PHOTONICS –
Our Vision for a Key Enabling Technology of Europe

PHOTONICS21

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PHOTONICS – Our Vision for a Key Enabling Technology of Europe

PHOTONICS21

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Our Vision for Photonics as a Key Enabling Technology of Europe

The 21st century will be the century of the photon – much as the 20th century was the century of the electron.

Following the paradigm of the rapid evolution of electronics that followed the invention of the transistor in the late 1940's, over the coming decades photonics will impact most areas of our lives, revolutionising societies and industries around the globe.

Photonics will enable:

- the development of the future internet infrastructure with multi-terabit capacity, able to leverage exciting new products and sophisticated services that fully exploit this connectivity, with huge potential impact on European society in all areas of human activities. These will have a major economical impact through nurturing radically new IT services and business models. Deploying new photonics concepts will dramatically reduce global energy consumption of our future telecommunications systems.

- new manufacturing processes with extraordinary quality that will allow mass customisation, rapid manufacturing and zero-fault production. Innovative laser processes will bring a major competitive advantage to European manufacturing industry. For example, through improving the efficiency of photovoltaic devices and enabling higher capacity energy storage devices, both these being key requirements for future electric cars and lightweight vehicles.

- radical new approaches to Healthcare moving from the current, cost-intensive treatment after onset of a disease, to the detection and prevention of the disease at the earliest possible stage. This offers greater patient survivability, less intensive treatment regimes, and significantly reduced post-treatment care costs. Gentler, less-invasive surgical methods using automated, miniaturised tools will be able to locate and entirely remove tumours. Non-invasive or minimally invasive, but highly targeted treatments based on light, used in combination with other targeted therapeutic approaches or coupled with real-time photonic-based diagnostics during treatment, will greatly improve the effectiveness of healing and speedup recovery.

- the transition in lighting from incumbent technology to low energy consumption, digital technology, built around LEDs, OLEDs, sensors and microprocessor intelligence. The thorough knowledge of lighting applications, residing in a few large companies and over a thousand SME's, positions Europe well to counter the emerging competition from the Asia-Pacific region. The introduction of advanced photovoltaics, low-energy light sources and intelligent lighting controls will lead to substantial reductions in lighting energy requirements.

- photonic sensing and imaging will contribute to a greener environment by advanced pollution detection, and enable higher levels of security and safety through the use of sophisticated surveillance technology and detection of unauthorised goods.

Additionally, the closely linked disruptive Organic and Large Area Electronics technologies will enable:

- the full integration of organic (or hybrid) photovoltaic generation devices and digital lighting control systems within buildings and windows, resulting in 'energy-positive' buildings and communities that generate more energy than they consume.

- smart organic labels that can provide electronic functionality at the level of the single item (the intelligent electronic barcode), setting the basis for a ubiquitous 'internet of things'.

Photonics Technologies – major Contributors for European Economic Growth

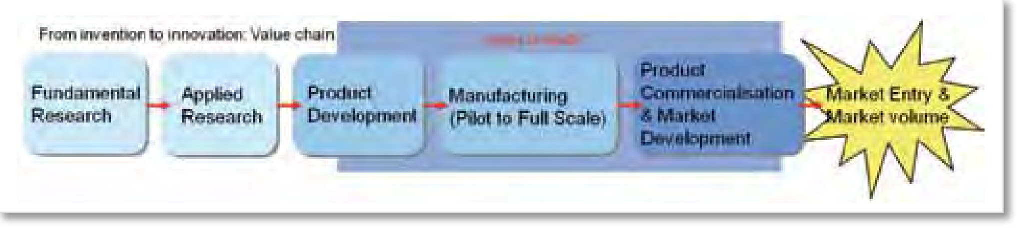
The current global photonics market is estimated to be €300 billion, and the leveraged impact of photonics in other enabled industries is substantially greater in terms of turnover and employment levels. Of this global market, Europe has an overall share of 20%, rising to as much as 45% in specific key photonic sectors. The photonics companies themselves currently employ about 290,000 people in Europe, with subcontractors employing many more. The sector is largely based on SMEs, where growth in demand is known to create proportionally more jobs than in a sector made up of big companies.

Despite the impact of the recent economic crisis, the estimated annual growth rate of the photonics sector is greater than 10%, which is 2-3 times faster than the overall growth of European GDP and faster still than the growth of the global market. This resulted in more than 40,000 new jobs being created in Europe between 2005 and 2008, a trend that is expected to accelerate in the future as better coordinated development strategies are implemented.

The Need for Speed, Size and Coordination at European Level

The European Commission has acknowledged the importance of Photonics by identifying it as a Key Enabling Technology for Europe. The time is now right to combine resources at all levels; European, national and regional, to significantly strengthen the sector, leading to the new advanced photonic technologies. This will allow photonics to address the grand challenges facing European society and maximise the economic benefits derived from the next generation of photonics products.

Europe's photonics industry and research institutes must now work with EC and national policy makers to coordinate an effective joint approach to innovation, and a pooling of investments, thereby enabling the rapid development of new products and minimising time to market.



Achieving a critical mass in this joint endeavour will be essential for identifying efficient, market-oriented partnerships and programmes between public and private stakeholders.

Our Vision for the Common Strategic Framework – addressing the full Innovation Value Chain in Europe

Previous R&D funding schemes have resulted in excellent research results, putting European photonics research in a world-leading position in many sectors, and it is critical that this be sustained through the adoption of a 'joined-up' funding strategy, thereby ensuring continued success and consequent economic growth. One weakness of European photonics innovation is the frequent failure to make the transition from successful science to industrial deployments, the latter being the stage at which new jobs are created. Bridging this gap must be a key element of the strategy underpinning the Common Strategic Framework (CSF).

Measures needed to make it happen

The dual challenge facing Europe is both to lead in photonics technology innovation and to exploit these results though successful commercialisation, thereby meeting the goals of solving the grand societal challenges and generating sustainable economic growth in Europe. In this way, the 21st century can truly become the century of the photon.

To achieve this a range of specific measures will be needed:

1. Research

For photonics to yield its full potential as an enabling technology it will be critical that the inherent synergies within the sector be exploited through integrated research aimed towards identified market solutions, rather than towards isolated components or applications. For example, advances made in laser technology must be undertaken in a coordinated manner if they are to address effectively the varying requirements of the multiple application opportunities in ICT, manufacturing or biophotonics. Such a coordinated funding approach would ideally provide support throughout the whole innovation chain from technology R&D and standardisation, through to deployment and market access.

2. Demonstration

Specific deployment programmes using photonic innovations will be needed to leverage EU infrastructure and create jobs. Such infrastructural projects could provide benefits to all 500 million people in the EU, and not solely to those directly involved in the photonics industry. Deployment programmes would be focused on life cycle and eco-balance applications and targets, and would be structured as jointly funded public - private procurements, enabled through the necessary regulatory changes.

The idea is thus to create coordinated market pull/push measures to seed and then accelerate market penetration, ultimately leading to wider technology adoption and consequent job creation. Measures would include:

- Launch of high-visibility, public-private demonstration projects that provide the European photonics industry with a first mover advantage in the global market.

- Application of a 'joined-up' approach for the deployment of European, national and regional funds towards the common goal of establishing innovative photonics manufacture in Europe.

- Support for the market deployment of photonics through public procurement, ensuring that issues such as lifetime costs, quality & technical standards, and sustainability are addressed.

3. Manufacturing

Underpinning all the proposed activities is the objective of growing photonics manufacturing in Europe and creating further high skill employment. This will be achieved at two levels; enabling the photonics products themselves to be manufactured in Europe, and ensuring that other key manufacturing sectors in Europe, dependant on photonics technology, can remain competitive.

To this end the following measures are proposed:

- Improve the infrastructure for photonics manufacturing in Europe. This involves making full use of the existing manufacturing excellence of research institutes for supporting industry, especially innovative SME's. Creation of such generic photonic foundries, based on public-private partnership, will enable cost-effective and widespread deployment of photonics technology in numerous applications, and ultimately lead to high volume production.

- Establish public-private pilot production facilities, in which industry and research institutes can jointly develop innovative photonics production processes, targeting applications relevant to societal challenges and economic growth.

4. Support for SMEs

SMEs lie at the very heart of the European photonics industry, and play a major role in driving innovation and economic growth. It is essential for the future prosperity of the European photonics industry and thereby of society that their competitiveness in the global market is sustained and grown further.

The following measures are proposed:

- Create a fast-track funding vehicle for photonics SMEs in CSF. This should allow SMEs to operate within a streamlined, more market-oriented set of rules, allowing prototype development for shorter-term commercialisation rather than being limited to precompetitive R&D only.

- Use of pre-commercial public procurements to facilitate greater access to capital for photonics start-ups. This addresses the fact that a large proportion of innovative photonics SMEs and academic spin-offs cannot access investment capital necessary for commercialising their research.

Towards an effective partnership of the public and private arenas for real economic and societal benefits

Photonics21 will expand its role to fully embrace and coordinate the wide range of activities and interests of the European photonics industry. The photonics industry currently invests some 10% of turnover into R&D, reaffirming its position as one of the most innovative industries in Europe. By working in partnership with European, national and regional funding agencies, and in particular within a CSF scheme focused on promoting innovation, this exciting sector will deliver major societal benefits and economic prosperity for Europe.

1.0 Information and Communication

Vision

Photonics is now revolutionising the information and communication technologies (ICT), exploiting the full capabilities of solid-state lasers and ultra low-loss optical fibres. Transforming modern societies into knowledge-based societies relies on using efficient means for managing, processing, storing, recovering and communicating information digitally. Today we are experiencing an explosion of world wide web-based services, but this is only just the beginning, and a simple consequence of the penetration of relatively conventional photonic technology into commercial communication systems. Emerging new concepts and disruptive photonic technologies will, over the coming decades, be key-enablers for revolutionary advancements in the telecom and datacom fields across the world. They will enable:

- development of the future internet infrastructure with multi-terabit capacity, able to fully address traffic demands foreseen in the core & access networks, and thereby facilitate sophisticated services in all areas of human activities.

- penetration of photonics at the board- and chip-level for next-generation routers, processing systems, super-computers. This will lead to novel digital "machines" with unprecedented computing power and sophistication, able to "feel", "think" and "react" in real time, with the potential to profoundly impact our everyday lives.

- disruptive new photonics concepts, some already pursued today, that will dramatically reduce global energy consumption of our future telecommunications systems.

Major Areas of Science & Technology Work

Much as petroleum was viewed in the past, bandwidth is now understood to be the "black-gold" of a future that will require our technologies to offer bit rates to end users that may be up to 1000-fold higher than can be obtained with today's DSL solutions. This requirement demands intense efforts and continuous advancements in a series of key scientific and technology areas:

- Novel components, architectures and systems for the optical wide-area, access and home networks that will enable efficient exploitation of available bandwidth, provisioning of diverse services, low-cost network operation, and security.

- Novel approaches for increasing the capacity of the optical fibers, such as the usage of advanced multi-core fibers, new multiplexing techniques exploiting the multitude of modes supported by novel optical fibers, and the exploitation of advanced modulation formats.

- New materials and advanced integration technologies for photonic components and subsystems. Large-scale integration represents the only way for photonic circuits and subsystems to meet the requirement to support advanced functionalities in a reliable and cost-efficient way, thereby meeting energy reduction and bandwidth enhancement challenges. The first link in the value creation chain is the development of advanced photonic materials offering novel combinations of optical properties, and the processing techniques needed to apply them. These materials will feed into the development of all the major integration platforms (including silicon photonics, III-V technologies, optical polymers and plasmonics) that offer solutions to the above-mentioned challenges.

- Novel optical techniques for signal processing. All-optical techniques have the potential to achieve data processing speeds up to 1000 times faster than what is achievable with conventional electronic signal processing, and so represent a key approach to reach the multi-terabit per second regime. Novel techniques, enabled by the development of new materials, will have the potential to extend the speed of operation even further, together with achieving a simultaneous reduction of power consumption.

- Optical interconnects: Photonics will also play a key role for future short-haul data communications and all-optical switching fabrics. The amount of information exchanged today in modern data centers is already creating serious bottlenecks for information transport. The incorporation of thousands of servers has created the need for transferring massive amounts of data between server racks, calling for the implementation of broadband connectivity using photonic interconnects. Optical interconnects within systems represent the disruptive technology that will eliminate capacity bottlenecks by penetrating into board and chip connectivity and ultimately into the chip itself. For example, bringing 'light-into-the-box' will be critical to achieving skew-free distribution of clock and data signals, even at ultra-high speeds between different subsystems, and will bring us one step towards the all-optical machine. Although all-optical computing still has some way to go before becoming a realistic prospect, within the next decade photonics still has the potential to replace critical electronic components of conventional computational systems, for example electronic RAM, that are now reaching their practical operating speed limits.

Impact

Today optical communications represent a large market with a stable annual increase of approximately 10%, despite the current global economic crisis. The significant share of European companies in this dynamic sector of economic activity is reflected by the presence of major European companies, a large number of SMEs, and hundreds of thousands of European employees in the field. Investing in emerging photonic technologies for communications is a strategic choice of major significance to ensure that European industry retains its current market share and further consolidates its leadership in the field. Indeed, the development of broadband applications and services supported by advanced photonic techniques and infrastructures is expected to have in turn a major impact on the economic growth and productivity of European economies in a broader sense. Additionally, significant societal impact will result, contributing to diverse areas and activities such as education, sustainable health, social care and e-government, including direct participation of citizens in the democratic process.

It is now widely recognised that reducing the level of global energy consumption is of paramount importance and must be addressed with urgency. Advanced photonic technologies offer significant advantages towards achieving this goal. Currently, the total energy required to power the Internet, including data centers, network nodes and user terminals, amounts to about 4% of today's electricity generation. With Internet traffic doubling every 18 months, a 64-fold increase in the Internet's total power consumption is expected in less than 10 years, and this would require a more than doubling of the required total capacity for global electricity generation! Fortunately the fundamental properties of light allow it to be guided with very low losses and enable significantly reduced power consumption switching & digital logic functionalities. Therefore, in addition to a reduction in device size, these visionary photonic-super-integrated circuits offer substantial reductions in energy consumption when compared to all-electronic solutions. It is evident that photonic technology indeed has the potential to offer substantial contribution to the fight against climate change by reducing the demand for energy of the ICT sector. The impact on energy savings will be far more significant when light-in-the-box becomes a reality. Clearly these major societal benefits and environmental improvements will be accompanied by a pronounced advantage to the economies that lead this technology development: Europe should embrace and further enhance its leading role.

It was photonic technologies and optical fiber communications that dramatically reduced prices for ultra-long distance communications in the 1990s, providing affordable connectivity between people across the globe. Investing in disruptive photonic technologies now is critical to assure the uninterrupted development of the next generation high-capacity broadband infrastructures that will bring communication connectivity and internet access to everyone on the planet, and with an accompanying green energy bill.

EU Spending

Drawing heavily on a broad range of technology areas, ranging from fundamental physical sciences through to fully engineered sub-systems and full system integrations, the photonics ICT sector depends upon intense, usually interdisciplinary, research efforts, and thus requires significant investments. Furthermore, the degree of complexity and difficulty of the tasks to come will far outstrip the capabilities of any single ICT industrial research organization, research institute or academic group. Future breakthroughs will be dependent on the clustering of players drawn from across Europe to assemble the necessary combinations of expertise from this broad area of related fields. The integration of large-scale photonic chips and the development of novel optical system architectures & prototypes, both of which are identified as absolutely crucial cornerstones for future development of the worldwide communications industry, are two clear examples that demonstrate the need for continuing public funded cross-border collaboration. Even though some public funding support of ICT technologies is being provided at the state level, the landscape is highly inhomogeneous in terms of size and prioritisation across different European states. Consequently, an EU initiative is vital to overcome fragmentation of efforts and to set a research agenda for activities for both short-term commercial impact and the longer-term visionary research endeavors that will ultimately lead to paradigm shifting inventions and breakthroughs. The European Commission has accumulated vast experience in developing its research framework programs. It can muster all players in European platforms such as Photonics21 and the Net!Works platform (former e-Mobility), and this unique capability will be indispensable. The EC has the influence, credibility and authority to act as the catalyst for setting the overall research agenda, harmonizing research programs with individual states, facilitating effective clustering of players, and avoiding fragmentation of efforts.

Partners & Instruments

To achieve the vast opportunities apparent on the horizon, equally substantial scientific and technological challenges must first be overcome. Collaboration across Europe has been the centerpiece of the successful R&D program developed and supported by the European Commission through the years. The need to collaborate is even more intense now than ever before. Equally intense is the need to exploit technology platforms, such as Photonics21, and to coordinate the key players in photonics research under a common, pan-European research vision. Coordination of similar activities within the same work group or of complementary activities within different work groups of the platforms is essential for overcoming fragmentation of work. Taking as an example the existing Photonics21 platform, fabrication of new photonic integrated circuits within the area of WG 6 should be supported by state-of-the-art common infrastructure established in generic foundries. Similarly, the research agenda for ICT developed in WG 1 is intertwined with activities in WG 6 on photonic component & platform development, with research, education and training activities in WG 7, and with activities on photonic system/subsystem development for the life sciences, medicine, metrology and security in WG 3 and WG 5. Natural partnerships exist and should be carefully structured between members of the different photonic communities represented in these working groups. Finally, broader scale coordination of the different platforms, such as provided by Photonics21 on photonics and the Net!Works platform on communication networks, will be essential for attaining a coherent research landscape with well-aligned efforts. The current innovation ecosystem employed within the EC framework programs, composing of the triangle of academic, research institute and industrial partners, and in particular with the active participation of SMEs, has proven highly effective at generating innovation for Europe. By facilitating such cross-fertilisation between workers in disparate research areas, disruptive solutions and advances in the state-of-the-art of photonics communications have been achieved.

The funding instruments currently employed are largely appropriate, although some tuning in their definition and scope may be advantageous, particularly with regards to simplification of (EC) procedures to allow SMEs to take full advantage of the European research forum.

2.0 Manufacturing and Quality

Vision

Photonics will be a strategic element and a key enabling technology in future manufacturing processes, even more so than it already is today. With tools using light in the form of a laser, processes can be handled automatically and flexibly, producing components and products with extraordinary quality. The trend towards customisation and the growing importance of industrial design, as observed most notably in consumer electronics, will require novel methods to enable new product shapes and lot-size-one production capabilities. The inherent flexibility of the laser tool makes it the ideal choice for meeting these requirements. Furthermore, the advantages of the wearless working laser tool and of integrated monitoring and control systems based on intelligent photonic sensing techniques, will allow zero-fault production to be achieved, leading to higher product quality and reduced wastage.

The laser is a key element for a future sustainable economy in Europe. Innovative laser processes will increase the efficiency of photovoltaic devices and enable energy storage devices with higher capacities, which is a key requirement for future electric cars. The ability of the laser to machine materials that are otherwise very difficult to process using conventional tools, makes it an ideal tool for fabricating lightweight and high-strength constructions, such as crash-safe car bodies or wind turbine blades. Furthermore, the laser itself will play a major role in facilitating green manufacturing, since laser processes allow for very precise, well-controlled and therefore highly efficient energy deposition on the work piece. A further environmental attraction of laser-based processes is the reduction of chemical usage, for example, by replacing the chemical etching baths currently used for the manufacturing of rotogravure cylinders by a laser cleaning process.

Today, photonics is not solely a driver for innovation in manufacturing; the photonic technologies, laser tools and process systems are themselves becoming products in their own right. In this way, photonics aligns well with the mission of achieving sustainable development, employing efficient use of energy for flexible and resource-efficient production.

Further future challenges are to broaden the spectrum of applications of laser production technologies, especially with the increasing demand for energy and resource efficient products. This applies to all sectors where laser technology can offer new production solutions, new product qualities and cost benefits. Key opportunities for this are energy conversion, electronics, hybrid materials, lightweight construction, mass customization and rapid manufacturing, print technology and product marking.

Major Areas of Science & Technology Work

Europe is in a world-leading position in the market for photonics in industrial production, with the world's largest laser companies and manufacturers of key laser components located in this region. Europe's laser technology leads in terms of innovation and optical excellence, when compared to other regions. To ensure that this competitive edge is maintained, the principal research and engineering efforts have to focus on more efficient lasers (more light output for a given energy input), longer-lasting components that can be readily recycled, and maintenance-free manufacturing equipment. The markets for new processing strategies and new photon transmission systems also have to be addressed. The most challenging problem in laser source manufacturing is price pressure, a result of cost competition exerted mainly by Asia.

The primary research areas have to cover all steps in the manufacturing process, from basic research and development through to the products themselves and their market penetration.
In terms of the photon sources and optical components, the focus has to be set on reliable, reproducible and precise methods for automated assembly of photonic devices and lasers with improved performance in terms of power, beam properties, efficiency and size, as well as better spatial & temporal control and stability - and all at lower cost. Further aspects include adaptive reconfigurable beam delivery networks capable of high power and intensity. New applications are expected, for example through the application of ultra-short laser pulses. However, to take full advantage of such new laser sources, new high-speed beam deflection technology also needs to be developed in parallel. These improvements will be critical for extending laser technology to rapidly growing market sectors such as green manufacturing or mass customization of consumer goods.

In the drive to higher product quality, process monitoring, adaptive control of the laser manufacturing process, and quality inspection of laser manufactured goods need to be further developed and implemented in production. Aspects of integrating laser sources within machine tools, in particular robotic manufacturing tools, also require optimisation and standardisation.

The physical and technical limitations of today's optical components can only be overcome through interdisciplinary research efforts in manufacturing technologies, microsystem engineering, nanotechnology, telecommunications and optics. More fundamental limitations must be tackled by basic research on the interaction between light and matter, on novel materials, and on new structures with revolutionary photonic properties. This will require work in materials science, quantum optics, thermodynamics and solid-state physics.

This research will open the way to groundbreaking new optical components and the corresponding technologies for their fabrication. When combined with the results of accompanying fundamental work in laser beam/material interactions and process control, exciting new photonic processes for manufacturing will be realized, offering more flexibility, more functionality and greater productivity. Such innovative components and processes are the key to realising this vision of strengthening and sustaining Europe's leading position on the world market for photonic technologies and mechanical engineering.

Impact

Lasers represent a versatile tool for handling a wide range of manufacturing tasks all along the workflow chain, from material processing through to quality control. Typically the added value generated with a machine tool or a laser is a multiple of the cost of the tool itself. Taking due account of this factor, the laser industry is a multi-billion Euro industry, which also has a leverage effect on many other industries, most notably in the European automotive sector.

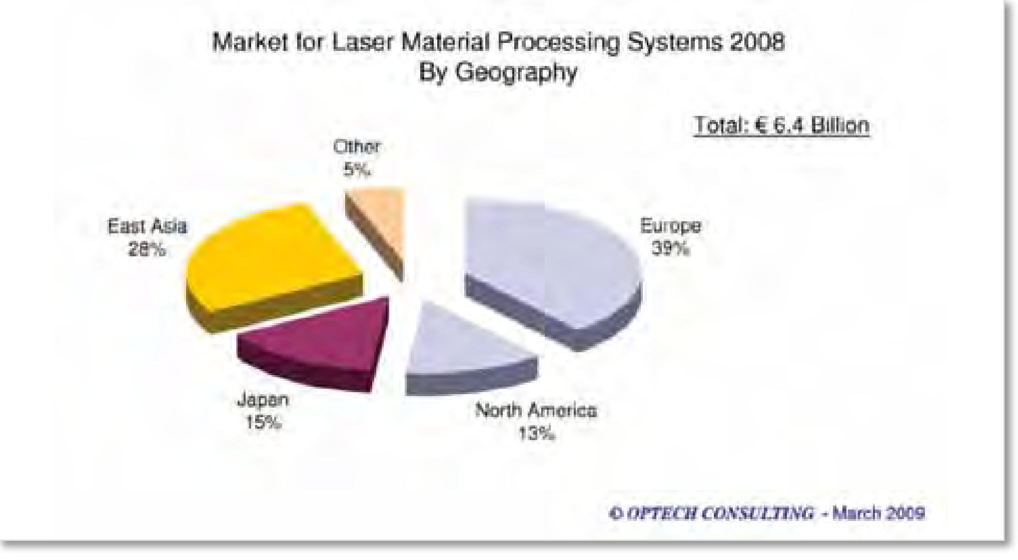
As a direct consequence of the financial and economic crisis, the world market volume for laser materials processing systems in 2009 was about €4 billion, down from the 2008 figure of €6,4 billion. However, leading laser market experts are anticipating a return over the next few years to the solid growth rates seen before the crisis. In terms of the global market volume, Europe currently holds a market share of 39%.

In addition to the clear economic benefit for Europe, the impact of next generation laser sources and photonic manufacturing processes on today's most challenging societal questions will be high. Three specific examples are:

- Sustainable (Green) Economy: Light weight cars, batteries and fuel cells, high-efficiency photovoltaic modules, to name but a few, all require laser technology for their production. A key element for green manufacturing is that lasers reduce energy consumption and chemical waste.

- Aging Society: From pace-makers to synthetic bones and from endoscopes to the micro-cameras used in in-vivo processes – laser technology plays a major role in addressing the needs of our ageing society.

- Information Technology: Laser-powered extreme UV-light sources will be the tool needed for the future miniaturisation and cost reduction of microelectronics.



In terms of the competiveness of European industries, the proposed research priorities have a major impact on maintaining the established industrial leadership of laser technology in Europe. They will have a direct and positive influence on the future advanced, laser-based manufacturing technology in Europe. Additionally, they will broaden the base of the manufacturing technology across Europe thereby overcoming current disparities and ultimately sustain economic strength.

EU Spending

To strengthen the overall European community and to bring together the best technical partners, international cooperation paves the way for future growth of the industry within Europe. Exchange of personnel will be one of the major opportunities to raise this, not only for improving knowledge transfer, but also bringing the European community closer together.

In order to maintain and improve the leading role of laser science in Europe and the competitiveness of its laser industry, solid and continuing funding for research and development is needed. Lasers are complex products that require a broad range of skills and application know-how for their effective development. However initial development of new equipment will be accompanied by high risk, with direct implications for the entire manufacturing process chains. Concerted actions in the form of support programs on a European level are thus a key success factor for a competitive role for European photonics.

Another justification for funding is the significant number of SMEs in this industry, in many cases representing the technology leaders. These companies do not usually have the financial resources to invest strongly in development and often lack the network needed (in the form of R&D organizations) to support their efforts. Here, the European community is well positioned and should play a major role in supporting the industry financially and in strengthening the integration of R&D organisations with industry, most especially for the SMEs.

Partners

Photonics is a cross-sector technology, and Europe-wide cooperation along the entire process chain will be essential for future progress and success. All the relevant players need to be involved in R&D projects, research networks and clusters, providing the scientific and innovative solutions to manufacturing problems.

New opportunities for design and manufacturing will require highly qualified personnel at all levels. Demand for skilled staff will continue to increase and special efforts in education and training will be necessary to meet this demand. The creativity of skilled individuals will be a key factor in ensuring innovation and maintaining Europe's leading position in photonics manufacturing.

3.0 Life Science and Health

Vision

Projected global demographic changes will have drastic consequences for the healthcare systems of the industrialized nations. The number of people living in Europe will most likely reach a historical maximum followed by some decline during the 21st century. The age group 0-15 is already shrinking, whereas the number of people older than 65 years will double, and amount to 1 billion worldwide, by 2030. As a consequence, the occurrence of age-related diseases like Alzheimer's, cardiac infarction, stroke, age related macular degeneration, and cancer will increase dramatically.

The growing burden of older populations on health systems is in direct conflict with the decreasing number of people of working age who have to fulfill the inter-generational contract of support. According to the Berlin Institute for Population and Development today there are 25 senior citizens in the age group 65+ for every 100 Europeans in the working age group (15-65). By 2050 this ratio will have deteriorated to 53 senior citizens per 100 Europeans at working age. In that year Italy, Spain and Bulgaria are expected to have the highest old age dependency in Europe. Whilst in Germany the ratio of working age to retired people will be cut nearly in half by 2050, from about 3 to 1.6. The health care expenditure per citizen of working age (the relevant metric for a solidarity-based health system) will multiply, and it will become an enormous challenge to provide adequate health care for all European citizens in the future. This challenge can best be met through breakthroughs leading to new cost-effective medical technologies.

In addition to increasing costs for social support and medical needs, the increase of elderly people with a lower mobility will be accompanied with a decreasing number of doctors. Providing comprehensive medical care along traditional lines will be increasingly difficult, especially in rural areas.

To meet these challenges we need a paradigm shift moving from the current cost-intensive treatment after onset of the disease, to the detection and prevention of disease at the earliest possible stage. Three quarters of the global health care expenditure is currently spent on the symptomatic treatment of progressed illness. Here, Biophotonics demonstrates its enormous potential as a key enabling technology to identify the root cause of diseases rather than easing existing symptoms. Technological advancements in Biophotonics will bring new hope regarding the diagnosis and therapy of diseases that cannot at present be treated. Point-of-care equipment can be expected within the next 5-10 years that will allow the investigation of a multitude of parameters in real-time. In the not too distant future, our personal digital assistant will not only remind us of important dates or recommend the nearest restaurant, but also be able to monitor our state of health and provide necessary guidance. Biophotonics will also greatly accelerate molecular diagnosis, and so constitute a great step towards personalized medicine and a better quality of life.

Major Areas of Science & Technology Work

Photonics will be a key enabler of this necessary healthcare revolution:

- Improved microscopic and spectroscopic methods will allow us to understand and manipulate cell processes, tissues and whole organisms, thereby gaining deeper insight into the origin and progress of diseases, and so develop effective strategies of prevention. Much better understanding of the cellular processes is a vital first step to ease the human and economic burdens of disease. Current methods must be adapted and enhanced, for example, to allow functional real-time measurement of three-dimensional biological samples.

- Some of the most widely used and effective medical imaging modalities of today come with risks and exposure guidelines. Others require surgical procedures to obtain diagnostic images. Gentler and less invasive imaging methods based on photonics or multimodal approaches bundling photonic and non-photonic techniques together will enable prevention and facilitate the early detection of diseases.

- Where surgical procedures cannot be avoided, innovative endoscopic methods based on microscopic and spectroscopic approaches ("optical biopsy") will render these techniques gentler and less invasive. The goal is to have miniaturized and automated tools that are able to identify autonomously and then remove tumors down to the last cell in cooperation with the surgeon.

- Diagnostics will be complemented by versatile 'lab on a chip' biosensors that are non-invasive, light-based, and ultra-sensitive. These will allow monitoring many important patient parameters at the bedside, in the doctor's practice, at home, or even during our everyday lives in the form of wearable equipment. They will offer unparalleled speed, low cost, and consequent higher effectiveness. Low cost and rapid operation genome analysis equipment based on photonics will speed up understanding of diseases and how best to treat them for each individual patient. Eventually they will be found in doctors' offices, helping us realize the request for personalized medicine.

- Non-invasive or minimally invasive, but highly targeted treatments based on light, such as PDT, used in combination with other targeted therapeutic approaches or coupled with real-time photonic-based diagnostics during treatment, will greatly improve the effectiveness of healing and speedup recovery.

- Improved optics and photonic components such as light sources (fluence, wavelength, etc.) and detectors (stability, sensitivity, time resolution) will in many cases be prerequisites for the above developments. At the same time, software solutions for data acquisition and evaluation, all guided by biological and medical understanding, will need to keep up with the physical science and engineering developments.

- New labels that can be used for in-vivo diagnostic imaging in humans will allow the transfer of existing imaging modalities from model organisms into clinical routine. Labels will greatly enhance the specificity of diagnosis and/or treatment, and thus will open new dimensions of applications.

Impact

At the present, many of the developments in the field are still in their infancy or at demonstrator status. They are far from achieving the essential safety and efficacy levels required for clinical acceptance or commercial utilization, neither do they match the ever shorter cycles of industrial production. Moreover, it is important to keep in mind the usability aspects of the end product to be simple and safe to operate. These steps take time and need major investment. Despite this, it is clear that the potential benefits of Biophotonics will lead to a multitude of new developments that will improve healthcare, life expectancy and the quality of life in Europe. Furthermore, they will cut costs significantly and will help to strengthen the European position and maintain its leadership in Biophotonics compared to Asia and the United States. Public funding has been key to the medical progress we have seen, and is unquestionably essential to further progress in health-care. Good health is undoubtedly something we all strive for, and a healthy population is a primary measure of the true prosperity of Europe.

EU Spending

Compared to other fields of science and technology, the multiplicity of Biophotonics comprising both applications in biology as well as in medicine is striking, perhaps even unique. Not only is Biophotonics rich in different subfields, but it also unifies many disciplines. However, this diversity is accompanied by national fragmentation that brings with it risks of inefficient deployment of limited intellectual and financial resources. This can only be overcome by a truly comprehensive European approach to help guide the multitude of disparate developments towards the solution of the current and looming economic and demographic challenges resulting from the ageing of society in Europe. Such an approach could also help to address the issues of transferring laboratory advances to clinical (bedside) solutions, and so solve the 'long time to market' obstacle closely connected to health and safety regulations, which themselves could be advantageously dealt with in a European context.

Partners & Infrastructure

To put these aims into practice, it is of the utmost importance to continue to involve the end-users (physician/clinicians and biologists) at the earliest stage of development. For clinicians in particular this poses a challenge, as research is at best secondary for them, and, no matter how enthusiastic a clinician may be, increasing time pressures inevitably curtail meaningful involvement. In general it is desirable to connect photonics to health at all levels, and to provide and promote the vital link between the researchers focusing on procedure and instrumentation and those that search for new biomarkers or molecular labels. This intensification of collaboration must also take place at the industrial level, including the photonic, medical and pharmaceutical industries. The ongoing collaboration with the ETP Nanomedicine should be intensified and extended, as there are substantial potential overlaps, especially with the WG “Nanodiagnostics.” In addition, the close cooperation with the Biophotonics Networks, such as the European Network “Photonics4Life” and the International initiative “Biophotonics4Life”, should continue, as they directly reflect the interests of WG 3 in the academic world and could also be a supplement for WG 7 “Photonics Research, Education and Training” with specific reference to Biophotonics.

The ageing of society will inevitably, also affect the field of education, where a shortage of skilled workers can be foreseen. To counter this, it will be essential to train students in an effective and motivating way to acquire transdisciplinary skills and thinking. Whilst a comprehensive multidisciplinary education does not seem feasible, projects and project groups should be initiated to increase the understanding between disciplines, and so help overcome the serious issue of the lack of a common language. Poor communication hinders the cooperation between individual disciplines that is essential for innovative health care advances. Additionally, closer linkage between industry and universities needs to be established. The latter must understand the needs of industry and gain an appreciation of corporate thinking and transaction. Close co-operation is needed to allow industry to contribute to translational medicine in a way that helps the educational institutions provide the best training for long term and fulfilling careers of students. These people will be the future professionals that will lead the healthcare revolution in hospitals as well as in industry, and thus ensure that the new developments reach the patients.

4.0 Emerging Lighting, Electronics and Displays

Vision

The massive market uptake of Solid State Lighting (SSL) will allow Europe's lighting industry to strengthen its number one global position. Concurrently, to prepare for future market developments, the European R&D community is shifting its focus to developing organic photonics and electronics in order to enable cost breakthroughs in the emerging fields of lighting, plastic electronics and displays. As a direct result of this concerted effort, Europe will maintain its leadership in lighting technologies, and at the same time become a major player in the emerging and rapidly growing field of organic and large area electronics (OLAE).

Over the coming decade, the lighting domain will make a transition from the incumbent technologies to new digital technologies, pivoting around LEDs & OLEDs, photonic sensors, and built-in intelligence. By combining its unique expertise in lighting design with its growing strength in photonics, the European industry will be the leading player able to offer high quality light with a lower carbon footprint. The deep knowledge of lighting applications, residing in a few large companies and over a thousand SME's, places Europe in the perfect position to counter the emerging competition from the Asia-Pacific region.

Exploration of the potential advantages offered by large-scale and eco-efficiently produced organic solutions will also allow longer term European growth in new application areas. The full integration of organic and hybrid photovoltaic systems into buildings and windows will contribute significantly to the realization of energy-positive buildings and communities. Cheap, mass-produced organic electronics and the smart systems built around them will result in the creation of many new business opportunities exploiting the use of electronics and digital processors. For example, smart organic labels can provide electronic functionality in the highly price sensitive logistics market. Similarly in healthcare, the adaptability of organic electronics to individualized solutions will pave the way to personalized diagnostics and medical therapies. Furthermore, the development of low-cost and scalable production techniques for organic electronics will provide a unique opportunity for Europe to re-capture market share in display manufacturing, fuelling the booming markets for smart, flexible and mobile signage & displays.

Major Areas of Science & Technology Work

Three overriding themes will be instrumental for realizing the vision outlined above:

- The need for new materials targeting performance enhancement.
- The need for better components, device integration, and system architectures to serve the needs of the different applications targeted.
- The need for sustainable, low-cost manufacturing methodologies and platforms.

Research into new materials for the lighting and display domain will be focused on improved performance at lower cost, whilst for the domain of OLAE, breakthroughs in materials performance and in scalability will be required in order to compete with the existing solutions.

In order to serve the market drive for sustainability, scalability, adaptability, and ease of use, the new photonics components need to be integrated in larger and more energy efficient systems. System integration is already a given for displays and smart systems, and with the advent of digital lighting technology it will also become instrumental in this application domain. When compared to ICT systems, the much higher node density and lower data exchange rate encountered in typical lighting systems will necessitate the development of new architectures to bring cost-effective solutions to the market.

As well as the impact of the materials themselves, the manufacturing processes employed will also have a substantial impact on the overall cost build-up. High-speed assembly, large area deposition & patterning, and roll-to-roll manufacturing will all be critical for reducing costs to levels far below those of today's solutions. For the area of mobile and flexible applications in particular, new printing and lamination techniques are expected to offer a more economical alternative to currently employed processes.

Impact

These planned actions will result in an increase of Europe's market share in lighting beyond the present level of around 35%. The global lighting market is projected to grow from today's €50 billion, of which less than €5 billion is based on SSL technology, to a €120 billion market in 2020, of which more than €90 billion will be accounted for by SSL. Future solid-state lighting sources are expected to outperform all other light sources in terms of efficiency, offering energy savings of 50% over the present installed base. When SSL is combined with intelligent light management systems to regulate the output according to ambient lighting conditions or to people's presence and activities, additional savings of 20% are anticipated. The McKinsey analysis of carbon abatement costs shows that lighting offers the second largest savings potential (exceeded only by building isolation). In this way SSL will contribute substantially to the targets set in the European Strategic Energy Technology Plan.

The integration of SSL, organic photovoltaics, and large area sensors into building components will create a huge advance towards the realization of low energy buildings and energy-positive neighbourhoods. However, to cope with the future energy demands of cities, huge areas of solar cells will also be required. With currently deployed silicon-based PV technology it will not be possible to accommodate this huge surface area requirement in the urban infrastructure. The big attraction of OLAE technology is the opportunity for applying it on many urban surfaces, including windows and facades, without interfering with the existing functionalities of these building elements, thereby making it feasible to match accessible energy-harvesting capacity with energy consumption needs. More than 40% of global energy use derives from the requirements of buildings, making this the primary priority area for achieving Europe's 2020 targets and the energy ambitions set for 2050.

The OLAE sector is projected to grow into a €100 billion market by 2020. Europe's strength in manufacturing equipment and particularly in vacuum coating and printing technology, combined with its present leadership in materials and application, will pave the way for capturing a substantial part of this new market.

Role of the EU

The cost of R&D in photonics is substantial, comparable indeed with the level seen in the semiconductor industry. Only by orchestrating the research effort at a European level, can effective use be made of the limited resources available. Vertical integration of the different domains within the Framework programme, namely materials, manufacturing processes, devices and systems, would prove a major step forward towards achieving a more effective European R&D effort.

In addition to the need for research, those nearer-to-market technologies will also require vital support for their industrialization and commercialization. This is because research alone does not guarantee commercial success - extensive efforts are also needed to overcome the barriers to market uptake. For example, despite the fact that over the last five years several high-level studies have proved that investing in efficient lighting rapidly pays back the initial investment costs, these initial costs are still seen by the users as a major hurdle to adopting this technology. The EU and other public authorities can play a critical role in changing the mindset of European companies and citizens. This would be to act as lead customers, thereby validating the results of Europe's R&D effort in real market conditions. Following the outcome of this validation, the EU would then be able to set precise requirements for green public procurement for adoption across Europe.

The effective protection of European citizens from sub-standard products and solutions imported from outside Europe requires that the EU accelerate the introduction of quality labels for SSL and PV.

Partners & Infrastructure

The vertical integration of the research effort mentioned above not only applies to the EU, but also on their main advising bodies, the European Technology Platforms. Bringing different platforms together around relevant societal themes is undoubtedly the preferred route towards coordinating the actions within the different EU instruments. Whilst placing industrialization and commercialization on Europe's radar screen, we also need to form effective partnerships with all players along the value chain, the users, owners, system installers, lighting designers and architects.

Sophisticated production equipment and its associated clean-room infrastructure are the primary cause of the ever-increasing costs of R&D. Through a lack of coordination, similar infrastructures covering many of the potential application fields are being built all over Europe. It is recommended that existing centres be given a clear application focus and that significant improvements be made to their accessibility for potential users throughout the lighting industry. Although industry is often able to build its own curriculum, the burden of training and education can be much higher for SMEs. Not only does this present a problem for photonics start-up companies, but also for the many SMEs operating upstream in the value chain. To address this, better incorporation of photonics at all levels of Europe's educational systems is needed.

5.0 Security, Metrology and Sensors

Vision

The twenty-first century is the century of the photon. The photon will drive all important technologies and applications: information & communication, manufacturing, healthcare & life science, lighting & displays, and photonics for safety & security. Accessing the advantages offered by the photon in every one of these fields requires that there must be an “eye” to see the light, thus making photonic sensors the indispensable enabling devices.

Photonic sensors are the key technique towards providing modern healthcare with manageable costs, particularly as the effects of the aging society healthcare start to impact. Photonic, ultra-sensitive “lab on a chip” sensors offer the prospect of non-invasive online diagnosis and reliable early recognition of diseases. Fiber-based sensors will be able to distinguish diseased tissue from the healthy, facilitating its removal using minimally invasive surgery. X-ray detectors offering the greatest sensitivity and highest resolution will reduce the x-ray dose needed for radiological examination well below the hazard limit, substantially increasing patient safety.

To ensure security within Europe, biometric data controls at national borders (airports, seaports, crossings) are becoming indispensable. In the future most of these controls will be performed by smart and highly sensitive optical sensors that will able to detect all necessary data (face & iris recognition, fingerprints, pathogens, etc.). These could be remotely positioned to allow measurements to be made across long distances and in real-time, thereby reducing waiting times to a minimum but without compromising security. This also includes the exploitation of “new” windows in the electromagnetic spectrum, for example THz radiation, which can penetrate many packaging materials, and thus has wide potential applications for security and food production. In particular drugs and explosives have characteristic signatures in the THz frequency range, thereby offering greatly enhanced capabilities for the detection of these materials.

Achieving sustainable manufacture will be a key challenge for Europe over the coming decades, where eco-friendly design and sustainable production techniques with minimized energy consumption are key requirements. Photonic technologies and in particular photonic sensors will play a critical role in achieving this. Compact, fully integrated, self-sustaining sensor arrays with low-energy consumption will be able to provide real-time, 3D measurement of key process parameters, allowing accurate monitoring of the full production process. The improvements in manufacturing techniques facilitated by such detailed knowledge of the process will make zero-loss production feasible, reducing economic risk and so maximizing commercial and ecological efficiency. Additional economic benefit will result from the ability to produce fully customized products with minimal equipment set-up requirements. Furthermore, the combination of optical sensors with low consumption light sources (LEDs) will provide the key components of future smart lighting systems, offering enhanced security and safety whilst minimising electrical power consumption.

Smart photonic sensors will rapidly impact numerous aspects of our everyday lives. For example, the car of the future will be full of smart photonic sensors: these will recognize the driver as he enters the car, instruct the vehicle electronics to adjust to the driver's preferred settings, and even monitor the driver's condition during the journey, allowing early detection and warning of the onset of 'micro sleep'. Additional photonic sensors will monitor the progress of the car during the journey, allowing intelligent driver-assistance control or night vision systems to ensure the safety of driver and other road users. In the longer term, photonic sensors will play a vital role in the development of fully autonomous vehicles, a development seen as being essential for maintaining the mobility of individuals in an aging society.

The increasing capabilities of ICT systems incorporating ultra-high speed communications, more powerful processors, or even optical computing, will require greater sophistication of user interface to maximise efficiency. Photonic sensors used in conjunction with smart displays will be used to provide gesture-based user inputs and augmented reality displays for the enhanced control of future computing systems.

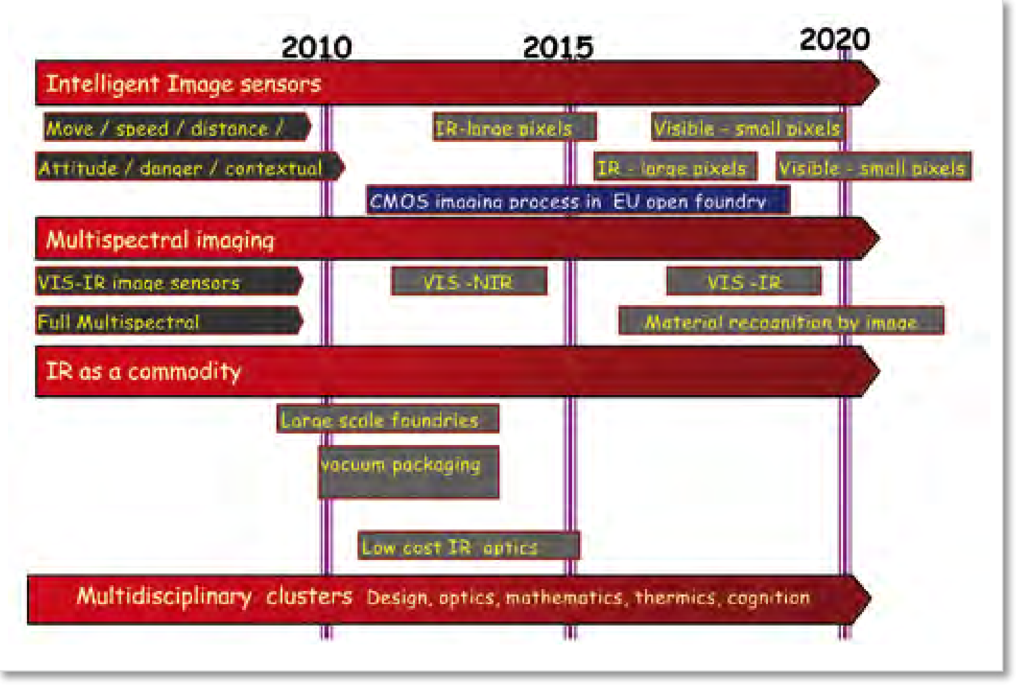
Major Areas of Science & Technology Work

The European market share for measurement and automated vision systems currently exceeds 30% of the total €23 billion world market. In order to preserve and extend this competitive position, Europe's R&D efforts in the field of optical measurement and sensors will have to focus on a number of key areas:

- enhanced sensitivity operation, single-photon detection.
- minimally invasive and highly functional sensors for in-vivo monitoring of patients.
- the ability to operate in all ambient conditions, including lighting, temperature, pressure, humidity, etc..
- new sensing functionalities, including unexploited wavelengths, active vision, 3D-Vision, etc..
- new large area conformable sensors and sensor arrays.
- computation & signal processing functions built-in at the sensor level leading to smart detector arrays.
- self-sustaining sensors with low ultra-low power consumption.

For many applications the goal of researchers has traditionally been to achieve ever-greater sensitivities. However, in some areas we are fast approaching the fundamental physical limits of these devices, and other approaches must be explored. This has resulted in recent efforts being focused on multi-functional devices that are tailored to the specific requirements of the particular application. These devices will be monolithic, stand-alone devices providing additional functionality through integrated computation and signal processing capability, implemented at the sensor level. Application-oriented research is essential for developing new detection concepts that integrate on-chip, pre-processing capabilities such as correlation, filtering, Fourier transforms, and other advanced functions. Additional European research activities will also be needed to develop ever more sophisticated functions, such as imaging in non-visible wavelengths, active sensing, quantum imaging & detection, direct detection of coherence & polarization, spectroscopic measurement, and distributed sensing technologies. These new functionalities will require radical new design concepts and adapted imaging theories to be developed, together with the corresponding enhanced simulation tools, and this will involve a significant degree of fundamental research. At this critical time, it is essential that investment be made in photonic sensor technology to secure and further extend the established leading position of Europe in this sector.

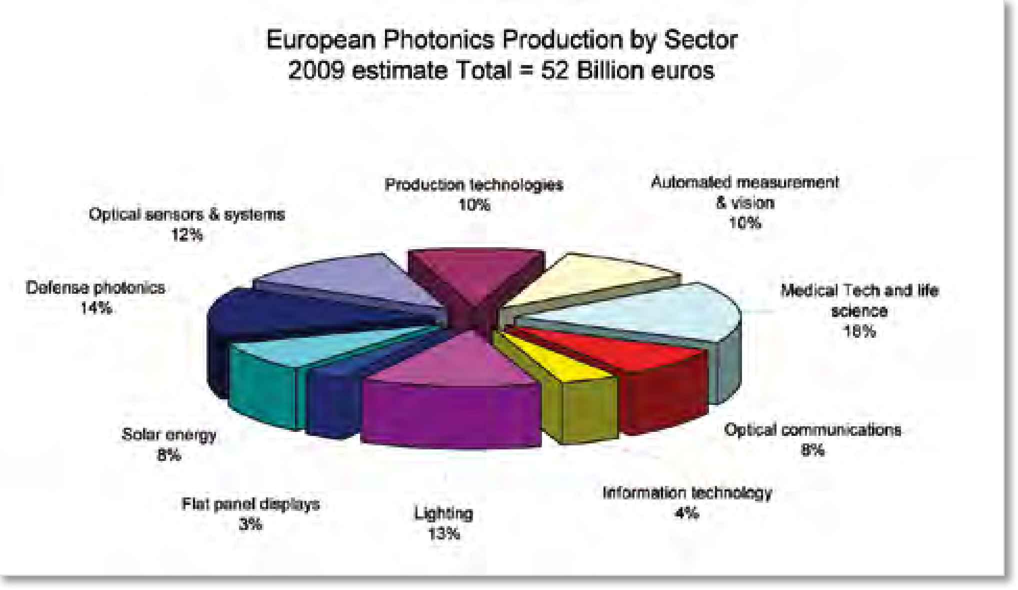
The diagram below shows the timelines for the specific technological development work needed for different wavelength bands of image sensors. It includes a specific infrastructure requirement for a CMOS-compatible imaging process implemented in an open European foundry. This will be needed to maintain European control of the whole value added chain, thereby securing commercial freedom and employment within Europe.



Technology development timelines for image sensors in three wavelength bands (VIS = visible, NIR = Near Infra Red, & IR = Infra Red).

Impact

As previously illustrated, photonic sensors are key enablers in a wide range of industrial production areas including, healthcare, surveillance, manufacturing and automotives. The resultant leverage makes photonic metrology and sensors a multi-billion Euro industry, current amounting to a €13.5 billion annual turnover (excluding €9.4 billion from Health Care and Life Sciences), employing a high degree of skilled European workers, and with little threat of Far East delocalisation. The field benefits from prominent leading edge research centres and universities, and is the largest photonics sector (representing 22% of overall European photonics activity, not including the part of defence photonics, see the following figure). Europe is currently the world leader in several market segments, including surveillance cameras, biosensors & structural monitoring sensors, and the proposed core areas of research will ensure this leadership is maintained.



The impact of photonic metrology and sensors on the major European societal challenges will be profound, as evidenced by the wide range of applications seen for this technology. A few specific examples illustrate this vividly:

- photonic sensors will deliver advanced diagnostic devices and enable treatments meeting the healthcare needs of an aging society in a cost-efficient manner.
- photonic sensors will enable a more sustainable economy by providing highly efficient manufacturing techniques tailored to the specific needs of the product.
- photonic sensors will make our daily life more convenient, safer and more secure by providing multi-functional and smart imaging sensors, for example in autonomously driven cars and surveillance cameras.

Role of the EU

To gain the clearly apparent rewards of a thriving photonics sensors industry there are inevitably some risks to be overcome. It is vital that Europe maintains its technological capabilities in photonic sensors through leading-edge research. To counter the intensifying international competition in this sector, the photonics community must create a larger, stronger and more coherent value chain. These ambitious goals will require substantial R&D efforts to develop completely novel approaches, and these will inevitably be accompanied by high risk. This task cannot be borne by single companies or national alliances alone. An EU funded initiative is essential for harmonizing research programs with individual states, facilitating effective clustering of players drawn from across Europe, and avoiding fragmentation of effort.

Photonics in Europe is substantially driven by SMEs, many of them highly specialized and individual technology leaders of their field. However, such companies typically do not have the financial backing to bear the risks of funding highly innovative research. This presents a vital role for the EU to target coordinated financial support to enhance cooperation and synergy within the industry. Continued funding though CSF of R&D into photonic sensor technologies will be essential, both to directly support the development of improved photonic sensor based applications, such as the development of autonomous vehicles, and for providing the enabling technology for a much larger value chain with consequent wide economic benefits.

Partners & Infrastructure

Photonic metrology and sensors technology is an essential enabler for a wide range of photonics applications, so that cooperation along the whole added value chain is a prerequisite for future success. This requires the involvement of all the major players; academic groups, research institutions, industry particularly the SMEs, and end-users. Collaboration in focused European R&D projects, and coordinated European research networks, clusters or platforms will allow effective dialogue and enable the distribution of knowledge and innovations. Dedicated infrastructure, such as large-scale fabrication facilities, will be required to maintain European independence and employment. Special efforts in education and training will be essential to satisfy the demand for highly skilled and qualified personnel at all levels, and this would be greatly assisted through the establishment of coordinated European education programs in photonics-related disciplines.

6.0 Design and Manufacturing of Optical Components and Systems

Vision

The diversity of industrial sectors represented in Photonics21 is testament to the fundamental importance of photonics in modern society. Its impact is felt not only in the photonic components and systems themselves but also in the larger entities that they enable. For instance, it is inconceivable that the Internet of today could have been built without photonics pervading every aspect of the world's telecommunications infrastructure. Laser-based techniques have revolutionised manufacturing industry and medical procedures; photonic sensors are ubiquitous in providing a safer environment and solid-state lighting is providing a key to the revolution in energy use that is required to achieve CO_2 emissions targets. Specific recommendations with respect to each of these fields are contained in the vision papers of WG 1-5. There are, however, numerous aspects that are generic to a wide range of applications: these are the enablers of our field and accordingly deserve focused attention in their own right. We emphasise here the development of technologies that have the potential to transform major sectors of our industry.

Our vision is of a European industry that is strong at every level, from devices and components through to systems, also embracing manufacturing equipment and methodologies. Although the economic impact may be most apparent at the higher levels of the food chain, for example in equipment and services (such as telecommunications, health care, manufacturing using laser tools), experience tells us that competitiveness here is vitally dependent upon access to the most advanced photonics technologies at the component level. Without differentiating technology, truly innovative products will surely be elusive, and without strong support for discovery and innovation, we cannot achieve strong added-value production. We therefore emphasise the importance of a European supply chain in strategically important areas of component and systems technology, embracing high-volume manufacturing as well as high-value, specialised components. We perceive major opportunities to build and sustain a vibrant manufacturing industry in Europe based on advanced technology, best-in-class design and innovative manufacturing techniques. In order to achieve this objective, Europe needs to grow and support a photonic eco-system having the critical mass of skills and capabilities to cover all bases. CSF provides an important opportunity to develop new design tools and processes, as well as enabling technologies, which will help to ensure that Europe has these skills and capabilities in place.

In the following sections we set out a top-level agenda based on a number of key enablers, including photonic integrated circuit (PIC) integration platforms, advanced semiconductor device technology, new materials and new technologies such nanophotonics, which constitute a prerequisite for Europe's continued ability to innovate in photonics and to be competitive in manufacturing.

Major Areas of Science & Technology Work

Our vision is built on the foundations of world-leading research in focused areas that are relevant to photonics across the board, coupled with initiatives designed to ensure that the resulting technology is put to use in the most efficient and effective manner. We have identified a number of priority areas for investment in generic technologies that will have a high impact across a wide range of applications, thereby complementing the recommendations of the applications-oriented working groups. These relate specifically to the following areas:

- Photonic integration, including the development of generic integration platforms and foundry models.
- Technologies for cost-effective manufacturing of components and subsystems.
- Integration of photonics with microelectronics at the chip, board and system levels.
- Semiconductor optical device technology, with particular reference to semiconductor lasers.
- Exploitation of new materials, including new semiconductors and nanophotonic materials (for example, metamaterials & plasmonics), multifunctional fibres, and their associated fabrication technologies.

Our first recommendation relates to photonic integration. As in micro-electronics, many applications can be addressed in a much more compact and cost-effective way by integrating the required functionality in a single chip of III-V semiconductor material (for example, indium phosphide, gallium arsenide), silicon or dielectric material. Largely as a result of past EU investments, Europe has a very strong position in these technologies. Whilst photonic integration is one of the most important keys to competitive advantage, present ways of working do not unlock its full potential. Not every supplier can be vertically integrated and access to technologies by smaller companies, for example, SMEs, is currently very limited. Furthermore the large variety of photonic devices and technologies that have been developed is beginning to limit progress in the industry. Europe has taken the lead in developing a new way of working, based on integration technology platforms supported by generic foundry manufacturing, which can provide a step-change in the effectiveness and applicability of Photonic Integrated Circuit (PIC) technology. European initiatives on generic photonic integration have attracted great interest and are beginning to be emulated worldwide, particularly in the USA. It is vital that these initiatives are carried forward into CSF, so that the most advanced PIC technologies are developed in the most efficient way and made accessible for exploitation to the widest spectrum of end-users.

The generic integration approach has proved highly successful in the microelectronics industry and although the challenges in applying the same methodology to photonics are different and are in some ways greater, we can nevertheless learn from the microelectronics experience. For instance, foundry-access programs such as MOSIS in the USA had a pivotal impact in the development of the VLSI industry, not least by training a large number of designers in circuit design techniques, and we recommend that a similar approach should be adopted in Europe for application-specific photonic integrated circuits in silicon photonics and III-V semiconductors. Furthermore, just as in microelectronics, we must invest significant scientific resources in the development and evolution of robust, accurate and efficient simulation and computer aided design (CAD) tools and in process and packaging technologies supporting the generic platform approach.

In order to expedite the future evolution of our chosen platforms, we propose research on large-scale integration processes allowing the seamless introduction of new technology. It is vital that the platforms can embrace new technologies with potential for improvements in functionality, compactness, energy efficiency, manufacturability or cost-effectiveness. Technologies such as photonic circuits based on membranes, nanowires, photonic crystals, metamaterials and plasmonics, including optical antenna structures, should be supported, and opportunities sought to integrate these elements into generic PIC capabilities at the earliest opportunity. In addition, extension to new wavelength ranges (for example, visible, UV) should be addressed. Further advances in manufacturing techniques will certainly also be required, for example, developments in high-volume, high precision, and cost-effective techniques, such as nanoimprint lithography (NIL).

Alongside the development of device and circuit technology, a concerted attack must be made on the challenges of cost-effective manufacturing of components and subsystems. Here we need to deploy European expertise on robotics, automated precision assembly and test technologies to offset the cost advantage of Far-Eastern manufacturers, and ensure that the full value chain can be addressed within Europe. We envisage here a synergistic exploitation of electronic, optical and mechanical technologies in an optimum combination. New structures with improved capacity for heat dissipation and thermal control are essential, as are strategies for managing electromagnetic design challenges. European strengths in hybrid photonic integration, including photonic lightwave circuit technologies, should be exploited, along with developments in new optical elements, including stacked micro-optics technologies and free-form optical surfaces. The emergence of laser-assisted manufacturing processes and of printing technology for additive deposition of functional materials offers further potential to enhance competitiveness.

Major opportunities will result from a close coupling of advanced photonics with current trends in microelectronics. For example, we are already seeing the application of powerful digital signal processing in link equalisation for high-speed telecommunications systems (40Gbit/s, 100Gbit/s), as well as in data communications over shorter links. This approach is revolutionising the design of such systems and allowing photonics to reach new levels of performance and cost-effectiveness. Close integration of photonics with electronics is also of major importance for micro-opto-electro-mechanical systems (MOEMS), sensors and medical devices. It is vital that we accept and embrace the importance of electronics in photonic systems and work to integrate the photonic and electronic parts very closely in our research and development strategy.

We note that IC manufacturers and processor architects are increasingly looking to photonics to provide the next level of performance in their devices, for instance in providing data links across individual chips, as well as between devices in a given subsystem. Besides improved functional performance, such approaches can also lead to significant improvements in power efficiency. The merging of electronic and photonic technologies at the circuit level will accordingly be a vital area of research, involving advances in heterogeneous integration and packaging as well as a holistic approach to integrated systems design.

European manufacturers have built up an enviable position in global markets for semiconductor lasers, ranging from high power GaAs devices for laser-assisted manufacturing, printing and medical uses to highly compact vertical cavity surface emitting lasers (VCSELs), such as are employed in human interface devices (mouse sensors, tracking devices), data links, data storage and biomedical/sensor applications. We must ensure that this European lead in III-V semiconductor device technology is maintained and strengthened. Research is required not only on the devices themselves but also with respect to integration with modulators, MEMS devices and electronics, as well as incorporation into the complete electro-optical subsystems.

Whilst specific aspects of laser and optical system development are covered in the applications-led work packages, we note here the importance of continued improvements in power scaling, efficiency and extension to new wavelengths, including the ultra-violet, green, mid-infrared (>1.5μm) and THz spectral regions, all of which require corresponding developments in semiconductor materials, device and manufacturing technology, as well as advances in related optical components. These advances will underpin important applications in industrial manufacturing, printing, medical systems, visualisation, 3D-recognition, and in sensing and spectroscopy for biomedical and security applications.

Finally, at the most fundamental level we recommend a continuing focus on emerging technologies based on new materials, semiconductors, metamaterials, nanostructures and plasmonics, as well as multifunctional fibres. A large proportion of the most important advances in photonics has been related to the availability of new materials. Nanophotonic materials and structures, as well as heterogeneous combinations of materials (for example, III-V/Si), can provide the basis for unique capabilities, permitting photonic functions with unprecedented performance in terms of size, speed, power dissipation and functionality. Nano-fabrication techniques with unique capabilities should be explored, including site-controlled epitaxy and epitaxy on patterned substrates. The potential of organic materials and organic-inorganic combinations should be fully investigated: whilst the role of these materials in OLED devices is discussed in WG 4, we envisage here a wider, generic applicability. Furthermore, these advances must be brought rapidly into use. Europe is performing well in many highly dynamic market areas that demand rapid innovation and the exploitation of disruptive materials and processes. This trend can be supported through coordinated research and the evolution of innovative manufacturing models. To summarise, a lead in the application of new materials and nanostructures in practical devices will underpin significant competitive advantage for European industry.

Impact

As has been noted elsewhere, photonics is one of the most vibrant areas of the European economy. The total world market of optical components and systems was estimated in 2009 to be in the region of € 15 billion with growth to more than € 30 billion expected by 2015. Given their pivotal importance across a wide range of industries and services, from telecommunications and information systems to healthcare, investment in generic photonic technologies can have a disproportionate impact. The leverage from advanced component technologies is extremely large: as an example, we may consider that the global market for telecommunications services, at more than € 2 trillion, is critically dependent upon the capabilities of its constituent photonic elements. Similar considerations apply in other market sectors. The leading players in communications, laser technologies, lighting and bio-photonics all require innovative optical components as the basis of differentiation in the marketplace. We should also note that photonics is a strong export industry: the European market of optical components and systems represents about 11 % of the total European photonics production, while the European market share in the global market place approaches 50 %. We note also that European manufacturers of production tools for photonics have a commanding position in world markets. In order to sustain this strong position against global competition, it is vital that momentum is maintained in the underpinning technology base.

The measures we propose will benefit small and large industries across Europe, as well as the public at large through the improved services that will be made possible with more advanced photonic technology. We recognise the importance of start-up businesses and SMEs in driving technical and product innovation, and several of the measures that we propose will be of particular benefit to SMEs. For example, the development of photonic integration platforms that can be made available widely through generic foundries should revolutionise access to high technology manufacturing for small companies across Europe.

Role of the EU

The R&D landscape is sufficiently complex that it is no longer possible for individual countries to develop a strategy on an individual basis. It is also the case that the costs involved are now at a level where collaboration at a European level is mandatory in order to achieve an economically viable and successful result. By working at a European level, we can deploy resources in a concentrated manner and develop solutions that have a high level of impact for Europe as a whole. In doing this, we need to cross-link many different strands of the European research effort, in solid-state technology, nanotechnology, device physics, materials research, manufacturing technology and other fields. Whilst maintaining a clear focus on the photonics effort, we note that it is vitally important that this is linked to developments in other fields, such as microelectronics and production technology. All of this can best be conducted at a European level. It is generally agreed that bridging the gap between research and exploitation is one of our most difficult yet vital tasks, involving the whole community, from SMEs to large industrial companies. An EU-led effort linking industrial and research policy is indispensable in this regard, and we warmly welcome the Key Enabling Technologies initiatives in Photonics and Advanced Manufacturing which will address this issue. We can however already identify a number of aspects that relate closely to research activities and to support actions that should properly be conducted within CSF: for example, steps to set up a generic foundry activity for integrated photonics. It is also vital that investments in technologies and methodologies for advanced manufacturing, not only at the device/chip level but also at the level of packaged components, subassemblies and systems, is conducted on a scale that can only be achieved at a European level. It is a matter of major importance that component manufacturing thrives in Europe, as so many European industries now depend upon it.

Partners & Infrastructure

We need to engage all stakeholders in the coordination of these efforts and the European Technology Platforms have a major role to play in this endeavour. The aim should be to build a European ecosystem, in which photonics and its client industries can advance together. As noted previously, this will require discussion and partnership with other industries, including microelectronics. Furthermore it is vital that we engage and support the full spectrum of industrial players, from SMEs to large manufacturing enterprises.

The fragmentation of European research infrastructure has long been identified as a limiting factor and the Network of Excellence initiative in Framework 6 was a first attempt to put this right. Certainly the aim of establishing larger virtual research teams and pan-European facilities, thereby absorbing capital cost as well as providing an intellectually stimulating environment, should be a factor in our future policy. It will be necessary to work with existing research and innovation centres to ensure the most efficient coordination of activities and maximum leverage on future investment. There are opportunities also for closer cooperation with related organisations in ICPC countries, particularly in the areas of photonic design systems and CAD software.

The photonics industry will have a continuing need for highly qualified personnel and we therefore recommend a continued and increased focus on photonics education and training. Photonics is a fast-moving, multi-disciplinary field and it is vital that Europe trains and nurtures sufficient creative, inquisitive, ambitious and well-educated scientists and engineers to maintain competitiveness at global level. At an even more fundamental level, we see a need for renewed vigour in our educational endorsement of the sciences. It is vital that we establish a trusted interface with society at large and that science has effective interlocutors to express the value it returns. We must accordingly reach outwards to young people and to a wider general public who are today largely unaware of the role that photonics is playing in their world.

7.0 Education, Training and Disruptive Research

Vision for Education and Training

The importance of photonics as a key enabling technology and its leading role in addressing the major societal challenges that we are facing have been widely demonstrated and discussed in detail in the previous sections. However, some general aspects need to be considered for dealing successfully with the needs of the workforce and setting the basis for long-term success.

Photonics has applications in many diverse fields, such as telecommunications, industrial production, life sciences, energy, environment, and many other areas of crucial importance for future prosperity, sustainable development and quality of life. The consequent interdisciplinarity poses a challenge in training young people for a career in photonics-related activities, since both a deep knowledge in basic science (notably physics, material science, mathematics, and electronics) and technological disciplines (such as engineering, computer science, nanotechnology, biotechnology, etc.) are needed, together with a detailed understanding of application fields. Cross-fertilization with other fields will be crucial to fully exploit the innovation potential of photonics.

The photonics industry expects a strongly increasing demand for high calibre Science, Technology, Engineering, and Mathematics (STEM) graduates. This will be fuelled by an increase in the number of STEM graduates needed in the workforce, the replacement of retiring staff in an ageing population, and the need to meet the challenges of globalization now facing European industry, which will continue to have a major impact upon both the supply and demand sides of the economy. Additionally, the rapid growth in outsourced manufacturing to countries with lower labour costs poses a real challenge, and this will force all areas of European engineering to concentrate on higher value-added activities, such as photonics.

A successful strategy for education and training in photonics requires focused actions at three different levels:

Outreach towards young minds

In order to reach out effectively to young people, one must first necessary look at the wider public perception of photonics, to understand what stimulates their interest in science and technology, and establish what motivates them to pursue STEM subjects in school. Then it is important to consider which media are best for reaching these groups. Today's young minds will be our skilled workforce in the future, so generating interest in photonics must be started in primary and secondary schools. Special attention should be paid to motivating young women into physical sciences and engineering generally, and towards photonics in particular, because the female representation within the high-level photonics workforce is still low. The involvement of teachers in innovative programs will be essential, so that they can stimulate and excite as they educate young students, engaging them in the world of photonics. To achieve the maximum impact, dedicated training programs for teachers need to be initiated.

Awareness raising activities aimed at the general public, such as dedicated exhibitions or permanent shows in museums, should be undertaken to widen their appreciation of how important and pervasive photonics has become. Television programs and advertisements are highly effective ways of informing people, as increasingly now is the use of online video, whose reach extends beyond television with distribution through popular Internet sites and online networks. Such awareness generating actions will play a vital role in overcoming the shortage of students undertaking advanced studies in photonics and photonics-related subjects.

High level education

A increased number of curricula dedicated to photonics are needed throughout Europe, together with greater emphasis on topics related to optics and photonics in engineering and physics curricula. Special attention to the needs of the industrial world is essential and should be achieved through targeted courses:

- new or updated photonics-related educational programmes (Bachelor, Masters, PhD) derived directly from the needs of industry
- industrial internship programs
- university courses presented by industry staff.

Topics related to technology transfer, entrepreneurial skills, management, and quality control should be included in advanced curricula. A growing need for well-trained personnel is also expected following the creation of large-scale infrastructures, in particular the "extreme light" infrastructures, which are being assembled in several countries throughout Europe.

Lifelong learning

Photonics is a relatively young, but rapidly evolving technology. Industries would benefit from a closer interaction with academia providing refresher courses and extension courses for technical staff. Courses for operators dealing with photonics in many application fields (telecommunications, medicine, architecture, environmental monitoring, cultural heritage, etc.) could be considered. Refresher courses for schoolteachers will also be essential for a long-term strategy of photonics dissemination and success.

At all education levels, mobility programs will be of great importance to meet the challenge of the global market, so a supportive infrastructure should be developed to foster and facilitate these.

Since all countries will have similar needs in terms of knowledge and skills, the photonics community would benefit greatly from the establishment of a “European Skills Observatory for Photonics”, wherein industry and academics could jointly collect and analyse developing trends in technology and research. The primary objective of this collaboration would be to anticipate the needs of the photonics sector in terms of workforce numbers and skills targets, and then to define the strategies needed to meet them.

Major Areas of Science & Technology Work: Disruptive Research

Many photonic technologies have reached a good level of maturity, whilst still having great potential for innovation and impact in addressing future priority societal challenges. However, there are some areas of advanced fundamental research, still in a pre-competitive, pre-industrial phase, which could become the breakthrough technologies for future long-term innovation in Europe.

Three main topics offering revolutionary potential impact are considered:

Nanophotonics

Nanophotonics uses optical nanomaterials to slow down, trap, enhance and manipulate light at the sub-wavelength scale. It has become a major research area producing important advances in optical communications, (nano)imaging, and sensing applications. Researchers are now also looking at the potential application of nanophotonics for photovoltaics and solid-state light emission to tackle energy issues. However, transferring the results of academic nanophotonics research to industrial manufacture requires that many practical obstacles must be overcome, for example, nanofabrication, up-scaling, costs, etc.

Examples of emerging in the field of nanophotonics include:

- *Photonic metamaterials* - these are artificial materials composed of sub-wavelength functional building blocks that are densely packed into an effective material. They are engineered so as to achieve functional properties that may not be found in nature. Indeed, they exhibit qualitatively new behaviour, such as magnetism at optical frequencies, a negative refractive index, giant circular dichroism, or enhanced optical nonlinearities. The major challenges for developing these metamaterials at optical frequencies are (i) reducing the losses, possibly by incorporating active gain materials, and (ii) realizing large areas/volumes of these structures (rather than just small planar structures). A cost-effective, low-loss metamaterial at optical frequencies would indeed represent a major breakthrough.

- *Plasmonics* - this takes advantage of the unusual dispersion relation of light at the interface between a metal and a dielectric, thus offering a promising route for delivering light at optical frequencies to the nanometer scale. Moreover, the high sensitivity of surface plasmons to the properties of the material on which they propagate paves the way for their exploitation in ultra-sensitive sensors for biomedical and environmental applications. Plasmon enhanced LED and OLED light emission has been demonstrated. The feasibility of solar cells with higher efficiency, resulting from the incorporation of metallic nanostructures, is being actively explored. These examples demonstrate the high potential value of plasmonics for photonic applications. However, accommodating and/or reducing the still relatively significant losses of plasmonic structures and waveguides, and their subsequent cost reduction remain major challenges that have to be tackled in the future.

Quantum Information

Photons are a natural candidate for quantum information (QI) transmission, quantum computing & simulation, optical quantum sensing, and metrology. However, processing quantum information with photons is one of the greatest technological challenges yet faced in photonics, since it requires the ability of controlling quantum systems with an unprecedented level of accuracy. Among numerous potential applications, photonics offers important instruments for optical quantum technologies, such as the possibility of miniaturising and scaling optical quantum circuits within on-chip integrated waveguides. Such architectures offer almost perfect spatial mode matching, which is crucial for classical and quantum interference. Integration of linear optics technology is also an important step towards the practical implementation of large-scale computational networks. Recent achievements in this direction include the manipulation of single-photon states, and photon entanglement directly on-chip using the path and polarization degrees of freedom (DOF) of the photon. Additionally, compiled versions of basic gates and algorithm have been implemented on integrated waveguide chips. Future developments will address the exploitation of photonic qubits encoded in further DOFs, and their manipulation and measurement on single waveguide chips realized by either femtosecond laser-writing or conventional lithographic technology.

Promising industrial applications of this research include advanced integrated devices for quantum communications, and new quantum technologies such as quantum sensors and high precision measurement devices. The synergy of photonic technologies with quantum information will soon lead to new links with industry, both at the level of commercial exploitation and in research programs, the latter making available new technologies, beyond the current capabilities and know-how of traditional QI basic-research oriented laboratories. In particular, links with micro- and nano-fabrication facilities and related technology centers will be strengthened, thereby encouraging further QI spin-offs.

Extreme Light Sources

The research and development of short-pulse, high-power lasers is driven by the relentless demand for the light sources needed for performing light-matter experiments at femtosecond and attosecond timescales across all possible spectral ranges. To achieve ground-breaking results in basic science, the close collaboration of three major communities is required: (i) laser science and technology researchers who are aware of the needs of the user community; (ii) researchers on laser-matter interaction science who are knowledgeable in laser technology and able to envisage and implement future steps; (iii) industries that can exploit these developments in future products and services. With this in mind, an initiative to build a distributed pan-European facility "Extreme Light Infrastructure" (ELI) has been undertaken. ELI will be positioned at the forefront of laser science and applications, and will focus on: (i) generation of ultra-short energetic particles (ions and electrons) and radiation beams in the X-ray region; (ii) attosecond sources capable of following electron dynamics in atoms, molecules, plasmas and solids; (iii) laser-based nuclear physics using radiation and beam particles with high energy suited to studying nuclear process; (iv) ultra-high field science giving access to ultra-relativistic regimes for particle physics, gravitational physics, and non-linear field theory. ELI will foster an aggressive technology transfer, and technological developments outsourced by ELI to European industries will help to maintain their leadership. With its broad scientific and engineering offering, ELI will attract and train a large number of young students in the fields of ultra-high intensity laser technology, ultra-relativistic optics, atomic and molecular physics, plasma physics, etc. The strong link between ELI and the wider photonics community will bring many important benefits.

Technology Transfer

The successful scientific achievements and innovations in these disruptive fields that can be expected over the next few years will need a strategy to support their implementation and exploitation. Universities and public research institutions are the natural environment to translate the results of fundamental research into demonstrators and prototypes, and they should be encouraged to pursue these activities. However, to move further along the value chain and bring products to market, several intermediate steps are needed. The availability of European venture capital for the creation of spin-off and start-up companies, supplemented by government support, will set the basis to bridge the gap between product development and market development, thereby changing the so-called "valley of death" into a "valley of opportunity". It should be emphasized that making available significant public funding at an early stage of technology transfer maximizes the ability of inventors to innovate.

Impact

As already described, photonics plays a pivotal role in the European economy and its worldwide market is growing rapidly. In several areas, the market share of Europe is comparable to that of the US and of growing Asian economies, often with a leading role in terms of innovation capabilities.

A strategy able to meet the growing need for highly qualified personnel would allow Europe to maintain its position and increase its importance in the photonics-related economy. In this respect, outreach activities are expected to have a strong impact. In particular, a strong involvement of primary and secondary school teachers through dedicated training programs should be a high priority. Addressing the general public through suitable communication media is essential. Concerning high-level education programs, the highest impact can be obtained through a careful analysis of future needs so as to anticipate and meet them. While the positive impact of the described strategies is clear, the risks facing the photonics community should such strategies not be implemented should not be underestimated. The lack of a sufficiently knowledgeable and skilled workforce would soon have a severe impact on the European photonics industry, especially when considering the major investments in terms of education and training that are being pursued both in established leading economies (US and Japan) and in emerging countries.

Providing sufficient investments in fundamental research targeted on a small number of selected topics offering great potential for innovation and exploitation could result in Europe establishing a leading role in emergent high value technologies. However, a crucial step for successful technology transfer and exploitation of these technologies will be the provision of early-stage public funding and increased venture capital.

Finally, it should be noted that innovation in photonics does not only mean increased employment and market share, but also provides a strong contribution to the overall quality of life in our society, through its broad contributions to solving the great social challenges facing Europe, namely its ageing society, and the need for energy saving, environmental monitoring, and safety & security.

Role of the EU, Partners and Infrastructure

Although the requirements for education and training will require a strong commitment from local authorities and educational institutions, globalization of the photonics market imposes some additional priorities that should be set at the European level. This means that a Europe-led initiative will be essential to define the broader aspects of education, training and research policy, and to foster cross-fertilization and mobility. In this respect, the Key Enabling Technologies initiatives is likely to provide a strong impulse for increased awareness of the importance of photonics. The next Common Strategic Framework should consider actions to promote the networking of highly qualified research centers encouraging exchange of best-practice, thereby increasing their impact in terms of outreach, education and training throughout Europe. The popularization of science and engineering amongst young people should also be pursued through mainstream media, such as television and online video. Additionally, closer collaboration with the programs in the “Science and Society” area would be highly beneficial, aimed at increasing a wider awareness of photonics.

A strong interaction between industry and academia will be essential for the future development of photonics. Existing and new large-scale infrastructures and research center networks should be an integral part of a European strategy to foster interaction with industries, primarily with SMEs who typically suffer from limited investments in R&D and would benefit greatly from the availability of distributed research infrastructures. Support in networking would also greatly aid the mobility of researchers.

Coordination between venture capitalists and the scientific research world at the European level is another key aspect necessary to ensure the highest efficiency and success of technology transfer, thereby maximizing the prospects for long-term impact on the worldwide market.