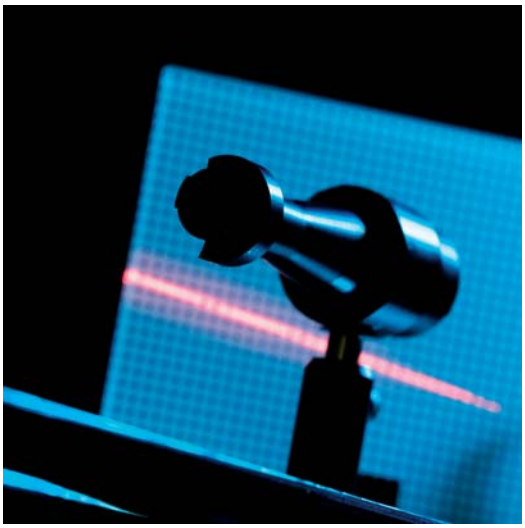
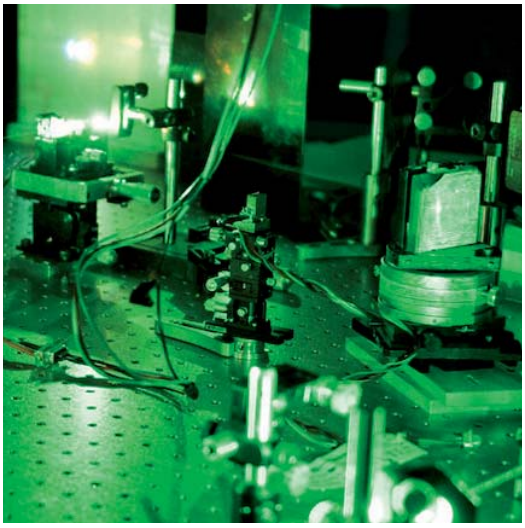
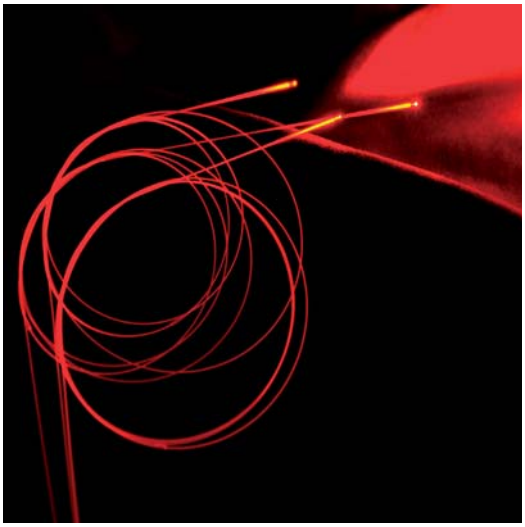
PhotonicSweden

The Swedish Technology Platform in Optics and Photonics







PHOTONICS AGENDA

Photonics, A Key Enabling Technology for Sweden

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The long version of the Photonics Agenda can be downloaded at **www.photonicsweden.com**

1 Summary

For the first time, a common strategic research and innovation agenda has been developed by the Swedish photonics community. Having experienced an extremely successful period in the 1990's, during which no common strategy needed to be formulated as everything was moving at a frantic haste, photonics in Sweden and elsewhere were hit quite hard by the dot-com bubble. As photonics worldwide has regained momentum and strength, the importance and vitality of photonics have repeatedly been recognized in Europe, in the USA, and in Asia, but to a lesser extent in Sweden. There is a strong urgency to make it clear to all stakeholders in Sweden the future potential and promise in the renaissance of photonics.

To make photonics more visible in Sweden is the task PhotonicSweden has set itself.

By visibility we partly mean marketing, but mainly the building of sustainable structures and networks enabling companies active in Sweden to plug into when the time comes to include photonics as part of their core technologies. These structures and networks must be based on people with deep knowledge and broad international connections in different areas of photonics, innovative people able to understand the global agendas underlying the fast development of photonics, creative people able to understand the business models and supply chains in which photonics is so often a hidden but crucial technology, and last but not least people having the courage and vision to take on to themselves the hard work to bring new ideas having photonics at the core to the marketplace.

Photonics is a transboundary enabler within many fields, not the least for Swedish areas of strengths such as telecoms, automation, security and medicine. Today, the Swedish photonics community consists of about 150 high tech companies with over 6000 employees, and many research groups all around the country. The vision of PhotonicSweden is that, in 2030, the growing Swedish photonics community will be a vigorous and dynamic part of companies and institutions that are key enablers to a sustainable, expanding and profitable Swedish industry based on research and innovation.

The aim of PhotonicSweden is to advance and support a sustainable growth of relevant industrial sectors in Sweden. Our objectives and proposed actions are grouped along six main areas: increased visibility, enhanced collaboration, intensified and structured networking, ensured skills supply, promoted technology transfers, and sustained excellence in research, innovation and management.

In addition to the telecoms where Sweden already holds a strong position, three areas of the Swedish photonics are especially promising: biophotonics, automation and green photonics. The conditions are very favourable for biophotonics, the use of photonic technologies for bio/medical applications mostly because of the exceptionally strong research activities in that field in our country. The use of photonics for automation can capitalise on the strong Swedish raw material production and make possible a more efficient Swedish production and many new innovative products that can be exported. Green photonics is the use of photonics to save or generate energy and to reduce all sorts of wastes. Here also, the conditions are ideal since Sweden is a leader in clean tech and environmental protection.

This agenda development was made possible thanks to the creation of the economic association PhotonicSweden in 2011, the initial financing and support from the European Commission that same year through the European project InnoPho21, and thanks to the support of VINNOVA in 2013. The agenda is also the result of the work of over 100 experts throughout the country.

För första gången har en gemensam strategisk forsknings- och innovationsagenda utvecklats inom det svenska fotonikområdet. Efter att ha upplevt en mycket framgångsrik period under 1990-talet, då ingen gemensam strategi behövde formuleras eftersom allt rörde sig i en rasande fart, drabbades svensk fotonik liksom andra områden väldigt hårt när dot-com bubblan sprack. Fotonikens stora betydelse och vitalitet har erkänts upprepade gånger över hela världen, men i mindre utsträckning i Sverige. Därför brådskar det att göra klart för alla svenska intressenter vilken framtida potential och möjlighet som finns i fotoniken.

PhotonicSweden har satt som sin uppgift att göra fotoniken mer synlig i Sverige.

Med synlighet menar vi dels marknadsföring, men framförallt att bygga hållbara strukturer och nätverk som gör företag verksamma i Sverige uppmärksamma på när det är dags att inkludera fotoniken som en del av sin kärnteknologi. Dessa strukturer och nätverk måste baseras på personer med djup kunskap och breda internationella kontakter i olika delar av fotonikområdet, innovativa människor som kan förstå de globala agendor bakom den snabba utvecklingen inom fotoniken, kreativa människor som kan förstå affärsmodeller och värdekedjor där fotoniken ofta är en dold men viktig teknik, samt sist men inte minst människor som har modet och visionen att ta till sig inför det hårda arbete som krävs för att få nya idéer till att föra kärnan av fotonik till marknadsplatsen.

Fotonik är gränsöverskridande och en möjliggörare inom många olika branscher, inte minst inom svenska styrkeområden så som t.ex. telekommunikation, processautomation, säkerhet och medicinsk teknik. Idag består det svenska fotoniksamhället av ca 150 högteknologiska företag med över 6000 anställda och många forskargrupper runt om i landet. Vår vision är att till år 2030 så kommer denna snabbt växande gemenskap vara en kraftfull och dynamisk del av företag och institutioner som utgör en viktig faktor för en hållbar, expanderande och lönsamt svenskt näringsliv, som bygger på forskning och innovation.

Syftet med PhotonicSweden är att främja och stödja en hållbar tillväxt av relevanta branscher i Sverige. Våra mål och föreslagna åtgärder grupperas längs sex huvudområden: ökad synlighet, ökad samverkan, intensifierat och strukturerat nätverk, säkerställande av kompetensförsörjning, stödd tekniköverföring och ihållande excellens inom forskning, innovation och ledning.

Utöver telekom, inom vilken Sverige redan har en stark position, treområden i den svenska fotoniken är särskilt lovande: biofotonik, automation och grön fotonik. Förutsättningarna är mycket goda för biofotonik, då användning av fotonik inom bio/medicinska tillämpningar främst baseras på den exceptionellt starka forskningen inom detta område i vårt land. Användningen av fotonik för automatisering kan dra nytta av den starka svenska råvaruproduktionen och möjliggöra en effektivare svensk produktion samt många nya innovativa produkter som kan exporteras. Grön fotonik är användningen av fotonik för att spara eller generera energi och att minska alla typer av avfall. Här är också förhållandena idealiska, eftersom Sverige är ledande inom CleanTech och miljöskydd.

Denna agendas framtagande har möjliggjorts tack vare skapandet av Ekonomiska föreningen PhotonicSweden under 2011, finansiering och stöd från Europeiska kommissionen samma år genom det europeiska projektet InnoPho21, och tack vare stöd från VINNOVA under 2013. Det är också resultatet av ett arbete genomfört med över 100 experter från hela Sverige.

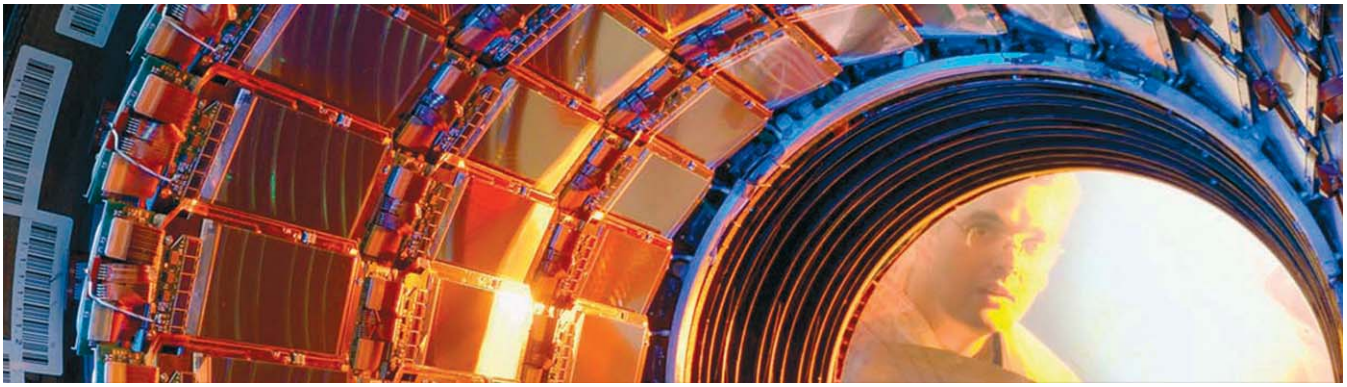


photo by Hamamatsu Photonics K.K.

2 Introduction – Make photonics visible!

PhotonicSweden was founded in January 2011. The main purpose of this economic association is to gather all different stakeholders under one roof, to be the voice that the Swedish photonics needs and, not the least, to make photonics in Sweden grow even faster. From the start, PhotonicSweden has got a strong support from the Photonics Unit at the European Commission. In September 2011, a three-year European project called InnoPho21 has started which supports Photonics21 and involves besides PhotonicSweden also five other national technology platforms in Europe. One of the main activities is to develop our national strategy in photonics and that is how the work behind this strategic research and innovation agenda (SRIA) started. In July 2012 we got a financial support from VINNOVA to develop a common strategy with other constellations in the field of electronics. This spring 2013, VINNOVA decided to also grant our Photonics SRIA.

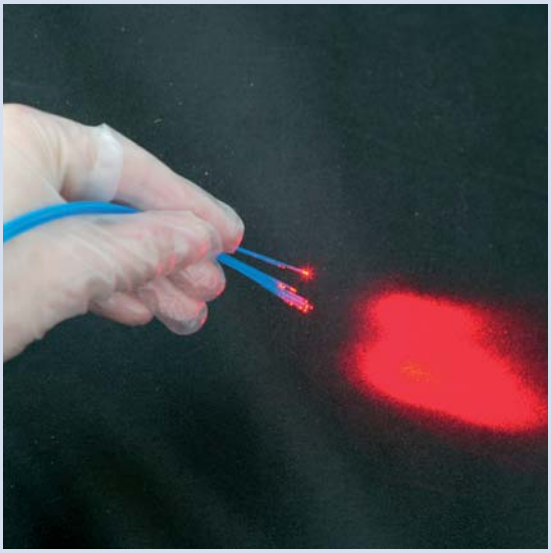


photo by SpectraCure

Two and a half years after the foundation of PhotonicSweden, there is no doubt that our association has fully succeeded in gathering the main actors in photonics, managed to represent the Swedish photonics community domestically and internationally, and coordinated the work underlying the creation of this SRIA. Still, the Swedish photonics community has just started the process which will make it grow faster! Photonics is nearly everywhere and, more and more, a key enabling technology, i.e. a technology without which a number of highly important products simply do not work. However, if we want the proper investments to be realized in Sweden in order to move up a gear or two, decision-makers have to understand the role of photonics in e.g. internet, mobile communication, smart phones, medicine, environment, climate change monitoring, safety and security and smart manufacturing and production. For this to happen, we have to make photonics visible! It is probably a long but very exciting journey we are starting here: to share with the public the wonders of the world of optics and photonics. Let us inspire children as early as possible, and let us open the eyes of decision-makers from industry and politics!

Optics & Photonics: What is it?

Optics – the science that deals with the generation and propagation of light – can be traced since the seventeenth century through the work of famous scientists such as Descartes, Newton, Maxwell, Planck and of course Einstein. During the last century, quantum mechanics confirmed the existence of quanta of light, the photons. The realisation of the laser in 1960, then boosted the emergence of infinite applications. The term "photonics" can be defined[1] as the "engineering applications of light," involving the use of light to detect, transmit, store, and process information; to capture and display images; and to generate energy. Photonics is hence not only dealing with the generation and propagation of light, but quite much as well with its manipulation. Throughout this document, we will sometimes use the expression optics and photonics, in which the wave-particle duality of the light is best expressed, but in most cases only the term photonics which is more and more used internationally. Other related terms are "electro-optics" and "optoelectronics" or simply "optronics" but we will not use these terms very much in this document.

Optics & Photonics: What is it good for?

Photonics technology is central to modern life. It enables today's internet as well as today's mobile communication. To rephrase it more dramatically: without photonics, neither internet nor mobile communication, as we know them today, would be possible. It enables the manufacture and inspection of all the integrated circuits in every electronic device in use. It gives us displays, optical fibres, advanced precision fabrication, sensors and medical diagnostics tools. Photonics technology has the potential for even greater societal impact over the next few decades. Solar power generation and new efficient lighting, could e.g. transform our energy landscape. New optical technologies will be essential to supporting the continued exponential growth of the Internet.[2] The broad deployment of optical sensors, not the least in industrial environments, will considerably enhance our ability to adjust processes and will enable a significantly smarter production and manufacturing. Photons are everywhere in more and more products, in some cases visible for the users, but in most cases invisible. More details about the applications of photonics technologies can be found in chapter 5.

Photonics, a High Priority for Europe

The European Technology Platform (ETP)[3] Photonics21[4] was founded in December 2005. It is one of the 38 ETPs recognised today by the European Commission (EC). Such ETPs are industry-driven and mostly intended to provide the needs in terms of research financing from the industry to the EC. Supported by the big countries, and before all Germany, Photonics21 was fully running from the start and the first Strategic Research Agenda (SRA)[5] was prepared within only 4 months and delivered to European Commissioner Vivian Reding in April 2006. In 2009 a very important report[6] about the economic impact of photonics in Europe presented very convincing numbers. Europe has a global market share of 20% a clear lead in optical components and systems, lighting and production technology. Germany alone represents 40% of the European production. Also in 2009, photonics was chosen as one of 6 Key Enabling Technologies (KETs)[7]. Since then, Photonics21 has been striving for creating a Public Private Partnership which will be launched together with the next Framework Programme in 2014 and the EC has been giving an increased budget share to photonics (nearly doubled during the framework programme FP7) and is planning for even more space in Horizon 2020. Europe is indeed investing strongly in photonics. On the other hand, the USA and Canada keep a very strong position and several countries in Asia are investing even more than Europe, so it is important to stay awake!

1 Sternberg, E. 1992. Photonic Technology and Industrial Policy: U.S. Responses to Technological Change. Albany, NY: State University of New York Press.

2 Optics and Photonics: Essential Technologies for Our Nation, National Academy of Sciences, 2012.

3 http://cordis.europa.eu/technology-platforms/home_en.html

4 www.photonics21.org

5 First version of the Strategic Research Agenda of Photonics21: Towards a Bright Future for Europe, 2006. The second version, "Lighting the way ahead", published in 2009 is available at: http://www.photonics21.org/download/Photonics21StrategicResearchAgenda.pdf

6 "Photonics in Europe, Economic impact", 2009. Available at: http://www.photonics21.org/download/Brosch_Photonics_Europe.pdf

7 A good description of how KETs will be dealt will in Horizon 2020 is given in a Communication from the Commission of June 26, 2012, entitled: "A European strategy for Key Enabling Technologies – A bridge to growth and jobs".

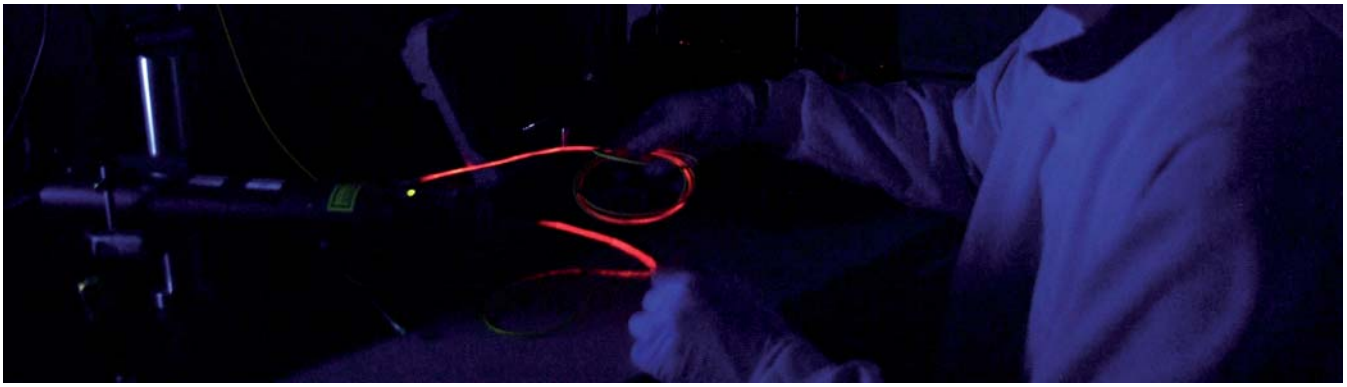


photo by Thorlabs Sweden AB

3 Vision 2020-2030

"In 2030, the Swedish Photonics community will be a recognized and important player delivering a key enabling technology to a sustainable, expanding and profitable Swedish industry based on research and innovation."

Milestones:

By 2020 ("photonics-to-photonics")

- The Swedish photonics community is strongly proactive in the new Public Private Partnership Photonics21.
- Photonics is made visible to the public and to decision-makers and is recognized as a Key Enabling Technology by national and local governmental bodies.
- Special focused actions and programmes have been established in the fields of biophotonics, industrial production and green photonics.
- Close collaborations have been established with photonic clusters in Europe, in particular in the Baltic Sea region and in Scandinavia.
- PhotonicSweden has become one important vehicle for helping start-up companies in the area of photonics to grow and to connect into the global photonics network.

By 2030 ("photonics-to-core technologies")

- Swedish Photonics is recognized as an important key enabling technology by the Swedish industry as well as society.
- Political measures have been taken to ensure the supply of talented and skillful students and engineers in the field of photonics.
- The Swedish photonics community is fully integrated in, and exploiting, the large and leading global markets where photonics is an important core technology.

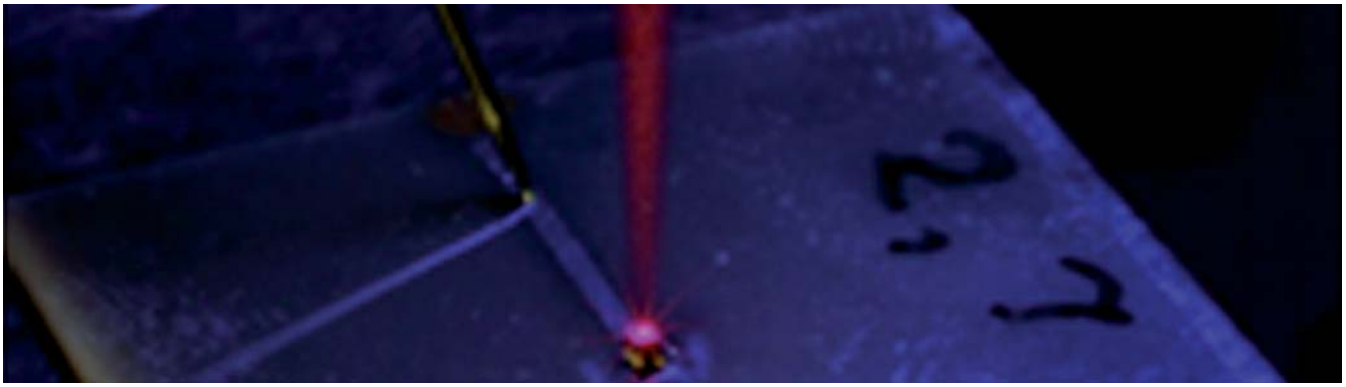


photo by Chalmers University of Technology

Objectives 4

Aim: PhotonicSweden will advance innovative photonics solutions enabling a sustainable industry in Sweden.

Photonics will be a key enabling technology in nearly all business sectors in the future. The Swedish photonics community increasingly contributes to the creation of competitive and innovative companies by supplying innovations improving the efficiency, speed, lightness, yield, energy savings or appearance of many products or processes and thereby making them more competitive in the global market. A strengthened Swedish photonics community will also have a 'knock-on effect' in other industrial sectors and thereby significantly contribute to solving societal challenges.

Envisaging the potential of:

→ **An average CAGR[1] of 5% until 2030.**

→ **A more than doubled work force until 2030**

for photonics companies active in Sweden and, to the benefit of the Swedish industry, the following actions need to be taken:

- **Increased visibility**
  The photonics technologies which are clearly visible in our society, e.g. laser pointers or scanners or in smart phones, are a very little fraction of the whole, not even the top of the iceberg (see chapter 5). How many politicians in the Swedish parliament know that their voice is transformed into photons when they make a phone call? How many of those who know it, know that Swedish photonics technology play an important role for the transport of information? How can a field be promoted if it is not visible and recognized? There is presently a lack of knowledge even at the highest levels. Decision makers need to realize that photonics has an increasing importance for our industry and society, has an annual growth of 5-10% and can aid in creating a bright future for Sweden.

- **Enhanced collaboration**
  - Within our community of companies, academia and institutes directly active in the field of photonics and in the main value chains.
  - With other Key Enabling Technologies: The collaboration with electronics in the framework of the "Smarter Electronic Systems in Sweden" will be reinforced as will the dialogue with Swednanotech.
  - With the significant, local and national governmental bodies.
  - With international partners, the European Commission, and clusters.

→ *There will be at least 10 close commercial and technological collaborations with photonic clusters in Europe, and most likely in Finland, Denmark, several Baltic countries and the Berlin-Brandenburg region, before 2020.*

1 Compound Annual Growth Rate

4

- **Intensified and structured networking**
  Networking is a very powerful tool. It opens doors to hitherto unknown people, alliances and information. We are organising seminars ("Optopubs") in Stockholm and some other cities and a national conference every year. An additional and very efficient tool for exchanges has been the working groups that were started for the preparation of this agenda. The intention is to reinforce the networking activities, open and broaden these both geographically and thematically. Broadcasting of meetings will be tested and, if found successful, implemented generally.

→ *The number of networking events will be increased by at least 50% by 2020.*

- **Ensured skills supply**
  The supply of skilled personnel is a serious problem in Sweden. The young generation has moderate interest in creating new hardware. Banking, services and software-related activities seem to promise an easier and better future. A very large majority of the students in faculties related to photonics are coming from abroad. Not much is unfortunately done to help them to stay after their studies, which would increase the return on investment. More Swedes should engage in relevant studies for photonics and we need also a higher mobility of skills between industry, academia, institutes and the public sector.

→ *The available work force for the Swedish photonics community should match the increased demand no later than 2025.*

- **Technology Transfer**
  The question how to make a successful journey from a brilliant idea to a well-established product on the market has been discussed very intensely when preparing Horizon 2020. Part of the solution consists of extending the domain of the European Commission's financing to higher levels of technology readiness. Another solution consists of adding other sources of financing (structural funds and national funding) to the new programme. An action can be to help more companies in being part of the European effort, and to provide them with coordinated help from different and usually straggling sources. Another one is to help making use of the long experience among Swedish actors.

→ *A mentor programme for photonics companies starting their journey in the so-called "valley of death"[2] will be put in place in Sweden during Horizon2020.*

- **Sustained excellence in research, innovation and management**
  Sweden has excellent academic research - an important pillar for continued innovative developments. PhotonicSweden will work for continued strong research financing in photonics and will increasingly facilitate collaborative efforts of Swedish research groups for clearer profiling and mutual knowledge.

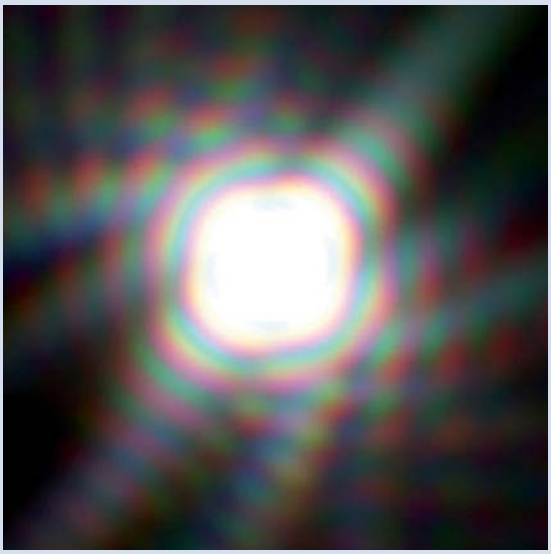


photo by ADOPT, KTH

Furthermore, PhotonicSweden will strive for that the research agendas at universities support the more applied research performed at institutes and companies. Research fields of different groups will be mapped and interconnected in a logical manner. Strengthening the role of institutes to allow better technology transfer will give rise to a more innovative climate. The Swedish photonics community being number 6 in Europe, but highly fragmented, makes the role of PhotonicSweden crucial. Therefore, PhotonicSweden will take upon itself the role of efficient management of collaborations, support companies to find relevant financing and liaise with the European Commission. For this effort PhotonicSweden require proper financing from industry as well as public support.

→ *Funding for Swedish photonics partners more than doubled in/during Horizon2020.*

→ *Public Swedish financing for R&D in photonics doubled by 2020.*

2 While the first financing is usually relatively easy to find, start-up companies often experience a long period during which the probability of dying off is high before a steady stream of revenues is established. The expression "valley of death" is often used in reference to that period.

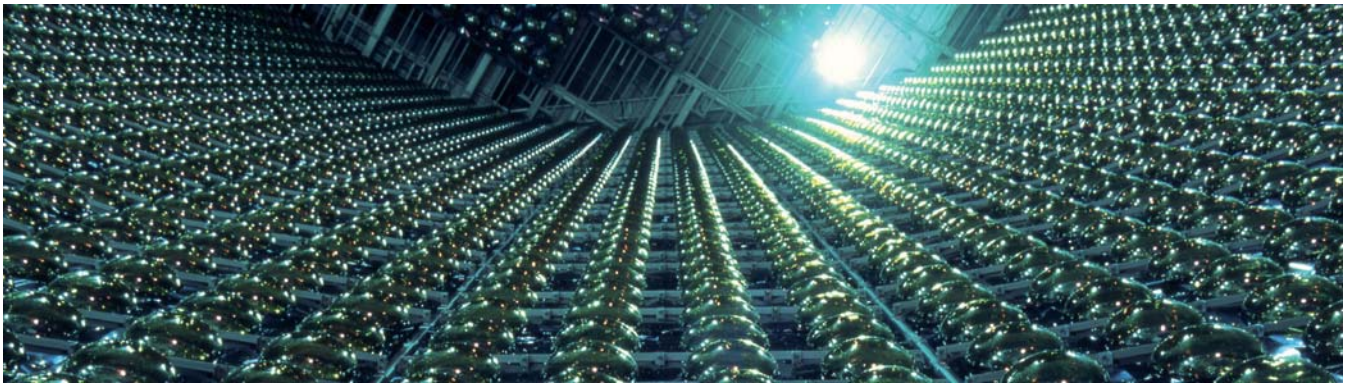


photo by Hamamatsu Photonics K.K.

Century of the Photon - Photonics in Industry and Everyday Life 5

Photonics is everywhere! One famous example to illustrate what has happened during the last years is the smart phone. Do you remember how a mobile phone looked like ten years ago? A greenish liquid-crystal display was where you could find photonics at that time. Today, a rather standard smart phone has a high-resolution display, one or two multi-megapixels cameras, and one powerful LED lamp. Many ultra-thin pieces are machined with high-precision lasers rendering the whole structure sufficiently lightweight. Of course, the radio signals are converted as soon as possible into optical signals launched into optical fibres to preserve proper data bandwidth.
Photonics is much less mature than electronics but will have an enormous contribution in the next decades on the key societal challenges of our society. The 20th century was the century of the electron, the 21st century will be the century of the photon!
Below follows a brief introduction of different areas where photonics plays a key role.

5.1 Information and Communication Technologies (ICT)

Information and Communication Technologies are underpinned by optical broadband communication technologies. Obviously, neither internet, nor mobile communication would be possible without the use of optical fibres and the optoelectronic components required at their extremities. An optical fibre has an incredibly low attenuation around the wavelength of 1550 nm (3 times longer than green light). Imagine a one kilometre thick glass wall nearly perfectly transparent (can you notice 2% attenuation?). The use of optical transmission as close as possible to the mobile users does make a lot of sense, when energy needs to be saved at all levels, and it is very likely that so-called mobile cells will become smaller and smaller with strongly reduced radio powers and directional antennas. Optical fibres are anyway eventually coming to all our homes and the latter will probably be used as mobile cells.
Optical broadband technologies are also coming to the rescue of overheated data centres, where huge amounts of energy are consumed in cooling all the electronic equipment. Miniaturization of integrated optical circuits with strongly reduced power usage and fibre interconnections between racks will hopefully help to avoid that the ICT sector be soon using 20% of all electricity produced! The traffic volume is expected to continue growing by 10 times within 5 years or 100 times within 10 years as it has been doing during the last decades. Innovations will be required to make optical networks faster, greener, closer to the end-user, as well as more transparent, dynamic and cognitive.
The role of ICT for our society and for our socio-economic challenges is well known and it is not our role to describe them here. One more time, we would like to emphasize the fact that photonic technologies are the real enablers of modern ICT and contribute therefore explicitly to solving many societal challenges.

5.2 Industrial Manufacturing and Quality

The competitiveness of industrial manufacturing relies heavily on the ability to increase productivity and quality assurance. The know-how and application of photonic principles using point sensors, 2D imaging, 3D imaging or spectral and other properties of light is a strategic tool in creating autonomous systems and faster in-line quality control systems in highly automated manufacturing. The whole automotive industry and traditional industry such as wood, paper, plastic and food as well as emerging industry benefits from using robotics and quality control of geometries colour and other parameters using light as a measurement principle. Future growth areas from the use of photonics in industry are machines for 3D-printing, recycling and robotics applied in autonomous transportation systems as well as in home or health-care applications.
For industrial applications, lasers are by far the most important photonic instruments, followed by vision tools and,

5 increasingly also, by optical sensors. The laser tool enables to handling manufacturing processes automatically and flexibly with an extraordinary quality. The development during the last two decades of highly energy-efficient and high power, although tiny, "lasing crystals", more commonly called diode lasers, has also made laser machining much greener compared to other energy sources. Lasers allow for the machining of ultra-thin materials, e.g. in smart phones. They allow for cutting or soldering difficultly machined materials, such as the ones used to make lightweight and high-strength constructions for e.g. wind turbine blades. A number of instruments, increasingly important for our ageing population, such as pace-makers, synthetic bones, endoscopes and micro-cameras used for in-vivo investigations, are also enabled by laser machining. The next generation lasers will need to be more powerful, more intense (i.e. same power on smaller spots) and with other wavelengths outside the conventional visible and near-infrared regions. Other innovations will be required to deliver the laser light in a more versatile manner.

5.3 Life Sciences and Health – Biophotonics

Biophotonics is a highly multi-disciplinary field involving physicists, chemists, engineers, as well as end-users in biology and medicine. Photonic methods and techniques are greatly contributing to solving several of the grand challenges of our time[1]: "sustainable solutions in areas such as… water and food, ageing societies, public health, pandemics…".

Optics and photonics are used in several fields of life science and health such as:

- Surgery and medicine (medical interventions).
- Diagnosis using imaging techniques and sensors.
- Biology and biotechnology.
- Testing food and drug quality and safety.
- Agriculture.

Many different types of lasers are commonly used for surgery. A proper choice of laser wavelength and pulse duration is necessary to target specific tissue sites. The Er:YAG laser is e.g. unique in its ability to cut bones with very reduced thermal damage. Lasers can also be used for treatment of skin cancers by using light-activated drugs (photodynamic therapy). The eye is probably the part of our body where lasers have been most widely used, for cutting, drilling holes, reshaping cornea surfaces etc. One can also mention that lasers can be used to solder living tissues by providing the exactly required amount of heat at exactly the right place for gluing cells together. Laser systems used in medicine have been traditionally very large. Visible diode lasers, diode-pumped solid-state lasers, light-emitting diodes, and compact optical parametric oscillators are now frequently used to build new and more compact systems. Lasers together with optical fibres can be brought inside the body for surgery. One specific example is the destruction of kidney stones by lasers (laser lithotripsy).

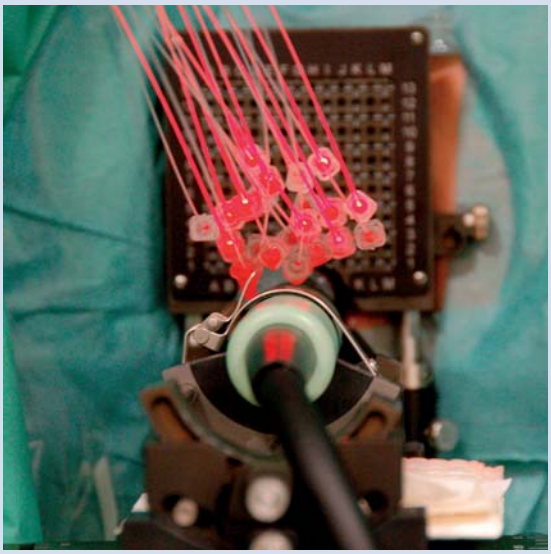


photo by SpectraCure

Optics has enabled the development of rigid and flexible viewing endoscopes that allow minimally invasive diagnosis and treatment of numerous sites inside the body, such as the colon, the knee, and the uterus. Another method to investigate the "digestive system" is by letting patients swallow a tiny camera taking many pictures on its way from ingestion to exit. When analysing outer parts of the body, loupes and microscopes are also used. Optical sensors can be used to measure e.g. oxygen or sugar concentrations in the blood or other biomaterials. The market for a minimally invasive measurement of blood sugar to avoid finger sticking would be huge, since diabetes is developing epidemically. This has been the subject of an intense research but is still a challenge.

In biology and biotechnology, photonics is used in many different applications. Confocal laser scanning microscopy and computed microscopy have enabled 3D imaging. The use of multi-photons imaging has opened interesting new possibilities, e.g. imaging inside living cells or fluorescence microscopy with resolutions well below the diffraction limit. An optical fibre end-shaped into a cone and metallized on the side can be used to collect light in regions as small as a few tens of nanometres (near-field microscopy). Fluorescent molecules or quantum dots replace radioactive tags rendering measurements much more practical and safe. Focused lasers

1 As described in the Lund Declaration of July 2009 of the European Union.

can trap cells and other small objects (optical tweezers) and manipulate them at will. Flow cytometry which is using lasers to excite fluorescence of cells in a liquid or gas flow can be used e.g. to realise a cell sorting. Lasers are essential to DNA sequencing and optics is being employed in a number of other biotechnology applications.

5.4 Energy-Efficient Lighting and Displays

Light emitting diodes (LEDs) convert electrons into photons much more efficiently than ordinary lamps. This combined with a smart optimisation of how the light is used will lead to energy savings between 40 and 70% as compared to a continued use of other types of light sources. LEDs give many new possibilities for lighting since the light comes from many small light points and the distribution of the light can hence be tailored very finely. The spectral characteristics can also be adjusted to a large extent, allowing for an adaptation of the colour of the light at different times of the day. Smart lighting offers very interesting business opportunities to several actors at different levels. Organic LEDs (OLEDs) are less mature than LEDs for lighting but open very interesting new opportunities. More distributed and flexible light sources can be realised with these. OLEDs are before all useful to make new types of displays. Energy-efficient displays can also be made with other types of LEDs.

5.5 Security, Metrology and Sensors

Safety and Security

Safety and security aspects are very diverse from food to transportation via explosives or air quality and in all these areas photonics brings or prepares solutions. For food safety, a major trend in Europe is to look for proper sensors. One option is develop a hand-held instrument based on multi-band IR sensing or imaging in an extended spectral range (from near-IR to far-IR, or 0.8 to 1000 µm). Optical sensors are being developed to monitor the quality of combustibles for cars to avoid counterfeits. The requirements of improved isolation in buildings make the monitoring of the air quality more and more important. CO_2 detectors based on IR spectroscopy do the job very well. Metrology using 1.5-1.8 µm IR light is very eye-safe because the maximum permissible exposure is about 100 000 times larger than for visible or NIR bands. New extended IR systems promise to provide accurate fingerprinting of gases such as explosives. In addition, optical techniques will allow for checking very large areas (or volumes) in a short time.

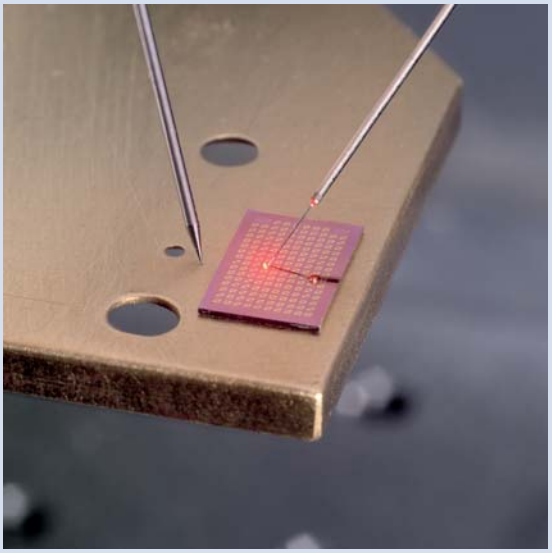


photo by Chalmers University of Technology

IR imaging is very useful for night vision in cars and other vehicles. 3D IR imaging, based on time-of-flight measurements will allow for an efficient day vision with low interference with day light. Finally, IR sensor could detect drugged or drunk driver on-the-fly even along motorways.

Counterfeiting accounts for 5-7% of world trade every year (or about 500 billion Euros). Different optical techniques are already commercialised or being developed based on extended IR to solve this problem.

Civil engineering constructions or ships or airplanes can be equipped with sensors, either embedded already in the structure or installed afterwards, to monitor the mechanical resistance and possible failures before they might happen.

Metrology

Ultra-high precision provided by photonics in metrology can be illustrated with two famous examples. First, the atomic clock based on a cooled fountain. Caesium or Rubidium atoms are cooled by lasers and the hyperfine optical transition measured with ultra-stabilised lasers. Additionally, optical combs are used for a convenient counting of optical frequencies. The second example is the fibre optical gyroscope which is the most powerful instrument to measure rotations (at the level of 0.01 °C/h).

Defence

Let us cite the latest report on photonics of the US government[2]:

"There is virtually no part of a modern defence system that is not impacted in some way by optics and photonics, even

2 "Optics and Photonics, Essential Technologies for Our Nation", National Academy of Sciences, p. 80, 2012.

5 when the system is not optically based. Modern defence systems are migrating toward optically based imaging, remote sensing, communications, and weapons. This trend makes maintaining leadership in optics and photonics vital to maintaining the U.S. position in defence applications."
Europe, and not the least Sweden, is of course also very active in this area. The defence industry is able to transfer technologies developed for military applications to the civil sector. The defence industry's experience in complex systems integration, as well as combining and presenting data from sensors and databases in many ways is indispensable for the development of situational awareness systems for civil applications.

5.6 Energy and Environment – Green Photonics

There are many facets of the so-called green photonics, optic and photonic technologies used for the generation of energy, a better control of the environment and a reduction of wastes. Some of them have already been described in 5.4.

Energy

Photovoltaic cells are used to generate electricity from the sun power. The energy generation from photovoltaic cells has increased by a factor of 5 between 2007 and 2010 thanks to governmental incentives and one predicts that 12% of the European electricity will be produced in 2020 in this way. Cells fabrication and extraction of charges are optimized by using laser machining. Fibre sensors and lasers are used to optimize the operation and maintenance of wind turbines. High power lasers are developed to generate ultra-small fusion reactors (laser fusion). Optical fibres and optical sensors are used to monitor currents and electric fields in electricity power plants and along high power lines. Distributed fibre sensors are used in hydroelectric dams to monitor strain and temperature.

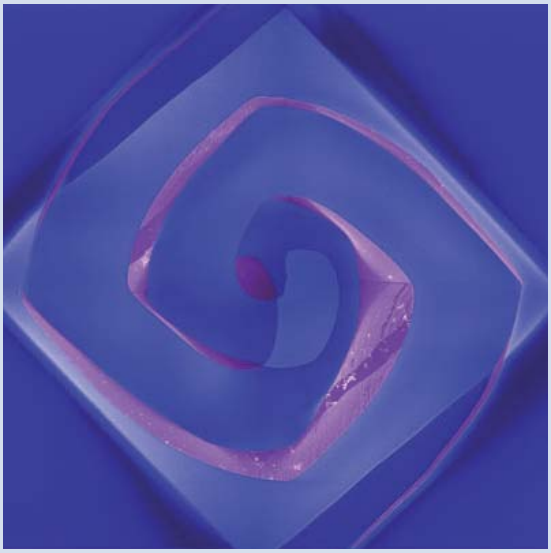


photo by ADOPT, KTH

Environment Monitoring and/for Waste Reduction

An excellent example is given by the monitoring of house isolation with infra-red cameras. The latter give very nice pictures of the temperature distribution at better than a tenth of a degree and thermal wastes due to bad isolation, are very clearly identified. Fibre sensors are used to monitor leakage of gas or liquids along pipelines. A very powerful technology for environment monitoring is the so-called LIDAR (light detection and ranging) which can map the concentration of molecules (e.g. ozone in the high or low atmosphere, NO, CO or SO_2 pollutants) over large volumes. Pulsed lasers can be focused on metallic scrap to generate a plasma which emits broadband light which will, after spectral analysis, give its signature (laser-induced breakdown spectroscopy). This gives the possibility to automatically sort out scrap for recycling.

Energy Efficient Communications

As mentioned earlier, optical fibres makes information transport optimally energy-efficient. Less energy is lost per kilometre of transmission than any other medium. Obviously what needs to be done at the nodes and extremities of optical fibre networks also has an important impact on the amount of energy used per transmitted bit of information. The emergence of very compact photonic integrated circuits is very promising to make data centres less energy hungry. Another major improvement comes from the fact that more and more optoelectronic components do not need to be cooled anymore. Passive optical components can do a lot of processing job that can replace a large amount of electronic circuits. Energy-efficient communications give more and more sense to teleworking to avoid unnecessary business trips and, why not, to avoid also quite often unnecessary commuting.

Clean Manufacturing

Laser machining allows reducing the amount of material waste. A big progress has also been made in the energy efficiency of laser machining equipment. For example the first welding lines for the automotive industry had an efficiency of 3% whereas the same kind of lines today have an efficiency of above 40%. The main improvements have been realised at the level of the laser sources with the upcoming of high beam quality diode lasers, single mode fibre lasers and kilowatt class ultrafast lasers.

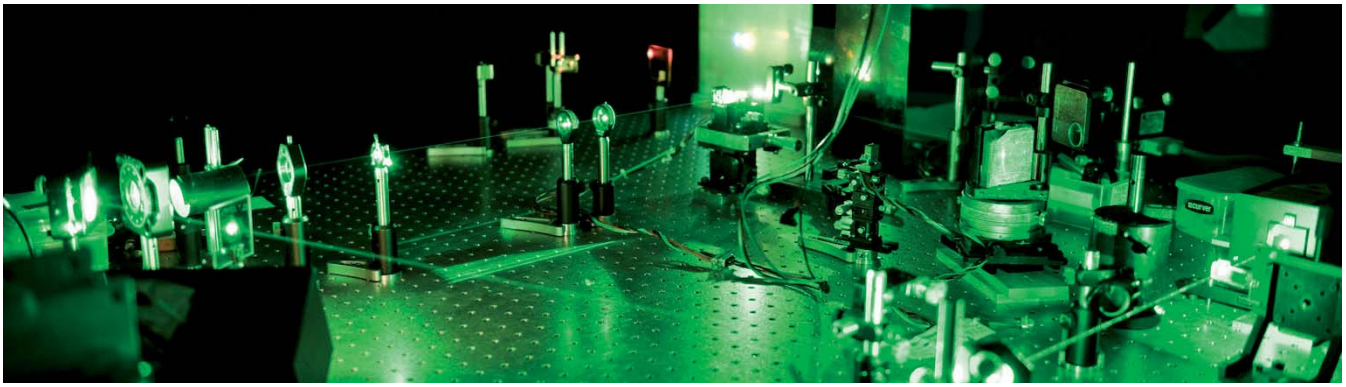


photo by ADOPT, KTH

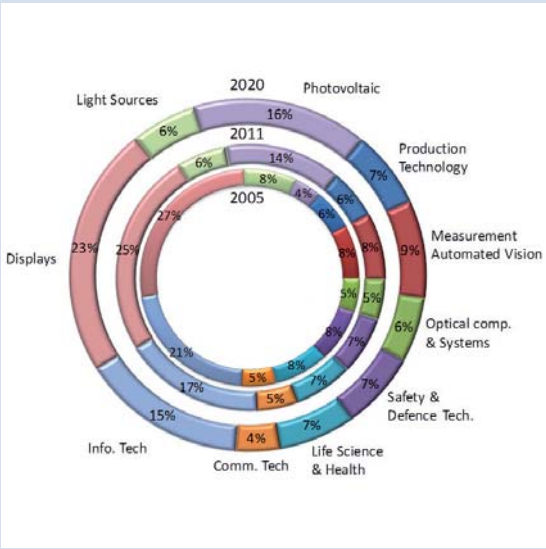
Photonics in an International Context 6

Photonics Worldwide

A recent German report entitled "Photonik Branchenreport 2013"[1] gives an excellent and well updated overview of the photonics industry worldwide. The world photonics market has grown from 228 billion Euros in 2005 to 350 billion Euro in 2011. This corresponds to a yearly average growth rate of 6.5% which is twice as fast as the World GDP and, of course, significantly more than the western countries' growth. Considering that the financial crisis corresponded to a "loss" of about two years for this growth, means that the growth has been even 1.5 times larger during the remaining four years, i.e. close to 10%. A study[2] from 2007 published by Photonics21 predicted a growth of 7.6% for the world photonics between 2005 and 2015, but had not predicted the crisis.

Europe had a share of 18% of the global market in 2011, which was slightly lower (19%) than the share given in the study of 2007. The shift of market shares mostly happens towards China which has now reached the same share as Japan, 21%. Asian countries account for as much as 70% of the world market and their share increases, mostly because of China. Europe is keeping its global position, while North America (12%) and Japan are losing shares. Europe has excellent global position in production technology (55%), optical components and systems (40%), measurement and automated vision (35%) and in medical technology and life sciences (30%). Germany has an outstanding position in Europe with more than 40% of the European market share.

The annual growth for the global photonics market until 2020 is predicted to be at the level of 6.5% in the latest study. This would be again more than twice the global GDP growth and probably significantly more than the growth in the western countries and in Japan. The global photonics market could then reach 615 billion Euros in 2020. The figure below, from that same report, shows the evolution from 2005 to 2020 via the year 2011, for the different market sectors. The study foresees a growth of 5.6% for the German market until 2020, slightly lower than the average of 6.5%. It is likely that the European growth will be very similar to the German one. This means that Europe would see its market share decrease slightly (<0.5%). On the other hand, it is also probable that North America and Japan will continue to lose market shares more markedly than Europe.



World Photonics Market

From the figure besides, one observes that the photovoltaic sector has been growing very fast from 2005 to 2011 (growth rate of 32%) but this growth is expected to saturate to around 12% in average from 2011 to 2020. Photonics is introduced more and more in industrial processes, since "Production technologies", "Measurement and Automated Vision" and partly "Optical Components and Systems" will increase their accumulated market share by 3%

1 Photonik Branchenreport 2013, Photonics Industry Report 2013, a study published in May 2013 by Spectaris, VDMA, Zvei: and the German ministry of education and research (report in German with a summary in English).

2 Photonics in Europe, Economic Impact, study realised by several German actors and published by Photonics21 in 2007.

6 points. Decreasing markets relatively to the others are “Displays” (-4% points) and “Information Technologies” (-6% points). “Safety and Defence”, “Medical and Life Science” and “Communication Technologies” are slightly decreasing in relative numbers.

Photonics Compared to the Other KETs

The Table 1 below, extracted from the High-Level Group Final Report[3] on Key Enabling Technologies and published in 2011, shows the world market for the six KETs selected by the EC in 2009. The growth figures are slightly more optimistic than those of the recent report, but interesting information is given about the trends and the relative size of these markets. Photonics has already today the largest market size, passing micro- and nanoelectronics a few years ago, and could be as much as 50% bigger than the latter in 2015. The market for nanotechnology, although having a very large expected growth rate of 16% in this table, is at least one order of magnitude smaller than the one for photonics.

	Current Market Size	Expected Size in 2015	Expected Compound Annual Growth Rate
Nanotechnology	12 bn	27 bn	16%
Micro- and Nanoelectronics	250 bn	300 bn	3%
Industrial Biotechnology	90 bn	125 bn	6%
Photonics	230 b	480 bn	8%
Advanced Materials	100 bn	150 bn	6%
Advanced Manufacturing Systems	150 bn	200 bn	5%
TOTAL	832 bn	1282 bn	

Estimated global market potentials of Key Enabling Technologies

3 The leverage effect of photonics technology, Final report to the EC, March 2011. Note that there is a mistake in that report since the CAGR for micro- and nanoelectronics is indicated as being 13% instead of 3%.

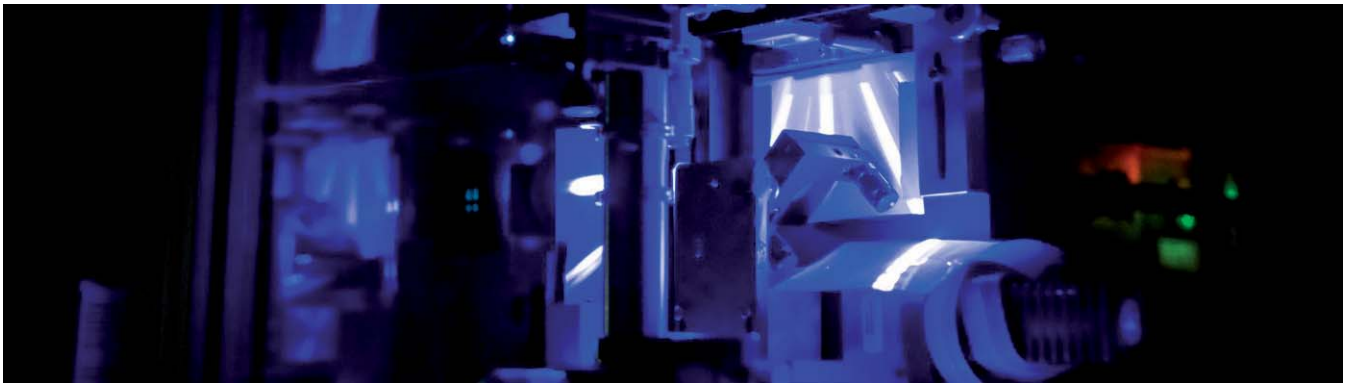


photo by ADOPT, KTH

Optics and Photonics in Sweden 7

This chapter gives a description of optics and photonics in Sweden. First some data regarding the companies will be presented. Then, the description will be made according to the different work groups of PhotonicSweden which are mirroring the ones presented in the previous Chapter 5 (and the ones used by the European technology platform Photonics21), with some minor modifications. These are:

- WG1: Information & Communication
- WG2: Industrial Manufacturing & Quality
- WG3: Life Sciences & Health
- WG4: Lighting & Displays – Smart Lighting
- WG5: Security, Metrology & Sensors
- WG6: Optical Components & Systems

The work group 7 on Research, Education & Training is the subject of chapter 8.

Data on the Swedish Optics and Photonics Companies

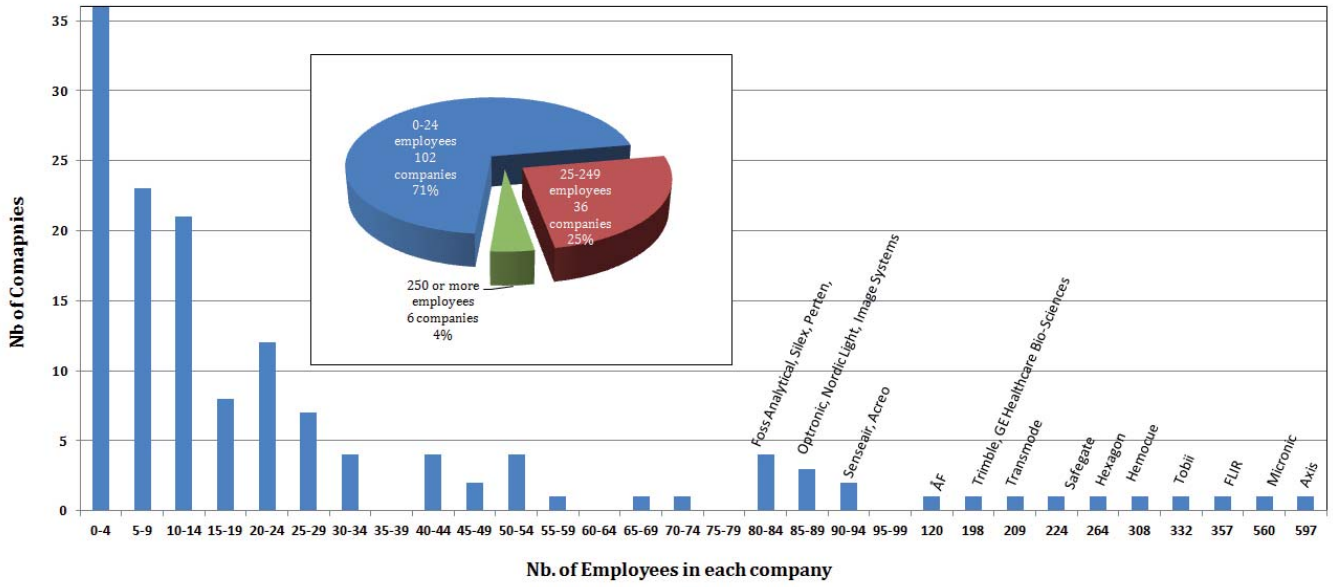
Criteria of selection: Companies developing, designing, manufacturing or selling optics and photonics equipment. For non-micro companies (10 employees or more) having several lines of activities which are not all related to photonics, the data obtained from allabolag.se have been weighted by estimating the proportion related to photonics.

Number of companies identified by October 2013: ~ 150

Total number of employees active in the field in these companies: ~ 6100 (2012)

Total turnover: ~ 17 billion SEK (2012)

The total profit 2012 for these 150 companies was about 600 million SEK. If one subtracts the result of 17 companies (most of them are start-ups), the result is about 1.2 billion SEK for the remaining 133 companies.



Large fragmentation of the Swedish photonics industry

7 7.1 Information & Communication

Information and Communication Technologies (ICT) built on optical broadband communication technologies, address many of the socio-economic challenges, such as sustainable development, securing energy supply, ageing population and ensuring human and environmental health.

Strengths and Opportunities

Swedish photonics ICT has a strong and long history driven by the large players Ericsson and the Swedish telecom operator, Telia, at an early stage focusing on and pioneering photonics, i.e. fibre optic communication systems and components. Large research programmes, also supported by the Swedish government, have laid the ground for the Swedish Photonics ICT industry of today. Although these larger organisations have moved up the value chain, new smaller companies have emerged focusing in certain niche areas but covering altogether a whole value chain in the field from nano-electronics/photonics via components and high-speed subsystems to fully converged fixed/mobile networks including network management.

Areas where Swedish research and industry have strong competence are:

- High speed coherent optical communication.
- Broadband access, fixed and mobile.
- Converged mobile/fixed back- and front-haul.
- Integrated- and nano- photonics, interconnect.
- SDN, software defined networks.
- ”Green” network architecture.
- National testbeds, from end-user to core.

Weaknesses and Threats

- Lack of international focus in research.
- Need to build stronger relations between national R&D players.
- Lack of larger Swedish ICT industrial players in photonics components and systems.
- Strong niche competences are not sufficiently well coordinated and complementary.

Companies

The early large investments mentioned above are still exploited today, not the least by companies like Transmode, Packetfront and NetInsight. The same is also valid for component and sub-systems companies like Proximion, Finisar (former Syntune), EXFO and TE Connectivity. Other companies active in Photonics ICT but not telecom are: Tobii, Neonode, Flatfrog and Micronic Mydata. Total turnover and total number of employees are estimated to 1,9 billion SEK and 700.

photo by Acreo Swedish ICT AB

Research

The photonics research driven by universities and institutes are focused on the most important areas where Swedish photonic research is in the forefront, for example; coherent high capacity transmission at Acreo, KTH and Chalmers, Photonic integrated circuits and High-speed TW-EAMs at KTH and high-speed VCSELs at KTH and Chalmers.

Recommendations

- Strengthen the value-chain, all the way from research at university and institutes through end-user service delivery via network cases and demonstrators.
- Strengthen national test-beds showing the value of e-services, such as e-health, e-government etc., in all aspects through demonstrators.

7.2 Industrial Manufacturing & Quality

Photonics within industrial manufacturing can be divided into two quite separate areas:

1. Process control and quality. Photonics equipment that inspects, measures and secures product quality and/or controls industrial processes.
2. Industrial laser material processing where photonics is used in industrial process such as cutting, drilling, welding, marking and surface treatment.

7.2a Process Control and Quality

Automation encompasses all systems relating to measurement and control of production processes, with the aim to improve productivity, quality, environmental management and human interaction. Photonics is a key automation tool where optics and vision systems control production processes and automatically inspect/measure/secure the quality of products. Automation is a necessity to allow competitive production in Sweden.

Strengths and Opportunities

Factory automation is a field in which Swedish companies and universities hold a world-leading position. Swedish companies within automation have a turnover of 50 billion SEK. Sweden is very well positioned to lead "Photonics for factory automation" in Europe:

- Sweden has already several world-leading companies in specific industry sectors and there are great opportunities to create new and expand existing companies that develop produce and internationally market quality control sensors and systems based on optics and vision technology.
- Manufacturing industries are strong in Sweden and they can grow by lowering the production cost and increasing the quality of the products thanks to photonics.

Weaknesses and Threats

(1 specific for this area followed with 4 not specific ones)

- Lack of specialized education within optics, metrology and vision technology.
- Lack of long-term strategy for the financing of the research and its commercialization.
- Financing for companies in initial growth phase is weak.
- Many small and few large companies providing photonic technology.
- Photonics as an enabling technology is hardly visible in coming national research agendas.

Companies

OptoNova AB, Gedevelop AB, Innovativ Vision AB, Shapeline AB and Svensk Industriautomation AB are five Swedish companies with world-leading products for automatic inspection and quality control. IKEA Industry Hultsfred produces more than 2 million wardrobes (called PAX) each year. The factory is running 24/7 with fully automated quality control with vison systems from OptoNova AB. All surfaces, edges, and holes are controlled on every furniture panel. Without automatic quality control this factory would have been set up in a low cost country according to IKEA management. Photonics enables cost effective production of consumer products in Sweden.

photo by OptoNova AB

Research

- KTH Royal Institute of Technology - Production engineering. Measurement and Optics.
- Luleå University of Technology- Experimental mechanics and wood technology - Optical measurement technologies in industrial applications.
- Sverea - Material and process development, Production engineering

- Acreo Swedish ICT AB/IMAGIC - Image sensors, fibre optic sensors and electro optic components
- Innventia - Research activities within paper and packaging. Including automatic inspection
- SP - Research activities within wood, glass, concrete, food. Included measurement and optics.

Recommendations

- Strengthen the education in photonics and computer vision for industrial applications.
- Improve the conditions for small innovative companies to grow within the field.

Our vision is that the Swedish manufacturing industry will grow and achieve **best quality at lowest cost** by using photonic sensors and vision systems (photonic eyes).

7.2b Industrial Laser Material Processing

Laser materials processing is an important area for future manufacturing in Europe. It involves quantum physics and several key technologies like process technology (interaction of photons which matter, thermodynamics, fluid flow), automation and robotics, process monitoring and control, machine systems and their design, sensors (optical), materials science, simulation of processes, product design and function. Laser materials processing systems use photons from X-ray to IR.

Strengths and Opportunities

Sweden is eminent in developing manufacturing processes like laser welding, laser hybrid welding, laser metal deposition, laser surface treatment, and laser cutting. Also Sweden is at the forefront in development and manufacturing of fiber optic systems and industrial laser robot manufacturing systems. The internationally recognized Swedish applied laser research is strongly interacting with, and supporting, the manufacturing industry. LaserGruppen is a strong group for the dissemination of laser technology.

Weaknesses and Threats

Some weaknesses and threats in the area are: small and uncoordinated financing of laser R&D and technology; low degree of competence in the field in industry; lack of strategic long term thinking and risk taking when planning new investments in manufacturing; expensive verifying of laser technology; few system suppliers of laser robot and special laser manufacturing systems.

Companies

ESAB AB - System supplier of laser hybrid welding system; Permanova Lasersystem AB - Laser tools, laser robot system integrator; Optoscand AB - Fiber optics and components; Stjernberg Automation AB - system integrator. Volvo Cars - laser welding of car bodies since 1990 in fully automated on-line systems. Ferruform AB,- full automated laser welding systems for on-line laser welding of rear axis for Scania with process monitoring and 100 % acoustic emission inspection; Alfa Laval AB - welding of heat exchanger components since middle of the 1980s; Swegon AB, laser welding of aluminum fan wheels; Volvo Construction Equipment AB - laser welding of transmission components.

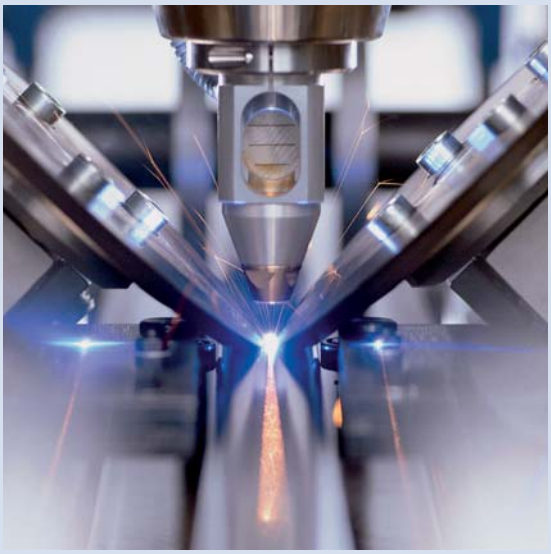


photo by Trumpf

Research

Luleå University of Technology - Laser materials processing with special emphasizes on laser welding and simulation (Prof. Alexander Kaplan). University West in Trollhättan - Welding and laser welding (Prof. Per Nyhlén). Swerea Kimab - Welding, laser welding (Prof. Arne Melander).

Recommendations

Intensified research and development of laser manufacturing processes; Education and knowledge transfer to industry at all levels; Improved and broader education in universities and high schools.

7.3 Life Science & Health

Photonics constitutes an important toolbox for applications in, e.g., medical diagnostics and therapy, biotechnology, pharmaceutics, food technology, and agriculture. The Swedish innovative part of this multidisciplinary field, biophotonics, has been studied[1], and a summary is presented in this section.

Strengths and Opportunities

The global biophotonics market is growing fast and the growth is expected to even accelerate in the next coming years. The current total Swedish biophotonics (industry, academy, and authorities) is estimated to employ about 3500 people and have a yearly turnover/budget of approximately 6 billion SEK, an excellent ground for growth. Further, the Swedish academic research and industrial R&D in photonics on one side, and in biomedicine and medical technology on the other side, have historically been very strong, and still are. Increased interaction between photonics and the bio/medical fields will accelerate the growth of biophotonics in Sweden. It should also be noted that the two regions of Stockholm/Uppsala and Skåne are at present the strongest Swedish regions in the biophotonics field.

Weaknesses and Threats

Strong investments in South-East Asia and North America, a lack of national long-term strategies, and declining conditions for clinical studies, feed a migration of cutting-edge knowledge out of Sweden, and early-stage R&D companies are vulnerable, due to a lack of venture capital funding. Further, Swedish biophotonics suffers from rather weak and not well-coordinated national interdisciplinary networks and multidisciplinary industrial R&D.

Companies

34 companies have been identified as primary innovative biophotonics companies in Sweden. These companies represent a wide range of applications, and several are world-leading within their specific business niche. The companies can be divided into the following subgroups:
Medical photonics diagnostics: Demetech, Derma Diagnostics Development, HemoCue, Optilia Instruments, Perimed, Redsense Medical, Serstech, WheelsBridge. **Medical photonics therapy**: Clinical Laserthermia Systems, Irradia Sverige, ProstaLund, SpectraCure. **Medical x-ray**: Scandidos, Scint-X, Xcounter. **Biomedical optics instruments**: Biolin Scientific, BioOptico, CellaVision, Gyros, Phase Holographic Imaging, Q-linea. **Analysis in food technology, agriculture, and pharmaceutics**: Foss Analytical, GasPorOx, UmBio. **Gas sensors for life science and health**: Höks Instruments, Masimo Sweden, Mindray Medical Sweden, SenseAir, Servotek. **Biotechnology components**: Cobolt AB, Silex Microsystems. **Assistive technology**: Low Vision International, Tobii Technology. **Research institutes**: biophotonics part of Acreo Swedish ICT AB.

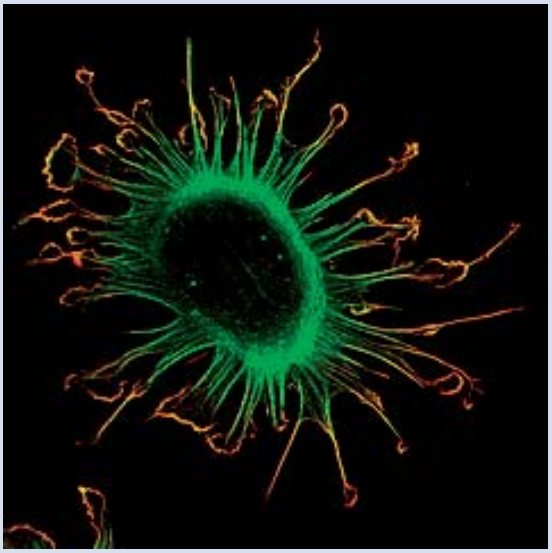


photo by Cobolt AB

Academic Research

Chalmers University of Technology, Gothenburg University, KTH Royal Institute of Technology, Linköping University, Lund University, Uppsala University, and the joint research centres MAX-lab in Lund, SciLifeLab in Stockholm/Uppsala, and the Centre for Biomedical Engineering and Physics in Umeå/Luleå all have prominent academic biophotonics research. Particular areas are bioimaging, biosensing, optical manipulation, spectroscopy, laser medical applications, and neurophotonics.

Recommendations

Increased interaction at all levels is proposed: between actors, between sectors, between academy, industry, and the public sector, and between system levels. Interaction interfaces create synergies: new ideas, new solutions, new collaborations, new funding, new businesses, new markets, and new job opportunities. This will require support, for example governmental support, in order to create new interaction infrastructures, as well as incitements that do not require short-term commercial results, for interdisciplinary interaction between industry, academy, and the public sector.

1 The complete report is available from PhotonicSweden, Work Group 3 – Life Sciences & Health, Karlsson D. et al., 2013: A Report on Swedish Innovative Optics & Photonics in Life Sciences & Health.

7.4 Lighting & Displays – Smart Lighting

Smart lighting focuses on system solutions to provide the right light, in the right place, at the right time. Solid state lighting (SSL) systems include LED, sensors, hard- and software, intelligence and user interfaces. The flexibility of Smart Lighting enables considerably higher user value than traditional lighting.

Strengths and Opportunities

Sweden has a great tradition in leading improvements of working and living environments, including innovation-promoting processes like the "branding" of the TCO screen. Numerous Swedish actors are very strong in development and utilisation of new ICT based system solutions. Sweden is leading in open innovation and renewal oriented value chain collaboration. Scandinavia is also internationally interesting as an early market for SSL and smart lighting. Furthermore, Sweden has leading research on new kinds of LEDs and nano-threads; leading business development actors in system solutions and ICT related business models. The evolving market for smart lighting is an interesting field of application for photonics and the above strengths show that Sweden can take a leading role in the accelerating deployment of SSL.

Weaknesses and Threats

There is low general awareness about the potential user advantages of smart lighting. The European promotion of energy savings presents LEDs as rather mediocre from quality-of-light point of view. The market is immature and at the same time ever more international actors are investing in deployment of SSL. The business development potential is great and many actors know this.

photo by L. Montelius

Market and Companies

A main part of the customer value of smart lighting is created close to the customers by means of flexible user adapted system solutions. Smart lighting has great potential as a value-enhancing work tool, for e.g. schools and elderly people. The added value is interesting for facility owners and companies in facility management, architecture, design, construction and interiors. The market is extensive for system building actors with a base in photonics. Companies in facility management, supervision and security, and e.g. daylight control, are building ever more advanced systems of sensors and control functions that can be extended to lighting. Ever more big software and ICT companies are also starting to show interest in smart lighting. The established lighting companies are aiming for high-quality LED solutions, e.g. IKEA, Aura Light, Fagerhult and Wästberg. A number of new actors like Nordic Light, Heliospectra and Aaxsus, are developing new LED-based products and there are a growing number of start-ups, e.g. Greinon Engineering, BrainLit and LightAB that are developing new SSL applications.

Research that is Valuable for Leading Swedish Deployment of SSL

Sweden has leading research on LEDs and nano-threads, e.g. at Linköping University and Lund University. This research has one basis in Material Sciences and electro-optics and consequently research on SSLs is one way to make use of the major investments in ESS and MaxIV. Sweden also has many kinds of applied research on system solutions, sustainability, working environments, entrepreneurship and open innovation.

Recommendations

One key to get started is to clarify the user value of Smart Lighting by demonstrations and development of instruments for assessment of lighting environments.

7.5 Security, Metrology & Sensors

Sensors, systems converting physical quantities into readable signals, apply here to two areas, security & surveillance and metrology. The first area deals with different kinds of control, security and assistance systems. The second area deals with different metrologies used among others in security & surveillance applications. The sensor could be anything from a 0-Dimensional Dot-sensor to a 3D laser-scanner. The spectral range of the sensor can extend beyond the visible up to terahertz radiation.

Strengths and Opportunities

Sweden has a unique position in the field of thermal imaging. Thermal imaging is a very important component in security and surveillance systems. Thermography was invented at AGA in the 1960-ies and FLIR has today more than 60% of the world market. Acreo has been very successful not only in the development of new sensors (Focal Plane Arrays, FPAs) but also in the production of the sensors in the clean-room facilities of Myfab[2]. IR Nova is a spin-off company from Acreo manufacturing IR-FPAs. On top of the production of IR sensors in Sweden, FLIR also has one of the largest facilities for manufacturing IR-lenses, a large part of which is exported. The development of cheap IR-image detectors, based e.g. on bolometers has also opened up new application areas, such as Driver Vision Enhancement (DVE) systems from Autoliv. Cheap Thermal cameras are also integrated in surveillance systems from Axis.

Weaknesses and Threats

Optical design and lens manufacturing is a very small and specialized field. One challenge would be to connect this field stronger with the education at Universities and Technical High Schools. The number of engineers with the skills to design optical systems and lenses is decreasing. However, there will still be a need for engineers to measure and verify optical performance and understand optical designs.

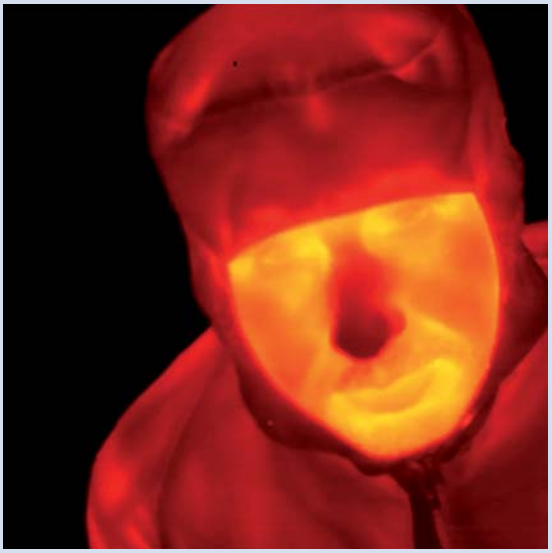


photo by IR Nova AB

Companies

53 companies have been identified as active in this field in 2012. About 75% of these companies are active in the metrology area and 25% are active in the security and surveillance area. The industry is quite diverse with companies working in many different sectors. At least 7 companies are manufacturing sensors: Senseair (gas IR sensors), SICK, IR Nova (IR camera chips), Fiberson (fibre sensors), Trimble, Acreo and SiTek (position sensors). 43 of these companies integrate sensors in their products (28 use imaging techniques and 35 use other types of sensors). Major companies in security and surveillance are Axis Communications, FLIR Systems, FOI, Aimpoint, Senseair and SAAB. Major companies in metrology are Micronic Mydata, Tobii, Trimble, Perten Instruments, GE Healthcare Bio-Sciences and Optronic. Major companies in "application" are SAAB, FLIR, Axis, Autoliv.

Research

Acreo and its spin-offs, like IR Nova are the main players in the development of infrared sensor. Acreo is also active in the area of fibre sensors. FOI and SAAB have been working on developing 3D-imaging systems. Asta Zero is a new centre for research on road safety that will open in 2014. This EU-sponsored project will make it possible to study "active" sensors in a realistic environment.

Recommendations

The truly unique competence in thermal imaging should continue with research in new detector technology in the IR-spectral region. These sensors should also be possible to use in novel gas-detection systems in for example environmental application.

2 Myfab – the Swedish research infrastructure for micro- and nanofabrications - offers distributed high-quality clean room facilities and associated expertise for advanced research and education to researchers and product developers at universities and high tech industries. It consists presently of the facilities of KTH in Stockholm, Chalmers in Gothenburg and from the University of Uppsala.

7.6 Optical Components & Systems

There is a large diversity of Swedish companies manufacturing optical components or integrated optical subsystems. Component manufacturing and subsystem integration are investment heavy, often requires clean rooms and are research intensive. They are in many cases the result of many years of research often basic and realised at Universities.

Strengths and Opportunities

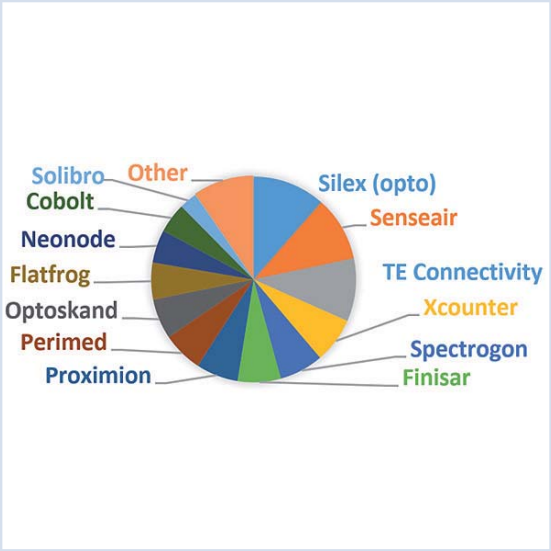
Sweden has historically had strong R&D in optical component manufacturing mostly driven by Ericsson and Telia for the telecoms. It shows an impressive high level where world leading research and manufacturing are made on a number of diverse types of optical components. The networked infrastructure Myfab is a precious facility for the R&D on new components and sub-systems. Beside this, there are also 4 clean-room facilities at companies in Sweden for semiconductors and optical fibres.

Weaknesses and Threats

Most people in the business are middle-aged and the telecoms are not the driving force in optical components anymore. The question is whether Sweden will be capable of fostering a new generation of talented people in the component area, who can create new companies and new components adding value in new areas.

Companies

Sweden counts approximately 20 companies in this area, which had a total turnover of about 1100 MSEK in 2011. These companies are in several cases among the best or best in the world. Three companies are now owned by global or foreign companies (Finisar, TE connectivity and Solibro GmbH) but the others are still SMEs. Most companies have their roots in Swedish university research and several have started as spin-offs from Acreo Swedish ICT AB.



Contribution to the total turnover of the optical component and subsystem companies in 2011

Research

Swedish universities have a strong position in material research and also have several research groups in optical components. KTH-ICT have component research in integration, epitaxy, photonic crystals, nanostructures, semiconductors, electro-optic polymers, silicon, metals (plasmonics) and meta-materials and KTH-Laser Physics in micro-chip and fibre lasers. Chalmers-MC2 develops e.g. VCSELs and Lund University studies the manufacturing and use of nanostructures for LEDs and photovoltaics. The universities of Uppsala, Stockholm and Karlstad have research in photovoltaics.

Recommendations

The national coordination in this area is still insufficient. The Swedish actors should be able to identify next generation components and sub-systems and make sure that a long term support be put in place. To create new component companies, Sweden is dependent on continued research at universities and at research institutes, which can continue acting as a bridge in to the market.

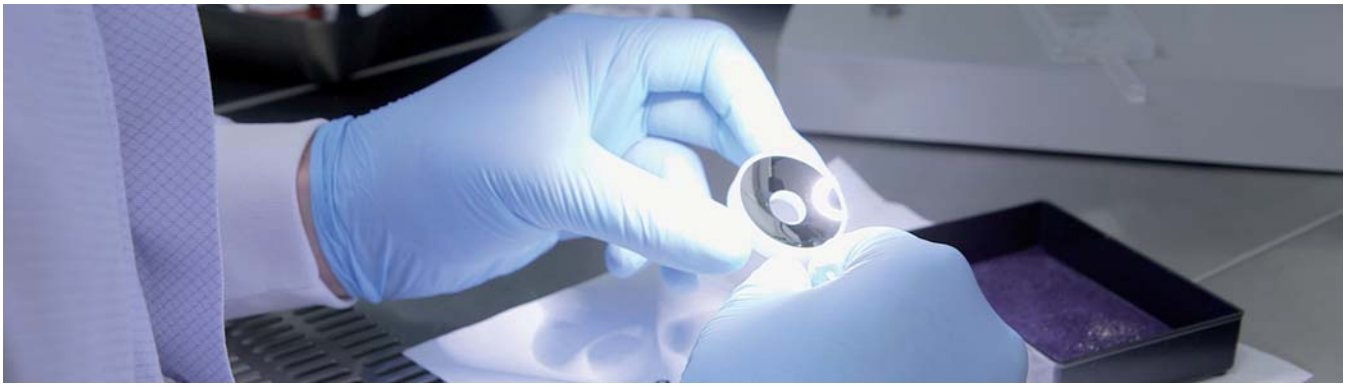


photo by Thorlabs Sweden AB

The academic education and research continuously supplies Swedish industry with well educated work force and competence in the photonics area. A brief account of photonics research and education at the larger universities is given below, ordered geographically from north to south.

Luleå Technical University (LTU)

LTU runs optics and photonics research keeping a strong focus on industrial applications: process diagnostics/automation, laser manufacturing, environmental remote sensing, and process industry (mining, pulp&paper, bioenergy). Recent implementations in medicine and environment (winter related problems) are also increasing in importance. Including PhD students, about 40 researchers are active in the field. For diagnostic/automation, various imaging methods like speckle methods/holography, hyper-spectral imaging, micro-tomography, opto-acoustic imaging, and time-of-flight radar are in main focus. For manufacturing, laser welding processes are of great interest. Remote sensing optics has strong profile at Institute of Space Physics (IRF) in Kiruna dealing with atmospheric diagnostics based on radiative transfer spectroscopy. Education in optics/photonics at the MSc level is a major part of the specialization in “sensors and signals” in the Engineering Physics and Electronics programs, and “remote sensing” - for Space Engineering MSc students. Students in Machine Technique are trained on laser manufacturing. Optics and photonics oriented PhD’s from LTU have throughout the last two decades brought their knowledge to local and Swedish industry: LKAB, Boliden, Assi, SmurfitKappa, Saab Combitech, Ericsson, Volvo Technology, Volvo Aero (GKN), and also in smaller niche companies, start-ups, and academia.

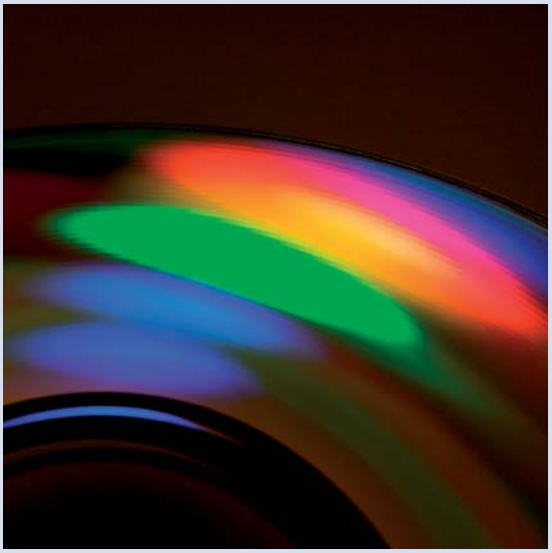


photo by ADOPT, KTH

Umeå University (UmU)

The research within the field of photonics at UmU, which primarily takes place within the strong research environment “Light in Science and Technology”, is performed along several directions, from fundamental studies of light and light-matter interactions, via the use of light for basic and applied investigations, to the development of various types of applications. Including PhD students and post-docs, about 40 researchers are active in the field. Examples of fundamental research include studies of extreme electromagnetic fields and plasmas, non-linear interactions, the quantum vacuum, and dynamics of atomic gases in traps, optical lattices and Bose-Einstein condensates. Application-oriented research take place in fields e.g. laser-based spectroscopic techniques for quantitative spectrometry; development of functional organic photonic and electronic devices in the form of flexible and large area light-emitting electrochemical cells and novel photo-chemical patterning techniques; development and use of non-invasive optical micromanipulation and force-measuring techniques, mainly optical tweezers, for biophysical applications; and studies of non-linear optical properties of new materials, e.g. graphene and nanowires, with application to frequency conversion. Examples of industrial collaboration partners are Siemens AB, FOI, SP, Optronics, and Airoptic. Education in the field is provided by the Engineering Physics program withing the profile "Photonics and Nanotechnology". The student can chose from the branches "Atomic, Molecular, and Optical (AMO) Sciences" and "Advance Material and Nanotechnology".

8 Uppsala University (UU)

Optics and photonics are connected to several scientific disciplines across Uppsala University, for instance in connection to biomedicine research at the BMC facility (now also including new premises for SciLifeLab Sweden) and clinical tools (such as a state-of-the-art PET-MRI camera) at the University Hospital. The core of research and education in optics and photonics is found at the Ångström Laboratory, where materials science, microsystems technology, nanotechnology, sustainable energy, solid state physics, solid state electronics, astronomy, particle physics, molecular biophysics, and several other divisions include optics/photonics in their research projects and give educational courses in optics/photonics-related topics. A large number of spin-off companies have been created by UU students with support from the university's holding company, several of them having also won VINN NU grants, e.g. Adamantis AB, Rolling Optics AB and Molecular Fingerprint AB. In addition, the industrial infrastructure in Uppsala, including large companies such as GE Healthcare, is a solid base for take-up of highly skilled students and PhDs.

Royal institute of Technology (KTH)/Stockholm University (SU)

Photonics and optics research at KTH is centred around the Linné Center of Excellence in Advanced Optics and Photonics (ADOPT) which, including PhD students, has about 100 researchers. Strong research programs within ADOPT are nano-optics, optical nano-devices, functional materials, near-field optics, quantum optics and quantum information, and optical fiber communication/photonics. Many projects involve tight collaboration at Acreo Swedish ICT AB/Swedish ICT, and in particular with the Acreo Fiber Optics Center (AFOC). Strong international collaborations exist in all the above mentioned areas, but the cooperation with Zheijang University (China) and Lund University through the Joint Research Center in Photonics (JORCEP) is worth a special mention. Spin-off companies were formed in several areas, e.g., frequency converted lasers (Cobolt AB), tunable telecom lasers (Syntune, now part of Finisar), x-ray scintillation detectors (ScintX), and semiconductor growth (Epilog). KTH has also a strong position in bioimaging with almost 50 people active at various levels, particularly in microscopy based fluorescent techniques, and in X-ray physics. These fields have contributed to spin-off companies where Sectra Mamea who has developed low dose mammography is the best example with more than 100 employees. It was recently integrated in Philips Digital Mammography Sweden AB. Excillum AB is developing compact X-ray sources for imaging.

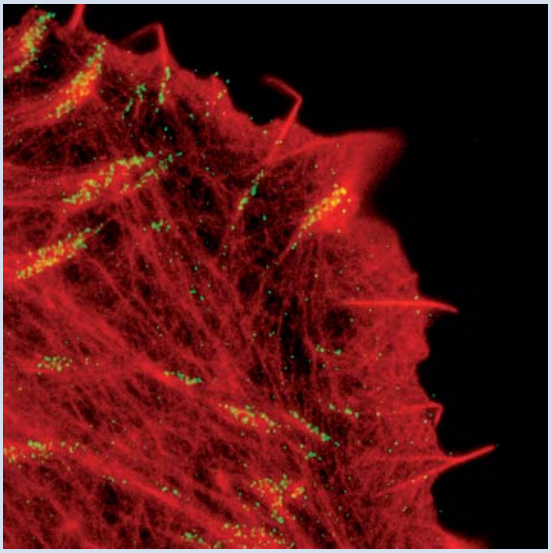


photo by Cobolt AB

Optics/photonics activities at KTH/SU have over decades provided the industry in Mälardalen with PhDs and engineers of strong research experience in this field, and nowadays there exists a strong bound between industry and academia. Over time employers have include larger companies like Ericsson, ABB, FLIR Systems, Celsius Tech, and Spectragon, institutes such as Acreo Swedish ICT AB and FOI, government agencies like Vinnova and Tillväxtverket, consulting companies such as Optronic and ÅF Konsult, as well as smaller companies like Tobii and Proximion, etc.

Chalmers University of Technology (CTH)

Two departments, “Applied Physics” and “Microtechnology and Nanoscience”, about 50 people in total (senior researchers and PhD students) drive photonics/optics research at Chalmers University of Technology. Covered topics include bionanophotonics, laser-matter interactions, liquid crystals, optoelectronic devices, and fiber optic communications. The fiber optic communications research center (FORCE) is the strongest national center on the subject, and comprises two departments with 30 researchers. The Chalmers research in photonics have spun off companies such as EXFO Sweden AB, and supplies highly qualified professionals to larger institutions with offices in Gothenburg (e.g. Saab Dynamics, AB Volvo, Ericsson AB, SP and Acreo Swedish ICT AB), and also a number of local SMEs, e.g. Optoskand, SiTek, Micronic, and Thorlabs. Chalmers' education in optics and photonics is found in the BSc programs in "Engineering physics" and "Electrical engineering", but more pronounced in the MSc on "Wireless, photonic and space engineering" and "Applied physics".

Linköping University (LiU)

Organic material based optoelectronics is pursued in the Linköping University environment. Courses in soft condensed matter and organic electronics are part of some education programs. Some ≈70 students and scientists are active in research in this field, in the campuses of Linköping and Norrköping, with accompanying activity in the technology transfer company Acreo Swedish ICT AB in Norrköping. Printed organic displays and electronics for flexible paper displays are developed in the Norrköping campus. A major field in optoelectronics is that of organic photovoltaics for energy conversion, pursued at IFM, LiU, and now in the phase of scaling up at a prototype reel-to-reel printer in the Printed Electronics Arena in Norrköping. Organic based light emitting devices is another activity, with spin off companies Eco Spark and Lumisigns.

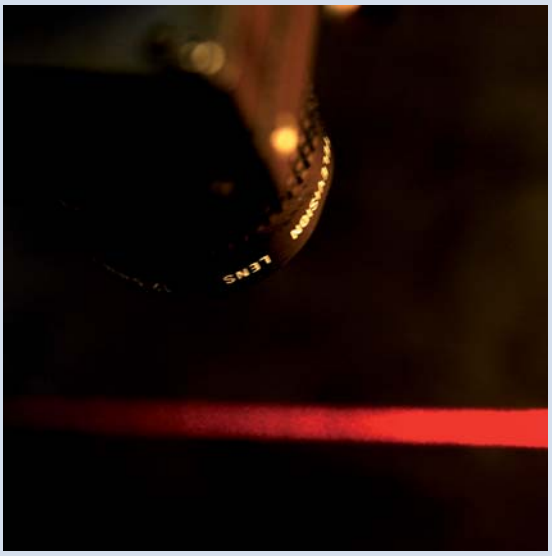


photo by Optronic AB

Lund University (LU/LTH)

Photonics and optics research at LU/LTH is centered around Lund Laser Centre (LLC) which has >150 researchers (including PhD students). At LLC, there is a major focus on spectroscopic applications and methods. In addition, optics/photonics research is also carried out within the nanometer structure consortium (nmC). The activities in Lund in atto-second physics and laser combustion diagnostics are among the leading ones in the world. Internationally strong or very strong activities e.g. also include research in photosynthesis and solar cells, biophotonics, quantum information, nano photonics, and activities integrating lasers and synchrotron radiation (connected to MAXlab). Spin-off companies have been formed in many areas, e.g. spectroscopic environmental and/or product monitoring (e.g. Opsis AB, Gasoptics, Gasporox), laser medicine (e.g. Spectraphos, Spectracure), spectroscopy-based process monitoring and process steering (e.g. Semtech Metallurgy AB), nanowire diodes, and solar cells (GLO, Sol Voltaics). A two year program with courses in advanced optics is offered. The photonics and optics activities at LU/LTH have over many years provided the local industry with experienced PhDs. Over time, employers have included larger companies like Sony-Ericsson, and profiled in optics/photonics companies like Anoto, Flatfrog, Opsis etc., as well as smaller startup companies.

Conclusion

The given overview shows that the higher education institutions provide competence boosting the local activities and supply the surrounding industry with photonics competence. It is also clear that other areas of Swedish industry branches gain from optics/photonics as well. In addition, academia is a cradle of new ideas, of which some improve existing techniques and processes, and some create new companies. In general, high quality fundamental and applied research at the universities, in addition to providing human capital and competence, play an important role for Sweden by picking up and introducing new technology areas and development.

Recommendations

Strong competitiveness and international recognition of the optics/photonics branch in Sweden is based on solid academic traditions, excellent experimental facilities, and developed research infrastructure. On the other hand, this field is fragmented with low visibility as enabling technology. This means that its job market potential is still somehow “hidden” for scholars considering professional opportunities.

Certain actions are urgently required for strengthening photonics as enabling technology such as:

- Coordinate education programs with photonics as a core subject at national level
- Positioning photonics as a mature research area, not only technology applications
- Improve educational cooperation and student exchange with other countries
- Establish better contacts with basic education via job market exhibitions, school visits, organizing topical museum presentations etc.
- Show the importance of photonics as driving technology for many industry branches and that it is big “hidden” job market

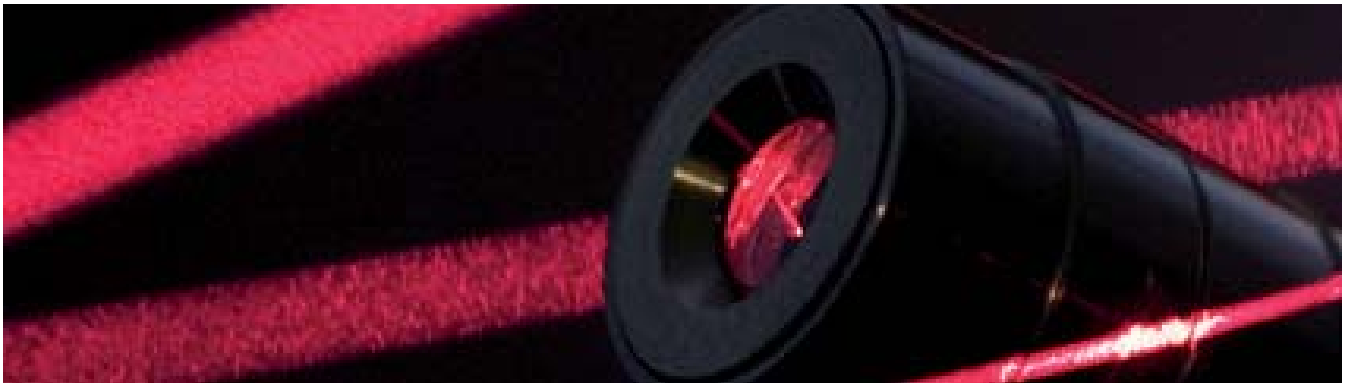


photo by Optronic AB

9 Recommendations to Partners, Financers and Politicians

In this chapter, the idea is to give recommendations to stakeholders outside the Swedish photonics community. Some of them are more general than really specific for the optics and photonics field:

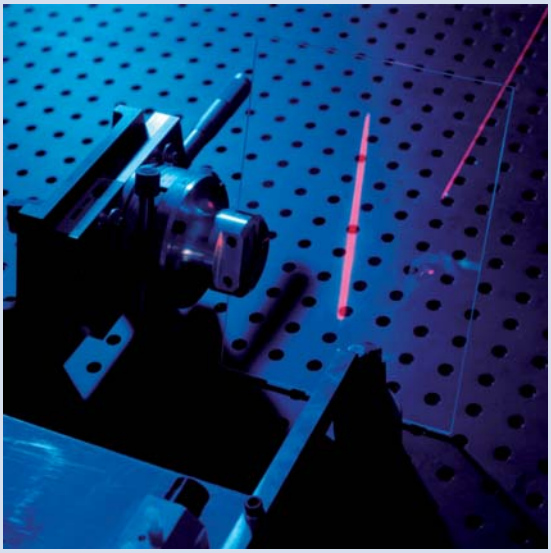


photo by Optronic AB

→ If you are planning for a technology project and, looking for a technological solution, connect to the photonics community. There could be solutions based on photonics!

→ Introduce a specialised education in photonics in the major universities!

→ Support the creation and realisation of specialised education programmes as well as training for technicians and employees in photonics companies.

→ Prepare calls for research and innovation projects specifically in the field of optics and photonics!

→ Support platforms for interaction between research and innovation areas! In other words: Entertain and strengthen what has now been created around the R&I agenda developments and the strategic innovation areas!

→ Do not miss the opportunity to profile the regions of Sweden in the framework of the Research and Innovation Smart Specialisation Strategy (RIS3) connected to Horizon 2020. In particular, the 3 strongest photonics regions of Stockholm (and Uppsala), Skåne and Västra Götaland (Gothenburg) should if possible include photonics in their RIS3.

→ Reinforce the investments in basic research on materials, nanostructures, components and sub-systems!

→ Create a group of researchers working on enabling technologies in the SciLifeLab!

→ Make use of the information available at PhotonicSweden: contact us!

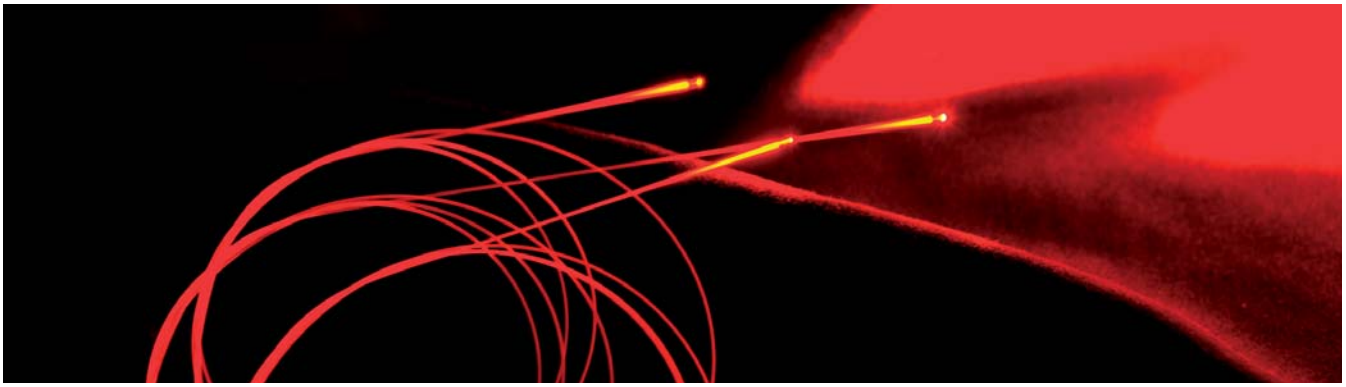


photo by SpectraCure

The Way Forward 10

From the vision and the objectives described in chapters 3. and 4. an action plan, the strategy itself, should be developed. Our agenda is part of a broader collaboration, the “Smarter Electronic System for Sweden” agenda. Therefore, the action plan for the Swedish photonics will in principle be synchronised to the one of the electronic agenda. What can be outlined at this stage are the following three main foci for the coming years:

- Focus on our collaboration with **different constellations in the field of electronics** in the framework of the electronic agenda and on an application to VINNOVA for a “Strategisk Innovations Område” (SIO). It is our belief that collaboration at this level is the key for the Swedish photonics for reaching the critical mass, since obviously photonics in Sweden has not yet the same position and status as photonics has gained at the European level during the last 10 years.

- Focus on further **strengthening PhotonicSweden**, a key instrument for the further development of our strategy and its implementation. Strengthening PhotonicSweden will help improving the support provided to SMEs, increase the visibility of photonics in Sweden, and reinforce the Swedish photonics network at all levels of the value chain and its connections throughout Europe.

- Focus on **interacting with other relevant organisations in Europe and in Sweden,** in photonics and, even more importantly, outside the field of photonics.

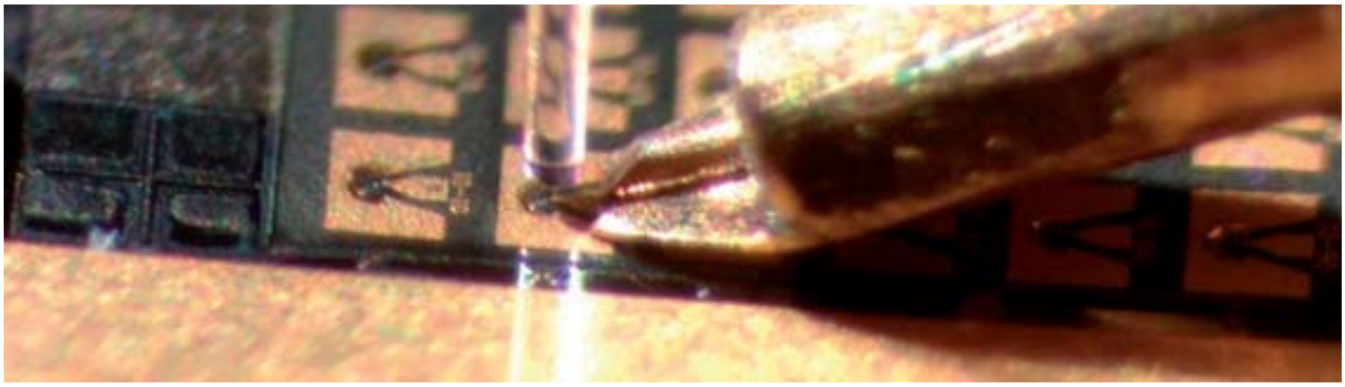


photo by Chalmers University of Technology

11 Conclusions

A strategic research and innovation agenda of the Swedish photonics has now been finalised. The self-knowledge is significantly higher than two years ago, when the work started, and there is a vision and clear objectives. Yet, this is just the beginning of a long way! From vision and objectives a detailed action plan will be set up. However, implementing the plan will only be possible if the positive spiral gathering all the different Swedish actors will be continued and strengthened. Fragmentation minimise the chances of visibility! Some companies will always be able to continue a successful lonely navigation exploiting proper niches. It is nevertheless obvious that the Swedish photonics community will only be able to make significant leaps by first organising itself and not the least increasing the collaboration with other similar areas and increasing the degree of interaction with representatives from all relevant application areas for photonics. More collaborations and interactions will largely increase the business opportunities, at least for the smallest companies[1].

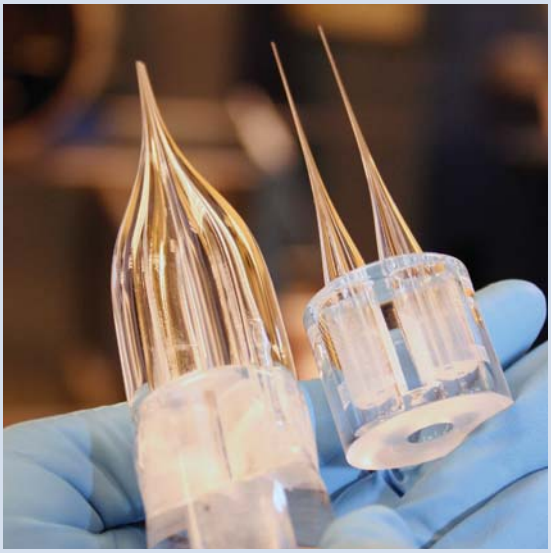


photo by Acreo Swedish ICT AB

The most evident collaboration partners in Sweden, at this stage, are the other key enabling technologies. Our closest partnership, the Smarter Electronic Systems for Sweden is also covering the fields of micro- and nanoelectronics. The nanotechnology field is already very close to photonics in our country and not much is required to make the collaboration work even more efficiently. The three remaining KETs are included in very large constellations of industries and powerful organisations. They are already largely covered by all the five first strategic innovation areas selected in July 2013, which is very good news. Increased interaction with representatives from application areas is a key to success, not the least because photonics is a, so far, largely ignored enabler.

To strengthen the Swedish photonics, and to achieve all this, it appears clearly that the coordination forces of the Swedish photonics community need first to be worked out. A growing Swedish photonics will for sure significantly contribute to solve the main societal challenges of our time.

1 71% of the Swedish photonics companies have less than 25 employees.

The strategic research and innovation agenda (SRIA) – Photonics a Key Enabling Technology for Sweden – also called shortly the Photonics Agenda, is led by the economic association PhotonicSweden. From the beginning on, PhotonicSweden was highly supported by the European Technology Platform Photonics21 and the Photonics Unit of the European Commission. This collaboration at the European level is very precious and allows getting inspiration and a lot of information from other national photonics platforms in Europe. VINNOVA supported PhotonicSweden to develop an agenda and additionally, we have followed their strong encouragement to work on a common agenda with several constellations within the field of electronics.

The work for the Photonics Agenda has been organised in meetings and workshops of the work groups of PhotonicSweden and consisted of many different parallel activities from PhotonicSweden, such as interactions with representatives from other agenda projects and activities of Photonics21. The work groups are mirroring the ones of the European Technology platform Photonics21. The reason is to more efficiently be able to interact with work groups from other European countries and, of course, with the work groups of Photonics21.

PhotonicSweden work groups with indication of the associated work group chairs:

- WG1 – Information & Communication, Pär Johanson[1], Acreo Swedish ICT AB.
- WG2 – Industrial Manufacturing & Quality, Hans Åhlén, OptoNova AB.
- WG3 – Life Sciences & Health, Daniel Karlsson, GasPorOx AB.
- WG4[2] – Lighting & Displays – Smart Lighting, Lars Montelius and Reine Karlsson, Lund University.
- WG5 – Security, Metrology & Sensors, Henrik Ludwigs, Saab AB.
- WG6 – Optical Components & Systems, Krister Fröjdh, Proximion AB.
- WG7 – Research, Education & Training, Sergei Popov[3], KTH.

PhotonicSweden has organised five workshops from November 2011 to June 2013 involving over 100 experts:

	Date	Place	Themes	# participants
Workshop 1	17th of November 2011	Hudiksvall	Present situation	29
Workshop 2	31st of May 2012	Kista	Present situation	42
Workshop 3	17th of October 2012	Albanova	Present situation	41
Workshop 4	14th of February 2013	Kista	Vision and Objectives	32
Workshop 5	18th of June 2013	Kista	Interact. with other agendas	62

An additional a web-casted meeting took place on September 20, 2013, to give the possibility to anyone to comment the first available draft of the agenda. Approximately 50 persons participated half of them physically and the other half online via internet.

Interactions with other agendas and constellations

- ”Smarter Electronic System for Sweden”: with 6 other agendas: 1) ”Svensk energieffektiv hårdvara inom elektroniksystem” 2) ”Elektronikhårdvara i Sverige”; 3) ”Branschöverskridande strategisk forsknings- och innovationsagenda för Elektronikindustrin” 4) ”Kraftelektronik - från milliwatt till gigawatt”; 5) ”Millimeter-wave and terahertz systems”; 6) “Antennsystem”.
- “Belysningssamhället 2020”: for our WG4 and ”Nanoteknik för hållbar samhällsutveckling”.
- Life Sciences and Health: ”Sverige som internationellt centrum för life science”; "En åldrande befolkning”; "VOIS - Vård och Omsorg i InformationsSamhället”; ”Patientinvolvering för tjänsteinnovation”; ”Hur världsledande forskning inom diabetes ska bidra till svensk tillväxt” och även ”Teknikens roll i dagens och framtidens sjukvård” och ”Bildbaserad medicinsk diagnostik - ett svenskt styrkeområde med stor potential”.
- Others: ”Innovationsagenda Säkerhet”; ”Processindustriell automation steg 2”, ”ICT enabled innovations” and ”IoT Sweden” (among other through our workshop in June 2013)

For more info, please contact the project leader Pierre-Yves Fonjallaz, **pierre@photonicsweden.org**!

1 Hans Mickelsson from Ericsson was work group chair during the first year.

2 Note that WG4 is today only focusing on Smart Lighting, but the intention is to create other sub-groups in the near future, not the least one dedicated to photovoltaics.

3 Fredrik Laurell from KTH was work group chair during the first year.

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