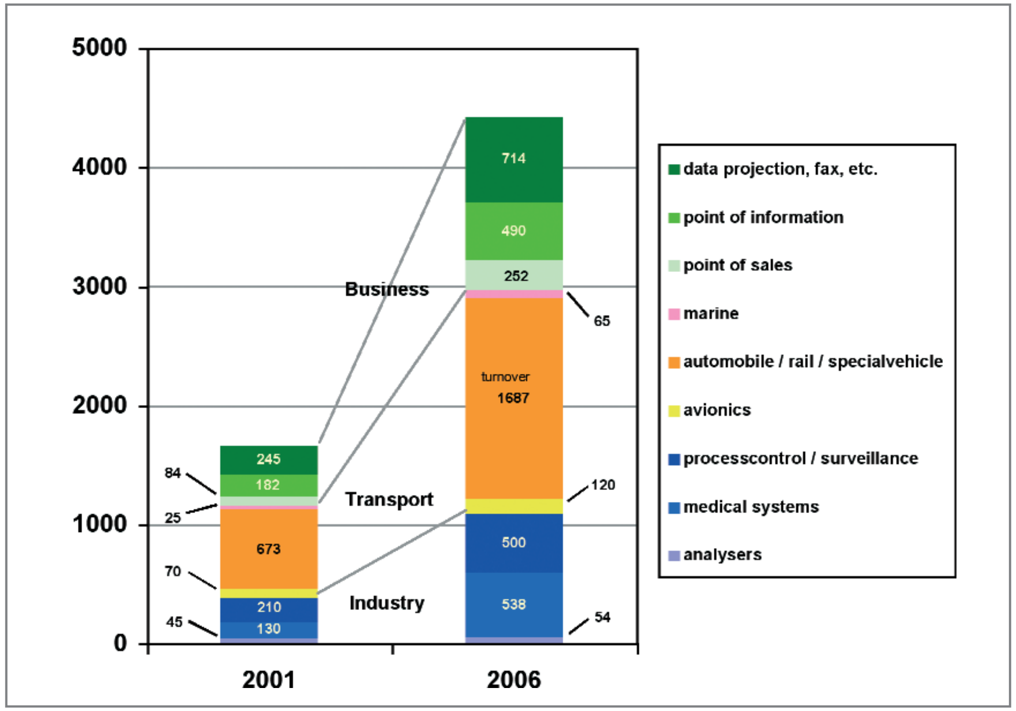


Fig. 3.4.18 Attractivity of industrial displays for different sectors. Sales per branch and market segments in Europe and North America in Mio. US$. © DisplaySearch, i-sft

3.4.5.3 Large Area Processing and Novel Processes for displays and lighting

Working towards the development of backplane and display effect manufacturing using novel production methods, we will require high resolution patterning and printing, backplane design customization, and roll-to-roll and roll-to-sheet processes for high-throughput processes and equipment.

Roll-to-roll processing is a technology which is applied e.g. in coating of films, printing of newspapers and opens up a new world for light sources. Not only would the source become flexible, but high speed deposition and processing of e.g. the whole OLED system would lead to dramatic cost savings. Such a flexible light source produced in a roll-to-roll process will be the basis for totally new concepts in the area of lighting and signage. The realization of such lighting solutions would be a milestone in the development of new approaches in lighting.

These technology paths will depend on new deposition, encapsulation, structuring, handling, metrology and inline process and control methods, for use in rapid prototyping centers of manufacturing excellence together with the development of the necessary equipment and processes to support the chain, done in an environmentally sustainable manner.

High-resolution patterning techniques will include, for example, ink-jet, flexographic, offset, and screen printing using inorganic and organic inks, laser patterning, high-resolution mask techniques for vacuum deposition, self-assembly systems, enabling further miniaturization while avoiding complicated and expensive patterning techniques, and thermal transfer of organic and inorganic layers.

Fig. 3.4.19
OLED development facility
© Philips

Finally, to enable high quality manufacturing at even small-scale levels, quality and yield management will need to be employed on a process-by-process basis to bring cost-competitive products to the market in a short time.

3.4.5.4 Displays and Large-Area electronics: a new chance to take the lead

As already stressed, large-area organic and inorganic electronics is emerging as a new area of printable large area electronics with a market potential even beyond displays. Since Korea and Japan have a very strong research base, with about 100 university groups as well as large corporate R&D divisions, regaining leadership in making commodity LCDs and plasma display panels (PDP) in the short term is nearly impossible. However, the standard manufacturing approaches of LCDs and PDPs today highly depend on glass processing.

In contrast, Europe has outstanding capabilities in printing techniques and in flexible displays, i.e. for non-rigid substrates. Europe is leading R&D in organic electronics, and Asia has limited comparable activities in this field so far. Apart from that, Europe is leading environmental R&D and has a track record in product design, which will both be largely affected by novel large-area electronics fabrication technologies and flexible displays.

This could provide a basis for success in opening new display markets, as already recognized in 5th and 6th framework programme projects. The move from sheet processing to roll-to-roll manufacture looks like a viable route for both displays and organic electronics fabrication and opens a manufacturing future not only for big OEMs but also for SMEs.

3.4.6 PRIORITIES AND IMPLEMENTATION OF THE RTD AGENDA

European companies have excelled in making and developing products that are well-designed for use by people, especially when compared with the technology-driven design seen in parts of Asia. Human factors, sustainability and environment protection have always played a higher role in Europe than elsewhere. European RTD in lighting and displays are of high value and need to be strengthened for the next-generation of SSL and smart displays for ambient intelligence.

The European research and development has a strong base in the lighting and SSL area. Europe is characterized by the fact that there is a tight network between universities and companies. The whole value chain starting from the production of the materials required, the light source, and the end product can be found within Europe. Many SMEs have a share in this value chain and it can be expected that their share will increase by the revolutionary new opportunities SSL is offering through the integration of light sources in products where no light was found before.

As a possible route to success, Europe's outstanding capabilities in the field of printed large-area electronics based on organic and inorganic materials can be leveraged. Display systems involving these new technologies coupled with LCD, OLED and other display effects, in parallel with innovative OLED lighting solutions will profit.

Combining its strengths in display technology, large area processing, signal processing, organic systems, and customized electronics, Europe can fully enter the stage of display and large area electronics manufacturing. With its strong electronics and printing industries, with its strong knowledge-base in organic materials, high-resolution patterning and processing of large-area electronics, disruptive manufacturing systems (including roll-to-roll) on flexible substrates, smart displays and concomitant novel applications (e.g. pixelated lighting, photovoltaics, disposable electronics, etc.) could be manufactured right here in Europe.

The great advantage of the approach to combine available know-how is that European core technology would be integrated into end products. Research results and inventions generated in Europe would be integrated into productions manufactured in Europe. This approach directly leads to a maximum exploitation of research and technology efforts.

...to strengthen the display and lighting landscape in Europe

The display RTD and industry is meeting increasingly tough competition from outside Europe. The buildup of strong clusters has helped Europeans to strengthen their position internationally and even create unique selling points. However, the enhancement of local production of displays through disruptive manufacturing methodologies and novel display systems will help overcome the risk in this area. The move into viable products will be the crucial point for competitiveness in the large area electronics field. The latter will of course also benefit significantly from local production.

Therefore, in order to stimulate such production activities in Europe, RTD has to put a much stronger focus on application driven research beyond demonstrator level.

In addition, state-of-the-art equipment and materials are increasingly crucial for the development of electronics products. This is especially true for SSL, smart displays and organic electronics, since low-cost fabrication will only be possible through world-class engineering and design. All of the issues in the value and supply chains will need to be addressed with close cooperation and participation between users and suppliers of equipment and materials if high performance and concurrent cost reduction are to be achieved. Today, only strategic partnerships are yielding productive solutions.

Existing infrastructures do not always meet the requirements of the industry, especially of SMEs. Technology platforms, where users and suppliers are working together, "open laboratories" with easy access for industry could effectively contribute to a precompetitively mature manufacturing technology.

Europe still has a very strong intellectual leadership in aspects of displays technology through a variety of expertise centres and commercial ventures. This is a fragile position that, despite supporting global leadership in companies such as Merck, Philips, ST Micro and others, is being eroded as the Asian houses consolidate their actions and build competitive advantage in internal supply chain development actions. Similarly in lighting, Philips and Siemens OSRAM have an excellent global position and brand, but it is extremely vulnerable to competitive pressure from the emergent Chinese market place. To sustain and nurture these strong businesses and opportunities and to build for future growth it is vital that the EU support this sector through a variety of actions. The creation of an RTD within the Framework VII actions is a very significant part of the support necessary to sustain European competitivenes.

Research topic	Technical objectives	Applications	Socio-economic relevance
Short term (1-3 years)			
Materials with increased chemical and mechanical stability, lifetime, higher efficiency and quality of light for OLEDs	Blue phosphorescence emitter for OLEDs, novel hole and electron transport materials	Full Colour Displays; OLEDs for general Lighting	The European strong position in the lighting market and the display supplier industry can be strengthened
Materials research for LED applications	Increasing the internal efficiency to 80%; alternative substrates with low defect density (e.g. GaN, AlN, ZnO), white colour converters for inorganic LEDs with CRI >80, efficient green and yellow emitting devices, alternative emitting materials (e.g. nanocomposites, quantum dots), alternative converters (e.g. nanophosphors, organic dyes, quantum dots), narrow bandwidth phosphors	Automotive headlamps, General lighting, display backlighting	The European strong position in the lighting market and the display supplier industry can be strengthened
Materials required for advancing technology in low-cost flexible substrates and large area processing	Thin film encapsulation for flexible displays and light sources; low-cost flexible substrates; improved light extraction from thin film devices	OLEDs for general lighting, novel lighting applications and displays	Competitiveness to Asian producers of OLED devices in terms of productivity and yield
Highly integrated and efficient RGB laser light source with Wall plug efficiency > 40%	RGB direct emitting lasers, frequency converted lasers, ultra compact devices	Laser projection, projection TV, Laser head-up-display	Europe's strong position in the laser market is strengthened
Packaging technologies for LEDs and lasers	Substrates with improved heat spreading properties, novel engineering technologies (wafer bonding, nanostructuring…), integrated first-level optics, advanced thermal management	LEDs for General Lighting, projection applications Compact laser sources for projection applications, IR lasers for night vision	The European strong position in the lighting market and the display supplier industry can be strengthened
Tailored light – photon management; concepts and components for generation and spatial/temporal control of light 1) LED device design 2) LED & laser light sources for general lighting, 3) amplitude and phase modulators & scanner-devices 4) 2D & 3D display systems 5) device architectures, control systems (drivers, power…) and data processing required for large area (flexible) light sources and displays,	Device modelling; designs for improved light extraction efficiency (>80%), high-flux devices with high current density, high luminance devices, directionally emitting devices (resonant devices, photonic-bandgap structures), long-life devices, advanced (micro- and nano-)optics; advanced thermal management; advanced hybrid (wafer level scale) integration; video processing; intelligent colour management; integration of logic, sensors and power supply	LEDs for general lighting, automotive, projection applications, display backlighting OLED-devices, Compact laser sources for visualisation and illumination, Full colour OLED displays	The technological position of the European photonics industries is strengthened and leads to better and more internationally competitive products, small and medium sized enterprises can contribute strongly

Research topic	Technical objectives	Applications	Socio-economic relevance
Mid term (4-7 years)			
Large-area processing and novel manufacturing techniques	Development of the necessary equipment and processes, In-Line Process Diagnostics & Control, In-Line Test Methodology, Hi Speed/Large Area Manufacturing (e.g. R2R, R2S..), Low cost Patterning Technique (high resolution patterning and printing)	Large scale OLEDs for Lighting and displays	Competitiveness to Asian producers of OLED devices in terms of productivity and yield
Human factors research to improve end-user interactivity, perception and design of novel displays and light sources	3 D displays effects; colour perception (colour rendering); human acceptability factors and comfort; biological impact, safety and workplace productivity of lighting and displays; intelligent user interface for displays and lighting systems	Light sources for general lighting; Novel full colour display devices	Human well-being by atmosphere creation or interaction of light and health; Life quality by access to information via intelligent interfaces
Ultraefficient light source with environmental benign material and a lifetime > 50 000hrs: 150 lm/W mercury free lamp	Molecular lamps; (O)LED lighting systems, HID	Lamps for general lighting application	Energy savings and sustainability; less waste and pollution

Long term (8-10 years)			
Ambient intelligence, novel display effects	Novel lighting and display concepts; Electrowetting, Electrophoretic, Electrochromic, Integration of light sources and displays into an intelligent environment	Flexible displays, Full Colour display devices, Miniaturized light sources	New quality in human communication with technological environments
Organic Optoelectronics – synergies in lighting, display and backplane lead to integrated organic devices	Ultra-large-area processing, reliable organic electronics	Flexible, large organic sheets with both lighting and display functionality as well as electronics	New quality of lighting and information visualization

3.5 Security, Metrology and Sensors

3.5.1 MARKET OVERVIEW

3.5.1.1 Biomedical, environment and chemistry

The global pharmaceutical industry is one of the most important and fastest growing sectors of the worldwide economy. Its size exceeds $400b [1], and the revenues on tools used to develop pharmaceuticals and to deliver health care are estimated to be about $180b in 2004 [2]. Photonics is a key enabling technology for this **bioinstrumentation** market, providing high-sensitivity detection techniques for drug testing and development, biomedical diagnosis and therapy, food screening, environmental testing, emergency services and homeland security.
Today, **medical applications** of bioinstrumentation solutions are focused on diagnosis and therapies such as photodynamic therapy (PDT) or minimal invasive surgery in hospitals and central laboratories; in the long term, some of these tools will also be available as point-of-care services, thanks to the foreseen progress of photonics in miniaturizing these devices and significantly lowering their cost: Few doubt that the future belongs to the disposable lab-on-a-chip, whose detection mechanism is based on a highly sensitive photonic micro-system; in the medium term, the progressive introduction of new technologies, mainly optical sources and detectors, will enable considerable progress in the performances of therapy and diagnosis techniques, such as Optical Coherence Tomography (OCT) or UV fluorescence techniques, contributing therefore to a substantial improvement of medical care.

Pharmaceutical applications of bioinstrumentation focus on genomics (mapping of the genome of humans, animals and plants), on proteomics (mapping of proteins) and on drug discovery (automated systems that detect molecular responses to drugs). The pharmaceutical industry spends an average of $800m in direct costs to develop each new drug, typically requiring an R&D effort of 5-8 years, while less than one in three returns justifies the direct R&D costs [1]. For this reason, the biomedical and pharmaceutical industries are highly interested in new tools, to accelerate the structure determination of target proteins, to reduce the cost of identifying new drugs, to screen them, to test them for protein interactions, to reduce the cost and time of clinical validation, and to reduce the cost of diagnosis and therapy employing the approved new drugs. Therefore, the market for screening and detecting techniques used in the fields of pharmaceutics, biomedical diagnostics and life sciences is currently growing quite fast, at a Compound Annual Growth Rate (CAGR) of 20%, with an estimated size of $2.0b in 2004. The cornerstone of most of these instruments is a photonic detection mechanism, as detailed below.

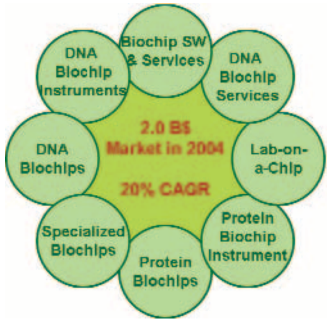


Fig. 3.5.1
Market for Bioinstrumentation and Services
© Callidosens

The two most important areas of this field are biochips and readout instrumentation for DNA analysis and for protein analysis. While the market of DNA analysis is more established, with a size of $500m and a CAGR of 15% in 2005 [3], protein analysis biochips and instrumentation grow at a much faster CAGR of 28%, with a size of over $250m in 2005 [4].
The total **biochip market** in the United States has a size of $436m, and it is growing at a CAGR of 20% [5]. The total biochip market in Europe, however, had only a size of $127m but it is growing at an increased CAGR of 25%, with a share of DNA analysis biochips of 90% that is expected to drop sharply in favour of the fast-growing protein analysis sector [6].

It is obvious, therefore, that Europe is still lagging behind significantly in the use of biochips and instrumentation, and it is concluded that the European **pharmaceutical, biomedical diagnostics and life science** companies urgently need to improve their processes in order to remain competitive; the best way to achieve this appears to be leapfrogging the international competition by developing and offering faster, cheaper and more versatile analysis biochips and instrumentation. This in turn, requires the development of new technological approaches, based on new generations of improved and optimized photonic detection technologies.

Apart from the larger and more homogeneous biomedical markets, additional opportunities for detector systems exist in **environmental and food sensing**. According to reference [7], the major markets today are in atmospheric and marine environmental sensing, vehicular emission control and testing, air pollutant control such as VOC (volatile organic compounds), ultra-fine particles and in soil and water pollution control. Niche markets include radon testing, earthquake monitoring and home safety (e.g. smoke and CO alarms). Although the size of the largest of these niche markets, imaging for environmental remote sensing, is estimated to be $1.1b [8], only a small fraction of this market is actually in photonic instrumentation.

Impact and relevance of photonics
The market analysis on biochemical and environmental sensors presented above is a clear confirmation of the well-known fact that photonics is an **enabling technology**. According to the different market studies consulted, the direct worldwide market of photonic components and systems in the domain of biochemical and environment sensing counts for few billion US dollars. The markets that are directly affected by the availability of these photonic sensing systems, however, are much larger, easily surpassing $500m and typically growing at a larger rate than the world economy. This is due to the increasing importance of life sciences, pharmaceutics, medical diagnosis and therapy, as well as a developing awareness of environmental issues such as healthy food, clean water and unpolluted air.

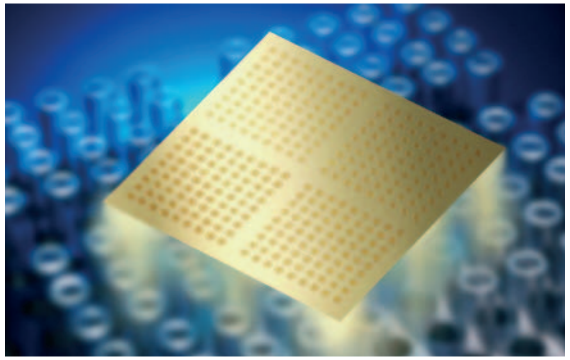


Fig. 3.5.2
Genomics (DNA analysis) and Proteomics (protein structure analysis) make extensive use of large arrays of sensing pads (bio-chips) that are read out optically
© CSEM

The reason for the **key role played by photonics** in most of the biochemical and environmental sensing domain is rooted in the many diverse ways in which light can interact with chemical compounds: Molecules can be recognized by their spectral signature ("colour") using appropriate optical spectroscopic equipment; molecules that attach themselves to binding sites on specially prepared surfaces change the effective refractive index sensed by light travelling close to this surface, which can be detected with high sensitivity, for example by grating coupler structures on biochips; individual molecules can be tagged with fluorophores, dye molecules that react to the irradiation of light with the emission of light at a different wavelength. Fluorescent microscopy, confocal methods, light scattering and imaging spectroscopy techniques have become cornerstone tools of biomedical analysis [9], because of their very high sen-sitivity (individual molecules can be detected), the high specificity attainable with custom fluorophores, the possibility to mark different sites on a macromolecule, the ease of use and the affordable price. Among these techniques, it should be outlined that spectroscopic measurements in the infrared region (2-12µm) are extremely powerful tools to detect the presence of pollutants at sub ppb concentrations with very low false alarm rates. (For further information on Photonics in Life Sciences and Health Care, see also chapter 3.3)

3.5.1.2 Process and quality control

European manufacturing industry is under strong pressure from many different economical, social and market factors: high labour cost, lack of flexibility, low efficiency for high customized production, high cost of technology acquisition and integration, ecological cost and impact, difficulties to adapt the production to the uncertainty of a high competitive global market.

Flexible production requires a continuous information feedback from the process in order to guarantee high production quality, process stability and cost optimization. Sensors are required to enable information gathering both from processes and products, enabling continuous management and guiding of the processes and quick reconfiguration of the tools and methods.

Nevertheless, effective reconfigurable and flexible production requires establishing a completely new paradigm based in virtualisation of both the processes and the products. Radical improvement is only possible if we are able to transform the physical world into a virtual universe of digital information, opening the door to knowledge based manufacturing.

Optical sensor technology is the fastest growing technology for industrial manufacturing, as a result of its flexibility, ease of use, high speed, accuracy, feasibility and capability for integration in high performance automated inspection systems. The engineers have a broad catalogue of different optical sensors to measure physical and chemical quantities, such as machine vision, 1D to 3D metrology, position location, optical tomography, photoacoustics, laser ultrasound, laser spectroscopy, X-ray imaging, infrared thermography, industrial tomography, temperature measurement, pressure measurement, colour measurement, and many other types of applications.

The current progress in semiconductor optoelectronics, laser diodes, fast photodetectors, optical modulators, MEMS and MOEMS technology, micro-electronics development and optical manufacturing technology opens new and improved perspectives for optical sensors and measuring systems, which integrate several components in order to achieve new functionalities.

Fig. 3.5.3
Analysis of air and fuel flows within ducting components through optical laser methods
© Bosch

Fig. 3.5.4
Quality control with white light LED detectors
© Siemens

Optical sensors will open a new era for online inspection of production processes giving access to high potentials of increase of productivity and quality.

Miniaturization of sensors, micro-optical systems
A global microsystems market of EUR 40 billion growing at 20% per annum and a European market of EUR 550 billion for products containing them clearly demonstrate that microsystems are important for Europe's industrial and economic future. Micro-manufacturing is now a key value-adding element for many sectors of industry – and the predicted nanotechnology future will also be largely delivered by micro-technologies. The silicon-based microelectronics revolution of the late 20th century is about to be overtaken in its scope; micro- and nano-manufacturing technologies (MNT) in the 21st century need to be directed to making use of a variety of materials, components and knowledge-based technologies that provide functionality and intelligence to highly miniaturised systems for personal, portable and wireless products, and sensors for health, environment and transport-related applications. MNT will impact society and lifestyles in an unprecedented way; the economic consequences will be dramatic – both for those who have the technology and for those who do not. It will allow the creation of products, which because of their minute size and potential ubiquity, will create new pressures for individual citizens, companies, governments and international agencies.

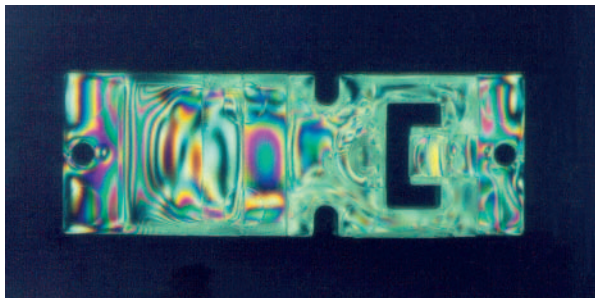


Fig. 3.5.5
Mechanical stress analysis of complicated objects can be carried out by employing the optical birefringence of polymers, showing up as color patterns
© CSEM

Intelligent optics: Digital holography
The combination of micro-optics, coherent sources and high definition sensors allow for new architectures of imagery; software reconstructed digital holography is a major tool for non-destructive testing, secured manufacturing and security checking. For instance, synthetic aperture techniques allow for accurate comparison of scene images taken at different times, revealing tiny displacements, distortions etc…

Data storage
The data storage market is driven by different factors. One of them is the demand to increase the storage capacity and to decrease the costs. While the primary today's end market for hard disk drives are computers, optical drives are used for both computers and consumer electronic devices like video recorders and even mobile phones. It is expected that by 2010 the primary end market for all digital data storage devices will be consumer electronics. The growth in the consumption of content storage by consumer electronic devices is expected to create the greater overall demand. The hard disk drives market is expected to reach $350b by 2010.

As a result, the density growth of data storage devices will continue. The size of a bit will become smaller resulting in new requirements for micro-mechanical and optical elements for storage and retrieval of the digital information. These elements also will need to be closer to the surface of the storage media.
When the disk in a hard disk drive starts spinning, a thin air cushion is created between the disk surface and the Air Bearing Surface (ABS) of the slider facing the disk. The aerodynamic property of the ABS allows the slider to fly above the disk surface and make a slight angle with the disk level. The recording head, located at the trailing edge of the slider is separated from the disk surface by the fly height (FHT). The FHT is actually in the 20nm range. To achieve area densities above 100 Gbits/inch^2 this value has to be reduced to below 10nm which requires an actuation with sub-nanometer precision.

The development of **optical** test and measurement equipment for the data storage industry is therefore mandatory. As nano-domain manufacturing not only takes place in the data storage industry, developments for this market will also be fruitful for other areas. 'Functional surfaces' like the ABS surface of a slider also exist in other areas like automotive. Structures with sizes below 1 µm are created to ensure lubrication in automotive engines. Surfaces with an even higher precision are needed for injection valves. MEMS are not only used for slider/actuator control, they are also used in cars to control driving parameters.

A report published by the Commission in April 2003 concludes: new paradigms of production and consumption will set the agenda for sustainable manufacturing to 2020. In this agenda the introduction of new processing technologies for new materials and the manufacturing of miniaturised products designed with an intelligent multi-material-mix will become a top priority.
The 4M Network of Excellence in Multi-Material Micro Manufacture seeks to establish a European Virtual Centre that integrates partner facilities and R&D programmes with total values exceeding EUR 100m and EUR 63m, respectively. The Network aims to co-ordinate research into major open research issues in the field of EUR 4m, to engage European industry in collaborative research, and to spread knowledge of this developing technology.

3.5.1.3 Security and safety

Typical examples of applications of photonics related to safety are in transport: continuous monitoring in cars, independently of the weather conditions, to reduce the risk of accidents, and to enable safer driving after dark.
Accident statistics show that driving at night represents a significant potential danger. In the U.S. alone, some 55% of fatal car accidents happen at night, although an average of 72% of all driving is done during day. And according to estimates approx. 560,000 people are injured in the dark in Europe and some 23,000 are killed.

Some car manufacturers have started to equip their luxury models with night vision system, e.g. Honda with its Intelligent Night Vision System, which uses "far infrared" cameras to detect pedestrians in or approaching the vehicle's path and provides the driver visual and audio cautions in order to prevent accidents involving pedestrians. The new system was planned to be made available on the Honda Legend. European car manufacturers are also investing in that domain.

Applications are also envisioned in the field of security: light, compact and highly performing detectors will enable an efficient monitoring of environmental risks and surveillance of borders, as well as weather conditions and amount of traffic. The emerging laser technology is already enabling the improvement of passenger security for example via real-time measurement of road friction and other parameters effecting driver safety. EU based companies are on the leading edge of this work, e.g. stand-off/remote detection systems for biological agents (the "dirty dozen"), explosives, small arms, mines, drugs and diseases with optical readout or compact multi sensor surveillance platforms for autonomous unmanned vehicles (air, ground, water, underwater).
This is also increasingly important to perform the monitoring of public spaces, such as railway stations and airports. In these areas, optical measuring methods and photo-detectors will be embedded into complex systems for image recognition/interpretation, crowd control, motion detection, gesture analysis and detection of energetic or hazardous materials. Intelligent access control will be guaranteed by a redundant combination of biometric sensors and video systems.

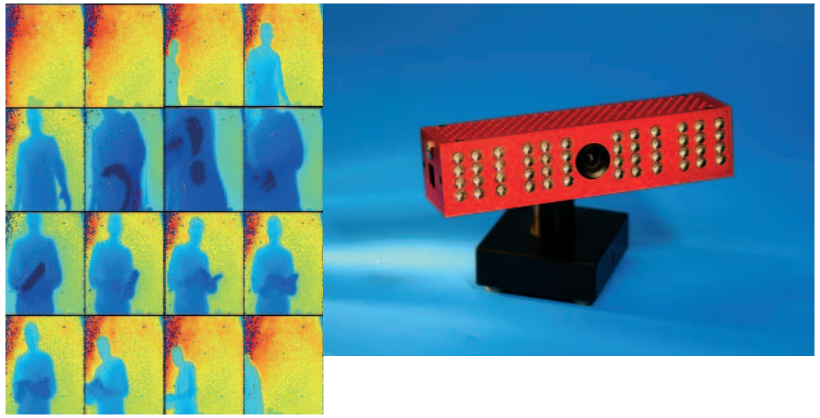


Fig. 3.5.6 Left: A few scenes out of a 3D movie acquired with an optical time-of-flight range camera. The distance images are color-encoded (dark blue = 10 cm; red = 750 cm); right: Miniaturized optical time-of-flight range camera with millimeter resolution, based on a custom CCD/CMOS image sensor with smart pixels © CSEM

The massive efforts taken in the US in the field of imaging systems for safety and security require a European-scale strategy to ensure competitiveness in the long term: until recently, US strategy consisted in gaining a technical advance, then in defining standards in accordance with the advance, and finally in manipulating export restrictions for commercial purposes. In cases where no advance versus e.g. Europe was achievable, then the strategy consisted in using European technologies to fill in the gap, and then to impose import restrictions when the gap was filled. The major consequences have been:

– Loss of sovereignty in institutional markets;
– Loss of commercial market shares.

Today, to avoid re-experiencing the same difficulty, the strategic answer at European scale should consist in securing a technical leadership, to be able to promote/discuss standards, but also to reduce the effect of vulnerability induced by fragmentation. Therefore, European detection industry must be able to make profits in security business by having at its disposal critical technologies, and by being able to protect them. Today, in most high-end applications, noise level rather than detector efficiency is still a limiting factor. If noise can be reduced, it could impact many areas particularly where detectors need to be cooled to about -20C. Standard photonics approaches have not succeeded in tackling this challenge. Therefore, it is strategically important for Europe to find an appropriate technical answer. Reaching such values will enable, in the long term, to market highly competitive photo detectors, likely to gain significant market shares of the rapidly growing from $7 billion worth video surveillance market to $13 billion within 5 years.

3.5.1.4 Transport, space and aeronautics

The increasing availability of electronic and informatics on cars, aircrafts, ships, etc. bodes well further usage of sensors in order to have a complete control of transport media. Almost everything can be sensed, and optical sensors can be the only viable solution in those cases in which there are problems of electromagnetic compatibility, fire or explosion hazard, etc. or where low invasiveness is required. It has also to be recognised that optics is not the best solution for everything, and sometimes it is not cost-effective, so integration with non-optics techniques thereby creating a complete, integrated and broad-spectrum sensing system/network should be envisaged. Moreover, data processing of the obtained data is a fundamental part in developing sensor systems: the key elements that have confronted in discussing sensors are applications, technologies and data processing. Use of sensors should not be limited to detection of events, but also include diagnosis and prognosis, so mathematical processes need to be developed alongside the sensors. The prognosis could be of particular interest in space and aviation, to foresee when to change some important parts of particularly critical mission in order to prevent accidents.

Fig. 3.5.7
Pedestrian and traffic perception by a laser scanner in a vehicle
© IBEO

Where applicable, it has to be considered that a huge quantity of optical fibres is installed along highways and railroads, and that a single fibre could be simultaneously used for both sensing and information transportation re-utilizing existing infrastructures.

Focuszing on sensors only will not be sufficient. For the same reasons for which in certain fields optical sensors can be an ultimate solution (absence of electronics near the place to be sensed or electromagnetic immunity), then also optical actuators could be necessary (for example, using the black-body absorption principle and thus having opto-pneumatic, acousto-pneumatic or opto-acoustic actuators: it could be possible for example to drive valves in the engine of a car).

Currently, Europe is very active in the automotive sector, especially relating to high-class cars, while there is no evidence of a strong research in optical sensors in the transportation field: the sector is mainly active in other technologies, while the strong optical background could be significant in re-utilizing competences and optical systems and components producers.
Research activities should lead to the definition of new applications, to be fulfilled with new or well-known technologies.

Upcoming technologies and applications
We believe that for applications described hereafter, the development of sensors networks and new network architectures should be a matter of significant interest.

Vehicles structures
Many sensors could be used for monitoring the structures of the vehicles, for example stress sensors (e.g. monitoring the forces on shock absorbers) pedestrian security/impact sensors (activating minimum-damage procedures), chemical sensors (monitoring gasoline level and detecting gases leakages in particular for future hydrogen or methane vehicles), occupancy sensors (for cars in order to activate safety belts, for public transportation to monitor correct occupancy and to activate ticketing activities.)

Transportation aids and security
Transportation security could be the real driver for the development of sensors, for example for safe driving in dark or foggy environment, traffic management (to obtain real-time statistics about traffic entity and to perform corrections such as variable speed limits, limited access to highways, etc.), 3D velocity and/or position detection, gyrometers (particularly useful for watercrafts), multi-spectral aided view systems with image fusion (recognition of obstacles in case of poor visibility, e.g. dense fog), safety in galleries (accidents, fires, explosions, gases, etc.).

Transportation structures monitoring
Since the structures involved in terrestrial transportation are subject to aging and stresses due to traffic, monitoring of their conditions could be of interest, for example structural sensors (for sensitive structures such as bridges and galleries or for railways) or pave condition sensors (to monitor conditions of pave in case of atmospheric events or aging) could be needed.

Air/spatial applications
For air operations, security is already a main concern; civil aircraft are still vulnerable to terrorist attacks (on-board attack or missile attack). A single attack may result in a durable slow-down of the air traffic, which would have a catastrophic effect on the airlines, aeronautics business and therefore on the global economy. Photonics can address these concerns through different kind of equipments: spectroscopy for explosive detections, mid-infrared detectors and sources for missile detection and deceiving equipment.
In air/spatial applications, prognosis can be more important than diagnosis, in order to foresee when a particularly critical part of the craft (wings for example) should be substituted before breaking, in order to prevent from disasters. Data processing is a fundamental part of this topic. It could also be very important to develop accelerometers (in order to measure gravity or acceleration forces) or atmospheric pressure sensors as well: information or multi-wavelength or some other techniques could only allow for one sensor for measuring multiple phenomena.

Possible technologies

A lot of technologies are available today for producing optical sensors, hereafter a list of the ones that could be of interest for the described applications, some for further investigation, some others for further development/industrialization:
– Integrated optics
– M(O)EMS
– Quantum Cascade Lasers (QCL)
– Photonic band gap devices
– 3-D integrated optical circuits
– Non-TLC lasers, fiber lasers
– Micro-optics and silicon optical bench
– Holey-fibers
– CCD, CMOS, APD (with embedded image processing)
– Infrared detectors (uncooled IR sensors)
– Low cost infrared optics
– Monolithically integrated multi-junction lasers

Up to now, apart from a few sectors, Europe can not be considered a world leader in these technologies, however, it could be the most important consumer.

Market view for air transport security

– Explosive detectors for passengers/luggage screening in airports: by year 2015, the total number of detectors could amount to some tens of thousands tens of (very large airports would need more that 100 pieces), with a unit price between EUR 5 and 100 k, depending on the type of equipment (multiple sensor with data-fusion or single sensor, hand-held or portal); the corresponding market, only for airports, should range well over one billion Euros.
– Mid-infrared airborne anti-missile airborne equipment: in 2015, the total world fleet will amount to about 16,500 civil aircraft (with 100 seats or more); the price of the antimissile equipment will be about EUR 500k, the corresponding market could be worth EUR 8.25 billion; the operation of such equipment will also generate important revenues for its maintenance.

3.5.1.5 Multimedia

Photo-detection is exploited for general public applications in almost all areas of modern society (e.g. digital cameras, video camera, web cam, scanner, ...). Today, imaging systems are part of our everyday life. Camera integrated in mobile phone is no longer an option but a standard feature. Web cam is now a basic option for PC which allows for videophone communication. Likewise, scanners formerly used in professional environment enter home. Therefore, photo-detection has become a key market and a key application sector of photonics, where significant performance improvement can still be achieved in terms of noise detection.

Indeed, up to now the competition has been about more and more pixels. It was a first market response for an ever better image quality demand. But high pixel numbers alone do not implicate good image quality as sensors have reached 5 or 6 mega-pixel. And particularly if the device is small as a camera phone with no place for high aperture optics. This leads to noisy pictures and poor quality.

Next generation camera should improve this situation and bring at the same time new features. By reducing the noise, sensors which work under low light level conditions without the need of a flash could be feasible. The image generation processing by means of standard electronics with embedded software could also be speeded up if part of its time consuming functionality was implemented directly to the sensor. This will solve the problem of time-delayed release well-known by digital camera users when the selected number of pixel is increased.

In scanner and fax applications, there is a need for linear detectors. Scanner with CIS (contact image sensors) gather light from red, green and blue LEDs (which combine to provide white light) and direct the light at the original document being scanned. The light that is reflected from the original is gathered by a lens and directed at an image sensor array that rests just under the document being scanned. The sensor then records the images according to the intensity of light that hits the sensor. An improvement could come from the integration on the same substrate of light emiting diodes (LEDS) and sensors with pre-processing function. The image scanning should be speeded up and the component cost reduced.

Line CCDs with optics are also used in scanners. This technology could evolve toward new generation CMOS with improved performance and embedded image pre-processing.

Studies show that camera phone market is undergoing very high growth rates to the detriment of low-end digital camera market. Gartner [12] has estimated that camera phone sales have reached 295,5 million units in 2005 for a total of 812 millions, 14% more compared to 2004. For comparison, digital camera worldwide sales reached 55 million units in 2004. Camera phones count for 38% of total phone sales, 55% in Western Europe, 47% in the USA and 92% in Japan. In the coming year, the ratio will increase in favor of camera phones: 742 millions units on a total of 1095 millions in 2009.

On sensor market side, CMOS used in CCDs for general public applications because of their low cost and increasing performance are mainly produced in US and Asia. Few suppliers stay in Europe, the main one being STMicroElectronic.

The general public market in 2004 for scanner and fax machines for Western Europe reached 16 million units in 2005 with a forecast of 20 million units in 2008. Worldwide sales are 4 times higher. Only two scanner and fax manufacturers have stayed in Europe, Sagem Communication and Olivetti but there is no sensor supplier. These components are mainly produced in Japan (Canon, Rohm) or Taiwan (Lite-On, CSI). European industry in that area needs to be strengthened through at least patent registration. (For further information, please see chapters 3.1, 3.4, 3.5

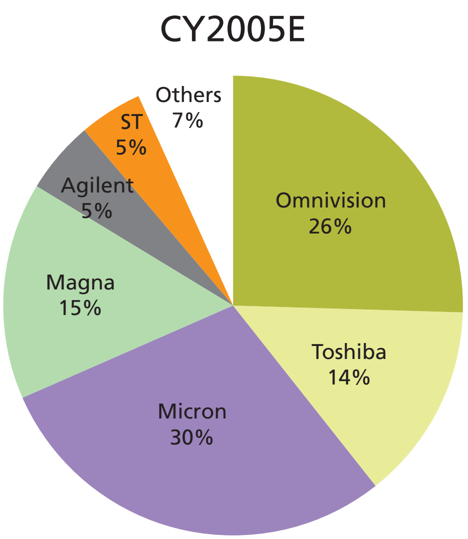


Fig. 3.5.8
Sensor market is dominated by companies from USA and Asia

3.5.2 RESEARCH PRIORITIES

3.5.2.1 High sensitivity image sensors

Imaging sensors are widely used in domains where measurement and control are required, ranging from medical applications to manufacturing control and surveillance. Most sensors used for high-end applications are ILCCD, EMCCD, EBCMOS. They exhibit good performances in term of sensitivity but do so at the expense of high cost. These devices are typically used in high level imaging for physics, astronomy, bio-medical or military applications. There is a demand for the same performances, but at a lower cost, which could be reached for uncooled solid state sensors like CMOS sensors used at present in general public applications.

Recent advances in solid-state low-noise image sensing, even based on commercially available CMOS processes, make it possible to realize image sensors with mega-pixel resolution, and a high sensitivity approaching the ultimate single-photon quantum noise limit [10]. Such single-photon imagers will shortly replace vacuum devices such as micro-channel plates (MCPs) and they are the basis for the development of true mass-market photonic systems operating at the limits imposed by nature.

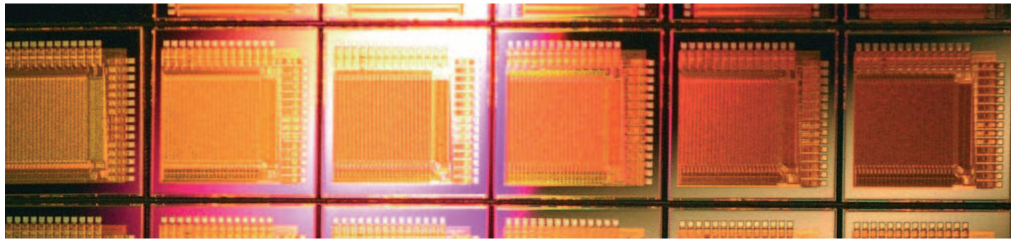


Fig. 3.5.9 Today's high-performance CIS (CMOS Image Sensor) technology is the basis for a large range of custom functionality image sensors © CSEM

Another promising way to improve sensitivity could be to exploit plasmon phenomenon. Plasmons are created in detectors embedding metallic nanostructures at the semi-conductor surface. Enhancing the matter-light interaction, the quantum efficiency is improved. This allows reducing active surface and volume keeping the same responsivity but reducing thermal noise thus increasing sensitivity.
It must be pointed out that plasmons may be used also to enhance electrical to optical energy conversion in inorganic LEDs and offer further potential applications in numerous other areas. The European research community is the world leader in almost every area of plasmonic research. Nevertheless, the US has started several large programs to push plasmonic photonics and in Asia companies like NEC or SAMSUNG have started to become very active in the field.

3.5.2.2 Extended wavelength image sensors

Photonic tools use various passive or active wavelength sources to light up objects or induce plasma or photoreaction, fluorescence, spontaneous and stimulated emission. This leads to the need for sensors which are sensitive to wavelengths beyond the visible domain toward UV or IR and multi-spectral fused sensors for different wavelength bands (UV, VIS, near IR, short-wave IR, mid-wave IR and long-wave IR).

In recent years extensive efforts have been deployed in the development of infrared (IR) imaging, both for cooled and uncooled detectors:
– uncooled detectors will be used for all applications where a detectivity of a few 109 cm (Hz)1/2/W is suitable; they will be always cheaper than cooled detectors, but this detectivity value cannot be overcome due to physical limits linked to the fact that they work at ambient temperature;
– cooled detectors which offer a detectivity 100 times higher, will be used in all applications where uncooled detectors are not able to reach the specifications and where a higher price remains acceptable.

Therefore, these two technologies will be developed in parallel for complementary applications.

Uncooled detectors
Advanced uncooled cameras using photon detectors would significantly impact civilian applications of thermal imaging such as medical imaging, automotive motion sensing, night or fog vision, pollution control and fast sparks and hot points detection in electronic circuits.
MEMS have enabled a first revolutionary breed of uncooled cameras. Quantum photonics can enable a second breed of faster and higher performance uncooled IR cameras.
Further R&D effort should be undertaken to use quantum photonic materials to demonstrate high definition fast and affordable IR imaging at room temperature (RT) or near RT (250K), by developing a new generation of uncooled photon detectors providing enhanced capabilities with low maintenance cost, reduced power consumption, and easy disposal.
Uncooled detectors should operate at 1,5 µm and in the 3-5 µm and 8-12 µm wavelength regions and should demonstrate high temperature operation (T > 250K), high operability (99%), high detectivity (D* > 5x1010 cm[Hz]1/2/W), fast response times with a small noise equivalent differential temperature (NEDT < 50mK) in photon detector focal plane arrays (FPAs). Advanced semiconductor material systems could be used (strained InGaAs/AlAs, InAs/GaSb and InAs/GaAs) to create nominally uncooled and bicolor QWIPs, superlattice and quantum dot photodetectors.
This new technology should lead to the manufacturing of uncooled efficient infrared cameras, addressing applications where microbolometers are lacking, and thereby open the market to civilian and high volume applications until now restricted to military and space niches.
However, IR quantum detector should be available in the long term. But now commercial markets already exist for low cost sensors. IR detectors like microbolometers are still an order of magnitude too expensive. Significant cost reductions could be achieved via research for further integration and miniaturization for example on wafer level packaging and wafer level bonding.

Cooled detectors
Cooled detectors will cover needs which cannot be addressed by the uncooled technology, e.g. when a detectivity higher than of a few 109 cm(Hz)1/2/W, or specific performance (high resolution, bi-spectral) are required.
Europe has acquired a very strong position on QWIP technology and may build on this basis an independent supply chain of high performance IR detectors / cameras, which will provide unique capabilities, such as:
– detectivity of a few 1011 cm(Hz)1/2/W
– more than 1 megapixel resolution at 3-5 µm and 8-12 µm
– bi-spectral
– polarimetric
– detection beyond 12 µm, up to 15-18 µm
Targeted applications: medical imaging, meteorology and environment.

UV sensors

UV imaging is traditionally obtained from silicon photodetectors. This is an excellent detector in the near infrared (below 1.1 µm) and in the visible in terms of linearity and sensitivity. With a modified technology, it also provides a very decent performance in the UV. Silicon detectors (e.g. CCDs, or CMOS-APS) are very sensitive at visible wavelengths. Moreover, EMCCD can provide photon-counting measurement. While a good performance is obtained in the near UV, the following problems need to be addressed:

- In order to reduce the dark current which is unavoidable in a small band gap material, CCD has to be cooled in order to yield a better performance.
- Secondly, silicon detectors are sensitive to the whole range of energy between the UV and the near IR. When a large visible light background is present (daylight or artificial illumination), the detection of a small UV signal becomes extremely difficult without any additional spectral filters.

Another approach consists in using photocathodes associated with multi channel plates. They offer a high sensitivity and in particular a possible partial rejection of the visible light by a proper choice of the cathode metal. But this spectral selectivity is moderate: they require solar blind filters based on interference filters with a low angular tolerance. However, they need a high voltage, need to be vacuum sealed and are thus quite bulky and fragile. They are also prone to blooming.

In general, these conversions from existing technology (silicon or photocathodes) have many disadvantages: they are complex, expensive, many of them are inherently unstable, and may distort the image without additional optical correction. More importantly, the conversion reduces the efficiency, compared to a direct detection within the sensor.

Therefore, semiconductors with a larger bandgap (and thus insensitive to the visible or near UV) appears to be a solution.

- Diamond is interesting for deep UV observations, in particular for astronomy, but its bandgap energy is too large for many applications; moreover, material growth will remain a bottleneck in the foreseeable future.
- GaN and its AlGaN alloy is a credible solution for detection from 3.5 to 6.2 eV. GaN and AlGaN alloys are direct band gap semiconductors, and provide a sharp absorption edge, which is a key issue for spectrally selective detectors. Compared to Si, another advantage of the nitrides is the larger band gap and the very small dark current (virtually zero in a perfect GaN) at room temperature or above. Hence no cooling system is required. Photon counting was even demonstrated in a GaN detector. Moreover, this kind of materials may be used as photocathodes in order to increase the rejection of visible light.

The development of GaN and AlGaN alloys detectors, as an enabling technology, would provide Europe with a leader position in many applications, such as:
- Biology: largest contrast is obtained around 260nm for DNA and 280nm for proteins,
- Security: missile threat warning, UV search and track, fire, flame detection, UV spectroscopy of gas on electric discharges and of plasma in reactors),
- Environmental monitoring: pollution, toxic gas detection, flame monitoring in aircraft engine, burners monitoring in gas turbines)
- Space applications.

3.5.2.3 Function integration

Optical sensor technology is the fastest growing technology for several industries, as a result of its flexibility, easy-to-use, high speed, accuracy and feasibility. Engineers have a broad catalogue of different optical sensors for machine vision, 3D metrology, position location, optical tomography, photo-acoustics, X-ray imaging, industrial tomography, temperature measurement, pressure measurement, colour measurement, and many other types of applications.

The current progress in semiconductor optoelectronics, MOEMS technology, micro-electronics development and optical manufacturing technology opens new and improved perspectives for optical sensors, integrating several components in order to achieve new functionalities and increase added value.

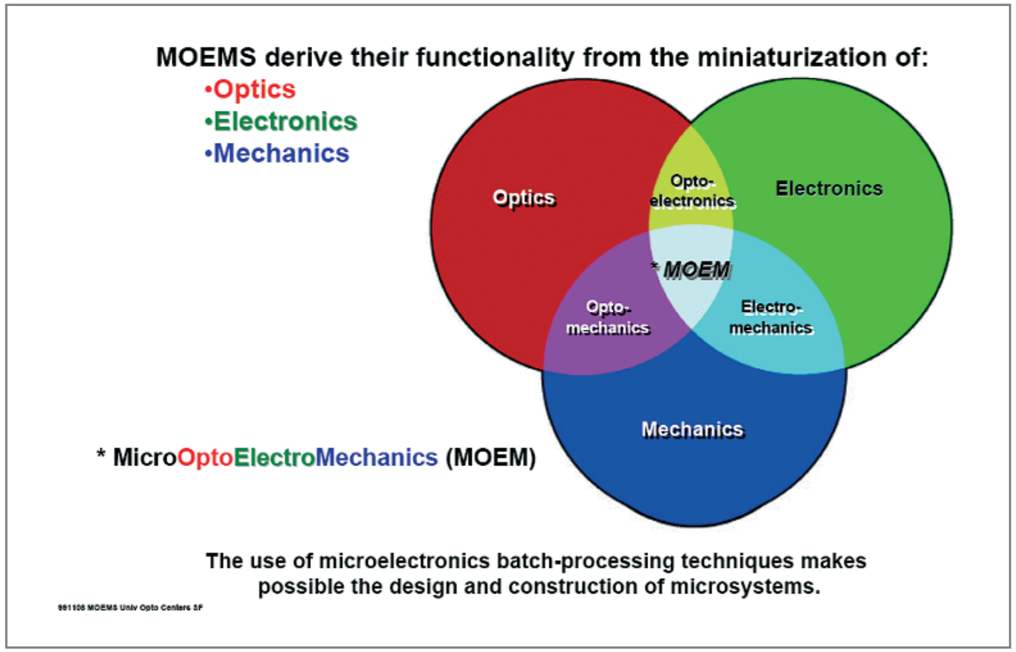
These new generation sensors could be:
- Multi-spectral.
- With embedded software for image processing and image enhancement.
- Hybrid sensors combining different functionalities (3D, colour, 2D, other) on a single-chip.
- Digital holographic imagers based on active multi pupilary sensing and image reconstruction algorithms.
- Active sensors integrating embedded lighting devices and adaptive optics with sensing devices on a single-chip or single-module.
- Camera chip with the flexibility and adaptability of the human eye in the following areas: contrast, colour differentiation, focus (variance of focus according to image content and "pattern interest"), depth of focus.

And more …

Hence it will be valuable to put R&D effort on:
- Smart pixel. The desire to acquire a large amount of data simultaneously and with ultimate sensitivity cannot be fulfilled with standard image sensors, due to their limited readout bandwidth. According to the recent "smart pixel" paradigm, it is possible today to perform a huge number of computations already on the pixel level, allowing for complex pre-processing and data reduction [11]. This makes it possible to employ noise-reducing measurement methods such as modulation/demodulation signal processing techniques, without compromising the number of pixels for which this pre-processing needs to be carried out concurrently.

- Extend CMOS capabilities. CMOS sensors are replacing CCD sensors in many applications, but will probably coexist in the near future. This is mainly because in large scale consumer imaging applications only the CCD technology provides certain features vital to machine vision such as synchronous exposure. In main stream vision applications, such as consumer video and still picture applications the technology change from CCD technology to CMOS technology has already been made. It is to be foreseen that within short the "technological working horse" of machine vision, the CCD technology, will no longer be available at reasonable cost. Some features keys to machine vision industry today are not available in mainstream CMOS vision sensors for consumer applications. Such features are: synchronous exposure, large full well capacity, defect free pixel array's beyond 1M pixel resolution, high readout speed.

– MOEMS technology



– Polymer technology. Polymers are promising materials for miniaturization and best suited for high volume and low cost production. Polymers with high refractive index and being resistant against chemical and physical stress could be used for optics. Polymer electronics and opto-electronics manufactured by printing technology offer new possibilities for disposal sensors.

3.5.2.4 Terahertz sensors and sources

The already established research in Terahertz technology enables new applications such as 3D imaging in diffusing medias such as dust, clouds etc.. The wavelength range (from far infrared to T-rays) generated through femto-second technology will give an access to spatial resolution in imaging systems. Terahertz technology coupled with time resolved spectroscopy provides structural and functional information on many materials, air, water surface, and soils. The technology applies to other fields than environment. Applications from security with identification to 3D imaging processes with the sectioning capabilities of the ultra short pulse approach can be also very fruitful.

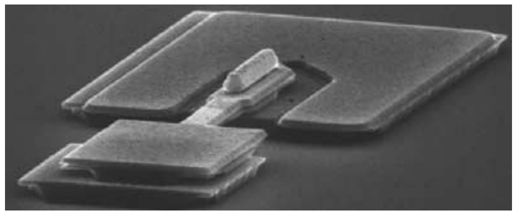


Fig. 3.5.10
C-Indium Phosphide hetero-junction bipolar transistor for THz generation (0.7µm wide emitter)
© Alcatel Thales III-V Lab

But many questions remain open; in particular, availability of THz components (sources, detectors) compatible with industrial requirements is a hurdle. Today, there are no commercial THz matrix detectors capable of producing imagery.
On the detector side, only elementary detectors are available for spectroscopic applications.

Golay's cell	0.3THz-15THz,	NEP=100pW/Hz1/2
Power meter	30GHz-3THz,	NEP=5µW/Hz1/2
Bolometer at 4K	150GHz-3THz,	NEP=2pW/Hz1/2

But matrix detector starts to appear in labs. The THz bolometer is being investigated in the USA by Raytheon which, at the SPIE Defence & Security conference in Orlando in 2005, presented a 22x28 THz focal plane with a CMOS reading circuit.

Another difficulty for large scale imaging is also the power generated by the actual "T-rays" generators, where amplified (large) laser systems too often have to be implemented. Research labs are now developing new concepts of Terahertz sources:

– Terahertz lasers of reduced size laser technology able to produce high power peak for the non-linear interactions needed on useful applications.
– Terahertz generation using ultrafast microelectronics devices (e.g. InP circuits)
– Terahertz generation through the beating of optical lasers, providing flexibility and high spectral purity.

A European R&D platform would have to support development of new imaging detectors and more robust and easier to handle sources. Industrial activity in this domain is still limited today but a large number of European research groups are working on THz-related topics. Technical competences are therefore available in our countries and should constitute a good basis for the build-up of an industry.

3.5.2.5 Specialised excitation sources

Utilization of laser light offers interesting possibilities for many applications. For example, laser jamming systems are a very promising solution to protect aircrafts against manpads. Detection of biochemical agents, hazardous and energetic materials could also be significantly improved by laser technologies like LIF (Laser Induced Fluorescence), LIBS (Laser Induced Breakdown Spectroscopy) and LIDAR (Light Detection and Ranging). For these purposes stable solid-state lasers at specific wavelengths, from the ultraviolet to the near infrared spectral range and at reasonable cost are required.
Thus, the development of compact, reliable, high power and cost effective sources is necessary.
– Electrically-pumped semiconductor lasers are a key technology. For instance, development of high power quantum cascade lasers in the mid IR range operating at room temperature would certainly be a very interesting approach in terms of system integration.
– When direct use of a semiconductor laser is not feasible, fiber laser technology and diode-pumped solid state lasers offer very attractive advantages like beam quality, efficiency, compactness and life-time.
– Utilization of femtosecond lasers could also add some value for the applications described previously but the potential of these sources needs to be confirmed.

The European laser industry is well positioned on the world market but has to face a very severe competition from the US (massive military investments) and China.

The importance of semi-conductor lasers should be outlined, as the key enabler for photonics applications to reach the market (examples include the emergence of the optical disc or of many medical applications such as photodynamic therapy); semi-conductor lasers offer miniaturization, reliability, and are compatible with mass production. However, some key factors still need to be improved in order to reach a wider market, in particular:

- Beam quality (measured by the beam parameter M2)
- Power
- Wall plug efficiency
- Wavelength range: UV, mid infrared
- Tunability

Regarding the beam quality and power, the trend is to aim at higher “brightness” by increasing the beam quality: for instance, a low power high quality beam will allow for coupling in the same light power to a monomode fibre as a high power low quality beam, whereas the former is much more attractive in terms of reliability, thermal management and power consumption.

Semi-conductor lasers can often be developed for multiple uses; a single development can address various markets. Such feature enables to address niche markets, for which a specific development would not be cost-effective.

Priority semi-conductor laser technologies for multiple uses are highlighted hereafter:

- Quantum Cascade Lasers (2-12µm): pollutant detection (automobile, maritime), bio-nano-captors for detection of molecules, explosive detection, protection of civil aircraft against missiles
- UV Lasers: optical storage, medical fluorescence imaging, detection of biological agents for security
- Near IR low line width, high power, high reliability lasers: Ultra stable atomic clocks/interferometers based on cold atoms

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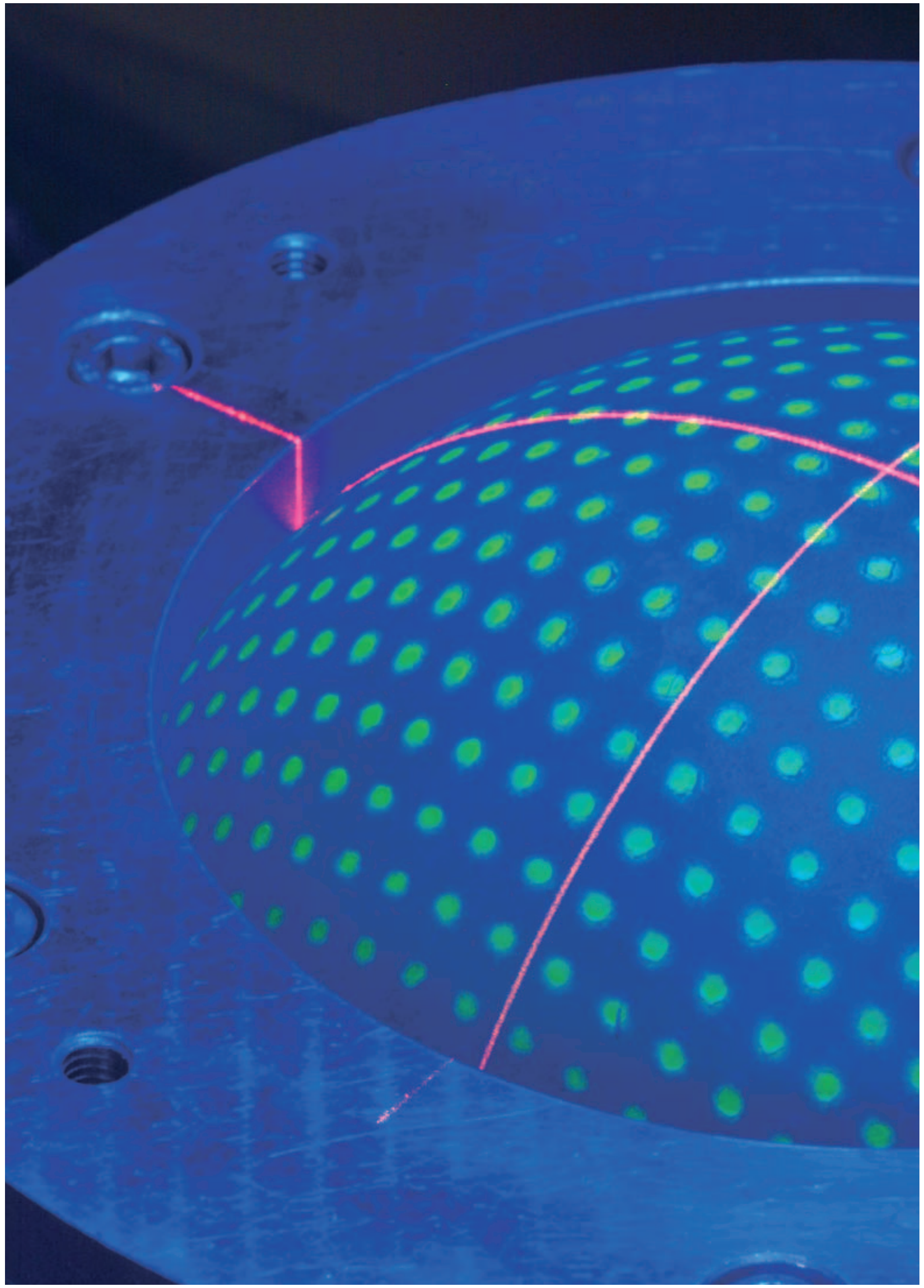
Research topic	Technical objectives	Applications	Socio-economic relevance
Short term (1-3 years)			
High sensitivity	Ultra low noise CMOS detector	Imaging sensors for multi-media and medical application, enhanced vision system for process & quality control	Gain competitiveness over US and Asia
Function integration	Active pixel sensor	Multimedia, medical & environment, enhanced vision system for process & quality control	Gain competitiveness over US and Asia
Specialized sources	Fiber laser	Medical & environment, process & quality control	
Mid term (4-7 years)			
Function integration	MOEMs Polymer optics	Medical applications: Lab on Chip, process & quality control	Reduce the cost of medical diagnostics to ease access to medicine
Extended wavelength	Low dark current array for imagery at 1,5µm Uncooled IR detector Large band gap detector array for UV imagery	Security	Reduce traffic accident statistics
		Medical & environment sensing, spectroscopy	New medical diagnostic, pollutant emission control
Terahertz sensors & sources	Sensors & sources	Security, Environment control, medical imaging, process & quality control	New medical diagnostic, pollutant emission control
Specialized sources	High power IR quantum cascade laser UV laser	Security, medical diagnostics and therapy, environment sensing, data storage	Prevention of criminal and terrorist acts, new medical diagnostic.
Long term (8-10 years)			
High sensitivity	Plasmon enhanced detector	Multimedia, medical & environment	
Extended wavelength	Uncooled IR quantum detector	Security, transport, environment sensing	

References

[1] Optoelectronics Industry Development Association (OIDA): "Worldwide Optoelectronics Market – 2004", Annual Review, June 2005.
[2] Strategies Unlimited (Pennwell), 201 San Antonio Circle, Suite 205, Mountain View, CA 94040, USA
[3] Affymetrix Inc. "Annual Report 2004", Santa Clara, California, 2004
[4] BioPerspectives: "Protein Biochips - Parallelized Screening for High–Output Biology", August 2004
[5] The Freedonia Group Inc., Information offered on their publicly accessible web page http://www.freedoniagroup.com/
[6] Frost and Sullivan, "Biochips in Drug Discovery in Europe", June 2005
[7] Global Information Inc., "Environmental Sensing and Monitoring – Technology Developments and Growth Opportunities", November 2004
[8] Frost and Sullivan "European Remote Sensing Market Survey", October 2001.
[9] X. F. Wang and B. Herman (eds.): Fluorescence Imaging Spectroscopy and Microscopy, John Wiley & Sons, London, 1996.
[10] P. Seitz , "Image Sensing with Maximum Sensitivity Using Industrial CMOS Technology", Proc. SPIE, Vol. 3099, 22-33, 1997
[11] P. Seitz, "Smart Pixel Arrays", in Encyclopaedia of Modern Optics, B. Guenther and D. Steel (Eds.), Elsevier, Oxford, 2004.
[12] Les Echos – 02/12/05



3.6 Design and Manufacturing of Photonic Components and Systems

The design and manufacture of components and systems underpin European and indeed worldwide photonics activity. Optical materials and photonic components serve as the basis for systems building at different levels of complexity. In most cases, they perform a key function and dictate the performance of these systems. The focus here will be on materials and components, whereas sub-systems and systems will only be described briefly in typical examples.

3.6.1 ECONOMIC IMPACT OF PHOTONIC MATERIALS AND COMPONENTS

New products and processes will generate economic activity for the European photonics industry into the 21st century. However, progress will rely on Europe's ability to develop new and better materials, components and systems. To achieve success, photonic components and systems must:
– Be reliable and inexpensive
– Be generic and adaptable
– Offer superior functionality
– Be innovative and protected by Intellectual Property Rights
– Be aligned to market opportunities

The challenge in the short-, medium-, and long-terms is to put a coordinating framework in place which will make the European activity in this technology area competitive with those in the US and Asia. In the short term, the aim should be to facilitate a vibrant and profitable European photonics industry to further develop its ability to commercialise advances in photonic related technologies. In the medium and longer terms the objective must be to place renewed emphasis on materials research and the design and manufacturing of key components and systems to form the critical link between science endeavour and commercial success.

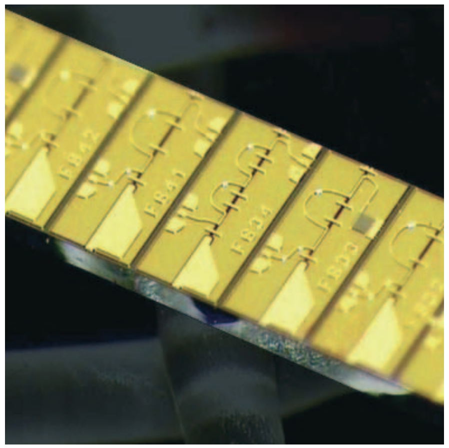


Fig. 3.6.1
Array of travelling-wave electroabsorption modulators with world-record speed. Each modulator is capable of transmitting 100Gbit/s into an optical fibre
© Royal Institute of Technology (KTH)

Market opportunities are enormous. The market for optoelectronic components grew 17% from US $23B 2003 to US $ 27B in 2004. In particular, laser diode revenues accounted for US $3.1B revenues in 2004 and are projected to reach US $3.5B in 2005 (OIDA).

In maturity, photonics lags electronics by some three decades. A similar development and impact of photonics as we have seen in electronics, is to be expected, enabling excellent research and business opportunities.

3.6.2 CURRENT STRUCTURE OF INDUSTRY AND RESEARCH IN EUROPE, CURRENT AND FUTURE CHALLENGES

Industry
The European photonics industries under consideration in this document include, but are not limited to, optical and micro-optical component manufacturers, production equipment manufacturers, companies making advanced materials (semiconductors, glass, polymers,.....), mask shops, packaging companies, subsystem builders, and various Computer Aided Design (CAD) companies. Europe has at present an appreciable number of worldwide industrial leaders in each of these domains.

The European photonics industry is highly structured and diversified, and a number of SMEs operate successfully on the world market. Independent of manufacturing of mass-produced goods in Europe, the SME's will be in need also in the future of the know how of advanced production technologies of photonic devices and systems.

For a long time manufacturing has been increasingly characterised by outsourcing to countries with cheap labour. Initially outsourcing was limited to simple mass-produced goods. However, the trend now is towards labour-intensive activities that require more skilled and educated personnel. Even instances of outsourcing R&D are starting to emerge. Outsourcing is a consequence of globalisation and is unavoidable. This presents challenges and opportunities to the European photonic component sector. The development of components with higher complexity and functionalities, as well as a higher degree of automation – thereby requiring the combination of highly educated people with major investments – should help to bring manufacturing back to Europe or reduce early outsourcing. A necessary condition for this to happen is of course that Europe is at the forefront of know-how and innovation.

Another, perhaps more recent, evolution, especially in the semiconductor segment, is towards fab-less component manufacturers. This makes sense for two reasons. First, one component fab can often serve many different applications and therefore a whole range of companies. Secondly, the economical risks taken by fab-less companies are considerably reduced and it allows for a much higher flexibility and adjustability. With well-supported and healthy foundries in Europe, one can expect a climate to arise in which fab-less companies can thrive and can form the link between foundries and system builders or end users. This is further elaborated below.
Europe needs to focus on technologies and industries where it has a competitive advantage. Central to this approach is the development of industries with products and processes where the added value is in the form of knowledge (both technical knowledge and market knowledge) and where generic technology and labour costs form only a small part of the final product. Photonics is one such industry offering technologies that are complex and integrated, based on advanced know-how and innovation. These technologies become increasingly capital-intensive; therefore component manufacturers need to have a relatively large critical mass. Material and component technologies have been the enabler of the giant advances we have seen over the past decades in photonics and will continue to play this role. The EU has been so far reluctant to actively support its industry, but the examples of governmental support to

industry, which can be observed in the US and in Asia, will most probably be necessary to follow. An EU perspective, even at the level of industry, is primordial.

Fig. 3.6.2
Top floor of the fiber draw tower where the preform is heated up to approximately 2000 °C in order to draw the fiber
© OFS Fitel

Research

The potential for Europe in the area of design and manufacturing of components is greatly enhanced by its world-class research community engaged in the science and engineering of photonic components. Over the past two decades it has evolved from a collection of relatively small and mostly isolated research units operating on the basis of local funding to a network of internationally operating units supported by a combination of local and international funding The various EU-funded framework programs have played a vital role in this development. *A key objective in the future is to more closely align national and European research activities to achieve strategic research goals.*

While the output of European research on photonic components is strong by global standards, there are a number of weaknesses and future issues that need to be addressed:

– *Research career development:* A structural weakness at present is that many photonic component researchers, after having completed PhD research and possible post-doctoral research experiences, have great difficulty to find positions in industry in which they can build upon their research expertise. The present industry in Europe cannot absorb this considerable and highly valuable human capital that is continuously lost to the sector. European industry has over the past decades considerably decreased the amount of long-term oriented research in photonic components. Central research laboratories hardly exist anymore and most of the ongoing research has a rather short time horizon. With an expanding and profitable photonics industry in the area of design and manufacturing of components, this situation would be rapidly rectified.

– *Capital Intensive research:* A major challenge for the future of photonic components research is that, as technologies move to smaller dimensions, as well as to heterogeneous material combinations, the research infrastructure is becoming more capital and maintenance intensive. It is no longer possible for a small or medium sized research unit to do independent research in the photonic components field. This calls for two complementary measures. In the first place a number of large scale facilities should be stimulated to develop and maintain high quality processes and to make them accessible to third parties for research purposes and possibly for prototyping. Secondly, and equally importantly, since the human capital of potential researchers originates from a fine-grained collection of several hundreds of universities, small and medium-sized research units should be stimulated to specialize in specific research topics and to structurally collaborate with larger centres equipped with the required technologies. These mechanisms are at present being experimented with in several Networks of Excellence under FP6.

– *Internationalisation:* Since it is unreasonable that research in each component technology will be exploited at an industry level in every country, national funding bodies should be flexible in their policies and should be open to funding research units even if part of the research is necessarily done in a different country and if the potential exploitation is also in a different European country. For example it is unnecessary to have a manufacturer of telecom photonic components in every European country, but it may be reasonable to have research groups in this field in every European country.

– *Current and future challenges* are to make the research system, academic and industrial to be as vital, dynamic and creative as its best global competitors and to see to it that there is adequate transfer of technology and expertise to sustain and create profitable high tech industries.

3.6.3 PREDICTIONS UNTIL 2015: UPCOMING TECHNOLOGIES

What is expected in terms of applications and technologies within the next 10 years

Considering the technologies in the scope of this WG, it has to be stated that to make a prediction based on a time period of 10 years is highly challenging in our fast moving world. However, there are a number of exciting technologies emerging in the field of photonics and some proposals can be aired at this stage.

Future and emerging technologies:

– *Novel or emerging materials:* Low dimensional or nano-scale semiconductors (II-VI, III-V, silicon, germanium...), organic materials, self organized materials, artificial or metamaterials, such as subwavelength-structured materials, in particular photonic crystals and negative index materials. An example of an emerging technology might be semiconductor nanoparticles made by colloidal methods. As noted above, it is largely the materials that shape the future of photonics, as proved by the optical fibre, the semiconductor heterostructures (Nobel Prize 2000) and they provide endless possibilities.

– *Novel phenomena:* These are largely supplied by quantum phenomena: Coherent light matter interactions, teleportation, and entanglement, with properties not completely understood. Quantum optics might seem esoteric, but one application has already generated start-ups, namely cryptography, and an EU project, Descartes, has been awarded. The area of coherent light matter interactions; electromagnetically induced transparency (EIT) offers virtually endless possibilities, if the wave function coherence properties can be mastered adequately, preferably at room temperature. As an example, the only reasonable electronics analogue to RAM memory in photonics can be implemented in EIT, albeit with significantly lower levels of integration. Applications in quantum computing and communications are obvious. Other possible applications are wavelength conversion, atomic clocks and certainly those not even conceivable now. The final commercial application, if any, is as usual hosted in successful and visionary research.

– *Novel devices:* There are virtually endless possibilities here, fuelled by the materials and phenomena described above. The devices will of course be studied in relation to the different applications, and the wide scope of photonics applications makes the variety of photonics device technology more ubiquitous than that of micro electronics. New mass-markets such as those in lighting, and in life sciences, e g for simple and rapid diagnosis are certain to emerge, in addition to that of telecoms. This also requires a subdivision of devices into different perspectives.

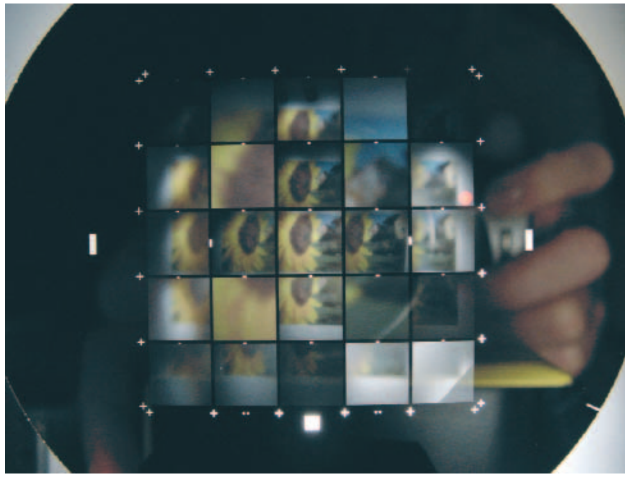


Fig. 3.6.3
Wafer with 5 x 5 ultra-thin (< 0.3 mm) artificial compound eye objectives (before dicing) imaging a picture of sunflowers
© Fraunhofer IOF

– In the short to medium term, the further development and refinement using existing technology will be seen. One aspect will include 3D integrated optical devices (3D-Integrated Optics) and stacked microoptics. One important – possibly extremely important - area is integrated photonics based on the tools of CMOS industry ("Silicon photonics"). The relevance stems from two considerations. First of all, if it is possible to implement a relatively complete set of basic photonic functions in compact and power-efficient devices manufacturable in or above Silicon by CMOS-compatible technologies, then the road is open for a massive number of applications. Secondly, CMOS-technology can act as a backbone for devices, built on Silicon, but involving entirely different materials (semiconductors, organics, glasses, metal nanoparticles etc) in a heterogeneous way. In this way it may be possible to overcome the generic "weakness" of photonics: dilution of research efforts and manufacturing capability over a massively wide range of materials. Another area is devices for lighting, where semiconductor technology married to photonic crystals is likely to emerge, as is already happening to some extent.

– Furthermore, nanooptical (metal and dielectric) devices will open the optical near field technology for super high density memory of data and for super resolution measurement technology. In an even longer term, there is a true plethora of potential devices, in some cases with unpredictable applications: plasmon based devices and metal optics ("generating x ray wavelengths at visible light frequencies" to quote Eli Yablanovitch), one-photon devices for generating, manipulating and detecting single photons, nano-photonics devices, novel functional all optical elements, which incorporates several functions in an integrated fashion, the most extreme example maybe the quantum computer, based on photons. Here one can also speculate on digital optics, and the possibility to perform digital functions by photons, complementary to or replacing electronics. It is hard to imagine today that photonics will ever reach the integration density of present-day micro-electronics. However, it is conceivable that it will be possible to make relatively compact photonic digital logic circuits. These circuits could use photonic crystal concepts to confine light and be possible to operate at clock frequencies and power levels much beyond what is possible with electronics. Given the now widely accepted understanding that further scaling of digital electronic circuits in density and/or speed is running into very basic and fundamental problems, this optical route is likely to gain momentum in the following decades.

– *Manufacturing and packaging technologies:* in a more short- to medium-term time frame technologies for the manufacturing and packaging of optical components and of devices with optical and electrical functionalities will be vital for the competitive production of products, based on such devices. The field addressed here is not restricted to semiconductor systems and sub-systems, but includes systems such as miniaturized low-cost lasers or display devices. What is needed in a 3 – 7 years time frame are controlled production technologies for miniaturized optical precision components and technologies for the integrated packaging of systems with distributed optical, electrical and mechanical functionalities. In particular for high-wage countries, typical of Europe, production technologies have to be developed, combining a high degree of implemented knowledge with low production costs and the possibility to individualise the product properties. The manufacturing business in Europe comprises about 2,5 million companies, of which 99% are small and medium size (SME). With research activities in the field of manufacturing and packaging technologies, this particularly important area of European industrial SME-activities can be addressed.

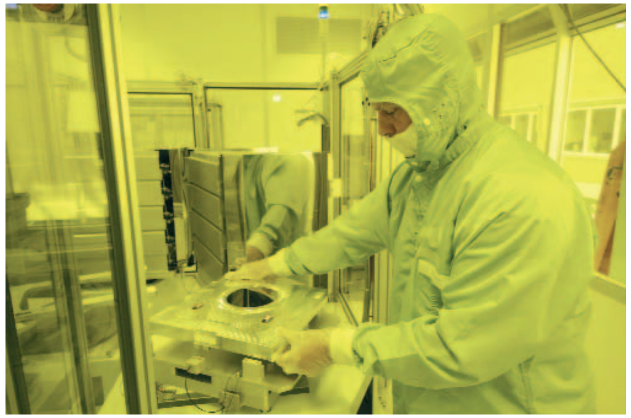


Fig. 3.6.4
MiPlaza cleanroom for interdisciplinary research on system-in-package technology at High Tech Campus Eindhoven
© PHILIPS

The expected evolution in different application areas, enabled by the new materials and component technologies, can be briefly described as follows. A more elaborate discussion of these applications can be found in the sections of other working groups.

– Industrial applications: The ability to generate very high optical powers in an energetically efficient manner, and to deliver them with low loss and high precision, is expected to lead to a large deployment of optical techniques in the processing industry. New system designs, competitive production technologies as well as new materials are important in this development.

– Sensors and bio-sensors: Inexpensive and highly sensitive optical sensors will enable optimised processes and quality control, environmental control, in-vitro and in-vivo diagnostics etc. The concept of a lab-on-a-chip is likely to lead to a massive industry in the 21st century. Generic integration technology platforms, also involving microfluidics, are keys for this development.

– Life science: High power laser sources at basically any desired wavelength are of major relevance for selective treatment and tissue engineering and are expected to be further and widely deployed within the next ten years. One can also expect the development of micro-instruments with substantial amount of optical technologies, optimised delivery of medicine and specific optical methods for local treatment, in particular, of cancer. Already emerging are technologies for disease diagnosis, protein tracking etc., employing optical technologies such as quantum dots and photonic crystals. Optical imaging techniques (e.g. of the brain) are also rapidly gaining in importance. Key to this wide variety of biophotonic applications is the availability of dedicated sources and detectors at specific wavelengths as well as the development of nanoparticle-based photochemistry.

– Image technologies: With extremely miniaturized cameras, 3D images will be recorded (e.g. time of flight method). Brilliant image formation will be possible anywhere using small matchbox digital projectors. Both allow the ubiquitous image recording and projection of 3D images. Ultraflat and ultrathin (wire) cameras open novel applications in medical diagnostics and security. This is further treated in another section on display technologies in the roadmap.

– Lighting: The pending replacement of the incandescent lamp by solid state lighting will have major implications for component and systems manufacturers and vendors in the area. This is also an example of the significance of photonics for the environment, in view of the vast energy savings made possible. This is further treated in the section on lighting of this document

– Telecom: Many technologies studied and/or tentatively, but often unsuccessfully, implemented as products during the last 10 years can be expected to see a new birth. In particular, the concept of all-optical networks, closer and closer to the end-users, is very likely to become a reality in a large scale of deployment before 2015. The very large efforts to decrease the cost of the components involved in such networks, will effectively challenge the impressive advances of microelectronics. Components to optically process the information will be a key for this development. With the merging of wireless and wired networks, a large development of optical components to generate, manipulate and detect millimetre waves is also expected. Photonic-assisted wireless communications using frequencies from 10 to 120 GHz or more will allow the delivery of wireless signals to the right user only, i.e. with a minimal energy loss and decreased exposure for other users. Photonics is, and will remain, one of the corner stones of the IT society: no other known technology can even remotely challenge the role of the optical fibre in the global network. This can also be shown from a pure information theory point of view.

– Data processing: The concept of optical computing, for a long time only seen as a chimera, is very likely to develop substantially within the next 10 to 20 years. This concept has been around for decades with little impact on the general area of data processing. At least two factors can have a significant influence in changing this situation: the emergence of the potentially disruptive technology of quantum computing and the development of novel materials and devices to perform specialised functions, adapted to photonic capabilities, such as non-linear and parallel processes. The issue of a partial or total replacement of current digital electronics remains a long term research question, involving fundamental (bosons versus fermions) and applied research with an uncertain outcome. Compact, integrated and low-energy consuming components operating at ultra high speed are in any case a key.

– Security: Devices for generating novel wavelength ranges will be further developed and made practically usable, including the THz range, where important security applications exist. A scenario with increased security will most likely make wide-spread use of optical sensors of all kinds.

In general it seems certain that the drive for integration and functionality will be even more stressed, being largely commensurate with the quest for added value of the EU-industries (and others), and that the progress in quantum optics and novel materials in a wide sense will lead to breakthroughs, most likely in unexpected areas. In order to match the development in electronics, the goal must be to develop circuits with element dimensions, much smaller than the vacuum wavelength. This is indeed the goal of the very rapidly developing (and somewhat fashionable) field of nano-photonics.

The common denominator is the ever-increasing pace of introducing new technologies, with ever-shorter time between the executing of the research and product launch.

3.6.4 CURRENT POSITION OF EUROPEAN INDUSTRY AND RESEARCH IN DEVELOPMENT OF THE DESCRIBED APPLICATIONS AND TECHNOLOGIES WITH RESPECT TO THE MOST COMPETITIVE COUNTRIES /REGIONS

Industry
The situation of the EU industry in the area of semiconductor III-V components will be given as an example, this maybe representative of a sector where the EU is most squeezed by competition from the US and Asia. The first observation is that this sector is somewhat contrasted.

On one side, the **optoelectronic infrared industry** is still undergoing a global reorganisation after the plunge of the telecom market from 2001. Thus, optoelectronics for telecommunications industry has seen major changes since the ‘dot com’ implosion in 2001. Worldwide capacity has realigned to the sustainable growth curve mirroring the insatiable appetite for data transport described in the WG1 report. Most major manufacturers have moved final assembly operations offshore, benefiting from low cost labour and to a certain extent access to low cost material infeed. Typically, the high technology end of manufacturing, including the III-V device technology, has been retained in the West, benefiting from consolidation and availability of the highly skilled design and fabrication labour necessary to run such facilities. The field of EU infrared III-V R&D and fabrication can now be described as follows : the number of main industrial actors has shrunk down to very few (mainly Bookham, Avanex, CIP), with a significant number of R&D “semi-academic” research centres still alive (like KPRC, III-V Lab, HHI, FBH, IAF…) and a still strong activity in academic laboratories. The market and demands are now beginning to grow faster, enabling organisations to move towards profitability. It will however need several years of growth and possibly further consolidation before the industry becomes truly self-sustaining (i.e. be able to support sufficient R&D to enable future competitive advantage). The advantages of close co-operation between system developers and component manufacturing are very clear – innovation in components and subsystems leads to system advantage; system expertise often acts as the roadmap for component innovation and research. *Building the infrastructure in Europe to achieve this is vital.*
The infrastructure for chip development and production is very expensive and consequently must be run at high utilisation to be profitable. For Europe to compete in future Optoelectronic III-V technology, a move towards foundry type manufacture will be required, enabling the product and technology innovation from our academic and start up industry to be transferred to global scale rapidly and cost effectively. For this to happen there will be a need for more stan-

dardization in optical chips, not only in terms of manufacturing equipment but also in terms of wafer size and type, component families etc. Design will become relatively more important than process, although there are likely to be many more years before 'process' becomes standard, as in the silicon industry. As higher levels of integration become enabled by improved design tools and process control, more of the component value is represented by the chip, or combinations of chips, and less by the potentially outsourced final assembly. As pointed out in WG1, the component and subsystem costs are an important, but only relatively small, part of the value added pyramid in the telecommunications system industry. However, innovation at the physical layer – both at component and subsystem levels – is essential to enable innovation and differentiation at the system level and hence enable the value added pyramid to flourish – *we must provide the framework for our industries to work strategically together, from material, through component and system development to user application.*
Increasingly, future start ups will be design and application based, relying on outsource of fabrication optoelectronic elements in many cases. Framework 7 must help European Industry towards this new paradigm.

On the other side, the **optoelectronic 'visible' industry** (LED and lasers at visible wavelengths) in the EU is growing and strengthening very quickly. The position of the EU is good but the competition is extremely hard and the EU activity is, strongly focused on a very limited number of actors (mainly OSRAM, Philips at the industrial level), who keep in-house all domains of activity including the back-end production. Here also the Intellectual Property is already well assessed and complete: new players have to focus on the periphery of the activity (i.e. low dislocation substrates, new materials,…).

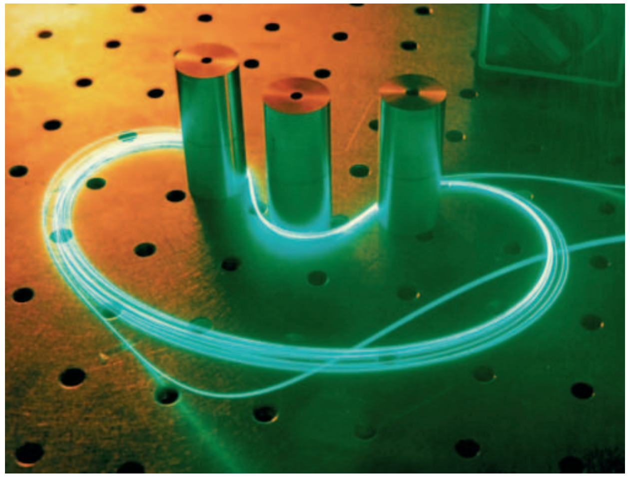


Fig. 3.6.5
Double clad fiber laser with kidney-shaped geometry for improvement of absorption behaviour
© Friedrich-Schiller-University

Research
In general, the EU *research* in the area of photonics has become, to some extent, coordinated and coherent as a result of the numerous EU projects. The presence of European research output in the field of photonic components and systems in peer-reviewed journals and at conferences is strong. However, other regions of the world, where the administrative entities admit more coherence and/or more resources, with the US as the most notable example, probably still have an advantage. In the US also military funding plays an important role. The EU has, in spite of the Lisbon declaration, difficulty in keeping up with the most rapid developments in photonics in the US and maybe Japan. In general, the EU method of support is administratively heavy and slow and does not show the speed required in relation to the comparatively small sums. At

the same time there is a large number of excellent research groups, nowadays especially in universities and institutes, since company research has decreased significantly. A major weakness, however, is the relatively difficult transfer process from academic research to industrial take-up, both in terms of the difficulty to find a suitable job in industry after a period of academic research as well as in terms of the many barriers in the process of creating start-up companies. These difficulties form a danger for research itself since they impact on the attractiveness of a career path involving research and they set a limit on the dynamics of mobilising new young researchers.
The mobility of European researchers has traditionally been relatively weak. In the last 5-10 years – and thanks to a variety of mobility funding schemes – there has been a strong improvement in this respect. There is a broader understanding and acceptance among young researchers now that international mobility is a natural part of a research career. This is particularly true for research on photonic components where necessarily one has to rely on centres of critical mass capable of maintaining advanced technological processes. One should not underestimate however that while mobility is simple for a single researcher, there are and will remain major barriers when mobility for a couple or for a family with children is at stake. Not only is the richness of language diversity a barrier here but also the large diversity in social security systems and the associated administration throughout Europe. Education in multiple languages remains essential even if the lingua franca of the research community is English. Convergence between social security and tax systems is a must.

3.6.5 RESEARCH PRIORITIES FOR EUROPE

Short term
Research in:
– Manufacturing and packaging of components and subsystems (cheaper, higher device density, more miniaturized, more functionality in less volume)
– Production strategies and systems for the integrated manufacturing of electro-optical hybrid systems such as low cost miniaturized lasers or display systems
– Development of manufacturing equipment
– Material and component reliability in high power optical systems
– Semiconductor lasers without cooling
– High power/beam quality solid-state lasers
– Optical generation of millimetre wave signals
– Silicon photonics based on CMOS compatible technology
– Improved materials for cheap mass-produced photonics, preferably integrable with Si, such as polymer based photonics (for both active and passive devices)
– Strong miniaturization of image recording and projection equipment
– Component and subsystem simulation tools
– 3D optical integrated circuits (e.g. ultra-short laser writing in glasses and semiconductors)

Medium term
Research in:
– Novel function enabling materials (meta materials) such as artificial materials based on subwavelength structures, making possible eg. negative refractive indices with low optical losses
– Controlled self-organization of structures, such as photonic crystals
– Controlled self assembling of hybrid integrated photonics devices
– Near Field Photonics (for data memory and measuring technique)
– Novel materials and structures for (tuneable) generation and manipulation of wavelengths in the far IR and DUV/XUV ranges (not necessarily based on nonlinear interactions)

– RT operating Quantum Cascade Lasers as THz sources
– Materials, devices and applications of coherent light-matter interactions
– Slow wave devices and applications
– Converging technologies: Integration with life sciences, nanotechnology, cognitive sciences.

Long term
– Blue sky issues relating to integration and functionality: Novel concepts relating to drastically reduced size, footprint, power consumption and increased functionality, for components and subsystems, to enhance EU competitiveness
– Development of novel functional materials with software controlled properties
– Development of component structures with properties controlled by software

3.6.6 RECOMMENDATIONS FOR IMPLEMENTATION

To lay down and implement a comprehensive strategy for EU in the area of design and manufacture of components is indeed a challenging task. It is clear that aggressive measures have to be undertaken if one wants to match global actors in the US and the Far East. For the academic research part, this is do-able given that adequate resources and efficient organization are provided. In fact, the status of EU research in the field is good, as described above. However, the issue of having a sustainable healthy and profitable industry in the area of design and manufacture of components is a much more difficult issue. This is so for a variety of reasons. One, and maybe the major one, being the ongoing "outsourcing" of manufacture (at many levels) from the EU. This is of course done in order to improve industry profitability, at least short term, and is touched upon above. It is also part of "moving up the value chain". Thus, the technical aspects are probably the least important ones, and it is industry that must lead development here, but supported by appropriate measure from the EU, some of which are outlined below. The issue treated here seems deeply entangled in trade politics and globalisation.

Industry
The recommendations here are somewhat generic, relating to optoelectronic components and subsystems for all the application areas of the SRA. The needs and support areas for the telecommunications industry are different to those of, for instance, biophotonics. However, both of these areas partly employ the same device technology, as mentioned above.

Framework 7 should help to put in place the next generation of optoelectronic semiconductor manufacture. Fabrication facilities, design tools and process development have become too expensive and specialised for individual companies to support. The options of relying on semi-industrial, academic or very process specific fabrication facilities leads to an inability to scale to truly global levels. Industry must be encouraged to put forward proposals which start to allow access to major process facilities such that start ups can access high technology with potential global scale. Networks of industrial and academic facilities must be set up, building in part on available infrastructure and also enabling cost effective growth and innovation in design and process capability. Close inter-working between academic, component, subsystem and system companies must be facilitated, allowing innovation to flow all the way up the value add pyramid. Innovation in new technologies for system and application advantage must be encouraged both in academia and industry, building on the technologies outlined in this document.
One concrete suggestion here would be as follows, again taking the semiconductor III-V industry as an example, but with somewhat generic comprehensiveness:

– To propose to the relevant EU Labs to publish the list of the Building-Blocks (BBs) of the processes they are mastering, defining BBs centers (could be Industrial and/or R&D centers). At this level, some information becomes public, just as some discrete elements of a Roadmap, but all specific know-how is carefully protected.
– To build advanced devices through technological interactions between BBs centers and other Labs directly involved in new device research (like active N-GaAs for example). To facilitate this interaction, it can be proposed that :
  – The subcontracted process to BBs center will be paid at some marginal cost (no development is required, involving only standard, well mastered, running processes)
  – In parallel, bilateral contractual commitments are established between the Labs so that, beyond this feasibility demonstration, if any new device development will occur, it will be developed jointly. This condition will pave the way for a BBs center involved in this feasibility towards the development of a future new product, based on the interaction with another research Lab.
  – The way of funding the development of this new device has to be discussed more precisely than in this first proposal, but this kind of interactions will result in the fact that each BBs center will develop the skills and know–how on which it has already some competitive advantage versus others, and by the way reinforce its competitiveness (see Ricardo's theory) in an open market economic model.
– Such a proposal will result in the fact that research Labs could refocus their effort on the cutting-edge research topics they are dealing with, relying on state-of-art BBs centers for full device feasibility demonstration. At the same time the BB centers reinforce their activity and prepare the development of new generation devices. Such a technological re-organization will help to increase significantly the amount of effort/equipment/know-how at the different technology levels with a given level of funding.
– Intellectual property and EU funding allocation (between BBs centers and research Labs) are the most critical elements to make this proposal operate.

Industry & Academia
– Identify strategic *focus areas* within photonics *applied* research. Establish a number of centres, distributed country wise and spanning particular focus areas, so that industry and academia can collaborate closely. This has to be shaped into an operative collaboration, so that there is a real and verifiable benefit to industry, otherwise the participation of industry is of no use. Thus, criteria of success have to be defined. Examples from Japan should be studied. The BB centers as described above are one type of such centers.
– Map these focus areas onto required or desired establishment or running of joint facilities in capital intensive fields, based on the existing regional competences from science and industry – an example being foundries for semiconductors.

Academia
– Participate in the centers described above
– Identify fields of photonics where long term basic research would, with some likelihood, have an impact in the component field and where EU research would be efficient and valuable. Form, where necessary, networks to make these fields internationally competitive. These networks could build on existing Networks of Excellence. However, future networks probably need to be more specific in their orientations and therefore need to be more numerous.

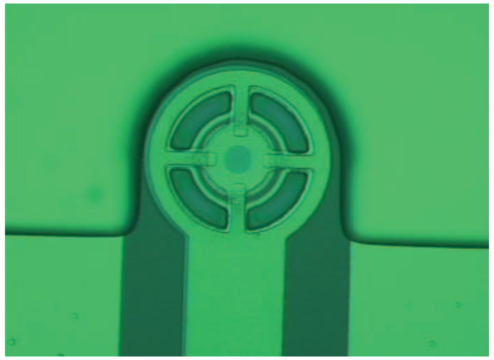


Fig. 3.6.6
Microscope image of a high speed VCSEL for data communication applications
© Chalmers University of Technology

Universities are the breeding places for the development of young people into creative researchers. The field of photonics, just as any other field of rapid innovation, should be able to draw the best human capital from an as large as possible collection of universities. Hence, photonics should be present as visibly as possible in the bachelor and master programs of as many as possible universities and there should be photonics oriented research groups in as many as possible universities. However, as explained before, the level of investment needed for many photonic technologies makes it impossible that all academic centres are equipped with the necessary high-end tools. In view of this, there is a dramatic need for a new paradigm in academic research whereby multi-site institutes or research collaboration networks of various kinds are created to ensure that people doing research can originate from anywhere but get a functional access to critical mass centres with state-of-the-art technologies, both mature and stable technologies as well as new innovative processes.

Public authorities, including National and European Funding Agencies
The public authorities will obviously, in addition to industry, have a key role in the implementation.

- Establish an *EU photonics board,* involving pertinent national financing agencies and EU (actually this covers the whole Technology Platform). The insight, initiative, strategic vision and EU perspective of such a national/EU body will be decisive for success. While there are initiatives to create a pan EU science foundation, to set up a smaller scale version for photonics should be quicker and easier to handle, and could serve as a trail blazer for more comprehensive arrangements.
- Ascertain that truly successful research groups have sufficient funding in the EU. This requires communications between the national bodies and pertinent EU agencies, including common definitions of success. If groups are creative and innovative and generate an impact in the community of photonics worldwide, the specific field of their research does not necessarily have to be of immediate use, not even of immediately conceivable use.
- Perform, where necessary, structural changes in financing and appropriately focus this financing. This implies an assessment of research fields and research establishments and groups. This has to be undertaken by the previously mentioned national/EU photonics board.
- Support the common usage of existing facilities (BB centers etc) mentioned above.
- Financially support, to some extent, research in companies; To facilitate R&D investments of companies. Ensure that EU companies are not at a disadvantage from an R&D financing point of view in relation to non EU companies. (This is actually more a governmental question).

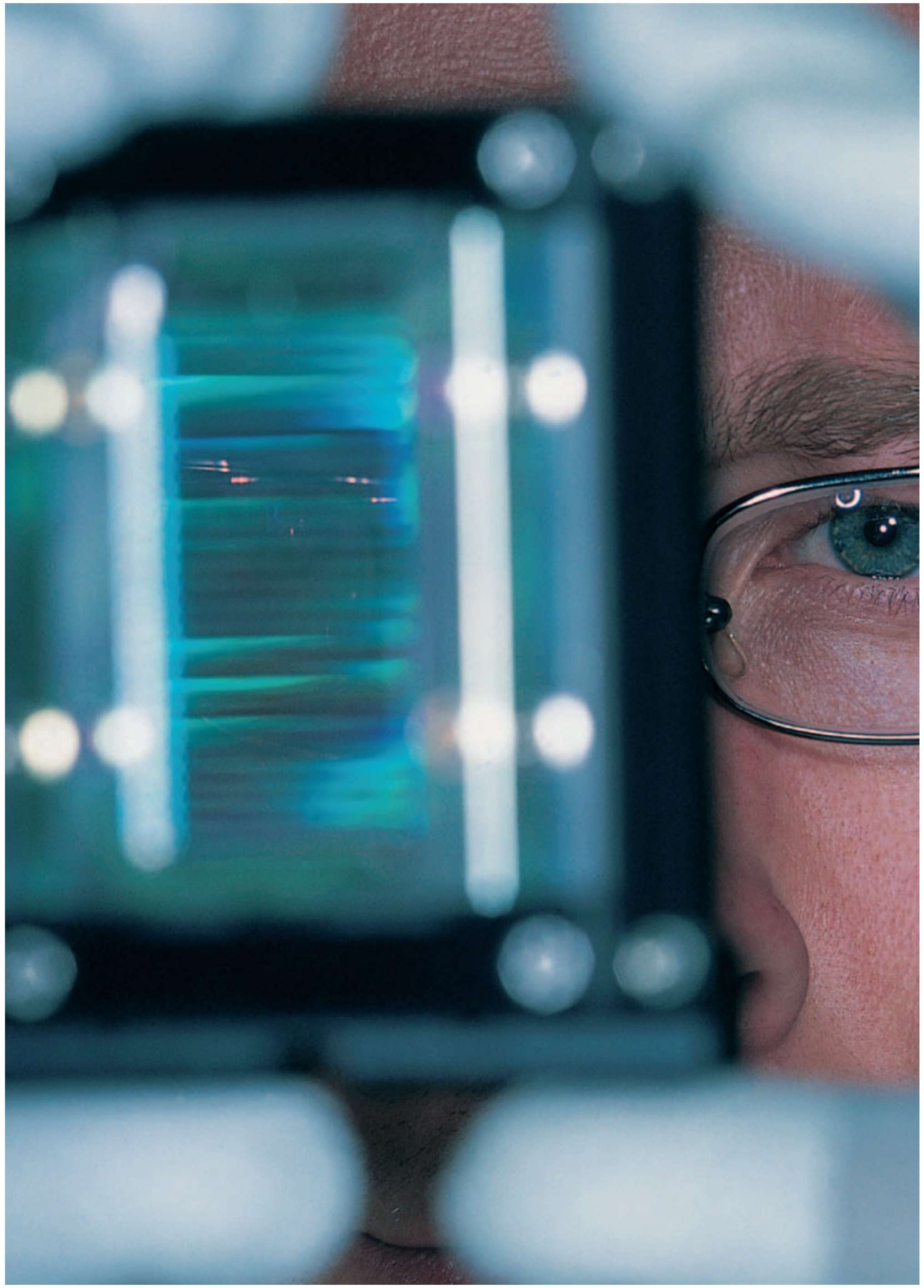


Fig. 3.6.7 Diode lasers are the most efficient artifical light sources existing. Due to their high efficiency and long service life, they have proved a success in many applications. The extremely compact diode lasers are increasingly gaining importance as light sources for direct treatment in industry and medicine and as highly efficient pumping sources in solid state lasers © Jenoptik

Research topic	Technical objectives	Applications	Socio-economic relevance
Short term (1-3 years)			
Production strategies and systems for the integrated manufacturing and packaging of components and subsystems	Cheaper, higher device density, more miniaturized, more functionality in less volume: Solving the high cost/low functionality of photonics, for hybrid as well as integrated systems	Virtually all	Access to higher functionality, lower cost technology, enabling more higher end job opportunities
Semiconductor lasers without cooling	Directly modulated at high bit rates	Mainly telecom	High impact on consumer, cost sensitive part of network
High power / beam quality solid-state lasers	Ultra-high slope efficiency, low heat generation. Could be directly semiconductor-based or pumped micro/mini solid-state lasers.	Telecom, Biophotonics, Displays, Security, Industrial such as welding	Improvement in consumer goods as well as in industrial productivity
Optical generation of millimetre wave signals	Large tuning range. Compactness, stability and reliability	Telecom, Transport safety, Security, Metrology	Impact on automotive industry and others
Silicon photonics based on CMOS compatible technology	Implementing as large a range as possible of photonic functions on CMOS wafers	All applications requiring co working photonics and electronics, or devices where photonics can advantageously use the existing CMOS technology	Enabler of a new industry, leverage of existing Si foundries
Mid term (4-7 years)			
Controlled self-organization of structures, such as photonic crystals	Ultra low-loss PC waveguides, and devices with extreme tolerances	Telecom, Biophotonics, Measurement technology	Could create new markets
RT operating Quantum Cascade Lasers	RT operation for THz sources	Security, Biophotonics	Same as above
Novel function enabling materials (metamaterials)	Artificial materials based on subwavelength structures, making possible eg. negative refractive indices with low optical losses	Biophotonics (Imaging…), Nanophotonics	Strong impact in life sciences
Controlled self assembling of hybrid integrated photonics devices	Rationalize production of the ubiquitous hybrid systems	Virtually all fields	Could create new markets

4 Photonics Education, Training and Research Infrastructure

The description of the 21st century as the "photon century" may somewhat sound exaggerated, but facts clearly illustrate the situation: photonics is all-encompassing, representing the indispensable technological pacemaker in industrial society. Highly qualified professionals well trained and supported by excellent infrastructure, are essential to sustain the growth of photonics, and the photonics industry in the 21st century. The diversity of photonics and its applications in industry, medicine, the environment and many other areas is why it is so important to Europe's prosperity and the quality of life of its citizens but this diversity poses a challenge in training young people for a career in photonics-related activities. As in other interdisciplinary fields, training in photonics requires knowledge from several fields, notably physics, materials science, computer science and engineering, and the successful application of photonics may also require a detailed understanding of fields such as engineering, biotechnology, nanotechnology, electronics or medicine.

In Europe at present, there are very few university-based degree programmes dedicated to photonics, in contrast to the USA where several very strong programmes are thriving (for example at the universities of Arizona, Central Florida and Rochester). University-based educational activities in photonics in Europe tend to be focussed into host departments, typically physics or engineering. There are a few notable exceptions at the national level, for example SupOptique in Paris, which may, through adaptation, be a model of Europe-wide initiatives. Recently, a European Master's in Photonics has been launched by 5 universities, with the first students admitted in the autumn of 2006 (http://www.master-photonics.org). There is a need for enhanced European activities to integrate photonics in educational programmes on university level.

Fig. 4.1
European Master Programme in Photonics
© Royal Institute of Technology (KTH)

Photonics is a so called "Enabling Technology". The conversion of knowledge into products and applications plays an essential role for the sustainable growth of European economy. Therefore educational institutions, together with, and used by industry, have an important role to play in developing a culture of innovation and develop a trans-national awareness and expertise in photonics and its relevance in the 21st century. To reach this, a variety of measures are needed in order to create the overall awareness for innovation. Interaction between Industry and Academia needs to be strengthened in order to improve successful technology transfer. European professional societies in photonics also play a significant role in promoting trans-national awareness and expertise.

Perhaps one of the greatest weaknesses of "photonics", unlike "electronics", is that it is hardly a household word, and in particular young people, when considering a career, have rarely heard of the subject. This is true despite the fact that photonics is a part of everyday life, from the human visual system through lighting and displays to communications and high-tech devices such as DVD players. Whilst there are a few examples of strong national outreach activities to schools and the general public, there is a need for a more coordinated European-wide initiative to promote photonics and in particular the wide range of career opportunities that training in photonics offers.

One of the most successful European programmes for training and research in photonics has been the creation of Networks, both the Marie Curie networks focussed on training and the FP6 Networks of Excellence. Various forms of Networks have been funded since the first Framework Programmes and have had a significant impact on trans-national mobility of young scientists and engineers and on the adoption of "best practice" in training for research. There is a strong feeling that programmes for Research Networks should be expanded and made as flexible as possible to meet the demands of the diverse fields of photonics. Summer schools, workshops and industrial fairs are required to enhance photonics education in Europe.

To date many highly sophisticated research institutes in photonics exist in Europe. Nevertheless regarding the general infrastructure of European photonics research, an emerging issue is access to advanced fabrication facilities, to diagnostic equipment and to facilities for basic research. In recent initiatives such as the Integrated Projects, Networks of Excellence and Integrated Infrastructure Initiatives of FP6, some progress towards establishing these has been made but there is an urgent requirement to address the long term viability of such facilities.

4.1 Human Resources and the Qualified Workforce

According to the needs of industry a three year technical vocational education programmes should improve the implementation of photonic skills in a variety of existing professions or lead directly to careers in industry as "photonics technicians". There is strong support for the development of such courses in many European states. At a European organisational level, the most valuable initiative in this area would be the establishment of trans-national industrial placement opportunities, to provide a wider experience for the trainees and to encourage industry to look to the pool of talent in Europe when seeking new recruits. One might envisage three year vocational programmes, mainly offered by technical institutes below university level with a strong cooperative link to industry in all of the areas of photonics highlighted in the earlier chapters. Harmonisation of vocational education programmes and European wide approval of the degrees is strongly recommended.

Following the Bologna Agreement, implementation of the 3+2 year model leading to the equivalent of a Master's Degree after five years (or a first degree after three years) is being adopted throughout Europe for third-level (i.e. university, technology college or equivalent) education. Such a model provides considerable flexibility for young people to pursue academic education and/or vocational training in the basic sciences and in multi-disciplinary areas such as photonics. In the case of photonics there is a need, if industrial requirements are to be met, both for three-year programmes in third-level education, and for two-year Master's programmes, the latter typically following a three-year programme in the basic sciences or engineering.

It is at the Master's level that European wide initiatives for the teaching of photonics would be most effective, both to promote quality and trans-national mobility. The concept that a student might carry out the first three years of a Master's programme at one university, probably studying physics or engineering, and then would move to a two-year specialist photonics course, possibly in another member state, is a very flexible one. Indeed the two years Master's programme might itself be taken at two different universities, for example ones specialising in different aspects of photonics. Funding at the European level to support two-year photonics Master's courses that embrace trans-national mobility is essential to the success of such a programme. We strongly advocate that such an initiative in photonics education be considered by the European Commission.

Opinion from the photonics industry suggests that approximately several hundred Masters students per year should be funded on trans-national courses, (on 10-20 courses), with the remaining places be taken by students funded from national sources. The cost of such an initiative would be on the order of 5m EUR per 100 students per year (50k EUR/student/year). There are several examples of successful Master's-equivalent courses (SupOptique, Paris, TU Berlin and Imperial College, London) that could be used as models of best-practice in photonics Master's education. Such an activity, sustained for a significant period of at least ten years, at the minimum possible administrative level, could transform the supply of trained personnel in photonics for European industry. It would, in effect, help to create a number of international centres of excellence in photonics education distributed throughout Europe.

Education beyond the Master's level, i.e. research leading towards a PhD degree, is now being termed "fourth level" education. At this level, education, training and research all blend together, the goal being to create the scientific, engineering and management leaders, mainly for industry but also for education institutions themselves. In Europe, various "research and training" programmes since the start of the framework programmes have funded trans-national mobility for PhD students, the main current activity being funded under the Marie Curie Programme (e.g. individual Fellowships, Early Stage Training and Research Training Networks). These trans-national training programmes, despite their large administrative and bureaucratic overhead, have been one of the most highly regarded EU-funded programmes by the scientific and educational community, and have made a highly significant impact on the integration of Europe. However, despite steadily increasing funding in each framework programme, these programmes are grossly oversubscribed (by a factor of 12 recently for Networks) to the point where any strategic impact for a given discipline is weakened and the problem of the large administrative burden placed on successful applicants has yet to be resolved. Therefore it is recommended to set a strategical focus on Photonics within the existing Marie Curie Programme.

Fig. 4.2
PhD work on Petawatt Laser with 1000 High Performance Diode Lasers
© Universität Jena

A further challenge at the PhD level is to harmonise the nature of PhD training and the normal length of time taken to complete PhD study. There is a move in some parts of Europe to move the PhD away from the traditional research-focussed agenda towards a more structured programme of training, particularly in management and administration. The formally allocated time taken to complete a PhD can be as little as three or up to at least five years.

A focussed strategy of education and training in photonics is required. For this reason, we strongly advocate the European Commission to fund as a strategic initiative a **PhD Scholarship Programme** for individual students to pursue a PhD in Photonics on a (partially) trans-national basis. These Fellowships could either be individual, offered directly to students, or offered as Early Stage Training packages to groups of institutions from several member stages. The basic instruments for such a programme exist in FP6 and FP7 but there is a need for a strategic investment targeted at photonics. The cost of such a programme would be on the order of 25m EUR per 100 students based on a three-year period of PhD study, with a steady state target on the order of several hundred students. Other possible initiatives at the bilateral level might include an expansion of "cotutele" PhD programme.

PhD and Masters level training exists in many member states in Europe but as a rule it is rather fragmented. There is a strong case for the creation of a network of European doctoral schools in photonics, to promote education of the very highest level and to promote trans-national mobility of both students and teachers across Europe. The trans-national aspect is crucial for effective transfer of know-how and best-practice in photonics.

When it comes to employment, European industry tends to think nationally for recruiting new employees, yet Europe has a pool of talent from which to recruit. Whilst trans-national mobility in the academic world of universities has been transformed in recent years, largely as a result of EU investment in research and training, particularly the Marie Curie Programme, industry has been slower to recognise that national boundaries are no barrier to employment. The trans-national perspective can be fostered by universities and funding agencies by encouraging placements in industry as a first step to long term employment.

4.2 Promoting Innovation

Europe is traditionally strong in the areas of general education and curiosity-driven basic research. However, the tradition for innovation – translating basic research into new products or processes – is relatively weak compared to the USA and Far East. There are, of course, notable exceptions, for examples Europe's dominance in laser technology, but in many areas Europe lags the rest of the world in translating scientific results into products.

Both universities and industry have a role to play in promoting a culture of innovation in general and specifically in photonics. In third level education, there is a growing movement away from the assimilation of facts and towards problem solving but this trend requires actions to accelerate the process further. These actions could easily be initiated by individual university departments as part of the teaching process. Universities need to focus more on teaching students how to learn and solve problems rather than simply teaching facts, which is currently prevalent particularly in the physical sciences.

Exchange of academic employees from industry to universities and vice versa should be emphasised on every level of responsibility (Prof., PhD, Master) in order to secure continuous technology transfer.

At the same time as promoting innovation, universities need to also focus on their role in basic research, and have clear policies towards the balance of basic and applied research. The discipline of photonics has emerged largely as a result of basic research being translated from the laboratory to products, and strong programmes of basic research in photonics are vital for the future expansion of the photonics industry. For that reason, it is important that there is a "level playing field" for photonics in the newly created European Research Agency, and we strongly recommend that photonics be recognised by the ERA is a distinctive subject with its own assessment panel.

Industry as a whole defines targets and provides incentives to education and training. Both large, small and medium enterprises (SMEs) make the premier contribution to the exploitation of basic and applied research, balancing investment against risk. Examples from the US and Japan show that a successful model is the large industry-university-government consortium with excellent financial investment. The FP6 Networks of Excellence have helped promote good examples of industry-driven innovation. To foster innovation, the European Commission could consider funding spin-off activities directly, providing grants to start-up companies like the Small Business Innovation Research (SBIRs) in the US. Apart from this, it is suggested to enable European research projects (bi-, trilateral) with a limited number of participants, from different countries, in order to solve specific scientific issues with regard to industrial applications on a rather short time period (demand driven).

4.3 Outreach and Information Dissemination

Photonics is an Enabling Technology and therefore hardly recognized and "invisible" in day to day life ("CD Player" instead of "Laser Recorder"). Since there are many appealing and challenging careers for young people, we need to make a special effort to highlight the importance and benefit that photonics brings both to our quality of life and to economic prosperity. Photonics differs from the fundamental subjects of physics, chemistry, biology and mathematics, in that it is highly interdisciplinary. In most member states of Europe today, 1st and 2nd level education (primary and secondary school) deals only with the core sciences, not interdisciplinary ones. This however offers a great opportunity for photonics, since it is ubiquitous and all pervasive presence means that it is part of all the basic sciences, an awareness of photonics can be introduced by appropriate outreach activities in schools. We need to "spread the word" about photonics, both in schools and to the general public.

Fig. 4.3
1st and 2nd level education in Photonics
©VDI Technologiezentrum

The awareness of photonics should take the form of interactive websites, experimental kits (perhaps provided by industry), CDs and DVDs, regular teacher mailings all fed into a distribution chain of information that needs to be established. Much of the material already exists, or is being continuously re-written and updated, but it is largely the result of local and national efforts and not known about throughout Europe (in outreach, the wheel is being reinvented many times over). The Europe-wide coordination should lie with a European Centre for Outreach and Information in Photonics: this could be run by a university, small enterprise or professional optical society, and supported by long-term EU funding. The main task of this Centre would be to collect, produce and distribute professionally designed information about photonics technology and its impact on society and wealth creation. One might envisage a single pan-European organisation with associated national structures where appropriate. This organisation would act as the focus, and distribution point, for the many uncoordinated outreach activities that exist today but which usually have a limited (national) impact.

4.4 Research Networks

Research networks have been amongst the most well received actions by scientists and engineers throughout Europe in recent years. They have had a disproportionately positive effect on European integration, through transnational mobility, and on the spread of best-practice in research methods and quality. These comments apply equally to the training-oriented networks (e.g. Marie Curie RTNs) and to the larger "Networks of Excellence" of FP6. This is despite the level of administrative burden and over-prescriptive nature of these actions.

The education and research community **strongly recommends the growth of more European-wide photonics networks,** both through actions of the European Commission and of National Funding agencies. As regards Commission programmes, there is a strong feeling that the size of research networks should not be pre-defined but any size appropriate to the sub-topic of the research should be considered. Networks could be focussed on training by active research at high level laboratories: flexibility is the key to success and overly prescriptive organisational constraints need to be avoided.

In addition to funding the Networks themselves, there is a need to coordinate the activities of the Networks. One of the merits of the larger FP6 Networks of Excellence is that they have successfully built up databases of training opportunities, courses offered, shared software, etc. A single "Network of Photonics Networks" could coordinate and disseminate knowledge through all the networks.

Current Networks in FP6 organise Winter/Summer Schools and short courses at varying levels of open participation. The organisation of Schools and courses open to the photonics community as a whole could be a more prominent role for Networks in the future. Such Schools and courses provide an excellent opportunity for innovation, creative thinking and new cross-disciplinary research.

National funding agencies need to play a greater role in supporting trans-national research projects and networks. One possible initiative would be for national funding agencies to agree a scheme whereby cross-border funding is permitted by national agencies on a quid pro quo basis.

4.5 Research Facilities

The fabrication of test devices for R&D laboratories is expensive and requires highly developed expertise. It can only be carried out in state of the art facilities: piecemeal funding in individual university-based groups is rarely effective. There is a strong need for well funded facilities across Europe if the EU is to compete well against the US and Far East. There are examples of well funded national facilities but these would be further enhanced if EU-wide roles were developed by these laboratories. Typical areas of these facilities are III-V growth and fabrication, nonlinear materials and their characterisation, fibre optics components and devices, optical sensor fabrication, and many others. Research facilities need not only be those offering high-tech equipment: for example, a pan-European facility for electromagnetic modelling in micro- and nano-photonics would require a team of software engineers providing user-friendly code for groups around Europe.

Many European member states have established large national laser facilities and in FP5 and FP6 these facilities have networked in a highly productive way, providing world leadership in many areas of basic research. Specifically, the Integrated Infrastructure Initiative (I3) in the laser sector, LASERLAB-EUROPE, comprising 17 major institutes in 9 states has been particularly effective in sharpening the profile of each institute, providing access to individual researchers from all Europe and to fill in gaps in instrumentation or expertise beyond the capabilities of any one nation. The instrument of Research Infrastructure Networks (I3) needs to be maintained and extended to other areas such as laser-based processing, laser medicine, laser-based communications and other areas.

4.6 Recommendations

Industry

– Support third and fourth level education by offering internships and other training stages on a transnational basis.
– Contribute expertise and vision to photonics education by providing lecturers and modules on third and fourth level courses, and on short courses and industrial fairs.
– Think European when recruiting. Compared to the education sector, industry tends to focus nationally when it comes to recruitment.
– Sponsor industrial scientists to go back to university for a PhD, thereby benefiting the individual, the company and the university.
– Educational programmes: Industry has to define the skills that are needed from future workforce (demand driven).

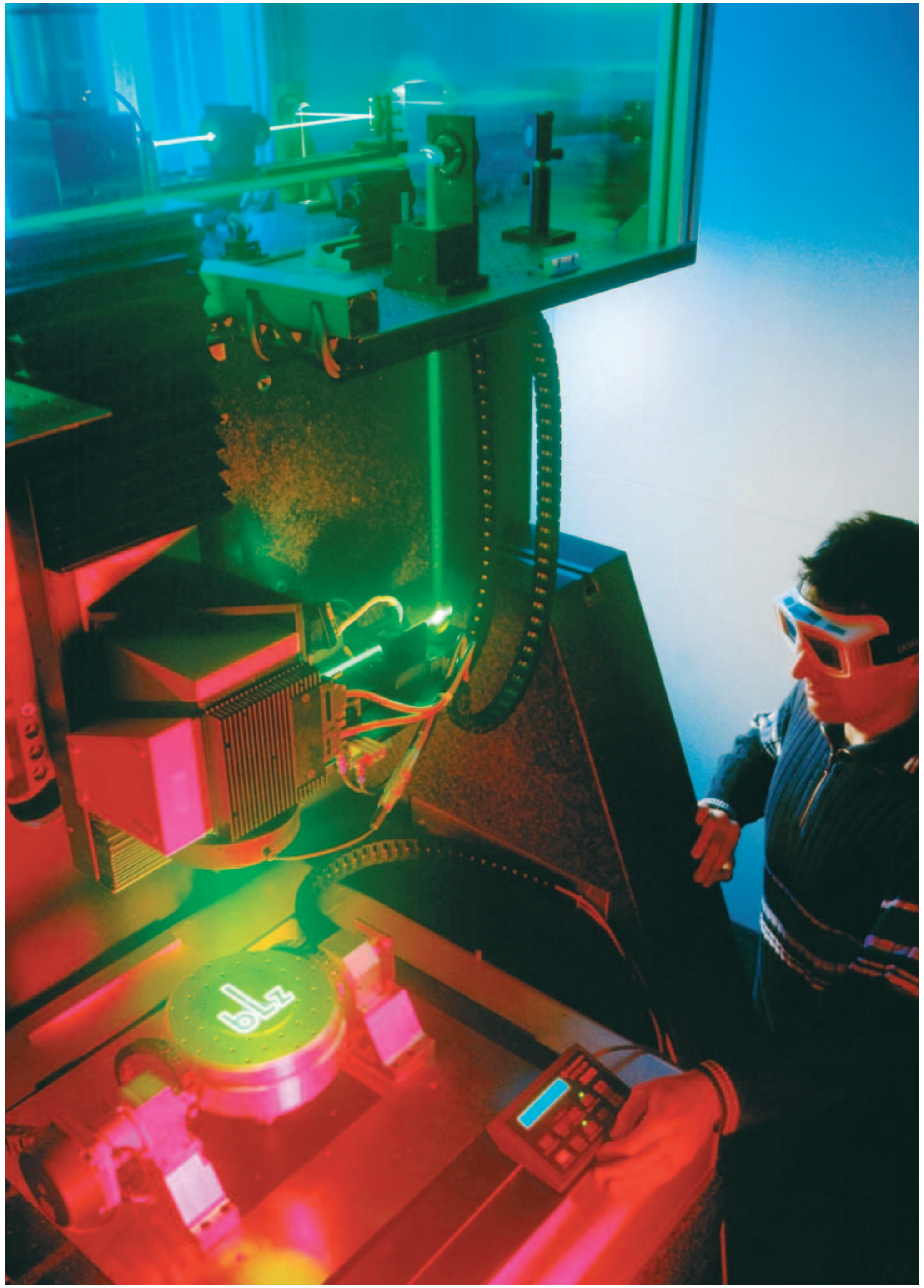
Academia

– Promote innovation in third-level programmes through increased emphasis on problem solving as opposed to learning facts.
– Promote photonics in third level education by offering photonics-related courses in every year of study.
– Promote photonics in second level education by outreach activities and by developing an awareness of photonics in engineering, medicine, the environment, consumer products etc.
– Work more closely with the industrial world by:
  – having industry-based stages in PhD or master programmes
  – promote exchange from academic staff (Prof., PhD, Master) to industry and vice versa.
– Foster more Summer/Winter Schools, workshops and short courses on a trans-national basis.
– Form European Doctoral Schools promoting the very highest level of excellence in photonics.
– Foster mobility amongst teachers as well as researchers.
– Develop new or update photonics related educational programmes (Master/Bachelor/PhD) that are derived from industry needs.
– Integrate photonic subjects into basic educational systems (Schools, Colleges etc)

National and European Funding Agencies

– Establish EU funding to support trans-national mobility of (3+2) year Master's level students to study for their final two years in specialist Master's level photonics courses.
– Establish EU funding for PhD scholarships, to support trans-national mobility.
– Establish a European Centre for Outreach and Information in Photonics, based in a University, small enterprise or professional society.
– Encourage second-level outreach activities in a coordinated way, for example by funding the development, distribution and use of educator and/or student photonics lab kits.

– Foster European Summer/Winter Schools, workshops and short courses, and industrial fairs in Photonics.
– Increased funding for research networks.
– Need for shared research facilities, either centralised (e.g. large lasers, III-V fabrication) or distributed (e.g. specialised fabrication or testing facilities).
– The European Research Agency should recognise photonics as a distinct discipline and appoint an assessment panel to oversee peer review of proposals in photonics.
– National funding agencies should consider how best to encourage trans-national research projects and networks, overcoming the present barriers for collaboration between researchers in two of more European states.
– Enabling European research projects (bi-, trilateral) with a limited number of participants from different countries for specific scientific issues with regard to industrial applications (demand driven).



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5 Implementation of the Strategic Research Agenda

The global photonics market recorded double-digit growth rates over the past years. The 150 billion EUR market (2005) is expected to more than triple within the next years and will reach 500 billion EUR in 2013. Many important European industries, from information and communication, industrial manufacturing, life sciences and health to lighting and displays and security rely on the same fundamental achievements in the mastery of light. Without strong European leadership in photonics technologies, these industries will be left vulnerable to strong competition from the USA and Asia. Photonics21 estimates that at least 2 Million of the European workforce, from solely considering the processing industry, is dependent on the photonics sector. Thus, concerted efforts are urgently required in order to strengthen European leadership in photonics.

5.1 Basic conclusions

Photonics21 has taken responsibility for bringing together all European stakeholders in photonics to develop a joint European strategy for photonics. In order to implement the Strategic Research Agenda, Photonics21 started establishing links between mainly SME based photonics industries, principal user industries, research organisations and public authorities. Today, already more than 350 Photonics21 members from 21 EU Member States and 6 associated and candidate countries joined in the common endeavours based on the following conclusions:

BASIC CONCLUSIONS OF PHOTONICS21

Conclusion 1
European photonics community is born.

Conclusion 2
Photonics is a key technology for the European economy and society.

Conclusion 3
Photonics is a common challenge for Europe (USA and Asia are strongly investing in photonics R&D).

Conclusion 4
European photonics industry and science is able and willing to make Europe the world leader in photonics – it's worth it!

However, the ambitious goals pursued by Photonics21 can only be achieved with strong support and commitment from the European Commission and national public authorities. Backing on the part of politics will be crucial in order to foster cohesion and co-ordination between the fragmented endeavours and lay the foundations for concerted action. Furthermore, political support will particularly be needed when it comes to creating for the necessary research environment capable of accelerating photonics research, enhancing cooperation, increasing public and private R&D investments and ensuring the mobilisation of the critical mass of resources. Photonics21 is prepared to work closely with the European Commission and national public authorities in order to enhance pan-European and transnational co-operation.

5.2 Key recommendations

During and in particular subsequent to the initial workshop in Brussels in December 2005, the Photonics21 members worked out the following key recommendations for actions to be taken. These recommendations address all relevant stakeholders from industry, research and politics and beyond.

KEY RECOMMENDATIONS OF PHOTONICS21

Recommendation 1
European photonics industry and science need to join forces under a strong European umbrella.

Recommendation 2
An increased public and private investment in photonics is needed.

Recommendation 3
Clear responsibility for photonics within the European Commission is needed.

Recommendation 4
A mirror group involving the relevant public authorities and funding bodies throughout Europe needs to be installed.

Recommendation 5
The present gap between photonics science and industry in Europe needs to be bridged through enhanced collaborative research and respective public funding.

Recommendation 6
Transnational and multilateral collaborative research projects should be stimulated through additional funding from the European Commission (e. g. by means of an incentive scheme).

Recommendation 7
The areas where R&D will lead to marketable products in ten years need to be identified in a systematic manner in order to derive specific roadmaps and strategies.

Recommendation 8
Detailed technical recommendations of the Strategic Research Agenda need to be updated annually by the Photonics21 members.

Recommendation 9
Photonics21 needs to seek cooperation with complementary Technology Platforms.

5.3 Key challenges

Despite the broad range and diversity of photonic applications, all of them are significantly affected by the same superordinate topics. These highly important areas need to be addressed and advanced immediately and thus should obtain high priority.

– **Light sources:** The effectiveness of photonic technologies depends on the generation of "custom-made" photons for specific applications. While today's lamps and lasers are based on different types of gas and solid state sources, future light sources will be smaller, more reliable and cheaper having excellent beam parameters; and very likely they will be made up of semiconductors only.

– **Wavelength range:** At present, photon generation is covering only few lines within the area from 193nm to 10600nm. The expansion towards the complete coverage of the range from 5nm to 30000nm will make new applications accessible.

– **Optics:** Optics and optical systems are indispensable for the transmission and manipulation of photons. In all areas of photonic applications optics will be become smaller and more complex. The main goal will be to integrate as many optical functions as possible in single optical elements.

– **Materials:** Technological progress with regard to all objectives mentioned above will significantly depend on advanced know-how in material sciences (e. g. epitaxy films, quantum dots, meta-materials).

– **Research coordination:** At large, industrial enterprises and research institutions in all photonics areas throughout Europe provide of sufficient R&D capacities. There is rather a need for more efficient coordination and cooperation than for creating new or centralised facilities. Thus, existing facilities, capacities and competences in Europe need to be mapped and evaluated in order to achieve best possible utilisation of the resources.

– **Qualified workforce:** In the near future European photonics industry will experience a shortage of qualified workforce at all levels – from technicians to graduates. In order to avert this severe threat to competitiveness it seems crucial to make photonic curricula an integral part of the education and further training for technicians, engineers and physicists.
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– **Standardisation:** In the past, European companies had lost out in the race for new international industry standards too often. More efficient and timely coordination in European standardisation will help to strengthen the market position of European companies and increase their competitiveness at a global scale, especially in areas like ICT, lighting, manufacturing and life sciences.

5.4 Required financial commitments on photonics R&D investment

In view of the massive efforts taken in the USA and in Asia, providing for sufficient European R&D investment in photonics will be an indispensable prerequisite for the future success of the European photonics economy and its competitiveness.

Today, private R&D investment by the European photonics industry amounts to EUR 3.3 billion p.a. which represents about 9% of the overall annual turnover. On the other hand, the public investment (FP6 and national funding) in Photonics presently lags far behind: the current ratio of public to private investment in collaborative photonics R&D is about 1:15 which is extremely low compared to other sectors.

Thus, two main objectives have to be tackled jointly by public authorities and industry:
1. The overall investment in collaborative photonics R&D needs to be increased in order to keep up with the global competitors and to achieve the 3% Lisbon goal.
2. The public/private investment ratio in photonics R&D needs to be adjusted which requires a disproportionately high increase of the public funding.

REQUIRED FINANCIAL COMMITMENTS

Private investment / agreed commitment from European Photonics industry:
European photonics industry is willing and prepared to increase today's annually EUR 3.3 billion R&D investment by 10% p.a.

Public investment / required commitment from public authorities:
Public funding of collaborative photonics research from the European Commission needs to be doubled (compared to FP6).
Overall national public funding of collaborative photonics research from the Member States should be doubled over the next five years.

The members of Photonics21 are convinced that jointly implementing the recommendations given and significantly increasing the R&D investment in photonics will have a major impact on meeting the goals of the European Lisbon Strategy and will lead to sustainable growth. A powerful and concerted approach is the route to ensure Europe's continued success and to ensure that its citizens can benefit from the thrilling innovations that lie just ahead.

Annex

Photonics21 Board of Stakeholders

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