Candy for the electronics industry

Finally! Years of research yield results at last! The effects will be seen everywhere in everyday life, but energy-efficient hybrid cars are a prime example. The results involve the diamond-like substance silicon carbide. The material has electrical and physical properties superior to those of silicon and is capable of the superior performance needed for high-tech applications.

Silicon carbide has frustrated scientists for decades. While possessing fantastic potential, it has been very difficult to produce, at least at full scale.

If you mention silicon carbide in Sweden, one name in particular shines brightest: Erik Janzén, Professor of the Department of Physics, Chemistry and Biology at Linköping University.

"It takes a longer time to develop technology than many people realise. Today's silicon-based electronics also took a long time to develop – from laboratory experiments to production," he says.

Excitement

In 1991 he was asked for the first time when he thought silicon carbide could be used commercially.

"I stuck my neck out and said 1997. The head of ABB Semiconductors at that time was really pessimistic. He was aiming for 2003. Nowadays I am fairly certain that the hybrid car will boost the market for silicon carbide within two to three years."

So what's all the fuss about, why all this excitement about a substrate that has been known since the 1950s?

The reason is that silicon carbide can be used as a new engineering material in the semiconductor industry and partially replace today's silicon.

Professor Janzén explains that silicon carbide is as hard as diamond and – compared to ordinary silicon – has lower current losses and can withstand higher temperatures, frequencies and voltages.

Semiconductor components of silicon carbide can therefore be used in applications such as mobile phone base stations, electrical converters and high-temperature environments, such as near airplane engines where lighter weight and higher heat resistance are important.

"One of the material's foremost advantages is its energy efficiency. Energy technology, which is dependent on efficient conversion between direct and alternating current, is more productive when silicon carbide is used in the semiconductor components. This means that the energy losses in connection with conversion and transmission in the power distribution grid are reduced," he says.

Wind turbines

One area of application is therefore wind turbines and solar cells, where current generation is not always even, since the wind can vary and the sun can cloud over. Silicon carbide in the power circuitry in these systems would lead to great energy savings. It could also permit the use of direct current cables on a larger scale, for both electricity distribution and power transmission between countries.

Silicon carbide is also used in LEDs (light emitting diodes), which can lead to more energy-efficient lighting.

In the long run, silicon carbide will be used in most everyday electronic products in the world around us and can greatly reduce our electricity needs. International studies show that silicon carbide could permit energy savings equivalent to SEK 40 billion per year globally.

New method

Silicon carbide has been manufactured by a couple of companies for several years now, but the production method has often led to uneven quality. The silicon carbide wafers have lots of tiny defects that make them unsuitable for demanding applications. Due to these defects the semiconductor material has degraded and the components have aged rapidly. Large parts of the production have simply not met the requirements and have had to be discarded, making the material expensive to buy. This was the main reason ABB abandoned its big silicon carbide project several years ago.

It all looked rather gloomy until a year or so ago when Erik Janzén and his research group at Linköping University developed a new production method. Together with ABB and the Finnish Okmetic group of companies, they came up with a manufacturing method called High Temperature Chemical Vapour Deposition, HTCVD. The method is based on using gas instead of solid material to make the crystals, resulting in material of more even quality.

Seed crystal

"Our breakthrough represented a paradigm shift in electronics and laid the foundation for the large-scale use of silicon carbide as a substrate material in electronics," says Professor Janzén.

In the HTCVD method, a continuous flow of silicon- and carbon-containing gases is pumped into a crystal oven, where the temperature is around 2,000 degrees Celsius. The silicon and the carbon crystallise when the gas flow reaches the seed crystal, the initial crystal from which growth proceeds. The electrical conductivity of the growing crystals can be controlled by adding precise doses of additives to the gas flow. After being taken out of the oven they are sawn into wafers a half a millimetre thick. Silicon carbide is a very hard material and can only be sawn with diamond-coated saw blades or wires. After sawing, the wafers are polished until the surfaces are completely flat.

The finished wafers can also be coated with another layer of silicon carbide only a few thousands of a millimetre thick. This growth method was also developed at Linköping University.

Today the new company Norstel in Norrköping manufactures silicon carbide crystals according to the new HTCVD method.

"Nowadays we don't manufacture large volumes of crystals ourselves. Instead we collaborate with Norstel on material development. We perform advanced calculations and material analyses, for example regarding the defects that arise if one silicon or carbon atom is removed. Experiments are also being conducted with other doping substances than nitrogen, such as phosphorus."

Efficient hybrid car

Norstel already has customers in the component industry in Europe, the USA and Asia. They are now working together to get new silicon carbide-based products on the market.

But Erik Janzén believes that the first major area of application for silicon carbide will be in the car industry.

"Hybrid cars require converters to control the voltage in the electric motor, and they have to be lightweight and efficient, properties that silicon carbide can confer. A hybrid car with the new material could be 20–40 percent more efficient," he says.

It's no accident that Japanese researchers at Toyota's central research and development laboratory are focusing on the manufacture of silicon carbide.

Professor Janzén believes that the development of silicon carbide is a matter of national interest for boosting the competitiveness of Swedish industry.

"Further development of silicon carbide technology will be more dependent on know-how and less dependent on the cost of labour or component manufacture. This is in contrast to today's microelectronics, where these factors have been dominant and led to a migration of production to low-cost countries."

HÅKAN BORGSTRÖM

Smart labels

What would you say to drug cartons that help the patient to remember to take his medicine? Or packages that ensure that the spare part is not counterfeit? Perhaps food packaging that guarantees that no one has opened it before purchase? All this is now possible when the research field of printed electronics is to be commercialised, and we are talking about products that can compete on the global market.

"We are the world leaders today in systems for printing components such as transistors, push-buttons and displays on paper. During the year we will form a company that sells services that include these components," says Magnus Berggren, Professor of Organic Electronics at Linköping University in Norrköping, Sweden.

Many companies have already expressed an interest in the products, including the photo paper manufacturer Agfa and the toy manufacturer Lego. Paper companies such as SCA, M-real and Stora Enso have long been interested in this research.

Shelf life

A great deal has been written about the successful joint project between Linköping University and Acreo for printing plastic on ordinary paper and cardboard to build electronics. The vision has usually been exemplified with food packaging that does not have conventional printed date stamps. Instead there is a small display showing that the fish has a remaining shelf life of X days. The text is generated by a tiny computer that is printed on the packaging and that measures the temperature and/or gases inside.

"Sure, that's one possible application, but so many exciting things have happened in the past two years that we now prefer to talk about a range of services called 'System-on-a-Sheet'," Professor Berggren says.

Look at me!

It's all about packaged services for companies. Many of them are familiar from the EU project Sustainpack. In this project, four areas of application have been defined for so-called communicating packages:

Traceability:	The container says: Here I am!
Security:	The container says: I am the one you think I am!
Sensing:	The container says: This is how I feel!
Attention:	The container says: Look at me!

"We are participating in Sustainpack and have among other things looked at security services. An example is that the packaging ensures that it has been unbroken on its way from supplier to end customer. It may also be a trademark protection, or assurance that the contents are correct," says Professor Berggren.
Yet another idea is providing medicine packaging with printed electronics that help the patient."

"We can develop a carton with a reminder function in the printed electronics. It may be a card of tablets with built-in electronics, including timer, indicating when it is time to take the next tablet."

Environmentally-friendly electronics

The technology is based on research that was initiated by Professors Ingemar Lundström and Olle Inganäs more than 20 years ago at Linköping University, and that Magnus Berggren's research group is now continuing together with Acreo. It all involves mixing conductive polymers in printing ink. The result is inexpensive, simple and more environmentally-friendly electronics for applications that contain no electronics at all today.

Magnus Berggren has been working in the field for many years, some of them at the Acreo research institute where he helped start the paper electronics project PAELLA (Paper Electronics for Low Cost Applications) back in 1998.

"Along the way we have developed a unique printing method. We were forced to find an economical method of printing."

As an example he mentions that manufacturing an integrated circuit with millions of transistors for an ordinary computer number may well involve over 10,000 steps. This isn't possible in a printing press.

System-on-a-sheet is a system of electronics printed on paper in the form of a label that includes: an electrochromic display for text plus a seven-segment display for numerical information, battery, push-buttons and logics realised in printed transistors on paper.

"We managed to reduce the number of production steps to between 10 and 15 by finding a printing company that had both the know-how and the technology for offset, screen and flexographic printing in the same machine.

Flexography is a printing method that is mostly used for printing on packaging and wallpaper, but also for newspapers. Together with the other printing methods, it comprises a whole that covers all the necessary electronics.

Offset printing is used, for example, for printing resistors. Screen printing is used to print batteries and displays, and flexography is used to print conductive patterns.

Disposable products

The services are advanced, but electronics similar to that in a personal computer is still far off. Paper electronics works much slower. But instead of going in for advanced electronics such as colour displays on paper-like materials like their competitors, Philips and Cambridge Display Technology, the researchers in Norrköping have chosen another path.

"We have always started with what is possible to print on paper and created our components from that," says Professor Berggren.

This means simple but inexpensive components for disposable products.

"We are delivering a new concept for electronics production. This is low-cost electronics that is produced in large volumes, and many people in Sweden have given up trying to do this," says Professor Berggren.

He says that the whole project has got better as time has passed.

"When the researchers at the university have understood what needs exist in the marketplace, they have been able to develop the right kinds of components."

He says that the new company will sell services, and not license out different technologies.

"We will build on the patents we have, which number around 50 or so today. If we were to sell one of the key patents, it could easily be a wedge that would stop the company's forward movement."

Organic memories

Magnus Berggren knows what he's talking about. He has previous experience from spinoff companies based on research ideas, for example Thin Film Electronics, which develops organic memories.

"This time we're going to use a different business model. Instead of selling a half-finished technology for a few million dollars, we will set up the entire production process ourselves."

But he has more irons in the fire. Professor Berggren has been working at Linköping University's Department of Science and Technology in Norrköping since 2001. Now he is studying how transistors made of conductive plastic can interact with living organisms. The work is based on putting transistors in contact with cells using the same conductive plastic material as that used for electronic paper and thereby affecting living organisms – such as human beings.

"We have been using titanium as an interface between electronics and humans for several decades. With conductive polymers we can create even more efficient biocompatible materials."

Electronic drugs

One example of future products is electronic drugs. The idea is to influence the action of drugs by means of external signals, or control the development of cells in the body to prevent various diseases.

"With the aid of our research we can replace certain biological systems with artificial ones."

Recently, Professor Berggren, together with researcher Agneta Richter-Dahlfors at Karolinska Institutet, received a Bio-X grant from the Foundation to develop tools that can control ion currents in cells.

"We are currently involved in a big project at the Tumor Biology Center at Karolinska Institutet."

A while ago he also received one of this year's five Göran Gustafsson prizes. The prize, which is awarded by the Royal Swedish Academy of Sciences, is the biggest given to researchers in Sweden.

Håkan Borgström

Digging for tree gold

Imagine a potential market worth around SEK 36 billion. Imagine annual revenues of more than SEK 400 million. All this awaits a small company in northern Sweden. A company chock full of unique expertise, patents and inventions. It all revolves around trees and wood.

"The market potential is enormous. Genetically modified plants and related businesses are going to explode. The big customers are outside of Europe – in Chile, North America, Southeast Asia, Australia and New Zealand," says Petter Gustafsson, Professor of Plant Molecular Biology and Vice President, Intellectual Property, at SweTree Technologies ABB, STT.

This is the story of how large research centres can be built up to serve society, with results of commercial value to industry – even though few people believed in the potential initially.

Basic research

But perhaps we should start from the beginning. Wood, Sweden's most valuable natural resource, is an important field of research. Intensive studies have been conducted all over the country for many years to find out as much as possible about how trees grow. Through basic research, scientists have been able to improve the quality of the wood and prevent tree diseases.

"The Centre for Forest Biotechnology and Chemistry, CFBC, was established at Umeå University in 1996. It was an association of some of Sweden's leading research groups who worked to bring together research in the fields of forest biotechnology and process chemistry," says Professor Gustafsson, who was one of the participants at that time. He is, however, careful to point out that the driving force was Professor Göran Sandberg.

The centre still exists, and its objective is to study everything from production of biomass and formation of wood in trees to improvements in the production processes.

Swedish economy

But wood is also of enormous importance for the Swedish economy. Wood is used as fuel and as a raw material for the pulp, paper and building industries. It was in part for this reason that the Umeå Plant Science Centre, UPSC, was established in 1999 in cooperation between the Department of Physiological Botany at Umeå University and the Department of Forest Genetics and Plant Physiology at SLU (Swedish University of Agricultural Sciences) in Umeå.

"They hoped to make the transition from basic research to more applied research, believing that this would yield great benefits for society."

It proved to be the right way to go. Around 170 persons work at the Centre today. They are among the world's leading experts in plant physiology and plant biology.

"No one in the world knows more about trees, not by a long shot," says Professor Gustafsson.

Controlled flowering

The scientists at the Centre study plant genomes, among other things. Poplar, a genus of trees that

includes aspen, has been chosen for gene mapping. Knowledge of the poplar's genes can provide a deeper understanding of how trees are formed and grow. This in turn provides insight on how flowering is controlled, how the wood is formed, how plants fight diseases, and how trees manage to live at low temperatures.

The group's research results can provide a better understanding of how different types of wood grow in different climates, and how the right kind of wood can be grown for a specific application. So far the Centre has identified nearly a hundred thousand genes in the tree.

"We soon understood that many discoveries were patentable and could be exploited commercially. That is why SweTree Technologies AB was founded in 2000," says Professor Gustafsson.

Gold genes

The company is an instrument for the patenting and marketing of research results in plant and forest biotechnology and chemical engineering for the forest industry. The idea is that STT should also channel commercially oriented research grants.

Petter Gustafsson says that the Centre has now mapped up to 30,000 important genes.

"Between 5,000 and 8,000 of these are active in wood, and of these about 2,000 can be used commercially. And of these 2,000 there are between 20 and 100 so-called gold genes, in other words genes that are very important for production purposes."

Suffice it to say that STT already has patents on 20 of these gold genes.

Individual drive

Hopes are thus high for the future. But the path leading up to today's bright outlook has been a thorny one at times. Not everyone appreciated the potential of their findings.

"At first only the scientists were foresighted enough to understand the future needs of industry – even though industry itself couldn't formulate those needs. A large part of our success is really due to the individual drive of the researchers themselves – combined with understanding research organisations," says Professor Gustafsson.

Once again Göran Sandberg is mentioned, but also enthusiasts such as Professor Mattias Uhlén.

"A couple of important milestones have also been passed along the way. One example is when Professor Ove Nilsson published an article on how the flowering time of trees can be controlled.

With fast-flowering trees, the breeding cycle can be dramatically speeded up, by up to 20 times. We just had to find the genes that control flowering. The main switch, the FT gene, was found by Ove Nilsson. If that gene is switched off, flowering doesn't occur at all, even though lots of leaves are produced. If it is switched on, flowering starts."

Rainforest

"Another example is when Professor Björn Sundberg came up with a way to slice a tree's annual rings into thin slices so you could see where in the ring different plant hormones, proteins and genes are active."

Other important results were also achieved. In cooperation with the KTH Genome Center in Stockholm, for example, DNA chips were created that were specialised in reading the different functions of the aspen genes.

Armed with this knowledge, the researchers can create tools for the forestry of the future. Tools that can be used to design trees to meet specific needs – short or long fibres, small or large trees, fast-growing trees with high quality wood.

"But it isn't primarily our northern Swedish forests that will be changed by genetic engineering. Genetic engineering could save the rainforests in countries where they are being destroyed today," says Petter Gustafsson.

Genetic engineering can be used to create high-yield trees that can be intensively cultivated in plantation forests on one-tenth of the forest land needed today. "The rest can be left alone," he says.

In this way we can save our forests, while at the same time Swedish biofuel can be produced more intensively thanks to the work being done at the research centre in Umeå, which is then commercially exploited by STT.

Fireproof paper

The Centre's portfolio of patents will thus provide vital tools for plant breeding. But that's not all. Petter Gustafsson tells about another line of research: Intensive studies are also under way to improve the cellulose material itself. At the Royal Institute of Technology, KTH, a group surrounding Tuula Teeri, Professor of Wood Biotechnology, has developed a technology that gives the cellulose entirely new properties. The aim is to develop a paper that resists water, cannot catch fire, cannot be counterfeited, and is furthermore flexible and easy to form. At the same time it is strong and binds readily to other substances. This technology (patent pending) is called XET technology after the enzyme that is used to achieve modifications of the paper properties. The patent is naturally owned by STT. "All of this has come about as an effect of the efforts funded by SSF in the mid-1990s," says Petter Gustafsson.

Håkan Borgström

Eliminating friction

Develop clutches for four-wheel-drive cars that work just as well at minus or plus thirty degrees Celsius – and that never need oil!

Develop a reliable system that separates parts of a satellite in space – and weighs almost nothing!

Improve today's lubricants so they are more high-performance – and environmentally-friendly!

These are a few of the problem areas that have been or are being solved by Swedish know-how. We are talking about a field called tribology. The word is derived from the Greek word tribos meaning "to rub".

Tribology is the field dealing with friction, rubbing and lubrication. The discipline is concerned with all situations where two surfaces move against each other while in mechanical contact, which includes most mechanical activities in modern society. All wear of moving systems that leads to damage, failure and repairs is caused by tribological factors. Knowledge of these phenomena provides competitive advantages in the form of prolonged service life, reduced costs, energy savings, environmental improvements and better products.

Leveraging knowledge

"Sweden has long been a leader in tribology research. But the national research programme HiMeC has brought these resources together and further speeded up the pace of development," says Erik Höglund, Professor of Machine Elements at the Luleå University of Technology.

But it's not just a question of high national expertise; HiMeC is of great international interest.

"We are constantly being contacted by organisations and companies in other countries. Today, for example, we have projects together with companies such as General Motors and Shell."

Another example is a satellite project called YES2 that has been carried out in cooperation with several European universities. The European Space Agency, ESA, placed one important assignment in Luleå.

"Our department has designed a separation system for satellites. The system will be launched into space in 2007. Its task is to separate two parts of a satellite in a controlled fashion. One of these parts will then be fired back to earth, while the other will remain in orbit," Professor Höglund explains.

Zero gravity

It is not a simple task. The system must combine intelligence with simplicity. It has to weigh next to nothing, it has to work in both extreme heat and extreme cold – and naturally it may not be based on gravity.

"Moreover, its reliability is must be absolute. It simply *must* work.

That's where all the knowledge acquired within the national research programme will come in handy. HiMeC, which stands for High Performance Mechanical Components, was started in the late 1990s. The programme was coordinated by Luleå University of Technology, but Uppsala University, KTH (the Royal Institute of Technology) and the Lund Institute of Technology also participated.

HiMeC has had both projects that have been specific for the company's special needs and projects invol-

In one of the projects included in HiMec, a new generation of clutches for four-wheel-drive cars has been developed together with Haldex Traction AB and Statoil Lubricants. In the picture, Erik Höglund is in the process of mounting one of the parts in a test rig specially developed for the purpose. With the aid of numerical models and validating experiments, new plate surfaces, custom-tailored lubricants and more sophisticated software have been developed so that the new clutches are maintenance-free for the entire life of the car and provide improved driving comfort for the driver.
Photo: Henriko Rikardo.

ving basic research. Every year, companies and researchers have gathered at conferences to discuss results, but also to network. The companies that participated in HiMeC were mainly from the engineering industry, but also among its subcontractors.

High level of technology

"The Foundation invested SEK 25 million in HiMeC. Together with investments from the companies that are partners in the network or participants in the project, considerable resources were made available for development in an area where success is quickly turned into profits for the companies. Even small improvements in tribological systems have considerable impact."

Erik Höglund explains that the programme not only generated generic knowledge at the academic institutions, but also led to applied research with concrete results at the participating companies.

"A good example of the latter is the multi-plate clutch project for better four-wheel drive cars. This led to a new generation of clutches. We were responsible for experimentation, simulation and modelling, Statoil Lubricants developed a new type of lubricant, and Haldex Traction AB was in charge of prototype testing and production.

It was a project at a high level of technology," according to Professor Höglund. The result was a clutch that does not require an oil change after a certain number of kilometres. In fact, the oil in the clutch never has to be changed at all! Furthermore it is adjusted completely automatically and can cope with temperatures from minus 30 to plus 40 degrees Celsius.

"Electronic control means that the driver doesn't notice any difference in different types of weather, and the power is transmitted smoothly. Furthermore, these kinds of results can be applied in many other areas as well."

In purely scientific terms, the project is about the same thing as other tribological problems: Finding out what happens when two surfaces rub against each other – and what type of boundary layer lubrication prevails.

"This particular project has also been continued in SSF's research programme in the area of product realisation, ProViking."

Labour market

All in all there are some 15 projects within HiMeC – all focused on friction and wear.

"One research project has to do with the real contact surface. When two surfaces meet, all parts of the surface layers are not in contact with each other, only the peaks, about 1–2 percent. We studied elastic and plastic deformation in these subsurfaces," says Professor Höglund.

There are also hopes that HiMeC will have a continuation. Several of the participants in the programme have formed a grouping called NEXT.

"This is a programme that aims to use current knowledge as a springboard to develop tomorrow's tribological know-how, simulation and modelling – tools that can be used by engineers. Tribology today does not have any computer-based tools for designers, such as CAD/FEM.

The idea with NEXT is once again to have projects both based on the specific needs of companies and dedicated to basic research."

The national HiMeC programme has, of course, also generated a number of PhDs. So far 10 of 15 doctoral candidates have already defended their theses, and the other five will do so during 2006.

"It is particularly gratifying that they will be able to step directly into jobs. Their knowledge is highly sought after by industry," concludes Erik Höglund.

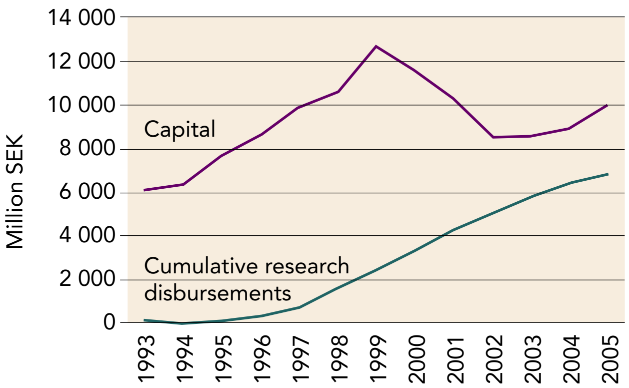
Håkan Borgström

Financial management and regional allocation of assets in 2005

Current state of affairs

2005 was a successful year for growth of the Foundation's capital. The market value of the assets increased during the year from SEK 8.9 billion to SEK 10.1 billion, despite the fact that SEK 650 million was distributed to various research activities. This very positive performance was due to excellent growth in the global stock markets and a careful and successful allocation of the assets. A graph showing the growth of the capital since the establishment of the Foundation in 1994 is shown in Figure 1, together with cumulative research disbursements during the same time period.

Figure 1: Foundation Capital 1993–2005



If this performance is sustained, the Foundation could live forever and increase its annual research funding, even though Article 3 of the statutes says that the capital may be expended. However, the Foundation must be careful and prepare for a more "bearish" scenario on the stock markets. For one thing is certain: sooner or later there will be a backlash with falling markets. The big question is when. It is thus essential that the assets are managed in a prudent manner so as to limit risks and secure a satisfactory yield. The lifespan of the Foundation is determined by the Governing Board, taking into account long-term commitments, the change in the market value of the assets and the funding needs for Swedish strategic research. Current policy states that the Foundation should continue to be an active and strong research funding organisation into the 2020s, which entails a long-term commitment to Swedish research funding.

Instead of building up an in-house capacity to manage the assets, the Foundation has decided to employ a number of external managers, mostly Swedish and international banks, for asset management. However, certain decisions are instrumental in obtaining a good return on the investments: firstly the allocation between equities and bonds, and secondly, but no less important, the choice of markets and managers. All those decisions are taken by the Capital Committee of the Foundation, which is a very important body in safeguarding a good return, even if decisions to buy or sell individual stocks are made by the different external managers.

2005 was a year of continuity in capital management. The Foundation made its first investment in Eastern Europe during the year by buying shares in a European Convergence Fund investing in the EU member states. The distribution of assets between bonds and equities in various markets in December 2005 is shown in Figure 2. During the year the Foundation also built a passive portfolio of directly owned