Acreo 1999–2009, ten years of innovation for growth

Mårten Armgarth

Ten years after the founding of Acreo we can be proud of having fulfilled the mission set out from the start; contributing to competitiveness, growth and entrepreneurship in industry and society.

Acreo was formed 1999 through the merger of the two research institutes IMC and IOF, dated back to the 50's and 60's, respectively, forming a larger enterprise building on profound competence and long term R&D experience in electronics and optics. By looking at the continuous achievements evidently the initial business concept is still valid. It is further strengthened by the addition of the area of communication technology and other new specialities within electronics and optics.

Creating value through research is our mission and one way of evaluating this is to study the growth of our spin off companies. During the 10 year period Acreo has spun off 17 new companies and transferred more than 100 highly competent experts to the industry. Despite a few turbulent years in the market these companies prosper today; representing new businesses employing more than 500 people and having a turnover of 924 MSEK by 2009. By including other successful projects, providing industry with new technology and new competitive solutions, the resulting turnover sums up to more than 1500 MSEK. This is a striking measure of our ability to create value based on research. This sum is more than 18 times the total national funding Acreo received last year. Assuming that 40% of the increased turnover is returned to the government in direct and indirect taxes this governmental investment in R&D has a payoff time of less than two months.

Based on this proven ability to deliver profitable technology solutions, Acreo has attracted hundreds of partners from all over the world in various projects over the last 10 years. With the focus on hardware oriented ICT, Acreo has widened its competence profile by starting up new areas and capabilities such as printed electronics, bioelectronics, broad band and communication technology, and specialty fiber production. Over all, ICT is an enabling technology in many areas and Acreo has thus broadened its ability to address problems in a variety of application areas.

In more specific technology areas Acreo is providing more focused R&D efforts by running competence clusters, engaging in a total of 45 companies and with the support from public research funding agencies such as VINNOVA, KKS and SSF. Today there are four of these competence clusters: Acreo Fiber Optic Center, IMAGIC- imaging sensors for invisible light, Centerprise – printed electronics and the Institute Broad Band Communication Center. Two of these, Acreo Fiber Optic Center and IMAGIC, have been selected as

“Institute Excellence Centers” by VINNOVA. Plans are also to form a new center for Silicon Carbide Power Electronics.

With technology transfer and business services as an important tool to contribute to growth and increase competitiveness of SMEs Acreo has proven very successful. The EU commission has recognised Acreo as one of the five top technology transfer organisations for SMEs within the EU. Our co-worker, Dr Walter Margulis, has been awarded fellowship of the Optical Society of America. International co-operation projects coordinated by Acreo have also been recognized. The TRAMMS project won the Celtic Gold Award, and the ALPHA project received the Best Demonstration stand award at the ICT Future Network and Mobile Summit this summer.

For the future we are confident that we will meet more partners that recognise the advantage of fast forwarding the competition through cooperation with Acreo. They can surely trust that we will create new solutions and value based on our first class research and expertise. With our staff of highly qualified professional researchers with various backgrounds and experience we see the possibilities and opportunities for new solutions, in which our technology platforms meet the requirements from our customers’ different applications.

Sincerely

Mårten Armgarth
CEO

Acreo AB contributes to increased competitiveness, growth and entrepreneurship by refining and transferring research results into viable products and processes in electronics, optics, and communication technology.

This document is written with the intention to give an overview of Acreo’s capabilities and achievements during the year 2009. However, as Acreo works with assignments from industry partners requiring confidentiality, the following reports are limited to the activities where Acreo has the partners’ consent to publish the results.

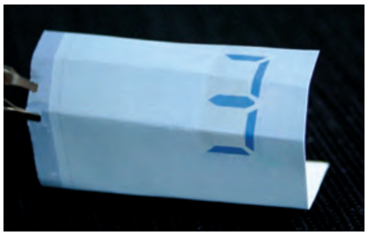
Printed Electronics

With the focus on large area, low cost and high volume production methods printed electronics has moved from development of basic materials and polymers to including a manifold of available printable functional materials suitable for mass production.

During the past decades the research on the so-called conducting polymers has moved from basic material understanding towards application oriented technology development with a potential for new products within a manifold of areas, such as smart packages, flexible display and lightning, printed batteries and disposable devices for healthcare, to give some examples. The principal interest in the use of polymers lies in the scope for low-cost manufacturing, using solution processing of film-forming polymers. Thus many researchers have focused their research towards these materials and various manufacturing processes based on printing techniques for what has been referred to as "Organic Electronics" or "Plastic Electronics". Nowadays in-organic materials such as for example silver, gold and silicon are available as printing inks and thus the terminology has moved towards "Organic and Large Area Electronics" (OLAE) in order to include the manifold of available printable functional materials, where properties like flexibility, unique form factors, large area, low cost and high volume production methods are characteristics.

Today printed electronics consists of many different components such as transistors, batteries, sensors, antennas, displays etc. However, not many systems or even sub-systems exist that have been fully integrated utilising printing technologies. Thus, in order to make the technology useful, there are needs for integration developments. The integration can be on two levels: 1) integration of various printed electronics components and 2) integration between printed electronics and silicon based electronics in order to accomplish more high end products.

1) True low cost integrated systems can only be achieved by making much simpler electronic systems that can be produced in just a few manufacturing steps. To accomplish this, the active materials should be multifunctional, so that the same material can be used in different devices in parallel. In addition, one should avoid mixing devices based on different mechanisms, such as field effect-, charge injection- or electrochemically based devices. In order to accomplish the target on minimizing the number of materials in the component toolbox, Acreo based the technology platform basically on one ma-



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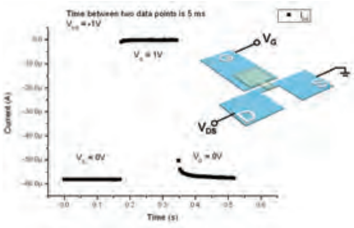

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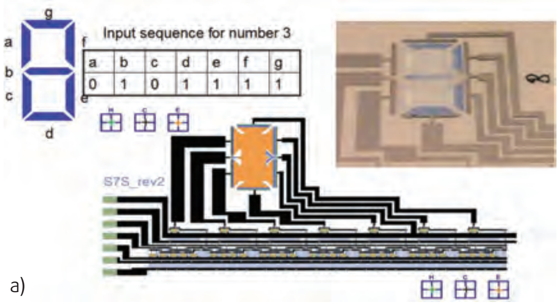
Some examples of existing components from Acreos toolbox are shown: a) electrochromic display, b) electrochemical transistor structure and I/V curve and, c) an antenna structure as processed in R2R technology utilizing the so-called DPP technique.



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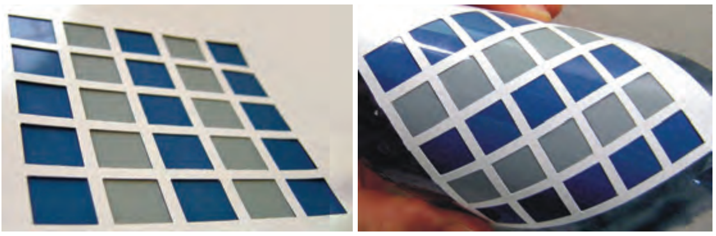
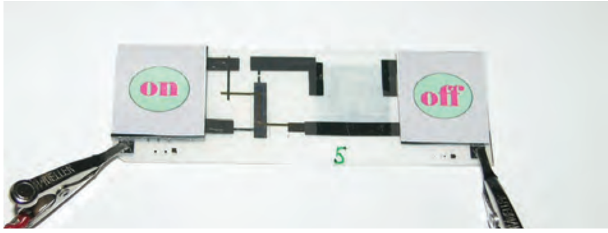

b)

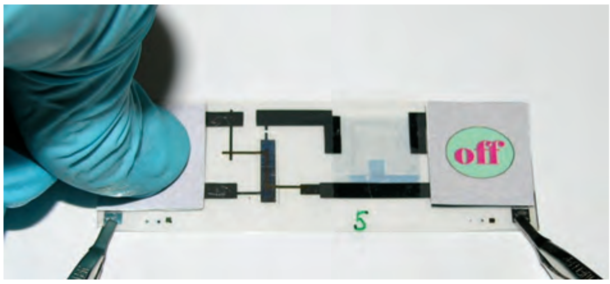
Two printed electronics sub-systems a) a seven segmented electrochromic display driven by decoder electronics based on electrochemical transistors and b) active matrix addressed pixilated displays utilizing a direct addressing by electrochemical transistors.

jor material, the PEDOT:PSS system. The PEDOT system undergoes both a change in conductivity and a change in the reflected color upon oxidation and reduction (doping and de-doping). These effects can then be utilized in components such as electrochromic displays, transistors, sensors and timers but also as conductors and resistors.

2) The complexity possible to achieve with the state of the art printed electronics technology is, however, limited. Thus, heterogeneous integration to create hybrid solutions would be a first step towards more advanced systems. With hybrid solutions in this context, we refer to the combination of printed electronics and conventional silicon based electronics. The development of printed electronics is driven by the wish for electronics that are flexible, cheap, and environmentally friendly and that could be fitted into basically any product. Although it is desirable to have a completely printed solution it is not always feasible. The limitations of printed electronics are relatively slow processing speeds and space consuming logic circuits. Integrating printed electronics with silicon microchip will take advantage of the high processing and storage capacity per unit area of silicon and the low cost per unit area and flexibility of printed electronics. Since silicon based electronics are rigid one has to mount small dedicated microchips directly on the substrate in order to keep the paper like feel and the flexibility. Hybrid technology is identified in Acreo's roadmap for printed electronics as a first step on the path towards a completely printed system. This includes an intermediate step where some parts of the logics will be made by printing electronics technology in order to minimize the requirements on the number of I/Os on the silicon chip. In the figure above two initial prototype systems are shown where a seven-segmented decoder and an EC transistor driven active matrix have been utilized in order to demonstrate the increased functionality from component level towards sub-system.

Although the printed components such as the EC transistors are relatively slow compared to silicon based electronics, the examples illustrate the usefulness of at least partly replace the silicon logics in applications where the demands on process speed is relaxed. Some more examples on integrated systems are discussed in the next sections. ■





Demonstrator before (left) and after (right) switching the display element.

Integration of different component classes into one system

A collaboration project conducted by Acreo within the frames of the Network of Excellence Polynet

Several different printed and organic components exist, but there are few examples where different classes of components have been combined and demonstrated to work together in a system. Acreo and Linköping University have demonstrated a system consisting of electrochromic (EC) displays, electrochemical (EC) transistor logics, push buttons and a battery, all gathered on a sheet. The electrochemical transistors are used to address the display elements. EC transistors are printable and give a high drain current, but there are also drawbacks that would be circumvented by using OTFTs instead. For instance, switching of the OTFTs is faster and the lower off-currents would be advantageous in an active-matrix display configuration. Another important difference is that the EC transistor is open at Vg=0, while an OTFT is closed. OTFTs cannot be printed though, and the drain current may only be sufficient to switch small display elements (~cm^2) within reasonable time. To sum up, EC transistors and OTFTs have different properties, and there are applications in which it would be advantageous to combine EC displays with OTFTs. With this example in mind it should be clear that there from a technological point of view is a need for strategies that allow the integration into systems of components that are produced in different equipment or even at different labs.

This collaboration project aims at the demonstration of a sensor system that converts a sensor signal to a visually detectable output. A touch sensor is used to modulate the gate voltage of an organic thin film transistor (OTFT) which, in turn, controls an EC display element. The most important tasks have been to design the circuit, to make a layout and to define a process flow, which takes material, process and equipment compatibilities into consideration. A demonstrator in which all components are integrated on a common substrate has been realized. The circuit includes two touch sensors, one OTFT, one EC display and a resistor. Manufacturing was carried out at three different laboratories in a number of different equipments. We have experimentally confirmed that the demonstrators work.

We have thus successfully realized a fully integrated sensor with display indicator controlled by OTFT on a Teonex substrate. We have proven that printing technology by careful planning can be combined with other deposition methods such as spinning, sputtering, and evaporation. ■

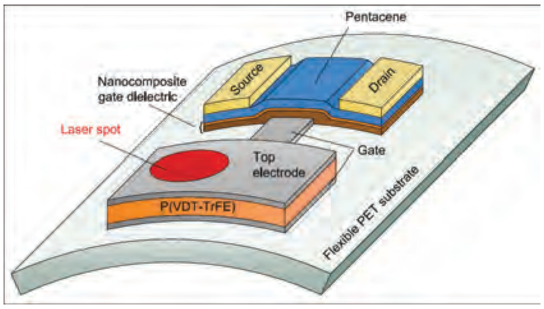
NoE PolyNet

The work was lead by Acreo and participants were Fraunhofer-IZM-M, Joanneum Research, Linköping University, TNO (Nederlandse organisatie voor toegepast natuurwetenschappelijk onderzoek), Technische Universität Chemnitz, VTT (Valtion Teknillinen Tutkimuskeskus).

The NoE PolyNet receives funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 214006.

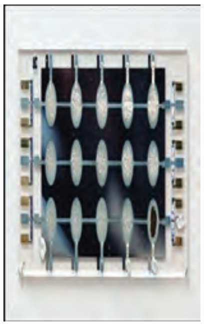
Untouchable sensors

With new sensors the future migth see electronic equipment controlled by just pointing a finger without actually touching the device.



Concept for an integrated pyro- or piezoelectric sensor element

Acreo is a partner of the European FP7 project 3PLAST (Pyroelectric and Piezoelectric Printable Large Area Sensor Technology). Within 3PLAST polymer sensors integrated with organic electronics on large area flexible substrates are developed. The 3PLAST sensors will provide accurate information on changes in temperature and pressure with a local resolution. The basic sensor device is comprised of a piezo- and/or pyroelectric polymer integrated with high-performance organic thin film transistors (OTFTs or electrochemical transistors (ECTs) operating at low voltages acting as impedance converters and sensor signal amplifiers.



Sensor array

The drawing shows the concept for an integrated pyro- or piezoelectric sensor element. The sensor can be activated either by light from an IR laser diode, by human body radiation (finger, hand) or by pressure. One of the most relevant materials for the 3Plast sensor technology is the PVDF-TrFE copolymer. PVDF copolymer solutions are developed and adjusted for printing processes.

Low-cost manufacturing will be enabled by high-throughput processes such as screen- and reel-to-reel printing. Examples for envisioned applications of the integrated large area polymer sensor technology are smart skin, large area human machine interfaces, large area security systems (e.g. pedestrian protection in vehicles) and self-controlled machine monitoring.

Acreo's main mission in 3PLAST is to transfer lab-scale thin film processes to large-area, production adapted printing processes. Printing techniques addressed are: Screen-printing, ink-jet printing, bar coating, and R2R printing. The components printed are: PVDF-TrFE sensor elements, electrochemical transistors (ECTs) designed for the sensor elements and electrochemical display elements. Finally, these components will be integrated into an all printed application human machine interface (HMI) demonstrator sensor device, namely a touchless key pad.

Printed pyroelectric sensor integrated with ECTs and OTFTs have been realized and tested. The sensitivity to human body radiation is demonstrated by waving a finger over the sensor. Next year the focus will be on pyroelectric and piezoelectric demonstrator fabrication. ■

EU FP7 project 3PLAST

Total Budget: 3.25 Mio €
Funding: 2.2 Mio €
Duration: Feb 08 - Jan 11
Web site: http://www.3plast-sensor.eu/index.html

PEA Manufacturing

PEA Manufacturing is a greenhouse for the development of prototypes and small scale production of printed electronics. As a greenhouse PEA Manufacturing is open to anyone that would like to test printed electronics in their products and processes. This includes start-ups, established companies, universities and institutes. The greenhouse gives the interested parties access to research, various manufacturing and printing methods as well as different support functions.

PEA Manufacturing is part of the Printed Electronics Arena (PEA) which is an autonomous unity formed by the municipality, university and private sector. The partners in the cooperation work together towards creating sustainable, long-term growth through commercialization and exploitation of the extensive research and development activities which are conducted at Linköping University (LiU) and Acreo in the new technological field of printed electronics. But PEA is not only promoting the technology platform developed by Acreo and LIU it is also a window to the world of printed electronics development at other locations. PEA aims to grow businesses based on printed electronics regardless of the origin of the research and the components.

Acreo has transferred its complete manufacturing process to the greenhouse which means associates can have access to a wide range of equipment and materials. Examples are:

- Inkjet printing equipments
- Flat screen printing equipment
- Industrial UV and heat dryers
- Dry Phase Patterning equipment
- Nilpeter reel to reel printing machine for screen and flexo
- Print analysis equipments
- Ink development & characterisation

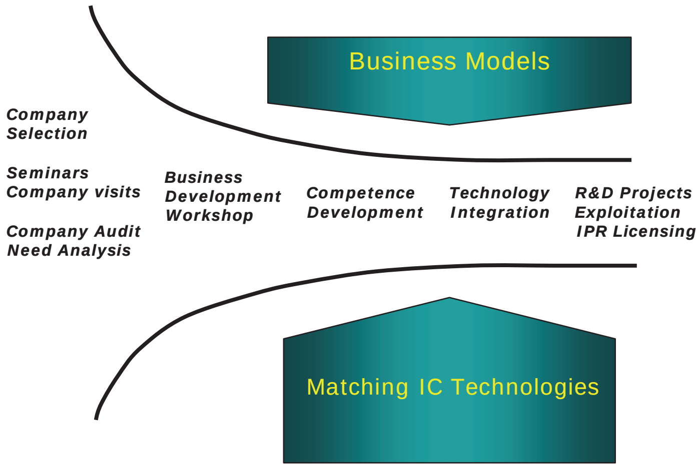
Equipment is important but without the expertise from researchers and operators it would be difficult for interested to make use of the facilities. PEA Manufacturing is run by Acreo and expertise is available ranging from graphic designers, physicists, chemists, machine operators to project leaders.

PEA Manufacturing was inaugurated in mid 2008 and has since then worked closely with entrepreneurs, different size companies and trade organizations. Completed tasks range from small scale experiments on solar cell manufacturing, greeting card prototypes to production of tens of thousands printed electronics give away demonstrators. Associates may work on their own in the laboratory (under supervision) or consult the trained researchers and operators working at PEA Manufacturing to carry out the work.

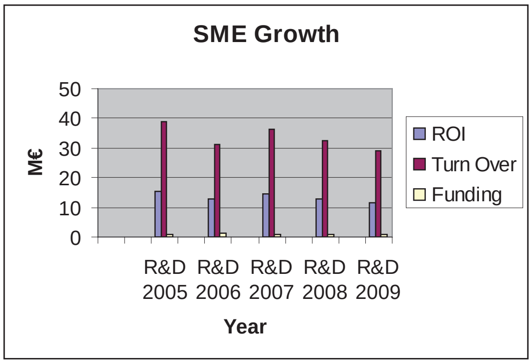
Web page: www.printedelectronicsarena.com ■

Business Services

Through different support programs Acreo helps small and medium size enterprises with new technology and business development. Several examples show that these activities have a large impact on the growth and competitiveness of the SMEs.



The importance of growing SMEs as the basis for tomorrow's successful large enterprises is widely recognised. Acreo has for more than 15 years been active with various SME support programs and has developed a successful model for helping SMEs become more competitive by new technologies and business models.



Acreo has developed a methodology based on creation of commercial values in Swedish SMEs. These commercial values are created through IC technology integration in existing products. By upgrading the products with new technology the SMEs takes an innovative step which keeps the competitors behind. Important is though that this new technology also implies enhanced functionality that generates new business opportunities.

The methodology includes the following important steps as pictured in the figure to the left:

- Company selection
- Company audit and the need analysis
- The business development workshop
- Competence Development
- IC Technology Integration in R&D projects
- Technology transfer with R&D exploitation and IPR licensing

Impact

Acreo reports annually the economic impact of its R&D activities in 15 to 20 SMEs on the consolidated yearly revenue from these companies. This result was in 2009 at the level of 29 M€ which corresponds to 11,6 M€ in RoI to financing institutions. In the RoI calculation we assume that 40% of the consolidated yearly revenue from the companies is a return to the state in terms of taxes and other charges.

Case example: Sensors ensure water quality

As a part of the minST program the SME Predect AB was helped by Acreo to assess new advanced sensors for their advanced water quality control system. Featuring the possibility of replacing random samples with continuous quality control the innovative system offers a number of new business opportunities.

Pure water is our most basic need as well as a limited resource. The continued population growth will further increase the demand for pure water. This calls for more efficient techniques to ensure the quality of both water supply and waste water treatment.

Today's standard way to monitor water quality is by taking random samples which are then separately analysed. To be detected a contaminant must have been present in the system just when the sample was collected. Quite often volumes of contaminated water can intermittently be flushed through the system and thus pass undetected.

The SME Predect AB was founded in 2006 by Sudhir Chowdhury and his wife Ulla Chowdhury who together have more than 20 years of experience from water treatment in for example paper mills and sewage industry. The business idea was to develop and market a new system for continuous water quality control. The system was built on laser and micro technologies. With a need for advanced sensors Predect contacted Acreo in the spring 2008 to conduct a pre-study where the range of existing sensors was assessed. The feasibility study was done with the support of the "minST" programme (Expertkompetens Mikro/Nano Systemteknik) funded by the Knowledge Foundation (KK-stiftelsen).

When the sensor detects a change in water quality a water sample is taken automatically for further analysis, and an alarm is sent to the operator. This gives an increased security since the right water sample is analysed and corrective actions can be taken without delay. Traceability is thus infinitely increased. Moreover, the method can not only find a problem but also exclude a pipe section as a source of proliferation.

Predect's equipment not only provides an early warning of increased levels of pollution. An equally important aspect is that it ensures the quality of the water. Thus today's routine addition of chlorine "to be on the safe side" can be reduced.

– There is approximately one incident per week with contaminated water in Sweden resulting in a recommendation to boil the water before use, says Sudhir Chowdhury. These incidents may involve significant costs. We have a fairly recent example from Oslo with contaminated water where the final bill for the contamination landed on a couple of billion SEK.

Last autumn Predect had already delivered four systems, besides a pilot installation that was started up in the summer 2008 in Lilla Edet on the west coast of Sweden. Predect has also started a research project in Borensbergs waterworks in Motala together with the trade association Swedish Water Development and the consulting company Sweco. In addition, Predect also runs a test facility at the

Rolf Andersson, Acreo, together with Ulla and Sudhir Chowdhury at the test facility in Hammarby Sjöstad wastewater treatment plant at Hammarby Sjöstad in Stockholm. There are three test beds and Predect is working with control of treated wastewater in bed number two. The plan is that they later on will be involved in the third bed where medical waste is studied.

– Right now we are working to determine how clean the wastewater really is, says Ulla Chowdhury. A second part is to ensure the quality of the drinking water.

The goal is to reuse waste water from various processes after purification. This requires very sophisticated quality assurance and continuous assessment.

The test facility at the wastewater treatment plant at Hammarby Sjöstad.

– In the future it should be possible to use purified waste water in a system where it can be reused as drinking water, says Sudhir Chowdhury. However, it is further into the future because of the practical, ethical and economic problems that must be addressed.

Besides help with the more technical questions concerning sensors Acreo has been able to help Predect to apply for financial support of development projects from VINNOVA and the EU. The intention is then that Acreo will be involved in developing a new sensor for Predect. Through Acreo's partnership in the Enterprise Europe Network, Predect has been able to find new R&D partners as well as new European distributors.

The market possibilities look bright. In Sweden alone there are approximately 2,000 water utilities, and world-wide the need is obviously enormous. Sweden is after all quite well off with ample supply of fresh water compared with the rest of the world with dry areas where water has to be purified and re-circulated much faster. The market is not only limited to water treatment plants, there are also consumers with an interest to check the quality of the water their suppliers deliver.

With Predect's method the world has moved a step closer to a quality-assured water supply, and new research projects are planned together with Acreo helping Predect to stay in the technical frontline. ■

IMAGIC

IMAGIC (Imaging Integrated Components) is the Institute Centre of Excellence dedicated to next generation digital imaging components and systems for non-visible electromagnetic wavelengths. This covers wavelengths from X-ray to terahertz.

IMAGIC has now been successfully run for three years, 2007-2009, and also has approved financing and challenging planning for the next three-year period.

Why imaging at non-visible wavelengths?
Imaging at visible wavelengths, through the use of a common digital camera for example, provides information on an object's geometry and texture. Imaging at non-visible wavelengths can provide additional information regarding the object's thermal, chemical, and mechanical properties. Furthermore, imaging in complete darkness can be achieved. Usually, the sensing is non-destructive and can be performed in a contact-less way and remotely. Thermal infrared imaging is usually carried out passively, i. e. without external illumination, as a result of that all objects emit infrared radiation depending on their temperature and emissivity. For other wavelengths the objects need active illumination, such as for X-ray, or UV.

Imaging at non-visible wavelengths is important for many applications. Examples of applications within various areas are:

- **Automobile**: night vision and collision warning
- **Medicine**: X-ray imaging including tomography
- **Safety and security**: night vision systems, biological agent detection
- **Process control and automation**: remote temperature measurement or chemical analysis
- **Environment**: monitoring of air quality

The IMAGIC projects
The devices developed within IMAGIC are based upon advanced semiconductor materials and their processing technology. These combined with innovative device designs provide a common platform throughout the Centre. Novel detector materials are preferably fabricated using the methods of nanotechnology or "quantum mechanics engineering" to create radically new and desired material properties.

The projects of the centre are divided between the Technical programme and the Generic research programme. Those in the technical programme are intended for development and production of specific prototype imaging devices of interest to one or more industry partners. The Generic research programme on the other hand involves the development of key components and processes that are generally applicable to several devices and/or of interest to several member companies.

IMAGIC project examples:
X-ray detection and imaging
X-ray imaging has experienced a ground-breaking technical revolution during the last decade when the older chemical film based cameras have successively been replaced by digital cameras. This has had major implications in all fields of application where X-ray imaging is used: medicine, dentistry, security (e. g. luggage check at airports), and non-destructive testing of materials or products. The advantages are: no handling of chemicals, instant images, easy image processing and distribution, and lower radiation dose.

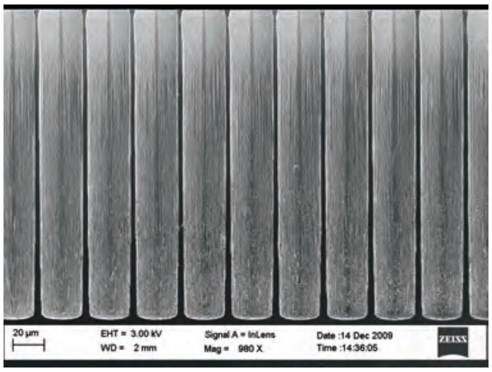
There are several different detector technologies involved that have their respective pros and cons.

Funding Partners

Knowledge Foundation
Swedish Foundation for Strategic Research
Vinnova

Center Partners

Autoliv
FLIR Systems
IRnova
KTH
NOTE
OptoNova
Optronic
Saab
ScandiDos
Scint-X
Zarlink



200 µm deep pores with intact sidewalls, demonstrating the excellent control that can be achieved with DRIE

The major technologies are:

- **Indirect detection**: integrated scintillator materials that convert absorbed X-ray photons to visible light that in turn is detected by a CMOS (or CCD) detector array
- **Direct detection:** semiconductor materials that convert absorbed X-ray photons to charge carriers (electrons and holes) that create an electrical signal output. There are several different possible materials to choose from: cadmium telluride, selenium, gallium arsenide, and silicon.

For the detector signal readout a CMOS or amorphous silicon thin film transistor (TFT) array is used. The latter method is similar to TFT display technology, and thus allows very large detector areas. In many applications large detector screens are needed since no focusing optics is easily available for the X-ray region.

IMAGIC is involved with both of the above-mentioned detection technologies. The IMAGIC member companies ScandiDos and Scint-X work with direct detection in silicon diodes, and scintillators, respectively.

ScandiDos manufactures instruments for three-dimensional X-ray and gamma radiation dosimetry, which is used for cancer therapy. Their dosimetry system is composed of a cylinder shaped body phantom made of PMMA (Plexiglass), which is a material that interacts with X-ray radiation similarly to biological tissue. Two orthogonally intersecting printed circuit boards carrying a large number of discrete X-ray detectors are mounted in the phantom. Employing the two orthogonal detector matrices, a three-dimensional image of the radiation dose within the phantom can be constructed. The detectors are silicon diodes which are currently manufactured by Acreo.

The work carried out within IMAGIC has involved development of next-generation detectors for application in the ScandiDos product. The first version of the detector involved component development and detector assembly. The second version has involved development of a novel design concept in order to meet even more challenging tasks.

Scint-X develops and manufactures microstructured scintillator plates that allow sensitive detection combined with a minimal amount of lateral light scattering that deteriorates the image quality. This is done by channeling the light through the plate on its way to the CMOS or CCD array, thus avoiding cross-talk between pixels. The process involves etching columnar holes into a silicon wafer, by either electrochemical etching or DRIE (deep reactive ion etching).

DRIE, an advanced processing technique

DRIE is a plasma-etching technique that enables the etching of trenches and holes in semiconductor material with straight sidewalls and a high level of design freedom. Within IMAGIC we are developing and optimizing the DRIE process for various detector related applications.

In conclusion we have shown that the DRIE technique is very promising regarding the production of structures for IMAGIC-related applications. Product specific structures with complex details, such as very thin sidewalls, can be fabricated with high uniformity, high aspect ratio and smooth sidewalls. ■

Silicon Carbide Intelligent Multi Chip Modules:
Next Generation of highly efficient Power Electronics for System Applications

The main focus of the Silicon Carbide (SiC) activities at Acreo is the development and fabrication of highly efficient rectifying and switching power devices and power modules for medium and high voltage applications.

Silicon Carbide epitaxy

Possible application areas are electrical power converters and inverters like e.g. motor drives for hybrid electric and electric cars or photovoltaic inverters for solar power plants. Such applications require power modules with blocking capability of around 1200V and current handling capability of 50-100A. In addition, the power modules should be able to work at elevated temperatures of 250-350°C to reduce the system cost by reducing the cooling requirements for the electronics. Such power modules have been demonstrated end of 2009 and will be available as engineering samples in the second half of 2010 to be tested in real applications. To increase the temperature of operation, not only the power devices should be made in SiC, but also the control electronics. Hence we are looking into the so-called Intelligent Multi Chip Power Modules, which will include basic logic electronics made from SiC.

The fabrication of the SiC devices is done in the Electrum laboratory in Kista, Stockholm, where a complete process line, starting with epitaxial material growth and ending with wafer dicing, is available for 100mm SiC wafers. The corresponding unit process technology is well established and monitored for many years. Our device concepts are based on epitaxial technology and the advanced device material structures are grown and optimized in house in our Vapor Phase Epitaxy (VPE) reactors for SiC layer growth.

During 2009 Acreo established the SiC device growth processes in a second SiC epitaxy reactor and both our reactors are now running on full capacity. We have established new processes like fast epitaxial growth (increased growth rate with no compromise on the layer quality) and growth on low off angle substrates. In addition, we continue to develop the critical growth processes for our SiC power device designs, like the growth on mesa structures or in trenches. These growth processes should overcome limitations of traditional doping processes like ion implantation and should increase the material parameter space available to device designers. The latter is especially important for the improved device performance at elevated temperatures above the limits of the traditional Si technology. We also develop growth processes in close collaboration with device manufacturers to enhance the performance of their SiC device designs by optimizing the epitaxial layer structure.

Discrete rectifying and switching devices based on our epitaxial material technology will be available during 2010 for evaluation. The devices are aimed for 1200V blocking voltage and 10-50A current handling capability and will be mounted in discrete packages like standard TO220 or customized power modules. The backend process for that is available in cooperation with TranSiC AB in Kista, and M.A.Kapslingsteknik in Kungssängen or at our device and system evaluation partners. The packaged devices should be included in two system evaluation projects planned for the second half of 2010. ■

COSMOS – Increased productivity using intelligent tool parts with surfaces embedded sensors

The industry is taken into a new paradigm when the COSMOS project develops a novel platform to fabricate surface embedded sensors under wear resistant coatings on traditional machine parts.

Intelligent machine parts that are capable of reporting their current physical status under real working conditions enable new tools for condition based maintenance with an early detection of deviations from normal running conditions. Such deviations can be damage initiations that can lead to failure. With continuous monitoring of the machine components, maintenance can be optimized which increases the uptime and decreases the number of failures.

The measurement of physical parameters such as temperature and pressure under real working conditions also increases productivity through online process optimization. For example, processes based on fixed times can be shortened by adjusting the process to the real fabrication conditions affecting the product. The in situ process monitoring also increases the quality control of each fabricated component individually. Also, by adding intelligence to the surfaces of machine parts we reduce the need of packaging and contacting of traditional discrete sensor components enabling simple interfacing.

Common maintenance approaches:

- Failure based maintenance is initiated by failures and the main objective is to put the equipment back in working condition as soon as possible.
- Preventive maintenance is planned and optimized actions using statistical methods to reduce the number of failures and their economical consequences, e.g. once every month or after each 2000 km.
- Condition based maintenance optimizes the time of intervention by monitoring the condition of a component, part or machine and thereby avoiding unnecessary maintenance stops and still have a protection against critical failures.

Thin film sensors are traditionally fabricated by subtractive or additive patterning of metal layers and isolation layers using conventional photolithography and cleanroom processing techniques. These processes require flat and smooth surfaces which in MEMS and microelectronic applications are handled by using substrates with perfect flatness, e.g. silicon, quarts or glass wafers. The fabrication of surface embedded sensors under wear resistant coatings on three-dimensional (3D) machine parts and other high-tech components is going beyond traditional cleanroom processing where such patterning is no longer applicable and requires new technologically demanding approaches.

There are several difficulties to address in order to fabricate working sensors on traditionally 3D machined metal parts:

1. The metal needs to be electrically isolated which sets new demands on the insulating layers since the surface roughness is typically higher (Ra > 0.1 µm) than for traditional MEMS substrates and therefore has much higher risk for defects and subsequent shortcut of the sensor structure to the substrate.

2. The sensor structure is patterned and fabricated on the surface which requires handling of 3D objects and conformal deposition techniques.

3. An electrically isolating wear resistant coating is required to protect the sensor from mechanical damage under real working conditions.

Through the combined expertise of the COSMOS partners we have fabricate several demonstrators; an intelligent bolt, a metal pin for plastic injection molding and inserts for metal forging.

The intelligent bolt is a standard industrial bolt with surface embedded sensors. It is used as a general temperature measurement device that can be placed in any system with a threaded hole. It can for instance be used to measure the temperature of a liquid in a closed system by making a hole in the container wall and sealing it by the bolt and an o-ring. It can also be used as a general feed through of electrical wires in closed systems just by replacing the sensor with open contact points.

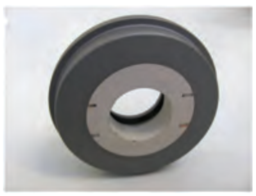
The bolt is made of an aluminum alloy on which we have removed two sections of threads leaving flat surfaces along the bolt. The complete bolt was electrically isolated and a thermocouple was fabricated by depositing a 1 µm thick Cu wire from the bolts head along one of the flat surfaces to the top of the bolt. A second wire of CuNi was subsequently fabricated along the other side of the bolt overlapping the Cu wire at the top. Both wires were patterned using shadow masking technology which offers a simple industrial processing technique. The thermocouple structure was buried under Diamond-Like Carbon (DLC) leaving contact holes for the wires at the bolt head. The DLC coating has several advantageous physical properties for industrial use, e.g. ultra low friction, fair hardness and excellent wear resistance.

The metal pin is used as a core in plastic injection molding. With temperature sensors embedded at the interface to the plastic part, the cooling process time can be optimized by adapting it to the real time measurements. The throughput can be increased as the process time is adapted to each individual part instead of using fixed time margins to cover process deviations. The individual temperature control also increases the quality of the fabricated parts by ensuring that the fabrication conditions are correct at any given moment. Such quality insurance is of great value for injection molded medical devices that also gains an additional advantage from the smoothness of the surface embedded sensors in comparison to the marks found in parts using discrete components.

Industrial M10 bolt with a plasma electrolytic oxidized insulating layer and patterned Cu/CuNi wires from the bolts head to the top forming a thermocouple sensor structure.

Intelligent machine parts with surface embedded sensors are taking the industry to new levels of competitiveness. Not only will such machine parts open up for higher productivity and reduced downtime through on-line control of tools and processes but also enable development of completely new ranges of products based on intelligent surfaces.

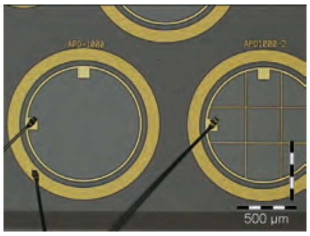
The COSMOS project is financed by The Nordic Innovation Center (NICe) and is a collaboration between research institutes and companies in Sweden, Denmark, Norway and Finland. ■



Several types of industrial tools can be equipped with surface embedded sensors. Here two thermocouples are integrated on the surface of a cylindrical insert (white).

Ø3 mm metal pin for plastic injection molding with a thin Pt100-like sensor element at the top (right end).

APD devices bonded for evaluation



Sensitive UV detection

UV imaging is continuously becoming more attractive for an increasing number of diverse applications

Digital detection of weak ultraviolet (UV) signals requires a very sensitive semiconductor device. This should have a high response to the incoming UV radiation, but very little response to longer wavelengths (visible and IR) so that these do not swamp the UV signal. The standard commercial solutions used today for UV detection are usually based on silicon, which although a mature technology, does not fulfil the criteria specified above. Silicon responds best to visible wavelengths, and so external filters are required to remove these wavelengths in order that the UV response can be seen. Also, silicon devices often need to be cooled in order that a sufficiently strong signal be achieved.

The most promising candidates for sensitive UV detection are wide-bandgap semiconductors, of which silicon carbide (SiC) and gallium nitride (GaN) are the most mature. Of these two, silicon carbide has the most mature material technology. Therefore, sensitive detection based on SiC has been under development within the Institute Excellence Centre IMAGIC.

Avalanche photodiodes (APDs) are devices that permit internal signal amplification and so enable detection of weak signals. APDs based on SiC are under development world-wide, but their main problem usually concerns their stability. For stable performance, it must be ensured that the signal created by the incoming UV radiation comes from the central region of the device. A signal from the edge of the device leads to loss of sensitivity and instability.

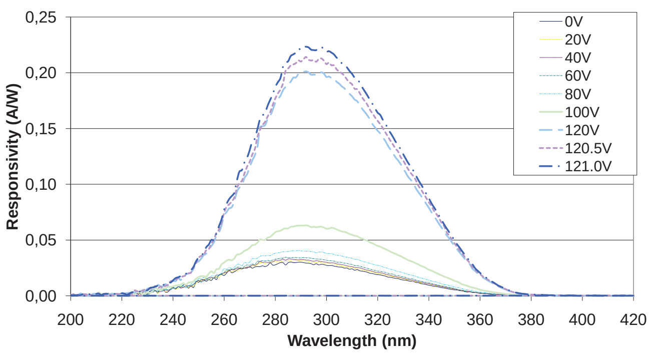
Here at Acreo, within IMAGIC, an APD based on SiC with improved detection sensitivity and stability has been designed and experimentally verified. A patent application has been filed for this novel device design.

The SiC material required for production of these devices was grown in-house, in the hot-wall CVD reactor located in the Electrum lab where all remaining processing was also carried out.

The resulting SiC APD devices were found to have excellent electrical and optical performance. The optical response to UV radiation peaked around a wavelength of 290 nm, but had decreased by around 3 orders of magnitude at 400 nm. This is sufficient to permit a significant reduction in the required external filtering of visible wavelengths, compared with that required for use with silicon devices. Upon application of bias to the devices, the SiC devices successfully demonstrated amplification of the signal by up to an order of magnitude, and so proved their suitability for detection of weak signals.

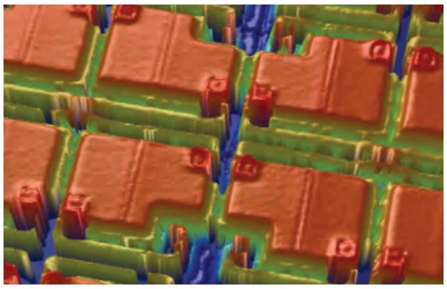
These SiC APDs are now prepared for use in industrial applications. One potential application is the detection of living organisms in drinking water. Others can be industrial machine viewing for the detection of small surface features, or detection of corona discharge around high voltage equipment. These devices can contribute to the technology of tomorrow. ■

Responsivity of SiC APD as function of illumination wavelength. The response is seen to increase by up to an order of magnitude with increasing applied bias.



Low cost infrared imaging

For many potential applications of IR imaging, the cost of today's systems has been prohibitive for wide spread use. The situation is changing with the development of new IR sensors not requiring cooling.



Micrograph of a SiGe sensor array showing individual pixel elements

Infrared image sensors can give a picture of the thermal radiation from for example humans or animals and are very effective in total darkness. Infrared imaging systems are generally divided into two categories: cooled systems which are often high performance, but require cooling to liquid nitrogen temperatures, and un-cooled systems which traditionally do not perform as well as the cooled, but can operate at room temperature.

Acreo has developed an un-cooled sensor based on a new thermistor material made by a multilayer structure of alternating Si and SiGe layers of nanometer thickness. The key benefits of this new material are excellent electrical performance with high sensitivity and low noise, and high temperature stability enabling novel MEMS techniques to be employed during image sensor manufacturing and packaging. All things considered, the SiGe thermistor material enables significant cost reductions and performance enhancements compared to current state-of-the-art un-cooled sensors.

The Si/SiGe based quantum well technology that Acreo has developed enables the use of several cost reducing technologies during manufacture of un-cooled IR sensors. Sensor material manufacturing is separated from read-out circuit manufacturing and the integration of sensor material with read-out circuit employs standard MEMS technologies. Furthermore, the material is stable up to very high temperatures allowing novel wafer level packaging techniques to be used, further reducing the unit cost.

The work at Acreo is multi faceted and spans the whole range from fundamental research on material properties to device design and component manufacturing. Several batches of the new sensor material have been produced and good agreement between measured temperature sensitivities and theoretical calculations has been obtained. As a proof of concept, a 16x16 bolometer sensor array was manufactured together with KTH on a CMOS read-out circuit. Despite its limited resolution, it was possible to clearly follow hot point objects and to detect a person in a room temperature environment.

In collaboration with Autoliv and Sensonor Technologies AS, a new read-out circuit is being designed. The ultimate goal is to design the read-out circuit to allow operation over a wide temperature range without temperature stabilization. The first generation of circuits with this design is expected during 2010.

In 2009 Acreo signed an agreement with Sensonor Technologies AS to cooperate on the industrialization of the new high performance sensor. The agreement includes licensing of Acreo's patented material technology. Sensonor plans to launch its first volume product in 2011 of the new sensor which can be deployed in small energy effective thermal imaging cameras for inspection, surveillance and security solutions in many areas. ■

Silicon Nanowires – Label free detection of biomarkers for qualitative point of care diagnostics

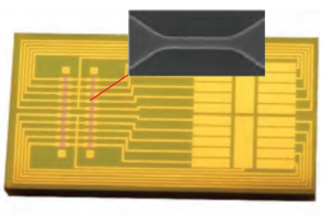
There is a continuous demand for diagnostic tools that can address the increasing number of analyses needed in health care.

Cost efficient, reliable and fast systems that can perform advanced analysis procedures at the point of care; i.e. at health care centers, ambulances or in hospitals; instead of sending samples to be processed in centralized labs. This application area is one of the main drivers for the development of portable sensor devices using microfluidics and MEMS technology, a combination that can provide effective on-site detection of highly specific biomarkers.

Acreo collaborates in a VINNOVA funded project with Jan Linnros (KTH), Shi-Li Zhang (Uppsala University), and Amelie Eriksson Karlström (KTH) in developing a portable biosensor. It is based on the extreme sensitivity of the channel current on charges at the gate of miniaturized MOS-transistors made of silicon nanowires. Biomolecules binding to specific antibodies attached to the nanowire surface may thus induce charge changes affecting the conductance of the nanowire. The sensor elements are fabricated with standard CMOS technology enabling mass production and a possibility for disposable use. Different nanowires are functionalized to detect several different target molecules simultaneously. Specific binding is registered by a change in the current output, thus it enables label free detection making the analyzing faster and more reproducible with fewer preparation steps, all to a lower cost.

Acreo is responsible for the development of a microfluidic delivery system to the sensor device. By combining microfabrication in hard (silicon, resists and plastics) and soft (PDMS) materials the sample volume can be minimized to take full advantage of the very high detection sensitivity. Our encapsulation process is compatible with the limitations in heat, process and solvent compatibility that are found in biochemically functionalized structures. The fabrication process also takes advantage of the high alignment accuracy provided by MEMS technology enabling well defined fluidic channels that can be connected to the macro world by using a standard tubing interface.

The project is currently focused on point of care health applications. However, the detection principle is very general, which means that it can be adapted to detect contaminants, bacteria or other specimens in our environment. ■



The Linnros chip design and SEM image of a typical nanowire with 100 nm width.

The Shi-Li chip design with microfluidic channels defined over four columns of silicon nanowires.

SIAM Project:
Silicon analogue to millimetre-wave technologies

Advanced high speed silicon processes such as CMOS Silicon-on-insulator (SOI) are allowing for new levels of integration and cost reduction for RF to THz applications. One of these applications is next-generation 100Gb/s optical transceivers.

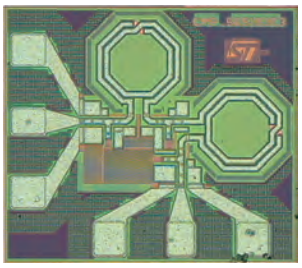
Acreo is investigating the capabilities of 65nm CMOS SOI technology from ST Microelectronics (ST) in Crolles, France for future 100Gbit optical transceivers.

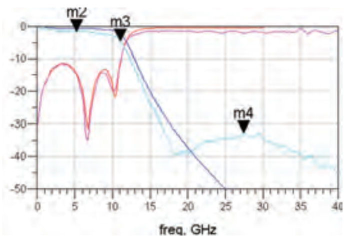
Internet infrastructure capacity needs are driving the evolution of network architectures capable of 100Gbit/s Ethernet (IP) based traffic. Within the CELTIC 100GET-ER project, different data modulation techniques are being examined for improved bandwidth efficiency and reduced cost, one of which is sub-carrier multiplexing (SCM). The EU MEDEA+ project SIAM is investigating the feasibility of a 65nm CMOS process on HR-SOI substrate for implementing an integrated SCM transceiver. SIAM is continuing through 2010 with Swedish participation from Ericsson Research (ER), Signal Processing Devices (SPD) and Acreo.

Within the SIAM project, ST is performing process development of 65nm CMOS SOI on high resistivity silicon substrates and 130nm BiCMOS. This process development is being done specifically with microwave and millimeter wave applications in mind which place high requirements on transistor performance.

As MOS transistors are getting smaller, they are getting faster. This is opening up new areas of high frequency applications for silicon which has traditionally been served by III-V semiconductors such as GaAs and InP. The evolution of nMOS maximum frequency of oscillation (fmax) from industry leaders is approaching 0.5THz, which allows for good performance for 100GHz low power applications.

Just as important for good high frequency circuit design is the ability to integrate high quality, low loss passive elements such as transmission lines, inductors, capacitors, resistors which are used to implement functions such as the 10.5GHz low-pass filter shown below:



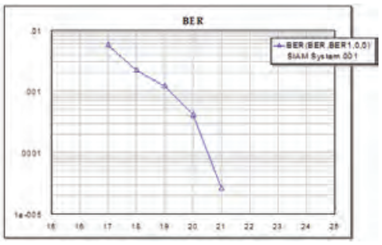


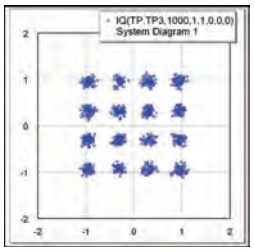
Low pass filter chip photo and simulated/measured results

The ability to design component performance with high accuracy and good performance is demonstrated by the good match between simulated and measured results.

The architecture of the SCM optical transceiver designed for 100Gbit/s data rate has been divided into key component blocks that are developed by the different project partners. Acreo is focusing on the TX IQ modulators and RF power combiner and the RX LNA. The requirements for the components are wide bandwidth (1-30GHz) and high linearity to avoid inter-channel interference.

SCM Optical Transceiver Simulated Constellation Diagram and BER





The RF power combiner has been implemented using a traveling-wave amplifier approach with early simulation results shown below to have good amplifier performance with 10dB of power gain well above 30GHz.

In order to define and make system tradeoffs with the component target specifications, Acreo has implemented the complete RF subsystem for a 100 Gb/s SCM transceiver architecture for a 16QAM, 7GS/s, 2-carrier system with optical polarization multiplexing using AWR VSS together with MATLAB. The individual RF front end component requirements, necessary to achieve successful data transmission at a satisfactory BER level, are established from these system simulations.

Using the simulation environment, data symbols can be input from the DAC and the resulting 16QAM IQ constellation diagram can be plotted to see the effect of noise, non-linearity and design parameters.

The complete opto-electrical transceiver performance can then be simulated with achievable component performances (as determined during the project) to predict system bit-error rate under the influence of non-ideal parameters such as noise, non-linearity and number of bits used to implement the DAC. In the above simulation results, a 4-bit DAC and 5th order TX LP and HP filters have been shown to meet the BER requirements for the system of >0.001 BER with 20dB of optical signal to noise ratio. The individual components designed and verified during the SIAM project are used to input directly into the system simulation results to verify that a complete SCM based 100 Gbit/s optical transceiver can be achieved using the 65nm CMOS SOI process.

In conclusion, the results after the first project tape-out show that the advanced 65nm CMOS SOI process seems capable of meeting the electrical component requirements necessary to achieve the system performance. The next step in the project is to make improvements and more integration in the component blocks for the last and final tapeout of the project. ■

SIAM Project

Project Name: 2T206: Silicon analogue to millimeter-wave technologies (SIAM)
Project Leader: Jean-Louis Carbonero, ST Microelectronics
Administration: Eureka Medea+
Sweden Financing: Vinnova
Participants: Acreo, Catena, CEA-LETI, Ericsson, IEMN, IMS, Royal Philips Electronics, Signal Processing Devices Sweden, ST Microelectronics, TU Delft
Countries involved: France, The Netherlands, Sweden
Duration: 3 years (2008-2010)
www.catrene.org/web/downloads/profiles_medea/2T206-SIAM-profile-outMEDEA%20(21-7-09).pdf

Innovations in fiber optics

Fiber optics makes a difference in almost every business area.

If you look inside instruments and equipment, you will find fiber optics at your doctors and dentists, in illumination systems at your local theatre, in airplanes and satellites, deep down in oil wells, along road tunnels, embedded inside bridges, on high power distribution lines, in car factories, on wind power plants, in steel factories, in food quality instruments, and perhaps in your own car.

Fiber optics in the steel industry

Better energy efficiency and environmental improvements within the iron and steel industry, are the targets in Flexinject, a European project within the Coal and Steel Research Fund in EU (RFCS). In particular, the project investigates how alternative carbon materials can be used to optimize blast furnace processes. LKAB and Acreo have developed fiber optic techniques that will be used in the blast furnace experiments within Flexinject.

A carefully designed fiber optic lance is mounted inside the carbon/oxygen injection channels to the furnace. Inside the lance, several optical fiber eyes look at the hot zone, collecting spectral data. With this information, it is possible to map the temperature distribution inside the furnace. It is now possible to provide real time monitoring of the temperature distribution within the hot zone ('raceway') in a blast furnace.

Very promising tests using this technique have been carried out in the LKAB experimental blast furnace and measurements within the Flexinject project are planned for 2010. Experiments using the fiber optic lance system have also been carried out in a steel converter process at SSAB, and further measurements are planned at steel converter plants around Sweden within the frame of a new collaborative project between Swerea/Mefos and Swedish ICT/Acreo Fiber Optic Center.

Fiber optic measurement in SSAB steel converter.

Moving from one extreme to another, fiber optics can not only improve traditional metal manufacturing processes, it can also enable efficient production of modern consumer products. One example is a nanoprecision chuck system produced by System 3R.

Fiber optic sensor system for nanopositioning. *Photo used with kind permission from System 3R.*

System 3R, a leading manufacturer of high precision pallet systems, has 30'000 users in over 20 countries using 3R systems in production processes such as electrical discharge machining, high speed milling and grinding. With an exploding demand of high quality optical components, MEMS and micro machined parts for consumer products, System 3R has recently introduced a new chuck system for the optics industry, the MatrixNano system. The MatrixNano has an impressive repeatability of 0.5µm in its mechanical clamping system.

Soon, the company will offer an optional add-on integrated in the MatrixNano chuck, a fiber optic sensor developed within Acreo Fiber Optic Center. The sensor will measure the absolute position of the work piece within tens of nanometers, and the machining process can be adjusted accordingly.

The fiber optic sensor system to be integrated in the MatrixNano chuck is another example of industrial solution developed within the Center. Combining the industrial users' perspective with components and systems expertise at Acreo and other partners, we develop systems that make a real industrial difference.

How can you use fiber optics to improve your products?

About Acreo Fiber Optic Center

Acreo Fiber Optic Center carries out research and innovation in fiber optics. Today, more than 20 companies are active within the Center, as well as several university groups and Acreo. Technical development is mixed with exploratory applied research, to ensure a long term general excellence in fiber optics, while providing industrially relevant new products and solutions for the industrial partners.

Acreo Fiber Optic Center has received an Institute Excellence Center award from Vinnova, SSF and KK-foundation. Industrial funding from 20 partners is matched by Vinnova, SSF, KK-foundation, Region Gävleborg and EU Strategic Regional funds. KTH and Mid Sweden University are sponsoring PhD students within the research program. More information and annual report from the Center can be found at www.acreo.se/fiber. ■

Specialty fibers

Optical fibers with protective coatings for use in oil and gas industry, preform glass for high power lasers, fibers for power delivery applications and microstructured fibers for sensing and components. These are some specialties at Acreo Fiberlab, one of the most advanced laboratories of its kind in the world.

The term “specialty fiber” is used for practically any optical fiber except the highest-volume communications type. Some types of specialty fibers have well-established volume markets, others are still used exclusively in research and development. The commercial demand for specialty fibers is growing steadily, with industrial, security and military markets making the most impact.

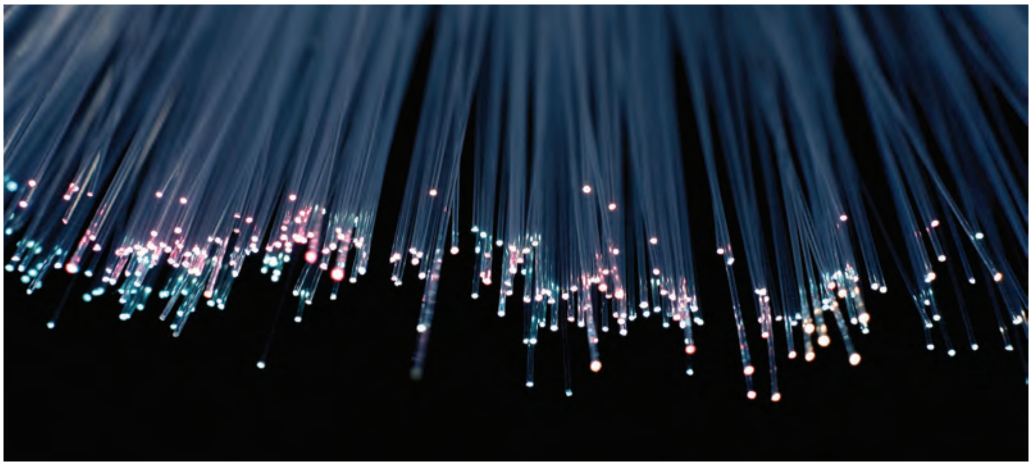
Major specialty fiber types include polarization-maintaining fibers (with applications in fiber gyroscopes, current sensors, lasers and pigtailing), polyimide-coated fibers (harsh environments), erbium- and ytterbium-doped fibers (lasers and amplifiers), photosensitive fibers, and multimode fibers for transport of high-power laser light.

Acreo has developed unique technologies and processes for designing and manufacturing specialty optical fibers. The expertise is used to develop new types of fibers together with national and international R&D partners, as well as to provide reliable and high quality production of fibers and preforms, for example for Crystal Fibre and Fibertronix.

Fibertronix, a recent spin-off from Acreo, provides customer-defined specialty optical fibers to industrial partners world-wide. The product portfolio includes a range of special fibers such as multi-mode and single mode fibers with polyimide, high temperature acrylate or hermetic coatings, small diameter, pure-core and high NA fibers.

In 2009, Acreo developed a new class of all-fiber high power components, combining expertise in glass processing, fiber drawing, coating techniques, components development, high power lasers and photo induced effects in glass. The development promise low-cost components for coupling and distribution of high power laser light. We also continued the development of hermetic fibers, taking the R&D results towards a commercially viable process.

The laboratory’s microstructured fibers, including the unique Gemini-fibers, were used to demonstrate new fiber optic functions in sensing, microfluidics and lasers. In particular, components based on our proprietary electrode fibers, are undergoing commercial verification during 2010, as described elsewhere in this annual report. ■



Controlling light at high speeds

Acreo and partners have developed unique technologies for all-fiber pulse control, which are now being verified for commercial use in fiber lasers and laser systems. Similar techniques is used to rapidly tune fiber Bragg gratings and to detect radar signals.

High speed control of light in an optical fiber is interesting for many applications, including Q-switching fiber laser cavities, single pulse selection, and even plain beam chopping. In-fiber modulation makes external bulk modulators, with their high optical loss and high price, superfluous.

Acreo have developed techniques to gate light in microstructured fibers with nanosecond control. The components use internal electrodes, a technology developed and patented by Acreo. Side-polishing is used for contacting the electrodes and still allowing for low-loss splicing. In operation, a high-voltage nanosecond pulse is applied to one electrode and heat is deposited in the electrode causing its rapid expansion. A pressure wave is created by the expansion that reaches the core in nanoseconds, birefringence is induced and the polarization of light is rotated. Combined with a polarizer or a polarization splitter, the components extinguish or switch light inside the fiber in typically less than 10 ns.

Recently, a hundred watts peak power pulses at 1.5 µm were generated in a cavity dumping experiment using the all-fiber polarization switch, for approximately 300 mW pump power. The switch is based on all-spliced silica-based single mode fiber. In 2010, the experiments will be extended to the 1 µm wavelength range, where most laser marking applications are found.

Acreo have earlier demonstrated and published that electrical control of fiber Bragg gratings, FBGs, can be achieved by applying the high-speed current pulses to a fiber with electrodes, in which a grating has been recorded by UV exposure. Since the first demonstrations, switching times of few nanoseconds have been demonstrated. The applications of such fast sweeping reflectors are diverse, such as fast tuning of lasers and filters.

A study of tunable long period gratings (LPGs) in fibers with electrodes was also started in 2009. It was shown that the Bragg peak wavelength can be shifted by as much as 8 nm with the application of an electrical pulse, to longer or shorted wavelengths depending on the input polarization. When current pulses are applied, amplitude excursions of 5 dB are obtained with nanosecond risetime. We expect this figure to be improved to at least 20 dB (i.e., under the application of a short electrical pulse the transmission would increase 100 times).

In 2009, we have also studied the switching performance of distributed feedback gratings, DFBs. Such gratings exhibit a spectrally very narrow transmission peak (< 1pm wide in wavelength, or only some tens of MHz in frequency). We succeeded in tuning DFB gratings from fully transmissive to fully reflecting in 2.5 ns. The use of such gratings for the rapid determination of the frequency of a radar pulse is of interest to Saab Avitronics as discussed below.

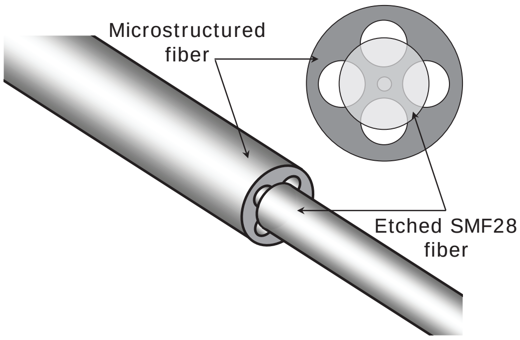
Microwave photonics is one area in which technologies developed for optical communications can assist RF techniques. Since the optical light (which carries the RF signal) has very high frequency, tuning that seems small in the optical domain corresponds to a large frequency sweep in the microwave domain. Optical DFBs have narrow transmission peaks and are ideal for filtering RF signals modulating an optical carrier.

Saab Avitronics specified the problem of determining an unknown modulation frequency of an optical carrier. Acreo supervised a diploma student to develop a photonic scanning receiver, using the components described above. If an RF-signal is set to modulate an optical signal, the optical spectrum responds with two symmetrical sidebands around the optical carrier, the sideband separation is determined by the RF frequency. In the demonstration, the RF-modulated optical signal was filtered by a fiber DFB grating with in-fiber electrodes. The RF-filter was tuned rapidly, allowing the scan of wide RF bands for the analysis of unknown microwave and radar signals.

The family of components and optical functions made possible by the internal electrode fibers are numerous. In 2010, Acreo, sponsored by Vinnova, is assessing the commercial potential of the components. ■

Fiber optics in Life science

Microstructured optical fibers integrate several functions and opens up great possibilities in for example life science.



Imagine an all-fiber instrument, thin as a hair. It can drill precise holes with laser guided in the fiber, finding its way by reflectometry. It has thin holes where liquid medicine or reagents can be applied, or that can be used to take biopsies and samples. The same fiber can be used for optical sensing, and can have integrated electrodes for electric stimuli of nerves. The instrument is biocompatible and can stay in the body for months without problems.

It may sound impossible but one could in fact imagine these functions to all be integrated into one single Acreo fiber. Few reports exist where microfluidics is combined with laser delivery for nanosurgery or ablation, or where optical coherence tomography is used to monitor laser surgery in real time. Generally, these application areas for fibers and capillaries are treated separately, and for this reason some of the potential functionality of microstructured optical fibers remains unexploited.

In 2009, Acreo Fiber Optic Center developed a new microstructured fiber system demonstrating three of the functions above simultaneously in a single fiber. Low-coherence reflectometry is employed for monitoring and positioning the microstructured fiber tip, high-power laser delivery for ablation of samples and microfluidics in the fiber side-holes for fluid collection.

The image shows a detail of the fiber used in the experiments, the splicing arrangement to allow for flow of liquids and coupling of light. One vital part of the system, the microfluidics, is made possible by Acreo's proprietary coupling method that allows for simultaneous flow of light and liquid.

Potentially, combinations like these should allow probing samples in very harsh environments, such as sampling radioactive material in regions of difficult access, in environments where a light weight is of prime importance, or where the minimally invasive fiber is advantageous to cause the least possible damage and contamination, such as in surgery interventions and biopsy in the human body. ■

Research for the Future Internet and Broadband Technology

Acreo is active with enabling research in several aspects of the future Internet ranging from the actual transmission and network technology to the interaction with end users.

We are living in exciting times. The Internet is revolutionizing human communication. Its impact on human society is profound and far reaching: It influences communication on all scales from mass media, to how we communicate with our friends and colleagues. It brings new ways of doing business and streamlines many sectors of our society. Is a basic condition for globalization and may provide means for address the most important challenge of our time – that of the global warming.

We are - at the most - in the middle of this revolution. We have already seen big changes and as the Internet reaches more with increasing bandwidth there are vast changes yet to come.

Acreo is performing exciting research in the area of future Internet and broadband technology. During 2009 Acreo published more than 40 research publications in the area, developed several patents and contribution to international standardization. At the OFC/NFOEC 2010 - the world's largest optical communications and networking event – research from Acreo was presented in five different presentations, two of them specifically invited. Examples of this pioneering research are presented in the following.

The phase of innovation of services is high on the Internet. New applications generating new patterns of traffic appear continuously. Many applications are connected video and important research issues are how video should be distributed and how to achieve a good quality. Acreo does IP traffic measurement to analyze traffic flows and detect changes that will affect how the network should be constructed. In particular, Acreo leads TRAMMS, a successful and awarded EU project in the area.

Access networks based on optical fibers to the homes is together with wireless networks the two important ways that will enable Internet to reach out further. How these optical networks should be built and operated and how they should be extended into the homes are very interesting questions intensively studied at Acreo. Read about future home networks later on in this issue, where plastic optical fibers is a technology which is quickly emerging.

To support innovation in a quickly changing environment, the Internet should continue to deliver generic connectivity. For example, future applications may have peer-to-peer or client server character. A meshed access network that is easily reconfigurable would be one strategy to support the future Internet. Acreo studies proposes architectures for optical access networks and also develops new automatic control mechanisms. In the area of home and access networks Acreo leads a big EU project, ALPHA, with participation from 17 partners, among them are several leading European system vendors and operators.

As the edge of Internet get higher bandwidth and reach more people, the traffic in the core inevitably grows. The growth-rate differs between regions and network segments but in many places the traffic approximately has doubled in 12 or 18 months. Traffic growth and the successes of Ethernet transmission has lead to a great interest in transmission at 100 Gbit/s. Acreo has developed new modulation techniques and performed ground breaking field transmission experiments.

The development is rapid, broadband and the Internet has changed human communication forever. Still we may only be in the beginning. Until now the Internet reaches computers and mobile phones. The interaction with humans and biological process are in principle restricted to eyes watching displays, to fingers touching keyboards or touch panels. If that barrier was removed or lowered, if our minds where in direct connection over the Internet we would enter a new era. That has not happened yet, and it may not happen. But these are exiting times! Get a glimpse of the future - follow the research at Acreo! ■

High-speed optical transmission

100 Gbit/s lab and field transmission experiments show the way towards higher capacity core and access networks.

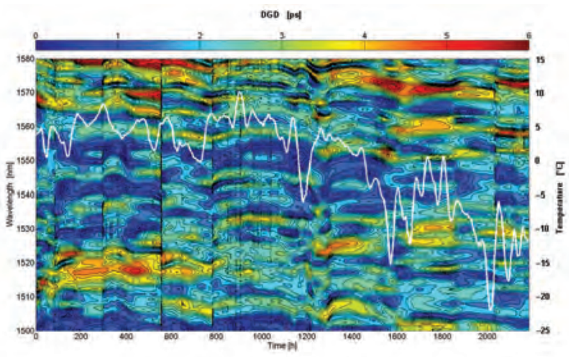
Successful experiments

Acreo has been involved in successful 100 Gbit/s transmission experiments carried out in the frame of two European R&D projects. Components developed in the HECTO project by KTH and others were assembled in Acreo's transmission lab and used for transmitting 100 Gb/s data from Kista to Norrtälje and back over 212 km of field installed fiber. While HECTO targets Ethernet interfaces supporting short to medium distances, the 100GET project develops DWDM interfaces based on advanced spectrally efficient modulation formats for transporting 100 Gbit/s Ethernet signals over metro and core networks. Within 100GET, Ericsson and Acreo have collaborated to perform experiments using SCM (Sub-Carrier Multiplexing) and 16-QAM modulation. The hardware, which is being developed by Ericsson, has so far only been tested in their lab but will later be used for field experiments between Acreo in Kista and Hudiksvall. Results from both the HECTO and 100GET experiments were presented at the world's leading international conference on optical communications, OFC/NFOEC, in 2010.

When upgrading networks to higher speed it may be critical to know the quality and properties of the fiber infrastructure. One important fiber parameter is PMD (Polarization Mode Dispersion) which is why Acreo has performed long-term PMD measurements on the installed fiber provided by TeliaSonera. PMD is a statistical process which depends on, among other things, environmental factors such as temperature. The measurements, which were active for more than 5500 hours in total, have revealed interesting behavior and correlations.

Other European collaboration

In addition to the HECTO and 100GET projects mentioned above, Acreo is involved in transmission activities in two large projects in the EU Seventh Framework Programme (FP7). In ALPHA, Acreo has started collaboration with Bangor University in Wales on OFDM (Orthogonal Frequency Division Multiplexing) in fiber-optic access networks. In EU-ROFOS, Acreo is leading an activity on nonlinear fiber effects and mitigation using DSP (Digital Signal Processing) with participation from other research institutions such as Chalmers in Gothenburg, Tyndall in Ireland, HHI in Germany and Politecnico di Milano in Italy.



Measured DGD (Differential Group Delay) for a buried fiber span together with outdoor temperature. The PMD of a fiber is the average DGD over time and wavelength.

COSYNET

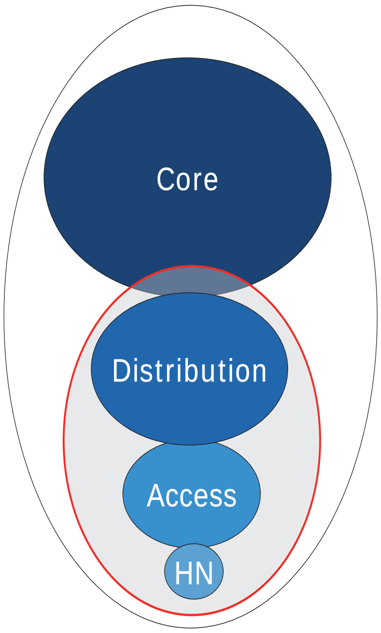
A new three year research project in the high-speed transmission area, COSYNET, was granted financing from VINNOVA and started 2010. The project focuses on coherent optical transmission systems with capacities of 40-100 Gbit/s per wavelength. Some issues to be considered are implementation strategies, laser phase noise and network upgrade scenarios. Swedish industry is represented in the project by Transmode, Syntune, and TeliaSonera.

New inventions

Acreo's research within high-speed transmission has led to three new inventions related to advanced modulation formats. ■

The ICT Alpha project from an Acreo control plane perspective

ICT Alpha, or Architectures for fLexible Photonic Home and Access networks, is a frame work 7 project that addresses the challenges of building the future access and in-building networks.



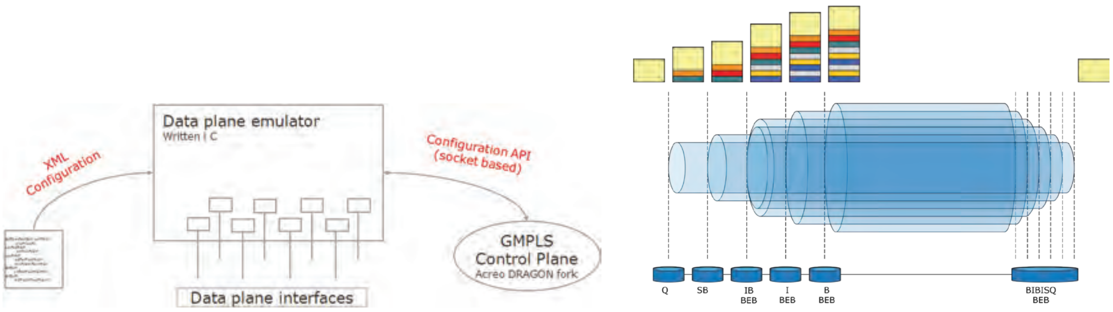
Acreo control plane scope in Alpha

The text below aims at giving some insight to what type of work Acreo is doing when it comes to multi-layer network architectures, and especially within the framework of ICT Alpha. Most of the below work is done in the Acreo GMPLS testbed that consists of a multi-technology network of both commercial and in-house developed network elements (NEs), where the latter is realised and emulated in an Linux environment with numerous NEs enabled through virtual instances.

Multi-layer Ethernet architecture

During the initial year of Alpha time was spent on a literature study of the IEEE multi-layer 802.1Q Ethernet standards, with amendments .1ad, .1ah, and .1Qay. The goal with this work was to create a deep knowledge base in order to get a set of requirements, parameters and functionality that a generalised multi protocol label switching (GMPLS) control plane needs to meet in order to apply this multi-layer Ethernet architecture to an access and access distribution/aggregation network with a GMPLS control plane.

Out of this work came a number of use cases that needs to be handled as well as a set of extensions of the GMPLS control plane protocols. Some of the things that the extensions needs to handle are; new label objects, methods for allocating end-to-end labels, methods for detecting Ethernet layer boundaries, technology specific parameters in signaling, and shared forwarding. One of the use cases leads to interworking with UPnP QoS in the home gateway. Initial work on the design of both GMPLS control plane protocols extensions and functions as well as the interworking with UPnP QoS has been done during Alpha year two but the main effort was spent on the below, leaving the bulk of the control plane work and the end-to-end demonstration to Alpha year three. The goal of this demonstration is to show end-to-end QoS enabled service provisioning over an UPnP QoS based home network and an GMPLS



A schematic picture describing the Linux user-space data plane emulator with its different interfaces. Also seen is one of the use cases involving network elements (NEs) from the IEEE multi-layer 802.1Q standard with its amendments .1ad, .1ah, and .1Qay. One can se the different layered tunnels and the corresponding headers that a GMPLS control plane needs to handle and signal in order to facilitate an end-to-end resource allocation.

controlled multi-layer Ethernet access and distribution network.

Multi-layer Ethernet data plane

The main focus in Alpha is on GMPLS control and management plane functions, but in order to do research and tests an IEEE multi-layer Ethernet data plane is also needed. The goal of the data plane implementation is to have the main functionality from the DIX Ethernet and multi-layer IEEE 802.1Q Ethernet (Q, ad, ah, and Qay) in the Linux kernel and/or Linux user-space. The software also includes a management/configuration interface towards our GMPLS control plane.

During 2009 initial demonstrations of intra-layer forwarding and inter-layer mapping and forwarding of a user-space multi-layer Ethernet software implementation has been done. An example of the first function is e.g. 802.1Q Ethernet learning and forwarding. Inter-layer examples can be split into two cases depending on if the interface handles all traffic on that interface in the same manner or if on a per VLAN level. I.e. per port handling at customer network ports - mapping all client layer traffic on a port into a specific server layer tag - e.g. un-tagged DIX Ethernet into C-tagged 802.1Q, or per port and VLAN handling at customer network ports - mapping all traffic of a certain set of client layer tags into a server layer tag - e.g. S-tagged 802.1ad into I-tagged 802.1ah. Initial tests has shown error free throughput in the order of 100Mpbs.

The next steps are added conformance to extended use-case scenarios, e.g. multicast forwarding and minor basic functions e.g. aging of forwarding table entries.

Excluded in this work is the loop prevention mechanism through different spanning tree flavours.

Path Computation Element (PCE) architecture

The Path Computation Element (PCE)-based architecture was developed by the IETF to address the complex problem of constraint-based path computation in large multi-layer and multi-domain networks, see RFC 4655. Generic requirements for a communication protocol between a Path Computation Client (PCC) and a PCE, as well as between cooperating PCEs, are specified in RFC 4657. A compliant protocol, referred to as the PCE communication protocol (PCEP), has been specified in RFC 5440. PCEP is a request/response protocol that can be used by a PCC to send computation request for one or more paths including constraints to a PCE and the PCE can respond using PCEP with a set of computed paths.

Initial work on PCEP and a multi-layer path calculation algorithm (ML PCA) has been done during year 2009. This includes the study of the above mentioned RFCs and the implementation of the main part of the PCEP functionality specified in RFC 5440. One use case for the PCEP protocol is to implement this functionality in the gate way (GW) in order to ease the hardware requirements of this network element (NE). Both the basic functionality of PCEP and multi-layer path calculation algorithm, which is a k-shortest path first Breadth First Search (BFS) algorithm, has been applied to and demonstrated in the current Acreo GMPLS testbed.

The focus of 2010 is to extend the PCEP and the path computation algorithm to include the Alpha AON scenario of an IEEE multi-layer Ethernet access and access distribution network. A complementary work is how to populate (via the routing protocol, the NMS/OSS etc) the traffic engineering data base (TED) with the correct information in order for the path calculation algorithm to do its job based on this information.

Protection and restoration

The Bi-directional Forwarding Detection (BFD) protocol is developed in the IETF as a generic method of detecting connectivity and loss of connectivity between two forwarding planes in a network, see draft-ietf-bfd-base. The core of the protocol is agnostic to how the connectivity is provided, the protocol itself may be applied on top of any packet transport mechanism (for example MPLS, draft-ietf-bfd-mpls). Our interest in BFD is to use it to detect forwarding plane connectivity faults (as opposed to control plane connectivity faults) on LSPs in our GMPLS controlled multi-layer Ethernet network in order to trigger protection switching (i.e. switch from a broken link/LSP to a working one).

The effort spent during 2009 has resulted in a basic implementation of BFD functionality in the Acreo GMPLS testbed environment. This includes asynchronous fault detection (i.e. periodical transmission of control packets) but lacks more advanced functionality such as demand mode (on-demand connectivity checks), authentication etc. However, these more advanced functions are not necessary for our purposes. This work also led to an increase of timing resolution (order of µs) than is normally seen in Linux implementations.

Further extensions are necessary in order to allow BFD session establishment via a GMPLS control plane as well as an encapsulation method for BFD control packets on top of Ethernet. ■

Cost-effective quality for HDTV

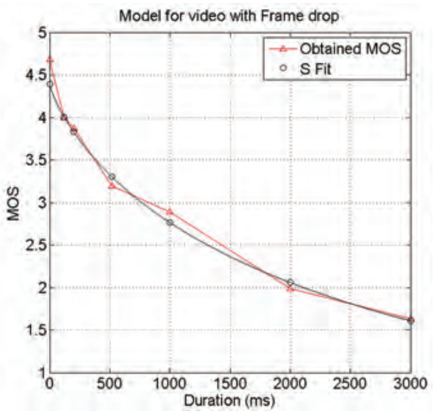
To be competitive is very often to be able to offer the optimal compromise between quality and performance.

Cost of equipment, maintenance, development costs etc could be calculated and is therefore fairly straightforward to estimate. Quality on the other hand is a much more complex issue to understand, because it is a subjective experience by the user. When asking two different people two very different answers might be obtained. Fortunately, there are systematic and scientific methods to use to investigate quality. It turns out that while individual opinions can have large variances, the mean of a panel of observers are usually very stable.

Acreo has during 2009 and for several years investigated the quality of video and displays in order to derive useful requirements and design guidelines. The most successful example has been through the TCO display label (www.tcodevelopment .se), which have had worldwide impact, where Acreo has developed the visual ergonomics requirements. We will here give a few examples of studies that have been performed during 2009 in this area

Impact of waiting time in TV-services

In a series of experiments waiting time in TV-services has been studied. It turns out that there are many similarities between the quality degradations, which induce waiting times on the user. For example, it has been shown that the reaction on waiting times in response of a web download is similar to a waiting time on a channel switch. This has given the useful design guideline that if the waiting time is kept below half a second the service is considered as good. Similarly Acreo has investigated, in collaboration



The Mean Opinion Scores (MOS) for different waiting time durations

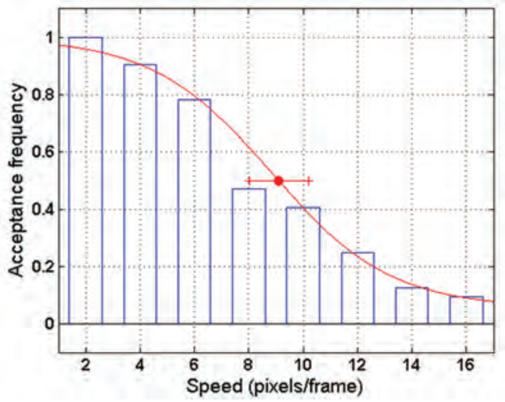
with TNO in the Netherlands, the experience of quality degradations of freezing in video and similar results were obtained.

Acceptable motion blur on flat panel TV

It has been recognized for some time now that LCD displays will introduce blur when showing moving objects or moving images. Common motion-blur measurement methods are usually based on capturing the blurred profile of an edge moving with a constant velocity. A normalized blurred edge width is then measured for several gray-to-gray transitions to give a motion-blur score of the display under test. However, these objective measurements are partly based on the behaviour of the human visual system and it is an open question how well they correlate with subjective experience of observers. We conducted a study in collaboration with the University of Nantes, France, in order to assess the annoyance and the acceptance of motion-blur.

One of the stimuli used in the motion blur experiment

The acceptability frequency as function of stimuli speed.



The figure shows one stimulus used in the study and the frequency of observers considering the blur to be acceptable, related to the speed of the moving object.

Acreo has participated in the development of measurement parameter that better describe the motion blur that people experience on LCD displays, called Blur Edge Time (BET). According to the study the following design guidelines was derived:

- Acceptable display: BET < 20 ms
- Good display : BET < 11 ms
- Excellent display : BET < 6.6 ms

Peer-to-peer TV vs broadcast

Video on demand (VOD) services is widely used nowadays to watch online videos. The VOD service, which combines the computer technology, network technology and multimedia technology together, allows users to select and watch video contents on demand via a set-top-box (STB) or a PC. VOD services are traditionally server-based or centralized which all users are connected to the related servers and the video contents are delivered from server to the end users directly. However, such centralized communication model has some disadvantages. One of the shortcomings is the poor scalability which is caused by the limited computing capacities of the servers and downlink bandwidths. Furthermore, the centralized network architecture will waste huge amount of uploading capacity of the end users. However, pure peer-to-peer (P2P) based architecture is not competent to provide video on demand service. In the work at Acreo, we simulate the access network and implement a suitable downloading strategy using the simulation tool, Network Simulator 2 (NS2). In this simulated access network, the VOD service provider and network provider cooperate with each other to guarantee the service quality. Based on the literature study, we propose to apply a server-assisted P2P VOD service on the access network and make the network scalable. Our system provides benefits in the following aspects: (1) The uploading capacities of the end users are utilized efficiently (2) The system supports to play high quality video contents. (3) The P2P network architecture makes the system highly scalable. The comparison between different downloading strategies has also been studied.

Conclusions

It is very often the market player that could deliver the best balance between price and performance that becomes most successful. To find this balance it is essential to know where the boundaries lie. Acreo has long tradition in studying quality related requirements for video and displays, which can be used as design guidelines when cost-effective solutions are developed. ■

IP Traffic Measurements and Analysis

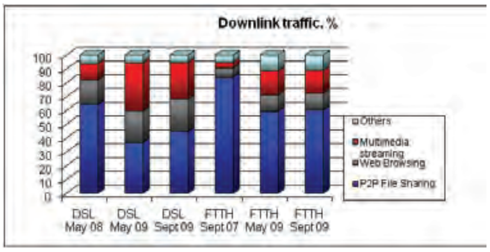
If you want to build the future Internet, you need to know how the current Internet is used. Therefore Acreo measures and analyses IP traffic in live access networks, in order to gain a better understanding of user and application behavior and their implications for the network.

It is often said that the IP traffic bandwidth demands are ever increasing. Is this true? In order to understand this, detailed measurements over long periods of time are required. Acreo performs IP traffic measurements in production networks, to enable research on network traffic patterns and user behavior. The measurements are unique in the research community, since they involve live networks, and are long term (years) and detailed (application level, household level). This way, it is possible to analyse user behavior related to certain applications, like e.g. gaming or video streaming, and also detailed traffic patterns per application. Apart from user and application behavior, areas of interest include e.g. content delivery analysis, traffic influence on network performance, network design and optimization, etc.

Acreo coordinates several research projects in the area. Among these projects are Celtic TRAMMS and VINNOVA Broadband Behaviour.

The TRAMMS project has been running 2007-2009, coordinated by Acreo. The main objective of the project has been to model traffic in multi-service IP networks, and to develop tools for monitoring of QoS and bottlenecks in networks. The models are built on data acquired in different parts of Europe and combined with the new tools developed in the project, they bring significant new insight into network traffic, bottleneck analysis, user behaviour and QoS monitoring. Measurements from application to packet level per household were collected in real networks located in different countries (Sweden and Spain) covering different types of access (FTTH, xDSL, CMTS, GGSN, university network). Measurements from a large amount of users were gathered for long periods of time (close to 3000 TiB of traffic volume was analysed in Spanish and Swedish networks in 2007-2009 in periods ranging from several days to several years).The project has impacted 7 product lines in 5 different companies. All of these products are aimed at finding the bottlenecks in the network and monitoring traffic and QoS parameters, and they complement each other to get a complete picture of the status of the network, from point to point performance (delay, jitter), through available bandwidth in real time, to monitoring of BGP events and deep packet inspection. TRAMMS has actively contributed to standardization of active end-to-end capacity measurement methods in the International Telecommunication Union (ITU-T). TRAMMS has also contributed as a participant to the creation of the Industry Specification Group, ISG MOI (Measurement Ontologies for IP traffic) group under the ETSI framework. The results of the group are intended to provide a solution for network operators, Internet service providers and businesses by providing metrics based on a common understanding of IP traffic management and measurement criteria.

The VINNOVA Broadband Behaviour project develops methods to evaluate Internet related user behavior. In this quest, the actual IP traffic measurements are refined and combined with test user interviews. This allows for benchmarking the measurements as well as the questionnaires, to better understand how to interpret the results. This work is performed in close collaboration with World Internet Institute, and so far a pilot study has been performed with a small number of households. Acreo has built up a data base with IP traffic measurements over several years for research on user behavior and traffic patterns. This data base contains detailed and anonymized traffic data, and is unique in the sense that it is detailed at the same time as it contains IP traffic measurements for several years.



Example of traffic measurements general results. Relative share of downlink traffic in a Swedish municipal network, with fiber (FTTH) and DSL access

The results from the traffic measurement activities are important not only for the research community and the operators, but for the society as a whole, since Internet and its usage play a very important societal and social role in people's daily lives. ■

Home networks

From having virtually no activities within home networks just a few years ago this research area has now grown to be very important for Acreo. The activities range from infrastructure aspects through gateways and telemetry to advanced control of the services within the home.

Infrastructure

Infrastructure is about how to transport information from the gateway or modem to the terminal equipment (PC, TV set top box, IP-telephone, home server, etc) and also between these. The most deployed infrastructure solutions include the telephone cables within the home, coax cable for TV, and wireless LAN (Wifi). However, none of these are able to carry the emerging demanding internet-based services in a proper way, their coverage is too limited, and telephone cables and coax cables are not even designed for IP-based traffic.

The work related to an infrastructure within the home is often quite practical by nature, as will be exemplified in this article. The lack of high quality home networks is becoming a bottleneck for the roll-out of services that require high bandwidth and/or very robust connections. Before the infrastructure problem is properly solved the services cannot be deployed to their full extend.

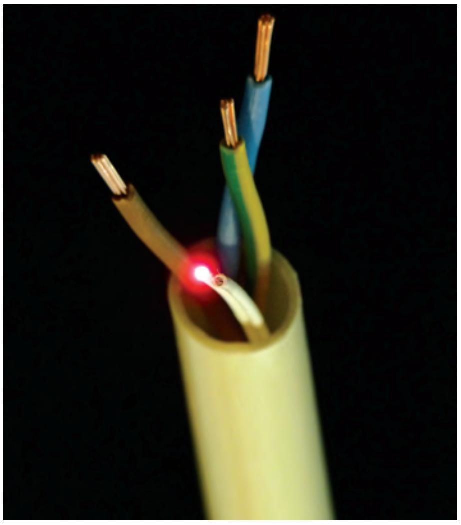
Gateways and telemetry

The gateway or the modem is the device that terminates the broadband connection from the access network and separates the services towards the home network. The gateway can contain multiple functions, and at Acreo we work with understanding and defining what functions should be included in the gateway, how they should be provisioned and managed (from the user or the service provider), how to connect to emerging services as e.g. sensor networks, e-health services, and telemetry. Key guidelines for our work are that we should use open interfaces and standardised solutions as much as possible, and that the solutions should have low power consumption or alternatively lead to reduced power consumption elsewhere.

Advanced control

The home of the future will contain a mix of different infrastructure technologies – wired as well as wireless. In such a heterogeneous environment with many more services than today there will be a need for some kind of quality of service (QoS) since not all technologies can support e.g. an IPTV stream.

This is a classical problem: Should the network be overprovisioned or should it be QoS-controlled – and the answer is probably in between. Whereas cables to all rooms is a kind of overprovisioning Acreo also works with QoS-control. One solution is to utilize the increasingly popular universal plug and play (UPnP) standards used for instance within the digital living network alliance (DLNA). Modifying the UPnP protocol makes is possible to control services within the home, and it is furthermore possible to make such a control system interact with advanced control planes in the outside network such as GMPLS.



POF cable collocated with electrical wiring in a standard 16 mm plastic tube

Plastic optical fiber(POF) collocated with the electrical wiring

In most newly built homes and apartments a network of Cat5e-cables (also known as LAN cables, Ethernet cables, etc) is routinely installed with outlets in several rooms. Such an infrastructure is very robust, and it can carry most of the services we can envision today.

However, the majority of homes don't have such an infrastructure. Retrofit installations of Cat5e-cables are done at some housing companies, often in combination with a complete renovation of the electrical cabling. Otherwise the alternative can be to install the cables just below the ceiling or at the baseboard at the floor. This solution leads to a technically robust infrastructure, but it is seldom esthetically pleasing, and it is impractical in case of painting or hanging up new wallpaper in the home. So Acreo started to look for alternative solutions for retrofit installations.

Within the EU-project ALPHA Acreo was introduced to plastic optical fiber, POF. Such a fiber has a core of 1 mm in diameter compared to silica (or glass) fiber with a core diameter of 9µm. This makes handling of POF much easier than silica fiber: whereas silica fiber requires special tools and trained technicians, POF can be handled with a sharp pair of scissors by anyone. The drawback is that whereas glass fiber has extremely high capacity over very long distances, POF can handle a maximum of 1 Gbit/s over less than 100 m. On the other hand, this is in most cases enough within a house or an apartment.

The POF equipment (cables, O/E converters, switches) is not developed by Acreo. Instead we are working with off-the-shelves products from partners and try to adapt the technology to Swedish housing conditions. As indicated above we realized that there are issues with Cat5-cables for retrofit installations, so we came up with the idea to collocate POF with the infrastructure for electrical wiring.

The vast majority of Swedish homes have electrical cables placed in tubes behind the wall, and if there is room for electrical cables in these tubes, there should be room for the much thinner POF cables as well. If so, the vast majority of Swedish homes already have a tube infrastructure than can accommodate a home network cable infrastructure that can be hidden for end user!

In order to verify this idea we contracted a local electrical installation company in Hudiksvall for making test installations in two apartments in Acreo's National Testbed.

POF installation in Acreo's testbed

For both apartments POF was inserted in the ducts for the electrical wiring with O/E-converters with RJ45-outlets at each power outlet.

The installation was performed by first inserting a semi-flexible reinforcement cable (originally from Ericsson's fiber cables) through the tubes. The tubes were standard VP tubes with 16 mm in diameter. The POF cables (2 x 2.2 mm) were then fastened with duct tape, and lots of vaseline was applied to reduce friction. In most cases this was sufficient,

Installation in the living room

but in a very few cases insertion was not possible and the existing electrical wiring was removed. New wiring was then inserted together with POF cables. In some cases the reinforcement cable wasn't even necessary to use as the POF-cable could be inserted directly from end to end.

The housings for the electrical outlets were exchanged by new housings that apart from the power outlets also included room for the POF-units with RJ-45 outlets. That is, the POF is not visible to the tenant/apartment owner.

Experiences from the installation

The installation was done by a professional installation company which received 15 minutes of training prior to the installation. That is, the idea of a POF network is conceptually easily understood which is important for low cost roll outs. The first installation took one working day for two installers while the second took 5 hours for two installers. With more practice it shouldn't take more than 45 minutes (everything included) for two installers to light up one double-outlet.

The installations went surprisingly smooth, and the only major issue were the lack of standardised plastic parts for the outlet housing, so these missing parts were home-made and thus expensive. However, for mass production the costs will be low.

Status today

So far (after half a year) there have been no problems with the POF network in the two apartments, and the tenants are very happy with broadband access in each room with no need for visible Cat5e cables across the apartment - which was the case before.

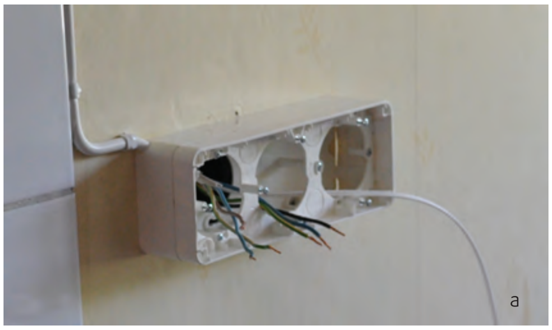
The costs for materials and installation are comparable to installing a TP-network in exterior ducts with the same amount of double-outlets. However, since POF is still commercially immature material costs are likely to drop in the future. In this calculation the cost of home-made plastic parts were excluded.

Discussion with a number of housing companies has revealed that the biggest issues preventing them from installing POF in large scale today are (prioritised):

1. There is only little prior experience with POF in home networks, and there is a concern that it will not work properly or that the cables will become fragile with time.

2. Active equipment will break more than passive cables, and the housing company therefore needs to take some kind of responsibility for support

However, there is also a wide understanding of the benefits of POF. The perhaps strongest argument for POF (at least for Swedish housing companies) is that if an esthetically pleasing solution is required at a reasonable cost, POF may very well be the only alternative! Cat5 cables across a house or apartment (with or without ducts) simply cannot be installed in a costly way without major esthetical issues. The next step for Acreo within this field is to make pilot installation in several apartments together with large housing company. ■



a) The new partly homemade box on the wall replacing the old box on the table. The POF cable is seen to the right.

b) The housing on the wall with two electrical outlets and one RJ45 outlet (with an O/E converter behind it). The visible electrical cable is a "home installation" connecting to another electrical outlet. The "real" electrical cabling is hidden behind the walls but visible through the housing in a).

Business models and market studies

Acreo strengthened and expanded its activities in late 2009 to meet increased demand in business-intelligence. It is mainly the public sector, but also other players, who wish to support. We provide advice, reviews, analysis and market-reports on ICT infrastructure, especially on business models and open networks

Communication has always been the most important driving force for the society. Today ICT- infrastructure is necessary for business, public sector and individuals. Municipalities and public sector will more or less, be involved in the future ICT-infrastructure.

New actors as municipalities and utilities use new and open business model to separate the network from communication and services. To understand the values and opportunities the “nontelco” need clear and specific information.

Acreo as a business guide can assists clients to understand the opportunity. The challenge is to deliver public service combined with increased value.

Our support is independent, our consultants have wide and varied experience in specific areas, as fiber to the home and open network models. We understand that each customer has different needs, different priorities and different market conditions. Although our services have a common structure, each is tailor made for our clients. Our experience includes working in the telecom environment and the public sector. We provide information on business models and regulatory issues.

We make studies aimed to take all interest into consideration, and bring incentives to invest.

Market understanding, regulatory aspects, municipality situation etc, gives a foundation for business strategy definition. Our studies and reports can be the prerequisites to invest and create innovation and competitiveness. We can provide clear and specific information on the broadband market.

Acreo continuously dialogue with municipalities and authorities to discuss potential benefits of fiberoptic as an ICT-infrastructure .We participate in many studies and research-projects. Acreo is also on a regular basis speaking on events and conferences. ■

Production Incubator - Small Scale Manufacturing

Acreo can help customers evaluate the market potential for the developed components and products by offering small scale production.

When volumes become high Acreo helps its customers fi nd a solution for mass production. In particular Acreo's advanced lab resources offer SME's and start-up companies' lab access for process develop ment and personnel training without exten sive investments. Below are examples of cases where Acreo's capabilities of small scale production/ production incubator have helped customers or partners.

Specialty fiber production

Acreo is trusted to manufacture specialty fibers for international customers. For example Acreo Fiberlab supplies the Danish company Crystal Fibre A/S with highly advanced glass cores incorporated into some of the fi bers produced by Crystal Fibre. Fibertronix AB, a recent spin-off from Acreo, provides customer-defined specialty optical fibers to industrial partners world-wide. The product portfolio includes a range of special fibers such as multi-mode and single mode fibers with polyimide, high temperature acrylate or hermetic coatings, small diameter, pure-core and high NA fibers. The fiber production is carried out at Acreo Fiberlab.

Manufacturing of advanced detectors for IR–imaging

IRnova AB, an Acreo spin-off company is successfully fabricating infrared detectors using Electrum Lab. IRnova's technology is based on Acreo's long experience in development and production of QWIP (Quantum Well Infrared Photodetectors). IRnova has now become more of a solution provider for IR-imaging. Besides supplying Focal Plane Arrays, IRnova is now also able to deliver complete, cooled modules as well as reference electronics which simplifies system development for IR camera manufacturers.

Recently IRnova started production of new special products for specific applications and customers. In addition IRnova is now also is offering it's processing and hybridization capabilities for R&D purpose and for manufacturing of other types of detector technologies.

Si Technology

Acreo successfully carries out small volume production of Si based MOS devices and diodes for Swedish SMEs. The requested volume per year for these customers is rather small but Acreo can easily handle such small volumes coming on a regular basis.

SiC Technology

The base for fabrication of SiC devices is the growth of custom designed epitaxial layers. Acreo operates two epitaxial tools to fabricate substrates needed for SiC device development and manufacturing. The volume of delivered SiC substrates is growing from year to year. Parallel to this activity, fabrication of different types of SiC devices is currently running in the laboratory. There are several companies which are active in this field of SiC device development and production: Swedish SMEs, international companies and also Acreo

Other companies in Electrum Laboratory

Our efforts to offer high quality laboratory resources which are accessible for SME's and start-up companies resulted in increasing interest for access to the Electrum Laboratory. At the moment there are up to ten companies who are daily active in the production incubator. Some of them, similarly to IRnova, are renting their own space in the cleanroom and investing their own funds to purchase equipment to be installed in the lab even for common use. ■

Lab resources

Acreo's activities are certified according to the ISO 9001:2008 quality standard. Our well-equipped lab and fab resources are important tools in our R&D activities.

NetLab

Acreo's Optical Systems and Networks resources include simulation tools for modelling of WDM systems, a complete transmission lab for 40 Gb/s WDM systems experiment and characterisation of optical amplifi ers. A new recent investment is a high speed Bit Error Rate test set to be used in 100 Gb/s transmission experiments. The test bed for broadband communication with its open network architecture is an important tool for developing different aspects of broadband communication. The testbed is a real access network delivering Internet and TV services to residential end users. Ideas ranging from services to hardware can be developed by the help of various types of tests and experiments.

Electrum lab

Electrum Laboratory is a joint effort of KTH and Acreo. Laboratory resources include a semiconductor lab with a clean room area of more than 1300 m2 and variety of characterisation tools outside clean room including AFM, SEM, TEM or SIMS for material analysis and wide range of method suitable for electrical characterization of fabricated components. The Electrum lab constitutes a world-class resource for nano- and microfabrication.

One of the key technologies in the lab is photolithography. Currently, there are four different methods available for semiconductor processing: contact lithography with a help of mask aligners, projection lithography using steppers, direct writing on wafer and nanoimprint lithography. To maintain compatibility with industrial partners a stepper for 8 inch substrates is available in the laboratory. The lithography line also includes an automatic track for spinning and developing of photoresist on 8 inch wafers.

During 2009 a new SiC epitaxy tool was purchased and installed in the clean room. Thus doubling the capacity for growing SiC epitaxial layers which is the basis for fabrication of SiC components. In additon the capacity was increased by investments in a new RIE-etcher and thermal evaporator. These investments was done to meet the growing demand of deveopment and fabrication of advanced SiC devices.

Acreo's lab activities focused on component development and fabrication. Our unique position is related to wide processing capabilities, including several different component processes that run continuously in the laboratory. We offer process lines to fabricate devices in several material systems as well as possibility to test components electrically on wafer level. We also have several back-end processes available for chip mounting and access to various analytical methods to investigate semiconductor materials. ■

Electrum lab – Application examples

III/V Technology

Virtual line using GaAs or InP semiconductor materials for fabrication of devices like quantum well infrared photo detectors (QWIP), vertical cavity surface emitting lasers (VCSL) or spatial light modulators (SLM). IR sensor manufacturing is the main activity within this technology, fabricating commercially available components in small scale production.
Key equipment: GaAs and InP epitaxy tools, PECVD, dry etchers for III/V, and evaporators and sputters offering a variety of metallization schemes.

SiC Technology

This line includes processes for other types of wide bandgap semiconductor materials like GaN. SiC line is currently operating for 3 inch substrates and is fabricating diodes. The line can also handle bigger wafers sizes (4 inch). *Key equipment:* SiC epitaxy tool, Direct Write Lithography and Ion Beam Sputtering.

Silicon Technology

Complete line for fabrication of Silicon MOS devices for special applications like sensors, nano-device research or material development.
Key equipment: Si/SiGe epitaxy tool, stepper lithography, Rapid Thermal Annealing and state of the art multi chamber tool for etching of poly-Si, dielectrics and metals.

MEMS Technology

Fabrication resources for both surface and bulk micro-machining in Silicon, quartz and glass. MEMS technology is used in several projects and applications like microfluidics, different types of biosensors or fabrication of passive optical components. *Key equipment:* wafer bonder, mask aligner for contact lithography and RIE tools for deep etching of Si and SiO2.

Nano Technology

Development environment enabling device research in nanoscale. The main approach is to test existing processes on nanostructures to develop new technology. Results of these studies are going to be implemented in next generation devices. *Key equipment:* UV-NIL aligner combined with other "traditional" tools.

Post Processing

Enables further steps towards system construction. Devices fabricated and tested on wafer level can be separately mounted as parts of the systems. *Key equipments* dice saws, wafer cleaving tool, wire bonders and flipchip bonder.

Measurement Laboratories

Electrum Laboratory offers a very wide spectrum of analytical equipment for both material characterizations and electrical measurement of components. Examples of available analytical methods are microscopy (optical, SEM and AFM), spectroscopy (SIMS) or diffraction (XRD). For electrical characterization of components on wafer level automatic probes stations are available together with different apparatus for both DC and high frequency measurements.

Interconnect and Packaging Lab – Polymer electronics

With the focus on technologies for making electronics smaller and better Acreo's lab in Norrköping provides a unique resource for R&D and small volume production.

Our competence and capacity covers organic polymer electronics as well as a broad field of electronic packaging and surface technology. The idea is to provide a facility suitable for development of process steps, process sequences and manufacturing in small quantities where the results are easily transferred into mass production fabs.

Development in the microelectronics area, based on experiences and knowledge from thin film deposition techniques, have a focus on novel substrates and packaging concepts for components and sub-systems for frequencies above 10 GHz. Included in the lab resources are a number of important facilities for characterization and evaluation. In particular we are very well equipped for the RF and microwave field, see text box. ■

RF & Microwave resources:

- 26 GHz Spectrum analyzer & Phase noise analyzer
- 7 GHz Noise figure analyzer, 6 GHz Digital signal source
- 67 GHz Network analyzer incl. Karl Suss PM5 probe station
- Logic analyzer & Pattern generator
- Shielded anechoic chamber incl. Antenna characterisation system

Acreo Fiberlab
– Specialty fibers and preforms

Preform technology
MCVD (Nextrom OFC12 lathe)

Drawing towers
Two 12 meter towers, versatile and custom designed

Coating technologies
Acrylates, polyimide, silicones, high temperature acrylates, custom coatings, hermetic carbon, colored coatings

Buffers (in collaboration with Fiberson AB)
Nylon, Tefzel

Extensive instrumentation for design and characterization, including systems for
- geometry and refractive index profile of fiber and preform
- fiber and cable strength
- attenuation spectrum, modefield, and cut-off wavelength, PMD/DGD, and chromatic dispersion of fiber
- material and surface characterization using SEM, EDS, FT-IR, and access to e.g. SIMS and ToF-SIMS, Raman, XRD

Examples
Microstructured fibers, capillaries, High-NA fibers,
Pure-silica core fibers, Fibers with internal electrodes
Polyimide coated fibers
Large diameter fibers, Doped fibers and preforms
Special coatings, including acrylates, polyimides and silicones
Fiber diameters 50µm to more than 3mm
Hermetic fibers

Components and subsystems
- Extensive instrumentation, including PMD/DGD, PDL, insertion and return loss, OTDR, OFDR, RF and microwave equipment, lasers, light sources and spectrum analyzers
- temperature cycling
- EDFA and Raman amplifier characteristics, incl gain, noise profiles and transients
- access to Acreo competence and resources for e.g. BER measurements, commercial WDM systems and field trials.

FiberLab

Acreo Fiberlab is a unique resource in Northern Europe equipped with the latest instrumentation for manufacture and characterization of advanced optical fibers. The laboratory houses international research collaborations, custom development of specialty fibers and preforms, and production.

Acreo's fiber Bragg grating laboratory is custom designed to be highly controllable and flexible. We are design ing and developing gratings for visible wavelengths, high temperatures and with advanced wavelength characteristics.

In addition to these two major facilities, Acreo has well equipped laboratories for fiber optic component and subsystem development and characterization. ■

Fiber Bragg gratings laboratory

Technology
Multiple fringe printing technique: allowing complex grating structures for custom-designed spectral characteristic

UV source
100 mW frequency-doubled argon-ion laser, wavelength 244 nm

Design and synthesis
Custom-developed softwares

Grating characteristics
- Wavelength: 500-3000 nm
- Max. grating length: ~25 cm
- Max. chirp: ~100 nm
- Apodization / phase profile resolution: ~20-100 µm
- Writing time for sensor grating (1cm, 80%): 1 min
- Grating operating temperature: < 1000 °C

Acreo is owned by the group Swedish ICT which gathers research institutes in the information and communication area. Together, the institutes in the group hold competence in the whole ICT area, ranging from hardware to software. Swedish ICT consists of Acreo, IMEGO, SICS , Viktoria Institute, Interactive Institute and Santa Anna IT Research Institute.

Majority owner (60%) of Swedish ICT Research AB is RISE Holding AB which is a holding company owned by the Ministry of Enterprise, Energy and Communications. The industry through the two associations FMOF and FAV is together holding a minority post of 40%.

Acreo has its head-office in Kista, but is also located in Norrköping and Hudiksvall.

By April 2007 Acreo spun off its successful infrared detector activity to a separate company, IRnova AB. All figures below refer to the Acreo group including IRnova.

Human resources

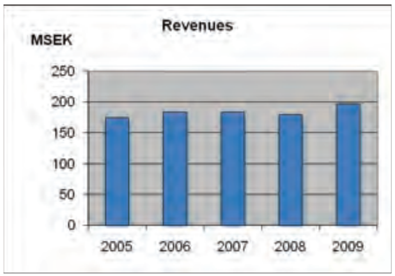
In year end of 2009 the Acreo group had a staff of about 143 highly qualified scientists, engineers and support personnel, with a high proportion of graduate engineers and scientists, PhD candidates and PhDs. 31% of our employees are women, and 23% of non-Swedish origin.

Quality

Acreo Kista and Norrköping are certified according to ISO 9001:2000.

Patents

Acreo holds 60 patents in different technical areas. ■



Financial information

Key figures (MSEK)	2009	2008	2007	2006	2005
Revenues	196,8	179,6	182,7	182,7	174,5
Profit/loss after financial items	1,2	2,2	2,6	-3,3	0
Total equity	28,7	27,3	25,3	22,8	25,9
Total assets*	94,6	95,9	90,3	82,3	104,5
Total investment	11,5	10,6	5,6	5,3	8,0
Cash and bank balance	29,5	21,7	61,3	24,2	47,7
Equity/assets ratio	30%	28%	28%	28%	25%
Employees	131	130	130	134	130

* In calculation of the Equity and Asset ratio for the year 2007 the balance sheet total has been adjusted with 42.2 MSEK. The amount emanates from EU-project support that received in December 2007 as a whole was transferred to other project partners in January 2008.

Acreo´s revenues 2009 show a slight increase from 2008. (Figures from 2007 include IRnova.) Industrial financing accounted for approximately 45%. During the last ten years Acreo has invested approximately 157 MSEK. About 40% of this has been financed by different external contributors.
IRnova is owned by Acreo and the employees, with Acreo as the major shareholder.

Departments/Business units

Business Services: Stellan Granström
Fiber Photonics: Åsa Claesson
Innovative Electronics: Leif Ljungqvist
Nanoelectronics: Jan Andersson
Networking & Transmission Laboratory: Anders Berntson
IRnova AB: Bernhard Hirschauer

Managing Committee

Mårten Armgarth, CEO (from Jan 1, 2010)
Anders Josefsson, Marketing Manager & Patent Issues
Maja Fredriksson, Human Resources
Åsa Klingensjö, Economy
Lars Erik Ridderström, CFO Swedish ICT Research
Stellan Granström, Business Services
Leif Ljungqvist, Innovative Electronics
Jan Andersson, Nanoelectronics
Åsa Claesson, Fiber Photonics
Gunnar Jacobsen, Broadband
Anders Berntson, Networking & Transmission Lab


Mårten Armgarth


Anders Josefsson


Maja Fredriksson


Åsa Klingensjö


Lars Erik Ridderström


Stellan Granström


Leif Ljungqvist


Jan Andersson


Åsa Claesson


Gunnar Jacobsen


Anders Berntson

Acreo Board of Directors

Leif Bergström, Cambio Företagskonsult
Stefan Bengtsson, Chalmers
Hans Hentzell, Chairman (from Jan 1, 2010), Swedish ICT
Hans Malmkvist, FMOF
Sten Nordell, Transmode
Olof (Olle) Viktorsson, Ericsson Research
Malin Gustafsson, Employee Representative
Ingemar Petermann, Employee Representative
Anurak Sawatdee, Employee Representative

At the shareholders' meeting June 1, 2009, Sten Nordell was elected as a new board member, and Bengt-Olof Larsson resigned.


Leif Bergström


Stefan Bengtsson


Hans Hentzell


Hans Malmkvist


Sten Nordell


Olof (Olle) Viktorsson


Malin Gustafsson


Ingemar Petermann

FMOF – Acreo's Partner Association

Hans Malmkvist
FMOF Chairman of the Board

During 2009 the research institute IMEGO in Gothenburg was included in the Swedish ICT group. IMEGO has its main focus in the application areas of sensors and sensor systems based on fundamental nano and micro technologies, IMEGO therefore represent valuable complementary competence to the Swedish ICT group.

To further strengthen the collaboration between Swedish ICT and its industry partners the concept of advisory boards has been further developed during 2009. Especially the advisory board for Broadband communication/Future Internet has engaged a large number of ICT-companies and made significant contribution to the strategic planning process of Swedish ICT. Based on results from the well established board for Vehicles Swedish ICT has during 2009 initiated in cooperation with the vehicle companies an extensive research programme coordinated by Viktoria Institute focusing on vehicles and transportation.

Input from the board of Security has supported the establishing of a new ICT-security group at SICS.

FMOF has continued a close collaboration with our sister organisation FAV and RISE Holding AB, a company owned by the Swedish government and the major owner of Swedish ICT, with the purpose to develop a common strategy for the research institutes. As a result a new shareholders agreement for Swedish ICT has been signed by FMOF, FAV and RISE. The new agreement includes a detailed description of the process of the advisory boards, owned by FMOF and FAV, as well as the nomination process to the boards of the daughter institutes and subsidiaries.

In summary we believe that during 2009 our interaction with Swedish ICT and our partners FAV and RISE has assumed a more definite shape that will acts as a strong platform for the future development of Swedish ICT. ■

FMOF – "Föreningen Mikroelektronisk och Optisk Forskning" (The society for Research in Electronics and Optics) is a not-for-profit industrial association representing companies in business areas where hardware oriented ICT:s are enabling technologies.

The main objective of FMOF is to support the development of the ICT industry and the ICT technologies in line with the needs primarily of Swedish industry. This is fulfilled by influencing the industrial and financial conditions for research and entrepreneurship in general, and the direction of actual research within Swedish ICT Research AB. The FMOF has 18 members representing large international companies as well as SME's.

Membership benefits: As a member of FMOF your company can have a strategic influence on the activities and projects of the various parts of Swedish ICT. FMOF is represented in the nominating committees of the boards of both the Swedish ICT group and the daughter institutes Acreo, SICS, Interactive Institute, Imego and Viktoria Institute. FMOF operates the "Strategic Research Councils" whose task it is to identify future key development areas for Swedish ICT. Membership in FMOF also means support of lobbying activities with the purpose to strengthen the funding of research and development resources in the areas of electronics/optics and ICT. FMOF acts together with its ownership partner RISE Holding AB, government controlled, to influence and encourage the Ministry of Enterprise, Energy and Communications to increase overall investments in the research institutes. In the past years these efforts have resulted in an increased financing of competence development and support of research programs in the Swedish ICT group. Membership in FMOF also includes a number of benefits associated with Acreo. For detailed information please visit Acreo´s web site at www.acreo.se/FMOF.