Aperturen is published by Acreo AB
A part of Swedish ICT Research

Legally responsible
Mårten Armgarth

Editors
Anders Josefsson, 08-632 77 87
anders.josefsson@acreo.se
Lena Lindmark, 08-632 77 12
lena.lindmark@acreo.se

Acreo AB
Electrum 236 (Isafjordsg 22)
164 40 Kista
Phone: 08-632 77 00
Fax: 08-750 54 30
www.acreo.se

Acreo AB
Box 787 (Bredgatan 34)
601 17 Norrköping
Phone: 011-20 25 00
Fax: 011-20 25 01

Acreo AB
FiberLab
Box 1053 (Håstaholmen 4)
824 12 Hudiksvall
Phone: 0650-366 00
Fax: 0650-180 02

CEO: Mårten Armgarth
marten.armgarth@acreo.se
070-528 2500

Title page:
Intelligent power module based on silicon carbide3

Production
Sollentuna Grafiska AB
2010-05

Mårten Armgarth
marten.armgarth@acreo.se

If you are a loyal reader you might notice a new face on this editorial page. I have taken over the position as CEO of Acreo since January 1st this year. It is with the greatest respect of my predecessor Dr Hans Hentzell, that I now approach this new challenge. He is still engaged in Acreo as the chairman of the board of directors.

This issue of Aperturen presents our efforts in helping small and medium sized companies to adopt new technologies within the area of ICT to gain competitiveness, and thus creating sustainable growth. I have had the privilege to start and develop a high tech spin-off company which gave me relevant experience since one of our important missions is precisely to assist the buildup of new start-ups. I am confident that the authorities will continue to support this important work and we are prepared to even intensify our efforts.

Besides SME support the main focus of this issue is on cleantech and sensors. It addresses some of our major societal challenges and there are several reasons to assume that those fields will become even more urgent in the coming years. Sensors are of special interest for me personally since I spent my years at the academia in the field of semiconductor based sensors. *Messen heisst Wissen und Wissen hat Zukunft…* and we are here to invent the future.

Please enjoy your reading and do not hesitate to contact us for further information.

Mårten Armgarth

Cleantech – An introduction

Jan Andersson
jan.andersson@acreo.se

A healthy environment combined with a resource efficient industrial technology is of utmost importance for a sustainable society. Important concerns regard e. g. combustion engines used in transportation, and pollution caused by industry, agriculture, fossil fuels, or natural processes. Global warming and the role of greenhouse gases and other factors are in addition under intense debate and shape the agenda for the future society. Other environmental concerns when looking worldwide are depletion of the ozone layer, acid rain, and desertification in over-populated areas.

In this context *clean technology* or "*cleantech*"[(1)] is a concept that signifies a new knowledge-based technology that aims at improving performance, productivity or efficiency of processes and equipment, while reducing costs, inputs, energy consumption, waste, or pollution. It is in essence multidisciplinary and includes ICT (information and communication technology), chemistry, biotechnology, as well as areas such as architecture.

Many big companies invest huge resources in this technology worldwide, such as General Electric in US (GE), and Toyota and Sharp in Japan. In 2005 GE launched a program called "Ecomagination" that intended to develop tomorrow's technology, including solar technology, hybrid locomotives, fuel cells, lower-emission aircraft engines, and efficient lighting. Toyota has also one of the largest industrial activities on hybrid electric vehicles (HEV). The Toyota Prius was the first HEV in the world to become mass produced. The consumer electronic company Sharp is involved with solar cells. China and India have also major industrial cleantech related activities. In Europe, especially Germany and Spain spend huge resources on cleantech such as solar and wind power.

One conclusion to draw is that it is necessary to radically change the present technology, processes and equipment. The following areas have been identified as major clean technology sectors that need to be addressed[(2)]:

- **Solar power**. This includes converting solar radiation directly to electricity as in photovoltaic devices (solar cells). Alternatively solar energy is used to heat water or other working media that in turn can be used e. g. for heat pumps of different types. Still another technology is to exploit thermoelectric devices that can convert a temperature difference into electricity. Furthermore, since solar power is intermittent there is a need for energy storage and/or to combine it with other energy technologies in order to achieve continuous availability.
- **Wind power**. Includes wind turbines for conversion to electricity. Huge assemblies of wind turbines, "wind farms", are often built off-shore.
- **Biofuels**. Used to replace gasoline for combustion engines, in cars and other vehicles. Examples are bio-ethanol from sugar palms, and biogas from fermentation of organic materials.
- **Green buildings**, involves efficient use of energy, water, and other resources, in addition to reducing waste, pollution and environmental degradation.
- **Sustainable personal transportation**, i. e. strengthening or replacing the current transport systems of an urban/suburban area with more fuel-

(1) For a definition and description of cleantech, see Wikipedia, **www.wikipedia.com**.

(2) Pernick and Wilder, "The Clean Tech Revolution: The Next Big Growth and Investment Opportunity". ISBN-13: 978-0060896232 .

Images: Wikipedia

efficient and space-saving transportation alternatives. Electric or hybrid cars are important examples.

- **The "smart grid"**. An "intelligent" electricity grid for optimum management of power supply and demand. It consists of an aggregate of multiple networks and power generation companies based on various sources, with multiple operators employing varying levels of communication and coordination. The introduction of bi-directional metering is important since homes and businesses will no longer be just energy consumers but also energy producers.
- **Mobile applications**. There is a need for portable, lightweight, long-lasting power sources for various consumer devices; for remote, rural villages in developing nations; for disaster recovery zones, and for the defense.
- **Water filtration**. To develop new methods of guaranteeing access to clean water using for example nanotechnology as a challenge. There is plenty of water on earth but usually it is not clean but polluted in various ways.

The new power technology necessary introduces huge technological challenges. There is a need for advanced electronics for handling power as efficiently as possible. This includes taking care of and avoiding waste of high-quality (low-entropic) energy as much as possible. Silicon carbide electronics is a possible solution to this. Silicon carbide allows the fabrication of efficient, compact, and low-weight modules and systems of different kind (converters, transformers, etc.). The technology is now mature enough to be utilized in next-generation power systems, including smart grids, solar and wind power modules, and in hybrid electric vehicles.

There is a need for novel types of energy production with renewable energy sources. Examples are solid-state solar cells, thermo-electric devices, and wind turbines.

In addition, in order to remedy all this it is important to develop efficient measurement systems such as sensor networks that comprise a variety of different sensor types that help to monitor the relevant aspects of the environments. Sensors will include physical (optical, ionizing radiation), chemical, and biochemical ones. Sensors often need to be located in harsh environments, such as high temperature and exposure to corrosive chemicals. This necessitates the use of new material technologies such as silicon carbide when possible.

This issue of Aperturen intends to give an overview of the field of clean technology or "cleantech", from the point of view of the area of ICT – information and communication technology. There are examples from: smart electronic systems for optimal energy efficiency, sensors in harsh environments (in gas or water environments), and imaging sensor networks. ■

Energy and energy efficiency

One of the grand challenges is the world wide accelerating demand for energy. Improved efficiency in both production and consumption of electricity is a key factor on the road to a sustainable energy future. Hybrid and electrical vehicles and silicon carbide electronics play an important role.

Mietek Bakowski
mietek.bakowski@acreo.se

Individual energy consumption in Europe has been growing almost exponentially in the history of mankind, accelerating from the middle ages and throughout the industrial era, and it continues to grow. Similar growth in energy consumption is now taking place in the developing part of the world. At present 25% of the world population is consuming 75% of the energy. At the same time the world population is growing rapidly. The world population is predicted to reach 9 billion people by the year 2050, which is a 5 fold increase since year 1950. Most of this demographic explosion takes part in the developing countries. Consequently, a large increase in global energy demand is expected in the coming years.

There are two environmental challenges related to the production and consumption of energy. One is the limited supply of the fossil energy resources (oil, gas and coal), and the other is climate warming due mainly to CO_2 emissions.

Electricity

The demand for electricity is also growing steadily. The consumption of electrical energy worldwide is estimated to grow by 160% by the year 2050. Access to this basic commodity is very unevenly distributed in the world and the biggest increase will take place in the developing world.

Electricity is generally thought of as an environmentally friendly and clean energy source. However about 70% of electrical energy generation in year 2025 is predicted to still rely on fossil energy sources, with only about 20% on renewable energy sources and 10% on nuclear power.

Focus on energy efficiency comes from two sources. First is the necessity to preserve natural resources by transforming them into electrical energy in the most efficient way, and second is the saving of electrical energy by using it in the most effective way, mainly by reducing losses in the electrical power systems.

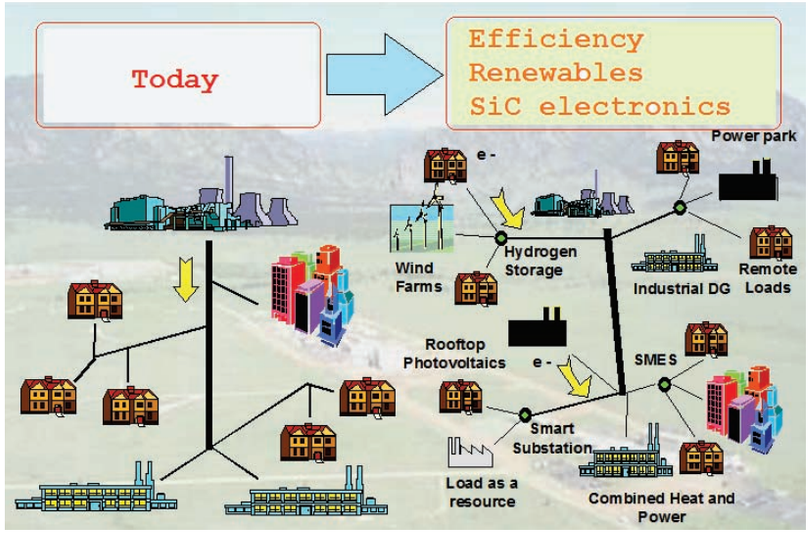
Electric grid of the future

"The cheapest source of new energy supplies is increasing efficiency of current use"

There seems to be a general understanding that global strategies towards a sustainable future should adopt the following directives; a) increase efficiency when transforming energy into services in transportation, lighting and motor drives, b) replace technologies based on problematic resources or those harmful to the environment.

Electric energy is assigned a crucial role in the sustainable future strategies and the key factors are increased efficiency, renewables and electric systems. Development of silicon carbide electronics fits perfectly into this global perspective because of the low losses and high working temperature of SiC electronic devices. Both properties facilitate high efficiency as well as reduced weight and volume of power systems, due to increased power

density and frequency. The above translates into key role for silicon carbide electronics in the power systems for electric energy generation from the renewable energy sources, as well as into higher range of the electrical vehicles due to lower energy consumption.



Electric grid of the future

Electric energy saving – A European perspective

Energy saving, improved energy efficiency and environmental protection have become top priority political issues in Europe. The demand for electricity is expected to grow much faster than the demand for other energy sources until the year 2050. The consumption of electrical energy is predicted to grow from 40 % to over 60 % of all energy consumption. It is becoming urgent to reduce consumption by increasing efficiency, and to improve generation by increased use of renewable energy sources. Power electronics assumes a key role in this perspective.

Key role of power electronics

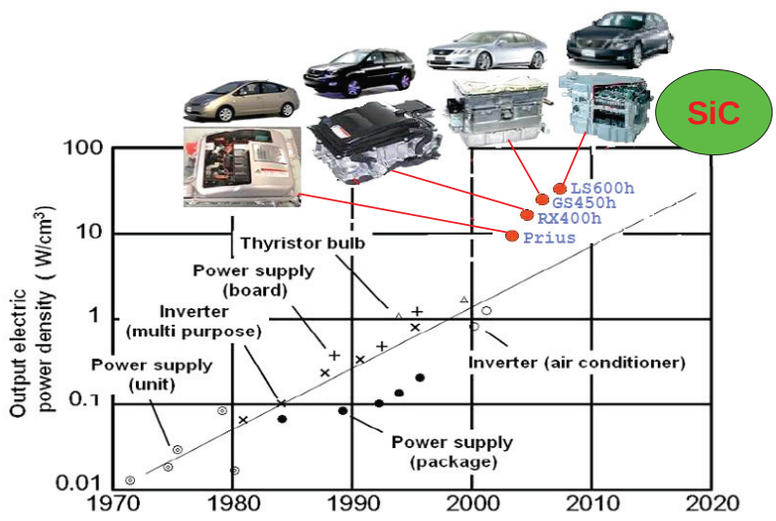
Power electronics is the key technology for controlling the flow of energy from source to load. The proportion of total electrical energy which is controlled by power electronics, for example in variable speed drives (ac motors) in industry, transportation and home and office appliances, is estimated to increase from the 40% seen in the year 2000 to 80% in 2015.

Power electronics is also “the” enabling technology for efficient use, distribution and generation of electrical energy. Advanced power electronics can for example realize savings of more than 50 % in energy losses when converting from mains or battery voltages to that used in electronic equipment.

Some examples of energy saving potential and the key role of power electronics are: (a) in power supplies by reduction of losses and stand-by consumption, (b) in motor drives by the use of power electronics controlled ac motors, (c) in home appliances by use of electronic thermostats in refrigerators and freezers, power electronics control of compressor motors and reduction of stand-by consumption, (d) in lighting by control of fluorescent and High Intensity Driving ballasts, (e) in intelligent buildings by control of lighting and occupancy sensing, (f) in connecting the renewable energy sources (solar and wind) to power grid and (g) in automotive applications in power trains of hybrid and electrical vehicles.

SiC in power electronic systems

The efficiency of power electronic systems depends on losses in active and passive components. The efficiency can be greatly improved by replacing silicon devices with silicon carbide ones. The specific



Power density in typical electrical systems and in Power Control Unit (PCU) in hybrid vehicles

material properties of SiC translate into high added value for electronic power systems. Specifically, high electric field breakdown in combination with reasonably high electron mobility and high thermal conductivity translate into improved efficiency, dynamic performance and reliability of electronic and electric systems. It is relatively straightforward to envisage savings on the cooling requirements connected with an increased working temperature of the devices well above the 125 to 150°C typical of silicon power devices. Reduced noise can also be envisaged, as well as the size and weight of the systems due to greatly increased operating frequency. To overcome temperature and frequency limitations has long been desirable, especially in high voltage applications above 1 kV where bipolar silicon devices must be used. Such devices are necessarily slow and suffer from high switching losses due to substantial recovery charge which makes them the limiting component in the performance of many systems.

The appearance of SiC power devices on the market will bring about and accelerate new development in the areas of packaging, passive components (capacitors), circuit and system design, as well as improvements in the construction and operation of electric motors. In general it will not be most effective just to substitute Si devices by SiC ones in existing circuits. It will be necessary to adopt new solutions in order to utilize the full potential of increased operational frequency and working temperature and reduced size of active devices. The advent of SiC power devices will reinforce thinking in terms of the total power system, including electrical, mechanical and electromechanical components. It will provide an incentive towards an increased integration of electronics with electromagnetic and mechanical parts of the system. Electrical motors will also have to be improved in order to take advantage of the benefits of high frequency operation.

The most dynamic R&D areas in the near future are:(a) advanced device concepts and high temperature (wide bandgap) power semiconductor materials (SiC, GaN, diamond), (b) compact high power density system design for Si and SiC semiconductors, (c) new interconnection technologies for ultra-high power density systems and high temperature electronics, (d) advanced materials for insulation, high thermal conductivity, high temperature compact passives and sensors, (e) for lighting smart and simple dimming concepts, high efficiency light sources (LED/OLED) and their power electronic

drivers, (f) load management by power electronics in distributed energy generation networks, (g) multi-domain/level modeling and simulation, (h) stress analysis and build-in reliability, improved system reliability and fault-tolerant systems.

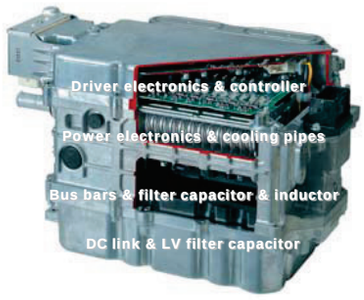
Hybrid and electrical vehicles

The area of electric and hybrid vehicles is of special significance when considering environmental protection and replacement of fossil fuels by clean electric energy. Transportation stands for 25% of CO_2 emissions. Environmental gains (CO_2 reductions) due to fuel regulations, new cleaner fuels and more efficient combustion engines are quickly offset by the increasing number of vehicles, which is predicted to grow constantly from 0.5 billion vehicles year 1990 to 2 billion by 2050. This makes the development of hybrid and electrical vehicles a necessity.

The application area of automotive electronics and especially hybrid vehicles is suitable for the introduction of SiC components with power semiconductor ratings of 10-400 A and 300-1200 V. Efficient, compact and light power electronics is also of great significance in hybrid and electrical vehicles.

The heart of the energy system in an electric road vehicle is the semiconductor switches in the power converters. By manufacturing these in silicon carbide (SiC) the power losses can be reduced and the operation temperature can be increased to 250°C. This implies that adjacent equipment must also withstand higher temperatures. A solution to this is the integration of gate-drives and protection functions into an intelligent module which can withstand high temperatures.

It is important that SiC-electronics can reduce the power losses. Even more important is the fact that the energy systems can become considerably more compact with intelligent power semiconductor modules. Efficient and compact energy systems in electrical and hybrid vehicles enable reductions in weight and volume of the vehicle, which in turn



PCU, an example of 3D modular construction

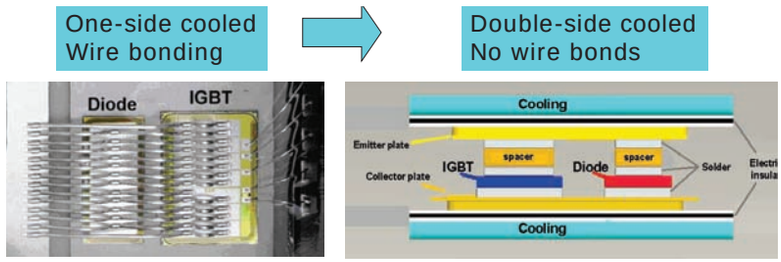
results in reduced energy consumption. The weight reduction of the complete vehicle may thus be more important than the energy savings in the system itself. All together, this leads to a considerable reduction in fuel consumption for hybrid vehicles and reduced energy consumption in electric vehicles.

Development trends of power electronics

Trends in power electronics are modular construction of systems and increasing integration and compactness. These lead to increased power density and high power density systems. This development necessitates 3D-concepts in design and construction, and increase in the working temperature capability of the system. Higher working temperatures facilitate an increase in the operational frequency and a reduction in the cooling system.

The development towards higher frequencies of operation is a longstanding trend. This development is fuelled by the desire for lighter, smaller, less noisy and more efficient power systems. However the high dV/dt and dI/dt generated by the fast switching devices have to be handled by the rest of the system and by the motor in motor drive applications.

Development in the field of power electronics is going furthermore in the direction of increasing integration of devices, control and drive electronics, protective circuits and convertors in the power systems. It is increasingly important to think in terms of the total power system when considering different device concepts and technologies and different de-



sign options. We are moving away from the isolated power device design thinking towards multidisciplinary system integration of drive electronics, devices and circuits involving snubber circuits, inductive and capacitive components and cooling. As a consequence, device design can no longer be a relatively isolated activity treated separately from the drive and control electronics and system aspects. The challenge is now to unite the system and device aspects of power electronics development in a coherent and fruitful fashion, and to create a truly system conscious and system oriented way of thinking and working.

For the next two decades, however, power electronics development will be dominated by packaging and interconnection technologies, high power density system integration together with advancements in Si and SiC devices, and system reliability.

Packaging and module technology

The necessity for new solutions is most apparent and urgent in the area of packaging. The modular solution utilising parallel connection of small chips, as opposed to large area single devices, will be the most efficient way to increase current handling capability for a long time. This actualises the necessity for high temperature, high frequency and high packing density module technology.

Module technology is the basic building block of power electronic systems for ac motor control. The maximum operating temperature of a semiconductor device is determined by the band gap of the semiconductor material and by the doping level required for the operational voltage. This is why we can expect silicon modules to achieve a maximum operating temperature of 200°C for 600 to 1200 V devices, but will achieve only 110°C for 10 kV devices. In the case of SiC devices, the maximum operating temperature is entirely determined by the available die attach, interconnect and encapsulation technologies. At present such technologies are developed for maximum 175°C.

The urgent task at present is to develop compact, efficient and intelligent power modules able to operate at a high temperature (250°C) that contain control electronics, sensors and switching devices, for electric motor drive and specifically for control of electrical motors in electrical and hybrid vehicles. SiC based modules allow low losses and increased working temperature. This results in more efficient, compact and lighter power systems for electrical and hybrid vehicles. Next generation SiC based power modules should contain control electronics, together with important protection and diagnostic functions integrated into the module. This will facilitate extremely compact power systems and development of computer controlled mechatronic and embedded systems.

Industrial change

The accelerating integration of electronic power systems forces integration of the traditionally separate disciplines of knowledge and know-how. It also accentuates the necessity for close relations and cooperation between different industrial companies on one hand and different institutions and universities on the other. The formation of centres and consortia with participation from industry, universities

and institutes is a good way to combine necessary knowledge and resources in order to be able to solve the extremely demanding tasks.

The automobile is a good example of development towards complex, intelligent and efficient systems with a high content of knowledge characteristic of the future economy. Knowledge, boundary processes such as communication and interaction between different specialisations are necessary when the car is seen more and more as an intelligent mechatronic device containing embedded electronics.

Recent developments in the automobile industry indicate the approaching paradigm shift from product oriented mass production economy to knowledge based economy. This means an economy based on sophisticated products with a high content of know-how and knowledge where services and knowledge become commodities. This transition will have consequences for all industry and development organisations, with focus shifting from competition to communication, cooperation and flexible definition of milestones (deliverables) to avoid stagnation.

We stand also at the threshold of a paradigm shift in power electronic systems. It stems from the fact that sustainable development in the global perspective is linked to the increased role of electric energy and increased utilisation of power electronic systems. It stems furthermore from the fact that this development will be accelerated by the transition to next generation technology with silicon devices being gradually replaced by silicon carbide. The transition to silicon carbide material and device technology will revolutionize power electronic systems by facilitating low loss, more efficient and more compact systems. This will fuel the further spread of power electronic systems into new areas and contribute to the reduction of CO_2 generation globally. As a consequence, silicon carbide is seen as an essential factor in attaining sustainable development.

The most important issues in focus during the next decade are energy saving, improved energy efficiency and care of the environment. These concerns will accelerate the evolution towards more intelligent systems in various power electronic applications. In consequence we will see transition from modular concepts to the integration of power electronics, information and communication technology, sensors and advanced mechanical construction resulting in compact systems with increased power density. The crucial role in this development will be played by new semiconductor materials, such as silicon carbide. The new wide bandgap materials will be the key for the realisation of intelligent integrated electronic power modules. The introduction of high temperature power electronics and high power density mechatronics based on the new semiconductor devices will facilitate the realisation of extremely compact, small, light and efficient power electronic systems.

The main mission of electrical engineering education is to convey this message to the students and inspire them to become involved in this great challenge and opportunity. We have reached a unique situation in the development of mankind, where social structure, well being and preservation of mankind and our planet is so closely and clearly linked with the technical development in the area of electrical energy and power electronic systems. ■

Further reading:

"Strategic research agenda on Intelligent power electronics for energy efficiency" ECPE 2008, **www.ecpe.org**

K. Hamada, "Future automotive technologies and potential of SiC for sustainable mobility", SiC User Forum, 2007

K. Hamada,"Present status and future prospects for electronics in electric vehicles/hybrid electric vehicles and expectations for wide-band gap semiconductor devices", Phys. Stat. Sol. (b) 245, p.1223 (2008)

Using Silicon Carbide sensors to decrease emissions from solid biofuels

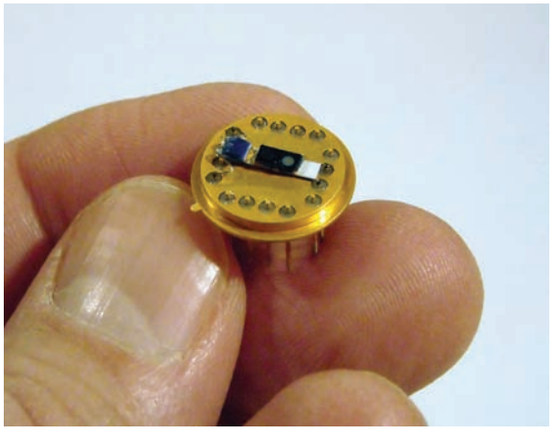
The increased interest for domestic heating using solid biofuels calls for better control of the combustion process to achieve high efficiency and low emissions. In-situ high temperature gas sensors based on Silicon Carbide promise to be a key component in new control systems.

Lars Hammarlund
lars.hammarlund@sensic.se

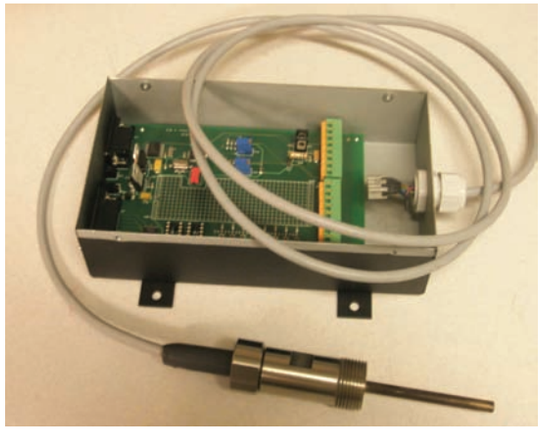
One example of an application which draws a lot of attention today is bio heaters/ boilers for domestic heating. Wood based pellets, chips and logs are becoming increasingly popular for domestic heating in many countries in Europe, mainly because of the low price. With today's prices pellets is approximately 50% cheaper than oil and electricity, which makes it a very competitive alternative. The downside of solid biofuels is that there is more or less always a difference in the water content of the fuel, dependant on e.g. which base material it was made from. The firing cycle as such is also complex, with different phases of the combustion process of varying lengths, making it difficult to optimize the efficiency over time. A non-optimized heater will, besides being less efficient and thereby use more fuel, produce excessive emissions of noxious compounds such as unburned hydrocarbons, carbon monoxide and nitrogen oxides, but also soot, which the end-user needs to take care of.

Tests have been made (by e.g. SP Technical Research Institute of Sweden, www.sp.se), showing that by using a combination of oxygen and carbon monoxide sensors we can have a much more efficient combustion control. In SP's evaluation a Lambda sensor and a separate carbon monoxide sensor were used and an algorithm for the control of air flows was developed. In this way "dynamic Lambda value" control could be implemented. The carbon monoxide sensors used at SP are based on galliumoxid. They are not yet commercially available. Using two types of technology for sensors increases the cost of electronics and therefore cannot be used in cost sensitive applications.

The start-up company SenSiC AB has developed a new in-situ high temperature gas sensor based on Silicon Carbide. Among all the properties of the Silicon Carbide wide band gap material (3,2 eV), the most important for SenSiCs applications is to remain a good semiconductor at very high temperatures, e.g. 800° Celsius. These sensors are designed for a number of applications in the field of combustion, and normally operate around 250 – 650° C, depending on the application and the gas to be detected. One advantage in particular with the SiC sensors is that one can install a variety of sensors for various gases in the same area and use the same electronics which simplifies and keeps the cost down. In the long run a sensor, for many different gases, which can be manufactured in a semiconductor process, as SenSiC's sensors, will be the most cost efficient way to manufacture the products.



Small but very fast and efficient!



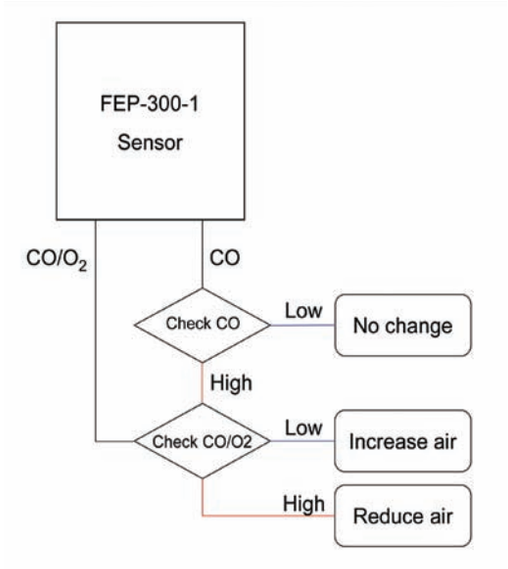
Complete evaluation system.

The sensor itself comprises a silicon carbide based Field Effect Transistor structure (FET). The FET is used in a diode-coupled configuration with a catalytic layer on the Gate area. All of the materials in the sensor have to withstand high temperatures, ~ 650C, and aggressive environments for long periods and in some applications for many temperature cycles. Various combinations of gate oxides and catalytic metals are used to gain selectivity through differences in adsorption and disassociation processes of the gas molecules of interest.

SenSiC's sensor measures both CO and CO/O_2 relation continuously in one solution which gives a superior information and control capabilities compared to gas sensor alternatives available on the market today. The electronics required to run the sensor are also relatively simple and inexpensive.

Evaluation of the sensor has been performed during a period of 4 months and it has shown a stable and reliable conduct all this time. The sensor is also very tolerant to soot and tar, both of which are burnt off from the sensor surface due to the catalytic activity and the controlled temperature of the gas sensitive parts of the sensor.

The sensor made it possible to increase the system efficiency with up to 10%, reduce hydrocarbon emissions with up to 90%, and soot by up to ~75%!



Simple scheme for combustion control.

By focusing on flue gas CO levels the sensor can very effectively compensate for variations such as quality and moisture content of the fuel. The sensor also makes the heating system more fault-tolerant to air leakage, excessive soot and ashes.

Ongoing development targets another attractive field of applications for SenSiCs gas sensors; Automotive applications such as EGR (Exhaust Gas Recirculation) and SCR (Selective Catalytic Reduction of nitrogen oxides in e.g. diesel engines), both considered important NO_x abatement strategies for the future, as well as on-board diagnostics (OBD). The main difference to the field of bioheater control is that the sensor chip needs to withstand temperatures as high as 700° C, at least for many of the automotive applications. This in combination with temperature cycling and requirements on long lifetime with stable operation and sensing function is the next challenge. This project which is in the early stage and some preliminary tested prototypes are expected 2011.

For these applications, EGR and SCR, one needs in-situ sensors for O_2, NH_3 and NO_x. Over the last year SenSiC has developed sensors for O_2 and NH_3 and is now in the design phase of a NO_x sensor chip. ■

SenSiC AB is a spin-out company from Linköpings University. The base for this research has been done by Prof. Anita Lloyd-Spetz and Dr. Mike Andersson.

The bioheater sensor is based on the work of Mike Andersson and his PhD thesis *"SiC based field effect sensors and sensor systems for combustion control applications".*

Nanotransistors for environmental monitoring

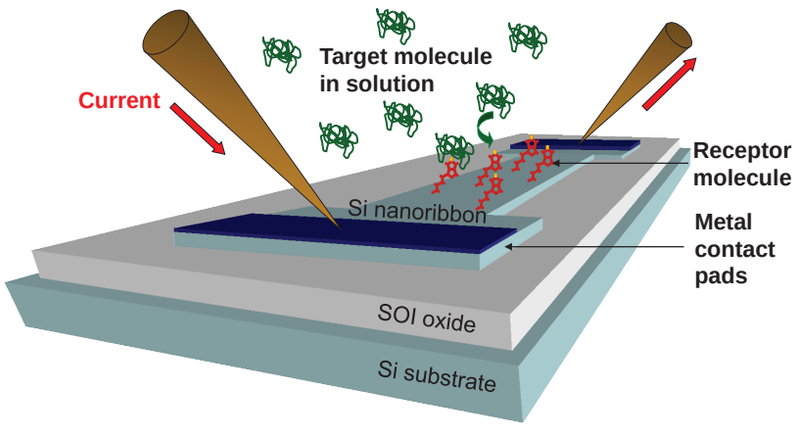
Nanowire sensors allowing label free monitoring in field with small sample volumes

Per Björk
per.bjork@acreo.se

Jan Linnros
linnros@kth.se

Environmental monitoring of specific target molecules is today required to protect us and our surroundings from potential toxic contaminants and pathogens that can be released into a variety of media including air, water and soil. A large number of field sample analyses are thus needed. In this regard, portable sensor devices that effectively can provide rapid on-site detection to avoid costly laboratory analyses show large potential.

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

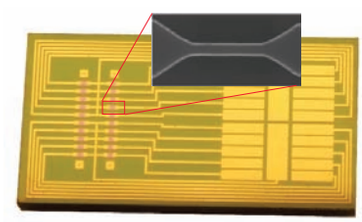


Sketch of the nanowire sensor element and the detection principle. Binding of specific bio-molecular targets induce charge changes affecting the conductance of the nanowire.

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 analysis 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 sensor development is at the moment 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, drugs or other specimens in our environment. ■



Old chip design and SEM image of a typical nanowire 100 nm in width.

New chip design including microfluidic channels defined over four columns of silicon nanowires

Imaging for sustainability

Teresita Qvarnström
teresita.qvarnstrom@acreo.se

Mattias O'Nils
mattias.onils@miun.se

Imaging technologies and sensor networks: essential tools for environmental monitoring

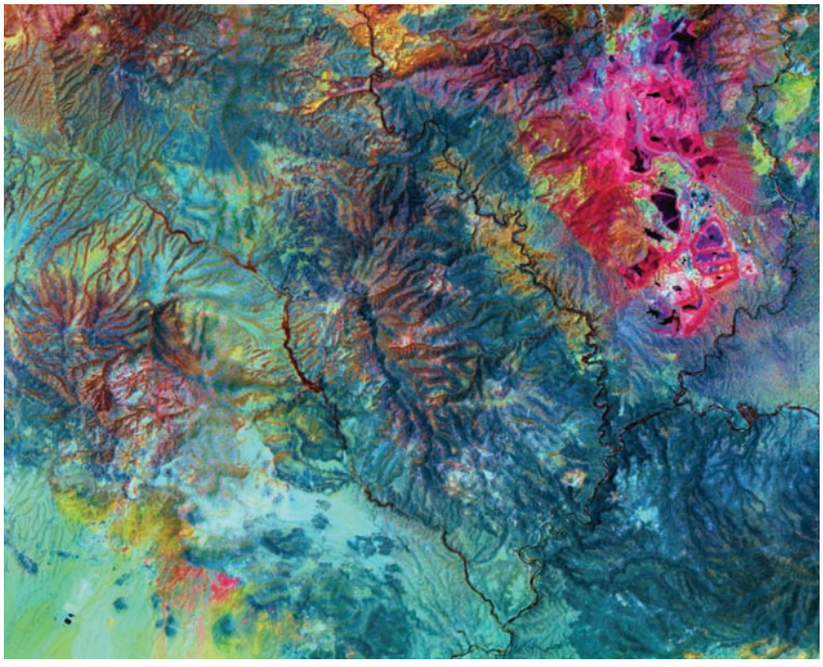
Imaging techniques are quite important to monitor systems aiming to improve operational performance or to efficiently control energy consumption or pollution levels. Higher performance, efficient use of the resources and reliable methods to measure relevant diagnostic parameters are the keys to sustainable development. The contribution that imaging technologies can make is clear.

The use of imaging technologies for environmental monitoring often involves imaging of many wavelengths simultaneously. The use of "large-area imaging systems", where image information is obtained from extensive areas (meters to kms) using single detectors, arrays, or multi-sensors, is an interesting choice since monitoring of the environment often involves global parameters or, at least parameters affecting extensive areas.

Spaceborne (i.e. satellite-based) or aircraft-based imaging systems and ground-distributed large-area sensor networks are clear ways to address environmental monitoring. And the diversity of solutions is broad.

Take as an example the Hyperspectral Imager for the Coastal Ocean (HICO) which was launched on September 10, 2009 together with the Remote Atmospheric and Ionospheric Detection System (RAIDS). Both systems are in use since their arrival at the International Space Station (ISS) for real-time monitoring of space weather and the ocean environment. The HICO is a cost-constrained visible and near-infrared maritime hyperspectral imaging system for observation of coastal ocean environments. Since the orbit of the space station is not sun-synchronous the monitor system provides information about the ocean environment at different times of the day. The data collected includes water clarity, bottom-types, bathymetry, and on-shore vegetation maps. The Remote Atmospheric and Ionospheric Detection System (RAIDS) is designed to study upper atmospheric airglow emissions, the very weak emission of light always present in the planetary atmosphere. RAIDS observations will be used for remote sensing of the neutral atmosphere and ionosphere on a global scale to understand ionospheric storms that might affect radio communication at all latitudes. The RAIDS scans the altitude interval 75-750 km and covers the wavelength interval of 50-870 nm.

Imaging with LIDAR (LIght Detection And Ranging), or LADAR (LAser Detection And Ranging) as it is called in military applications, is another interesting example of how imaging technologies contribute to monitoring of environmental changes in extended areas. LIDAR is a system equivalent to radar and sonar that uses optical wavelengths for remote sensing. An interesting use of LIDAR is the monitoring of forest structure evolution by visualizing the canopy in the infrared or at even larger wavelengths. Complementing this technique, UV LIDAR imaging gives very high quality images of the terrain under the canopy. Together IR and UV imaging show a much more complete picture of the forest structure and if used for longer periods of time it can be used to monitor forest degradation. These technologies can also be used in different industrial



The Morenci open-pit copper mine in southeast Arizona is North America's leading producer of copper with production of 382,000 tons of copper per year. This ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) image uses short wavelength infrared bands to highlight in bright pink the altered rocks in the Morenci pit associated with copper mineralization. IR mapping of the area minimizes injuries to the landscape.

Image Credit: NASA/GSFC/METI/ERSDAC/ JAROS, andS./Japan ASTER Science Team

applications for classification of large storages of materials.

Examples are many, and they extend to the whole band of radiation detectors developed at Acreo. Imaging in the infrared, ultraviolet, X-rays, terahertz and even particle radiation is to improve the capability of environmental monitoring systems.

Moreover, the access to low-cost wireless communication, new sensor technologies, low-cost complex electronic systems, new compact intelligent imaging systems with higher level of integration and low power consumption allowed the use of sensor networks to monitor larger areas. Today's imaging technology allows streaming of advanced image data at high frame rates with on-line intelligent machine vision. When the imaging system is integrated together with a low-power interpretation of the images it enables imaging in more places and imaging in new contexts. Novel real-time image processing techniques are being developed. Together, image processing and data fusion from streaming imaging techniques are expected to make a strong impact in the development of new systems for remote sensing in networks including sound, temperature, gas or imaging sensors.

On top of all this, the spin-offs of the new techniques and their application to new fields are giving an even broader contribution to sustainability. The use of hyperspectral imagers in agriculture for process monitoring leads to increased production yields and higher food safety. The advantages of large-area sensor networks for environmental monitoring promotes the development of new energy efficient systems, new sensors, better alarm systems, and more. Newer imaging techniques promote the development of higher quality environmental monitoring systems and higher demands of environmental monitoring systems pushes imaging technology to even further horizons. ■

Business Services

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 to become more competitive by new technologies and business models.

Stellan Granström
stellan.granstrom@acreo.se

Acreo has developed a methodology based on creation of commercial values in Swedish SMEs operations. 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 for a certain number of years. Important is 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 below:

- Company selection
- Company audit and need analysis
- Business development workshop
- Competence development
- IC Technology integration in R&D projects
- Technology transfer with R&D exploitation and IPR licensing

Company selection

The selection of companies is mainly controlled by the sector for the moment decided to be the target sector. Other important parameters we also take into account are the yearly revenue and result over the last three years and that the company has product ownership and is driven by good entrepreneurship. Through the years we have been targeting SME sectors with a lack of ICT technology as well as SMEs with a long ICT experience in R&D and technology integration.

After careful selection candidate companies are contacted for setting up a meeting where the offer of support is presented.

Company audit and need analysis

The company audit and need analysis is the key to business development since it covers market and sales strategy as well as competitors comparison, and profit and loss calculation on product level.

The final result of these analyses is an action plan that shows what ICT technology will be needed to be integrated in order to reach the functionality level that the market requires.

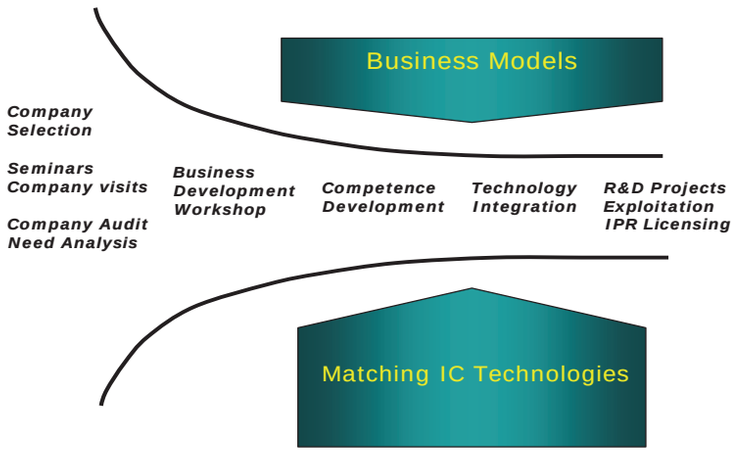
Business development workshop

If there is a lack of business planning we can offer SMEs to participate in a workshop for the generation of a business plan. The output from the workshop is a business plan draft that has to be finalized by the SME staff. The workshop is normally a one day action that also works as a training session for the SME personnel.

Competence development

Different training courses mainly within micro and nano systems as well as embedded systems technology is offered to SMEs in order to bridge over different obstacles and make the R&D project decision process easier.

When more special issues, like business or technology integration, have to be resolved we offer feasibility studies in order to clarify these issues prior



to the decision point of the R&D projects go or no go takes place.

ICT integration in R&D projects

When the technology to be integrated is chosen the R&D project planning will be carried out. Since many SMEs have problems to raise enough money for the R&D project we have invited companies to submit an application for financing by VINNOVA through Acreo. The financing level is 50% of the R&D budget up to maximum 500 KSEK. During the project one coach from Acreo follows all activities in the SME and works as support when the new technology is introduced. When a working prototype is demonstrated and the final report is approved the project is ended.

Technology transfer with R&D exploitation and IPR licensing

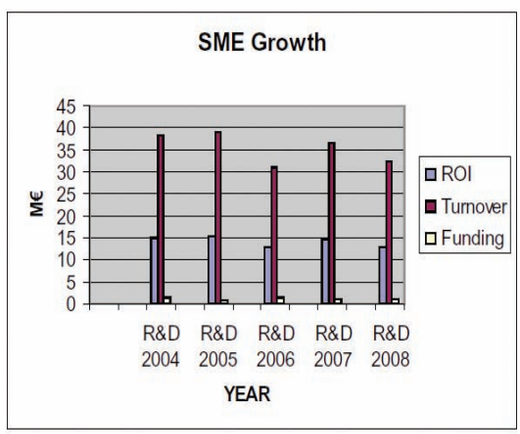
After the R&D project is finalized we can offer the SME exploitation through the Enterprise Europe Network. The SME can be assisted in finding sales channels and even clients for larger business cases.

If the company has limited marketing and sales competence and resources we recommend them to license the IPR to a client that has these resources. Another scenario is when during an R&D project a sub-contractor is needed that can not be found in Sweden. We can then offer a search procedure through the network for such a partner.

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. The result was in 2009 at the level of 580 MSEK which corresponds to 232 MSEK in RoI to financing institutions. The impact is carefully calculated from interviews with the SMEs where the increased revenue has to be based on the projects from Acreo.

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. ■



Business Services minST Project Predect:

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.

Rolf Andersson
rolf.andersson@acreo.se

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 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.

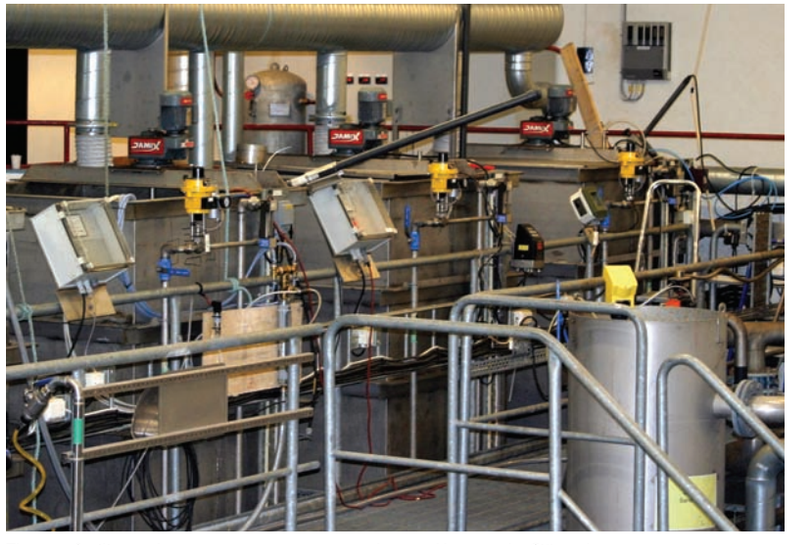
The goal is to reuse waste water from various processes after purification. This requires very sophisticated quality assurance and continuous assessment.

– 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.

Rolf Andersson, Acreo, together with Ulla and Sudhir Chowdhury at the test facility in Hammarby Sjöstad


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

With the Predects 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. ■

Business Services / INSICT Project Cardiolex :
Option for Exercise EKG

Traditionally the medical examination of the heart function by EKG has involved specialised equipment for rest EKG or exercise EKG. The SME Cardiolex AB has developed a new system based on a standard PC which significantly improves the price/performance and thereby can make heart examination more efficient and accurate.

Stellan Granström
stellan.granstrom@acreo.se

The VINNOVA project INSICT aims to help SMEs to become more competitive by introducing information and communication technologies in their products, services or production processes. Target companies are SMEs which are operating outside the ICT area. VINNOVA provides financial support up to 50% of the development costs to introduce new technology. Among the criteria is that the project should provide a significant technology shift or add a functional step to a product.

The SME Cardiolex AB is a Swedish medical technology company that develops and markets PC based EKG systems. Cardiolex was founded in 2005 to develop an EKG system primarily for the Swedish and European market. In spring 2007 Cardiolex released rest EKG as their first product, "Lexor EC Sense". The Cardiolex staff has a background from several years of development of electrocardiographs from amongst others Siemens Elema.

Cardiolex was selected to become an INSICT project based on showing a strong growth potential by introducing an exercise EKG option. The

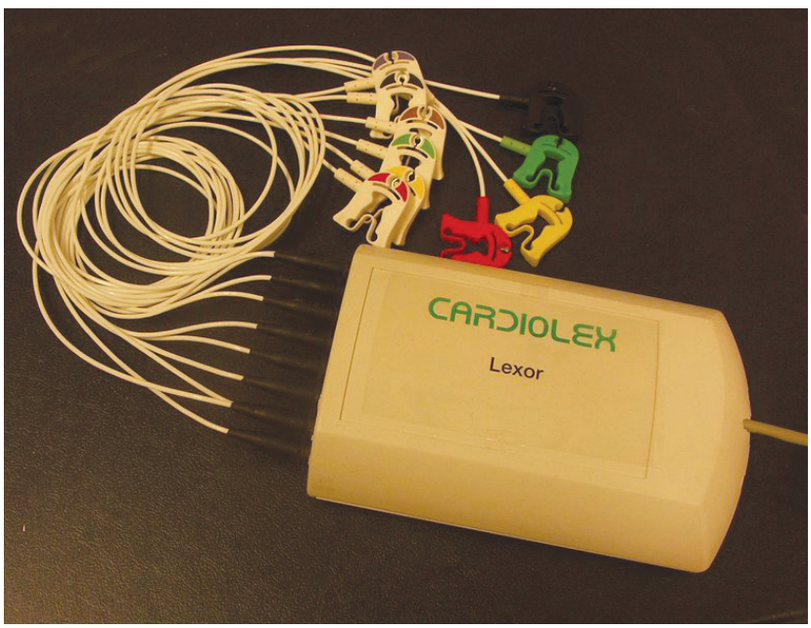
EKG system based on a standard PC

exercise EKG system was developed with INSICT support during 2007-2008 and launched on the market in the autumn 2008. Already by then Cardiolex received their first exercise EKG orders which generated in a revenue impact 2008 of 1 MSEK. In 2009 sales have continued to develop well and the revenue has increased to 1.5 MSEK.

From further development Cardiolex released products for long term EKG storage early 2009. The "EC Store" stores patient information as well as examinations in full resolution, guaranteeing zero data loss. Stored examinations can be downloaded to any Lexor or standalone edit station EC View for editing, printing or reviewing.

Acreo has also assisted Cardiolex in finding market requirements for the further development of the long term EKG storage. This further development covers mainly services for central EKG archiving for a number of clinics in large volume storage systems.

By adding the exercise EKG option Cardiolex has seen a very positive market acceptance. The market potential is very large for this efficient EKG device with a very powerful arrhythmia classification and ST analysis. Furthermore, the system has a significantly improved price/performance and makes heart examination more efficient and accurate. ■



Lexor unit

Business Services/INSICT Project UVtech :

Synthesizes the natural air purification process

UV radiation provides a natural, chemical –free and environmental friendly way to remove odour and polluting substances from the ventilation air.

Håkan Sehlin
hakan.sehlin@acreo.se

Located in Åtvidaberg, Sweden, UVtech AB specializes in developing, manufacturing and marketing UV air purification systems. Founded in 2004 they are the youngest company in the corporation Silver & Stål Holding AB. Still a small company, involving some ten people or so in their operations, they expect to grow thanks to new innovative products on an emerging market.

Mimic the sun

Nature has its own purification system that cleans the air on earth from odours, bacteria and viruses:
- The UV radiation of the sun.

The UVtech air purifier systems work according to the same principle. UV radiation of a specific wave length is used to split molecules of a wide variety, from large grease molecules down to parts of bacteria. As it splits molecules, the UV radiation itself has a great effect on the purification of the air and in many applications the direct exposure to UV radiation is the most important means of purifying the air from unwanted organic matter. As an added purifying step, the UV radiation also turns oxygen (O2) in into ozone (O3). Ozone as a free radical is highly reactive and it reacts with organic substances like fats, bad-smelling benzene derivatives, nicotine smoke or microorganisms like bacteria, viruses or mildew spores etc. The UVtech air purification system therefore also has a disinfecting effect. These chemical reactions yield biological substances such as water, oxygen and carbon dioxide, which are all odour-free, inflammable and biodegradable up to 100 % - An air purification process that is natural, chemical-free and environmentally friendly.

The air purification systems are found in a diversity of applications where they remove odours and polluting substances from the ventilation air: Waste rooms, restaurant kitchens, fast-food restaurants, public toilets, decontamination of cars and houses, and many more. For restaurants, this opens the possibility of recycling cooking heat using heat exchanging systems after the air purifier.

The systems are in size from portable units with 50 m^3/h airflow capacity to industrial installations capable of 18 000 m^3/h.

UVtech was granted R&D funding through the INSICT program managed by Acreo. The project was commenced last November. Within the project, a new control and interface unit will be developed. Increased functionality, higher level of modularity, remote accessibility, more user friendly interface are just some of the technical improvements. A higher level of process monitoring and “service needed” alerts enables a more efficient and optimized process as well as trouble free operation.

– Commercially, we expect increased sales due to easier acceptance and an increased number of business partners in Europe, says Managing Director Lars-Erik Lejondahl. This system will also strengthen and secure our brand as the provider of reliable and efficient air purification systems.

Lars-Erik continues: On an emerging market like this is, we also foresee an increased competition. And to secure our foreground position, we are establishing a scientific board with experts from universities and research institutes like Acreo.

This system will keep us in the technical forefront and enable us to contribute to a better environment on commercial terms. A good example of a Cleantech Business opportunity realization.

– With the strong support from Acreo, the minST programme and their associates, we expect a both technical and commercial success outcome of the project, Lars-Erik concludes.

For more information about UVtech AB, the technology and some of their prestigious installations, visit www.uvtech.se. ■

Språkspalten

"The Language Column"

The only Aperturen article in Swedish.

Vad är färg?

Sten Walles
sten.walles@comhem.se
Svenska OptikSällskapet
www.svenskaoptiksallskapet.se

I språkspalten oktober 2008 skrev jag, att en senare språkspalt skulle handla om färglärans begrepp och termer. Det visade sig, att detta område var mera invecklat att ge sig på, än jag insåg. Vid Svenska optiktermgruppens möte i oktober 2009 tog vi det befriande beslutet att avstå från all färgterminologi och att bara ta fram en enda sådan termpost för vår ordlista på Svenska optiksällskapets webbplats, nämligen *färg*.

Beslutet fattades mot bakgrunden, att Byggforskningsrådet under 1995 gav ut tre böcker, vilka innehåller resultatet av nästan 20 års forskning inom färgläran. Den som bläddrar igenom dessa böcker, vilka avslutas med en Färgordlista på 329 uppslagsord, finner att det redan finns en genomtänkt begrepps- och termbild på svenska. Den togs fram genom forskningen inom Stiftelsen Svenskt Färgcentrum under ledning av Anders Hård tillsammans med Gunnar Tonnquist och Lars Sivik.

I en av böckerna, Gunnar Tonnquists *Färgsystemanalys*, skriver författaren: ”Färgläran är tvärvetenskaplig. Frågan, hur det fysiska föremålet framför oss ger upphov till en sinnesupplevelse, som bl.a. innehåller det vi kallar färg, kan behandlas ur fyra aspekter: fysik, fysiologi, psykologi och psykofysik.” Alltså ett betydligt vidare kunskapsområde än det som Svenska optiksällskapets medlemmar normalt arbetar på. Optiktermgruppen drog slutsatsen, att färgläran ligger utanför dess bevakningsområde.

Hur definierar vi då färg? I vår termpost skriver vi, att färg är ”synförnimmelse av spektralfördelningen hos ljusstrålning från belysning och belysta eller lysande föremål”. I kommentaren hänvisar vi för detaljer till Gunnar Tonnquists bok och till ett prisbelönat examensarbete av Linda Johansson, *Färgåtergivning i katalogproduktion*, Linköpings universitet 2002.

Låt mig avrunda med att ge en idé om vilka slags termer vi således avstår från att behandla. De ligger inom så vitt skilda områden som perceptionspsykologi, datorteknik, grafisk teknik, material, målning, arkitektur och miljö.

I utomhus- eller inomhusmiljö talar man om *varm* eller *kall belysning*, beroende på hur ljuskällans färg påverkar vår känsla av trivsel. Inom urhandeln kallas det självlysande färgämnet på en urtavlas visare och siffror för *lysmassa* (*luminous mass*).

Ett färgsystem kan entydigt definieras i en tredimensionell *färgrymd (colour space)*. Den del av färgrymden som kan illustreras med ytfärger kallas *färgkropp (colour solid)*. En teknisk anordning kan producera färger endast inom en viss del av färgrymden, den har ett begränsat *färgomfång (colour gamut)*.

I det inom Svenskt Färgcentrum/Skandinaviska Färginstitutet framtagna NCS-systemet, som sedan 1979 är svensk standard, definieras en färg med de fyra storheterna *svarthet (blackness), kulörthet (chromaticness), vithet (whiteness)* och *kulörton (hue)*. Summan av svarthet, vithet och kulörthet är alltid 100 procent. Svartheten beskriver förstås, hur pass svart en färg ser ut, medan kulörtheten anger hur pass färgad den är; dessa två jämte vitheten kallas *nyans (nuance)*. Kulörtonen är det som vi i dagligt tal kallar färg, alltså röd, gul, grön, blå med flera. Varje kulörton kan framställas i de olika nyanserna. NCS-systemet har entydiga färgbeteckningar och illustreras med 1950 standardfärgprover i en *färgatlas* eller en *färgprovsamling*. Gå till färghandeln och fråga eller besök www.ncscolour.se ! ■