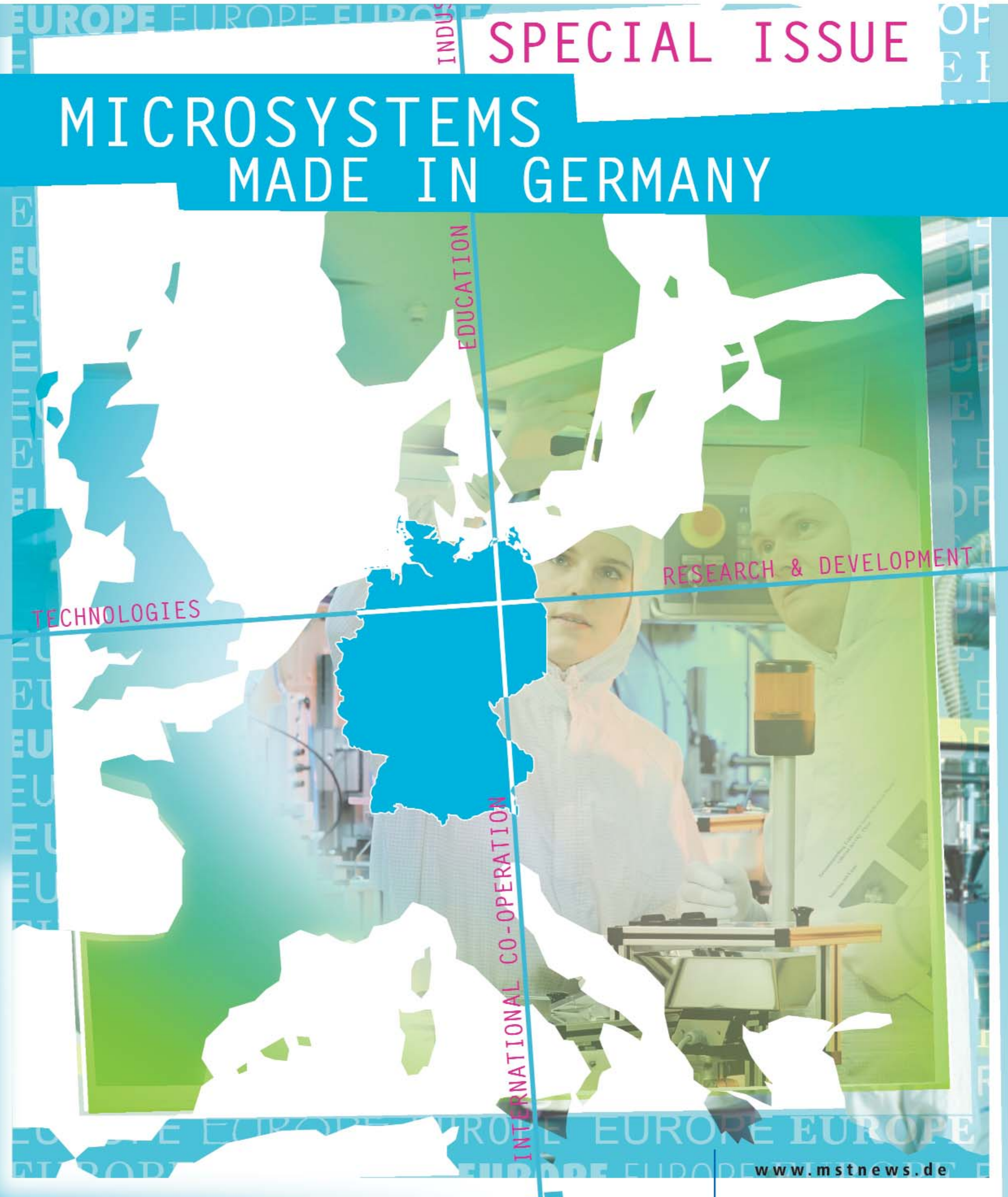
S I/05 - March 2005

international newsletter on
micro-nano integration

mst | news

SPECIAL ISSUE

MICROSYSTEMS MADE IN GERMANY



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Contents

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Special Issue

Dear Readers,

Those of you who have been familiar with mstnews since the 90s will remember two special issues on "MEMS in the USA and Canada" (June '96) and "Micromachining in Japan" (May '97). These as well as today's edition on "MST in Germany" are supposed to give insights into the respective national innovation systems in the field of microsystems technology.
We report on the current technological status and the degree by which MST has disseminated into selected areas of application in Germany to demonstrate the progression of German MST since the late 80s.
It is our intent to present not only the current status but also the dynamics of developing technology, markets, opportunities, challenges, demands and solutions that the German MST community is confronted with.
Due to its importance to our economy, the automotive industry should be mentioned first in this context. Along with microsystems in biotechnology, medical applications, logistic concepts, the information and communication area as well as in the chemical and manufacturing industry, this shows the strengths of the German industrial and R&D landscapes, which are usually well organized along value chains. The article by Jürgen Berger emphasizes the role MST played in the last decade in modernizing traditional German industries by enabling them to innovate and to stabilize their international competitiveness.
Skills development initiatives have also contributed to this process. Along with the technological advances, the MST education system in Germany has been well established through the creation of new professional profiles, both academic and non-academic, that meet the demands of employers in industry and science. Please refer to the article of Sabine Globisch.
In this context, I would like to mention the public funding of MST which is outlined in Lars Heinze's article. Today, with increasing importance, the system integration potential of MST allows the integration of function- and performance-defining components based on bio-, nano- and microtechnologies, which is indicated in various contexts by our authors.
I hope that this issue of mstnews will intensify the cooperation of institutions from all over the world with highly advanced German R&D institutes, at universities as well as Fraunhofer institutes, and promising internationally oriented companies. Being convinced of the excellence of the German education system, I'd like to invite students and professors from all over the world to visit and stay in Germany, which, contrary to the current general perception of the economic situation, offers many opportunities for highly motivated people in a diverse industrial and scientific landscape.

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Publisher:
VDI/VDE - Innovation + Technik GmbH
(VDI/VDE-IT)
Rheinstraße 10 B, 14513 Teltow, Germany

mstnews is published 6 times a year in February, April, June, August, October and December.

mstnews comprises newsletter pages from several European Networks (Nexus, Europractice, Eurimus, Patent-DfMM) and the German Microsystems Frame Programme.

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Microsystems: The Invisible Revolution

Jörg Thielges

"Even if something is small in size, it is not necessarily insignificant" - when the Roman politician, philosopher and dramatist Lucius Annaeus Seneca came to this conclusion 2000 years ago, he could not have anticipated the potential of microsystems technologies. At the beginning of the 21st century, microsystems technologies, often overlooked, initiated a revolution on the micro- and nanoscale. This hidden revolution has a deep impact on our lives.

There is a large number of appliances with microsystems at their core. Invisibly and often unnoticeably, microsystems have become an indispensable part of communication technologies, of the machine-building industry, of environmental technologies, of chemical and pharmaceutical plants. They are employed for energy supply, logistics, housing, in the automotive industry and medicine, to name just a few examples. Miniaturisation and system integration are major trends of industrial research and development.

The Information Technology Society (ITG) of the VDE - the Association for Electrical, Electronic & Information Technologies - strongly supports scientific and technological development of information technologies. More and more of our companies exploit microsystems for innovations. The IBM Germany Development Laboratory in Böblingen, for example, develops groundbreaking components for microsystems technologies. The so-called cell processor offers break- through functions in the area of three-dimensional, high-resolution visualization of complex processes, e.g. in the field of neurosurgery, HDTV or future game consoles.

The market for microsystems enjoys a sustainable growth above average. It is estimated that the world market for microsystems will grow up to more than $ 200 billion until 2010. In Germany, more than 680,000 jobs depend on microsystems technologies, 49,000 directly. This positive development is expected to continue. The VDE interviewed more than 300 international experts from science and industry. In their judgement, microsystems count among those technologies that rank first regarding the innovation potential for industrial developments. In the future, key technologies like microsystems will strengthen both new branches and traditional sectors of industry.

Microsystems technologies are an international topic. The share of industrial products using microsystems grows in all important developed nations. The leading countries in the field of microsystems are the United States, Japan and Germany. National and international co-operation forms the basis for all further developments. And it is worth looking to Europe and to Germany when planning new co-operations.

In Germany, microsystems technologies and their applications rely on well established competences regarding the development, production and employment of complex systems. In the year 2000, German industry realized a total turnover of 4.2 billion with mst-components and microsystems. Creation of value and economic development depend increasingly on microsystems, in particular in traditionally strong industrial sectors such as car manufacturing, medical technologies, the chemical industry or mechanical engineering. The German microsystems industry is characterized by a strong involvement of small and medium sized enterprises (SME). They are part of value creation networks that supply large enterprises with technologically specialized products and services.

More than 50 universities and technical colleges are involved in research and teaching of microsystems technology. The industrial qualification profile "microtechnologist" as well as university courses in microsystems technologies provide for a sound education and guarantee a qualified and motivated workforce.
This special edition of the journal mstnews presents a concise and comprehensive survey on the strengths and potentials of microsystems industry and research in Germany.
I hope, this edition will motivate scientists, engineers, managers throughout the world dealing with microsystems technologies to advance international co-operation with German partners and implement innovations on the basis of this future technology. Following Seneca's idea, we can achieve significant benefits relying on small things.

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Microsystems in Germany - Modernizing Traditional German Industry

Jürgen Berger

Microsystem Technologies, in short MST, have become a key technology with an astonishing innovation potential for traditional industrial sectors as well as for emerging technologies in Germany. The integration of numerous materials and functions and the trend towards miniaturization have been a powerful factor for the development of new innovation fields within the automotive industry, the chemical industry, manufacturing, automation, processing and the life sciences, thus profoundly changing the character of German industry. Today, a large number of small and medium enterprises have taken up the challenge of developing new products for emerging markets worldwide. These companies can rely on a strong innovation system with close links between education, research and development and industrial networks.

The tale of MST - a short glance back to where it all started

Once upon a time... when I started dealing with microsystems I wasn't aware of it. In the mid-80s, working on laser transmitter modules for fibre optic communication, I was faced with most of the problems discussed regarding microsystems fabrication today: lack of the appropriate tools for design and characterization, assembling of different materials and components with high precision, packaging, manufacturing equipment, economy of scales,...

And newspapers described the application of those lasers with the image of broadcasting within a few seconds the contents of Berlin's telephone directory of several pounds of weight through a hair diameter glass fibre. But nobody called it microsystems.

What has changed since then? First, for a couple of years now I have not had a telephone directory but a personal digital assistant. There are 6 telephones in my household used by 3 persons. My car is overcrowded with miniaturized systems, etc. So I'm deeply aware of microsystems in my daily life. Second, there is a well-established microsystems community in research, industry and politics driving the issue in Germany. I will come back to that later on. But third there is a rather poor awareness in the public because microsystems technologies are hidden behind the application. A microsystem is small, it's hard to catch sight of it and that's a pity from the point of view of "micro-lobbyists". On the other hand, this is an asset for the so-called old economy. As we have learned with the ongoing advance in the development and application of microsystems, the improvement of conventional products and industrial branches holds out great promise.

To me, this will provide both opportunities and challenges for German industry.

How did the story start? First, basic technologies for microsystems came into existence in the early eighties. Microelectronics had penetrated into many products, and the ability to store and process more and more information was impressive but not sufficient for most applications in a real environment. The question arose in what way all this information could be acquired and fed into the processor and also how to get the electronically generated result of processing responding to the environment. True, sensors and actuators were the answer and their miniaturized versions offered the most suitable adaption to microelectronic devices. Therefore the first definitions of microsystems sounded very simple as a composition of sensor, signal processing unit and actuator respectively. This is a function-related definition. Another kind of approach was to extend microelectronic techniques to other areas such as optics or mechanics. Rummaging in my historic drawers I found an image of this idea in an MBB (Messerschmidt Bölkow Blohm, a former aerospace company in Germany) brochure from the late eighties (fig.1). Nowadays this issue is seen in a more sophisticated way. Numerous materials, technologies and functions have to be considered with regard to miniaturization and integration.

Many terms are in use and the most experienced professionals for microsystems try to avoid a perfect definition, as I do as well.

Figure 1: Title of MBB brochure, ca. 1990, a simple image of MST

However, the pioneers were probably not aware of the long time and all the difficulties on the track to real products when they set out their vision. But they had the courage and the ability to overcome the limits of conventional disciplines and structures. Rarely there were constellations in Germany, that scientific and industrial stakeholders together with public authorities foresaw and created an innovation field at the right time. So, the German Ministry for Research and Technology launched support programmes for industrial collaborative research as early as the late eighties. It is worth remembering here some of the pioneers who made possible the impressive development of microsystem technologies in Germany over the last 15 years: Stephanus Büttgenbach, Thomas Gessner, Johannes Herrnsdorf, Anton Heuberger, Walter Kroy, Hans-Peter Lorenzen, Karl-Heinz Lust, Wolfgang Menz, Herbert Reichl, Reiner Wechsung, Helmut Wurmus, and many more persons in science, industry and politics have joined their efforts and involved themselves in the making of a new technological field with profound economic impact.

German research landscape - a base for industrial innovation
Industry can rely on a well-established research infrastructure related to microsystem technologies in Germany. Basic research is carried out in the so-called "Sonderforschungsbereiche" of DFG, the German Research Association. There is a long and strong research tradition in physics, materials and electronics, setting up a broad source for applied research at Max Planck Institutes and Universities. The University of Freiburg holds the largest faculty of microsystem technologies in Germany with a focus on design and micro fluidics. Other Technical Universities with broad competences for microsystems are those in Berlin, Hamburg and Munich. The Karlsruhe Research Centre of Helmholtz Gemeinschaft represents the largest facilities for both basic research and application-oriented developments as well with particular abilities in LIGA technology and non-silicon materials. Several institutes of Fraunhofer Gesellschaft are also involved in silicon and polymer microelectronics and microsystem technologies and their applications, covering the whole spectrum of materials and technologies. Their core competences are bundled in the Fraunhofer Microelectronics Alliance. Furthermore there are independent and/or commercial research institutes as for example the Hahn Schickard Institute for Microtechnologies in Villingen-Schwenningen and the Institute for Microtechnologies in Mainz. Altogether more than 50 universities and technical colleges do research and teaching in this important key technology area. With the introduction of vocational training for the professional profile of a microtechnologist and the academic course of microsystem technologies, important contributions were made to raising qualification and employment standards in the field of MST.

MST - the invisible revolution in German industry
German industry is profiting from core competences in microsystem technologies that have been developed over a long period of time: the development, manufacture and use of complex systems. The industrial motivation to deal with MST was the result of opportunities of exploitation offered by new and renewing markets. Thus the automotive sector was the main MST technology driver in Germany. Large enterprises like Siemens, Infineon, Robert Bosch, Daimler Chrysler etc. started their own research and development in the early nineties and they have coped with this issue up to today. Particularly micromechanics profited greatly from sensor developments as for airbags and electronic stabilization systems in vehicles. Following in the footprints of the "big shots", a number of small and medium enterprises achieved economic success with microsystems. Most of them serve as sub-suppliers, and they capitalize on the established applications of MST in the sectors of automotive, machinery and plant industry, automation and processing and medicals. In recent years a growing number of start-up companies have come into being. They supply dedicated microcomponents for niche markets and some of them are about to launch new applications, for example in the biomedical sector or in the field of chemical processing. Chemical processing represents a conventional and well-established industrial sector in Germany that enjoys the prospect of a new phase of renewal and innovation initiated by the application of microsystem technologies.

It is expected that this positive development of MST markets will continue. A 2002 survey [1] conducted by VDE, the German Association for Electrical Engineering and Information Technology, showed that MST is ranking foremost for industry in terms of its innovation potential. This study was conducted among more than 300 experts from industry and science and it pointed out that by 2010 key technologies like microsystem technologies will strengthen both new industries and traditionally important industries and business locomotives. Important factors for the successful realization of this industrial value-added potential will be a high application-oriented R&D process as well as high efficiency and reliability in the manufacture of microsystems. These results are corroborated by the present VDE-survey [2]. Microtechnologies - among others - will exert a high influence on innovation dynamics in traditional industries in the future.

In 2003 German industry generated sales worth 4.2 billion Euros with MST components and complete microsystems. Microsystem technologies are increasingly gaining in importance for the industrial net product and macroeconomic development in the Federal Republic of Germany. The production of components for microsystems employs more than 49,000 persons. All together, more than 680,000 jobs depend on microsystem technologies in Germany. And Microsystems are a key factor for strengthening the competitiveness of industrial sectors relying on MST applications.

The world market for complete microsystems is estimated to be about 50 billion US $, and German industry contributed a share of 8.4% to the world Market for complete microsystems. The United States, Japan, Germany and, depending on the special application fields, our European partners are the leading suppliers of microsystem technologies. It is expected, that the innovation potential of European Industry will increase significantly. In particular France, Switzerland, the Scandinavian countries, the Netherlands and Great Britain have engaged in R&D related to microsystem technologies. German research and industry is involved in a large number of international projects and has proved to be a strong and reliable partner for international co-operation. Developments in Germany have demonstrated the potential of MST for the renewal of traditional industries and the formation of emerging High Tech clusters. These competences of companies and research institutes are the basis for further innovations and the establishment of new international networks of partnership.

References:
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[2] VDE Technologie Barometer 2004. Frankfurt 2004.

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Microsystems for Automotive Industry

Sven Krueger, Roland Müller-Fiedler, Stefan Finkbeiner and Hans-Peter Trah

Microsystems also means automotive industry. The German automotive industry heavily relies on innovation and quality. MST sensors and actuators are the basis for machine perception and advanced closed-loop controls. RTD institutes, suppliers and OEM are perfectly organised to meet costumer demands - the success of German cars proves this. Especially the automotive industry offers established market introduction patterns and also willingly invests in promising technologies.

A success story

During the past two or three decades, we have witnessed a tremendous progression in automobile technology. Present-day cars exhibit a variety of features in which they vitally differ from their predecessors that left factories only a few years ago. Many of these innovations are, perhaps, not noted by the end customer at first glance. On the one hand, the outward appearance of passenger cars primarily reflects contemporary fashion and taste. Adaptations are required by ongoing efforts to further reduce fuel consumption by decreasing the air resistance on the other hand. So in order to find out about the real technical revolution, we have to look more closely under the hood or behind the interior panelling.

Modern cars comprise numerous electronic functions enabling novel approaches towards the ultimate ambition of safe, clean and economic automobiles in the near future. Therefore, innovative technical approaches aim at least at one of the three most important vehicle systems - safety, motor management and comfort. The tremendous pace of technical progress that lies behind us was facilitated by the achievements of microelectronics in a fruitful symbiosis with the emergence of microsystem technologies. All these achievements rely on the availability of accurate measurement data representing the actual condition of the driving situation, power train, engine load and vehicle environment. This is where microsystems, and predominantly microsensors, come into play.

Microsystems applications have become commonplace for automobiles: they enabled the introduction of a series of new functions and at the same time the replacement of existing technologies with MST-based devices offering improved performance and better value for money. In spite of the enormous progress made to date, the results achieved only mark the beginning of a revolution in the vehicle sector, which implies a complete transition from the mechanically driven automobile system to a mechanically based but ICT-driven system as part of a likewise complex environment.

Microsystems are indispensable for fulfilling customers ambitions, and in many cases they are the drivers and pacemakers for new developments. Today an average car comprises more than 50 sensors and in the luxury segment more than 100 sensors, roughly 1/3 might be based on microsystem technologies. Examples of these systems can be seen in figure 1.

The automotive industry and microsystems technology are closely tied together. However, the deployment of microsystems in the passenger compartment or under the hood of a car imposes harsh environmental conditions on components and systems: They have to endure temperatures from -40°C up to 1100°C, pressures up to 2000 bars, thermal cycling, humidity, salt spray as well as vibrational and shock type load. Time spans, e.g. for side airbags, as short as 20 ms are required, and a failsafe operation (i.e. failure rates of less than 10^{-9}) has to be guaranteed during the entire lifetime, which typically extends to 15 years. But car designers appreciate the small size, the light weight, the ability to perform a self-test and, most important, the low price of microsystems sensors and actuators.

More than 700,000 people work in the German automotive industry. About 5,500 suppliers contribute to the success of German cars. Their world-wide reputation is based on innovation and quality, and microsystems contribute to these values. A well-balanced automotive industry network is the source of ongoing success. Brands like BMW, DaimlerChrysler, Volkswagen and Porsche to start with the original equipment

System	Abb.	Sensors			
Distronic	DTR	3	Common-rail diesel injection	CDI	11
Electron. controlled transmission	ECT	9	Automatic air condition	AAC	13
Roof control unit	RCU	7	Active body control	ABC	12
Antilock braking system	ABS	4	Tire pressure monitoring	TPM	11
Central locking system	ZV	3	Elektron. stability program	ESP	14
Dyn. beam levelling	LWR	6	Parktronic system	PTS	12

Figure 1: Car functions and the respective sensors (source: based on DaimlerChrysler)

manufacturers stand for German engineering. Tier-one suppliers such as Bosch, Siemens VDO, ContiTech, ZF or Hella provide a reliable source for new ideas including MST. But the backbone for fast and flexible reaction on the ever-changing customer demands are the hundreds of small- and medium-sized enterprises, delivering all kinds of systems and components and coming up with innovative solutions. Companies like Micronas, Sensitec, FST, IBEO and IC-Haus are examples. Finally research institutes and organisations such as Fraunhofer (with 57 institutes e.g. IZM, ISIT and IFAM), HSG IMIT or technical universities like, for example, TU Berlin and TU Chemnitz greatly contribute to the automotive competence found in Germany. Therefore, Germany has all the key players for developing and manufacturing outstanding products throughout the entire supply chain.

Robert Bosch GmbH - the leading German supplier

Bosch develops and produces a large variety of sensors for automotive applications. Its product portfolio is currently based upon four preferential technologies:

- Ceramics and thick film technology for exhaust gas sensors, operating at very high temperatures (lambda probe)
- Magnetic sensors (wheel speed, steering angle)
- Thin-film sensors (high pressure)
- Micro sensors

The introduction of micro sensors by Bosch started with the market launch of the low-pressure sensor, manufactured in bulk micromachining. **Pressure sensors** certainly constitute one of the killer applications for microsystems in automobiles. Low-pressure sensors are needed for instance to gauge the absolute barometric air pressure. Manifold absolute pressure sensors (MAP) are also employed in the air intake manifold, where they measure the engine load by detecting the sub pressure as well as the turbo charge pressure. Silicon pressure sensors can either be based on the piezo-resistive effect or on a capacitive principle in order to transduce pressure into an electrical output signal. Figure 2 shows a photograph of the bulk micromachined pressure sensor. A thin membrane is shaped out of a 6" silicon wafer, the thickness of the membrane being defined by an electrochemical etch stop. The membrane carries four diffused piezo-resistors, forming a Wheatstone bridge.

Figure 2: Manifold absolute pressure sensor (MAP)

On internal combustion engines, the mass ratio of air and fuel in the ignited mixture strongly determines the amount of uncombusted fuel as well as the emission of pollutants such as NO_x and CO. The precise air/fuel ratio information is the key to facilitating the most efficient operation of a three-way catalytic converter. Consequently, the exact metering of the aspirated air mass is another salient parameter to gauge the engine load. In 1995, Bosch launched a micromachined **hot film mass air flow sensor** as the second important micro device within the application field of engine control. The sensor (figure 3) comprises a thin dielectric membrane with a heating element in its centre and two flanking temperature sensors.

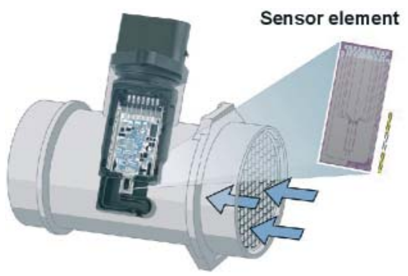

Figure 3: Micromachined hot film mass air flow sensor

While the current generations of the pressure sensor and the mass air flow meter are based on bulk micromachining, Bosch employs surface micromachining for the manufacturing of its inertial sensors. A well-defined sequence of depositing and patterning thin layers of polycrystalline silicon as a functional material and silicon dioxide as a sacrificial layer facilitates the precise shaping of movable beams. **Acceleration sensors** are certainly front-runners in terms of manufacturing quantities. They constitute essential components of vehicle safety systems such as passenger protection (air bag inflation, belt tensioners), ABS and ESP. Bosch launched its first acceleration sensor based on surface micromachining for restraint systems in 1997. Equally important members of the family of inertial sensors are **angular rate sensors** or **gyroscopes**. They measure rotational motions of the vehicle about the vertical axis (yaw rate) or the longitudinal axis (rollover). In interaction with acceleration sensors they provide the necessary data to take proper measures in the event of skidding to redress the situation by applying an appropriate braking force to individual wheels. Most angular rate sensors are based either on the Coriolis effect or on the conservation of angular momentum. Figure 4 shows a yaw rate sensor for rollover detection.

Figure 4: Yaw rate sensor in surface micromachining

New functions for ESP and future vehicle stabilization systems demand innovative concepts for the sensor system architecture. Future complex functionalities with cross-system applications will require intelligent sensor platforms that sense all the relevant parameters and then calculate the vehicle dynamic parameters in a common control unit. A large variety of new applications for microsystems will originate from innovative driver assistance systems needing **predictive sensors**. With the introduction of advanced camera systems, radar technologies and powerful communication devices, a wave of new vehicle functions such as lane keeping assistance, lane departure warning, automatic parking, automatic stop and go, emergency braking or intelligent light will become commonplace. A major challenge will be the combination and integration of diverse sensors for multiple measurands in a common architecture and the development of intelligent concepts for data fusion. The vehicle becomes an intelligent tool and partner for transport and entertainment.

For Bosch, the **story of microsystems** proved to be a real success story. At the end of 2003, Bosch celebrated a double achievement: the 300 millionth sensor in microsystem technologies and the 150 millionth micromechanical acceleration sensor came off the production line. In 2004, the total quantity of microsensors shipped to the customers was about 85 millions. Bosch produces all these sensors in Germany.

In its nearly 120 years of company history, Bosch has always been a global player. But even in times of an ever-increasing importance of global markets, Bosch is well aware of its German roots. The chairman of the board of management, Franz Fehrenbach, gave a clear commitment as regards Germany as a research location. He pointed out that in R&D-oriented business sectors, Germany can readily hold its ground in international reputation, as long as German companies retain and further enhance their innovative strength and apply it to new products and efficient processes. Bosch has increased its total expenditure on research and development in the space of four years from 2 to 2.6 billion euros, which corresponds to 7.3% of sales, and two thirds of our associates in research and development work in Germany.

There are several points that are crucial to promote Germany as a research location for a company in the automotive business:

- The German automobile industry runs strong. A remarkable fraction of the renowned car manufacturers is located in Germany, in particular with respect to vehicles in the premium class.
- Germany has a highly educated population and skilled engineers are readily available. Our universities produce some 70,000 engineers with every graduation.
- Germany has several research institutions with highest international reputation: Max Planck Society, Helmholtz Society, Fraunhofer Society.
- The German automotive market is highly receptive to technological innovations. While in many other areas a lower price is often the better sales argument, German customers in many cases willingly accept new technical features, in particular those related to safety systems.

Germany is still a world leader in basic research in a number of important fields. For successful research and development Bosch relies on the regional industry clusters and its tight network of customers, suppliers, universities and research institutions that has evolved over many decades. Bosch's strong, deep-rooted tradition strengthens the bonds between the associates and the company, and gives customers confidence. According to the philosopher Odo Marquardt, although the new replaces the old, you can't have the one without the other. Therefore, starting from a solid fundament facilitates the takeoff to new ventures!

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Microsystems Technology - Innovation Accelerator for Automation and Precision in the Machinery Industry

Helmut Kergel

The machinery and engineering industry is the third largest industry in Germany (behind the automotive and the electrical engineering industry). Using international benchmarking, it ranks among the world's leading three countries, characterised by a high export share (> 70%) and high investments into research, development, and education, according to the German Engineering Federation VDMA. In 2003, 864,000 employees generated revenues worth EUR 132 billion (HANDELSBLATT Oct. 15, 2004), dominated by small- and medium-sized enterprises with less than 250 employees (= 85% of all enterprises). As the machinery industry is structured along the value-added chain of

- parts and components supplier
- integrator of complex machinery in various application areas
- design and construction of complete factories
- technical and engineering services,

interest in microsystems technology is not found throughout the whole spectrum of the machinery industry.

Although the machinery industry is a very innovative sector, microsystems technology was seen as a rather secondary innovation field for a long time. It was, however, anticipated that sectors can be identified where the strong German positions in microsystems technology can be linked to classical innovation fields of the machinery industry. A systematic approach evaluating these prospects was started by the German Federal Ministry of Education and Research (BMBF) back in the early 1990's. Today, microsystems technology is well known as an important innovation sector in many engineering areas.

Providing intelligence to machines

Within the machinery industry, continuous trends towards increased process reproducibility and productivity through automation can be observed: printing machines (Heidelberger Druckmaschinen AG, and others), textile production machinery (Lindauer Dornier GmbH, and others), (electric) motors (Dr. Fritz Faulhaber GmbH & Co KG, Wittenstein AG, and others), pumps (KSB AG, Wilo AG, and others), and a large variety of other subsystems (Christian Bürkert GmbH und Co. KG, Festo AG & Co. KG, and others), to mention just a few segments. Serving these trends requires making continuous efforts to precisely determine machine and process parameters, directly at the process, in real-time, and in a cost-effective way, as a basis for automation. Especially for miniaturised machinery and components, the challenges are enormous. The availability of intelligent microsensors was therefore considered as a major issue for maintaining the high rank of the machinery industry within the global competition.

Intelligent microsensors have been considered as one of the key areas of microsystems technology from the early days of MST. The sensors industry in Germany, which is in a top position worldwide and is well prepared to suit the needs of the machinery industry, is based on traditional technology and precision mechanics. During the last decade, this industry has linked this traditional expertise with microelectronics and microsystems technology. The German sensors industry today consists of 600-700 sensors manufacturers, again mainly small- and medium-sized enterprises, generating an annual revenue of EUR 8-10 billion, and has had annual growth rates of almost 10% over the last decade, according to the Association for Sensors Technology AMA. Companies like AKTIV SENSOR GmbH (pressure sensors), Sensitec GmbH (magnetoresistive sensors), SICK AG (optical sensors), and many others are building up an agile industry structure, assisting the engineering industry by providing specific sensor solutions.

Due to limitations in lot sizes for the frequently very custom-specific products in the machinery industry, and due to limitations in (human) resources of these companies, a lack of microsystems-specific know-how and rather high costs for custom-made sensor solutions often hinder the successful application of advanced microsensors and microsensors networks. Therefore, the availability of adequate individual sensor solutions in a competitive price range is a general problem that has to be overcome. Several approaches to the modularisation of sensors are being studied today, increasing the re-use of already developed subsystems or adapting components from other application areas. Progress in this field will enable the engineering industry to introduce totally new generations of machinery in the future. It will also strengthen the sensors industry, relying on their flexibility to supply custom-specific solutions.

Increased accuracy of machines and processes
Precision is another key issue of the machinery industry. It can be achieved by an optimised mechanical design ("traditional" approach), by totally new mechanical concepts, e.g. parallel cinematics ("radical" approach), or again by sensor integration ("ICT" approach). The integration of very precise measuring devices for critical machine functions has already been well investigated. The integration of sensor functions directly into tools, e.g. depositing sensor structures directly on a cutting insert for milling and turning, is a rather new method that today is not yet fully developed nor exploited. Funded by the BMBF, such approaches are under investigation by research institutes like WZL/RWTH Aachen, Fraunhofer IST, IPT, and IZM.

Having exact data on machine behaviour and process parameters allows the introduction of automated strategies to constantly readjust working points of the machine and the process. Closed-loop machine subsystems like vibration controlled high-precision spindles or self-adjusting bearings are common. Another example of such self-controlled processes can be found in industrial robots with integrated optical sensors, force-controlled handling of work pieces, and routines for self-teaching processes.

Conclusion
Mastering the "digital network" around the mechanics of a machine in a cost-effective and user-friendly manner is the key challenge to be coped with in the machinery industry. In this area microsystems technology will play a role of increasing importance.

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Microsystems Technology in the Field of Pneumatic Industrial Automation Technology

Volker Nestle

As regards pneumatic industrial automation technology, Festo AG & Co. KG is among the most innovative national and international enterprises. The versatile product lines provide a variety of items for most of the pneumatic applications worldwide. New or enhanced products, often novelties, are constantly being made available to the market. In doing so, product development focuses on market-driven and technology-driven innovation.

General trends in automation technology - smaller, faster, more intelligent - are used to decide about the importance of relevant technologies in the future. "Smaller" corresponds to power density, that is more power in less volume along with little weight. "Faster" refers to the attainable stroke and cycle times concerning the typical applications of pneumatics. "More intelligent" stands for an additional integration, e.g. sensors, processors and software, that provides further benefit and opens new application areas. These development trends demand an extreme miniaturisation that also applies to pneumatic drive engineering:

- Integrating Functions (from component to system):
  The integration of functions and the reduction of external interfaces are the focus of a series of current product developments in the area of industrial pneumatics. They aim at increasing customer benefit through advanced functionality and productivity concurrent to the simplification of installation. However, components are becoming more complex and are increasingly developing into integrated systems. The classical component provider is changing into a systems distributor.
- Increasing power density with decreasing required space:
  a good example is the highly complex equipment in printing machines, textile machines engineering and in the packaging industry with an enormous packing density and continuously increasing demands on reduced installation effort and consumption of resources.
- Miniaturisation of parts handling:
  In this context, assembly process lines are to be mentioned, e.g. in electrical engineering, sensor technology, watch industry, optics and medical technology. Micro and precision assembly technologies will develop expansively.

Using the technologies that are being adopted in the technology field of pneumatics, the aggregation of power cannot be improved and the cycle time cannot be reduced decisively. Therefore, Festo is intensely engaged

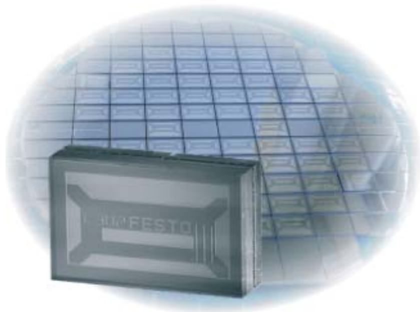

Figure 1: Micro valve in silicon micromechanics (source: Festo AG & Co. KG)

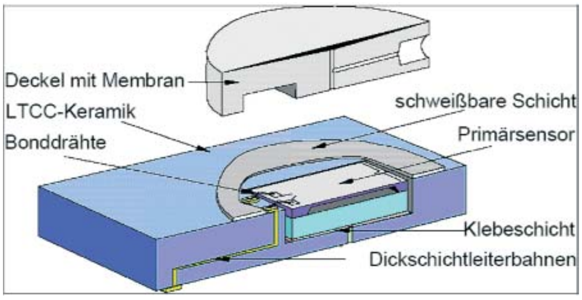

Figure 2: Idea of a modular pressure sensor (source: brochure microsystems technology: joint project MATCHDRUCK VDI/VDE-IT)

in optimising existing technologies and choosing new technologies, making them available and implementing them. Miniaturised technologies and microsystems technology are playing an important role. For example, the application of silicon micro mechanics for the implementation of micro valves in different research projects, in cooperation with a number of research institutes, is examined (figure 1). Furthermore, Festo participates in the development of modularly constructed, miniaturised, cost-saving and capsulated absolute, high and differential pressure sensors in industrial applications in rough environmental conditions (figure 2).

Festo has implemented product series based on construction kit principles for several years. The minimal structure is realised in so-called operational construction kits. In this way, diversified application areas can be served with acceptable development costs. The following examples show a selection of the manifold market segments that can be accomplished with these operational construction kits using miniature technologies:

- Miniaturised, controlled actuation (electrical, pneumatic) and highly integrated cylinder-valve combinations
- Micro valves and piezo-valves as pre-navigating valves and intelligent pneumatic systems
- Systems of handling and assembly technology with decentralised intelligence and the possibility of remote maintenance and remote diagnosis
- Sensors for the entire field of relevant measurements (pressure, power, distance, discharge) using new functional principles, e.g. optics or wireless techniques.

The technical and economic progress within pneumatic industrial automation technology is limited in dynamics and at the innovation level considering today's state-of-the-art technologies. However, the promising field of miniaturising technologies and microsystems technology is already applied to today's products and systems and will develop favourably in the future.

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RFID: Strong Position of German Companies and Research

Peter Gabriel

RFID (radio frequency identification) is a well-known and robust technology for communication between a transponder attached to a physical object and a stationary reader. Almost all analysts predict a strong market growth for RFID systems. The research company Frost & Sullivan forecasts a market volume of 11.8 billion US$ in 2008. While for traditional RFID market segments, security and access control, public transportation, animal tracking, and toll systems further growth will slow down, a boom is expected in the asset tracking segment. The driving forces will be retail logistics, manufacturing logistics, and, in the USA, military logistics.

A number of retailers have already started RFID pilot projects, in prominent place the German retailer Metro AG. The constant tracking shall reduce stocks, prevent sold-off shelves, and shall help to monitor the transport of perishable food. Additionally, the German high-volume automotive industry is interested in such systems, allowing a more decentralized production control.

Germany is not only one of the most active users of RFID technology. RFID technology is posted forward by a great number of German companies and research institutions.

Industrial Activities in Germany
The sub-segments of the RFID market are quite different from each other: While silicon chip production is dominated by a few large semiconductor manufacturers, manufacturing machines, inlays and readers are produced by a large number of small and medium enterprises. German enterprises have strong positions in most of these sub-segments. Moreover, as in mechanical engineering, German SMEs are often at the forefront of RFID technology development. A prominent example is Microsensys GmbH, which developed a coil-on-chip design for small-sized transponders.

Figure 1: Many German RFID vendors participate at the METRO pilot project

In the German-speaking countries Infineon AG is the only manufacturer of smart label chips. The company operates the "RFID solution excellence centre and system lab" in Graz (Austria). A small number of German companies - some of them subsidiaries of US-based firms - provide smart label inlays, among others: Checkpoint Systems GmbH, ExypnoTech GmbH, Fleischhauer Datenträger GmbH, and X-ident technology GmbH. Germany has a very strong position in smart label manufacturing machines: Besides the market leader Mühlbauer AG, suppliers like bielomatik Leuze GmbH & Co. KG, F&K Delvotec Bondtechnik GmbH, and Robert Bürkle GmbH are active. Adhesives are most important materials for smart labels since they connect the chip to the antenna. Important German vendors in this sector are the US-based 3M Deutschland GmbH and DELO Industrie Klebstoffe GmbH & Co. KG.

RFID readers are provided by many medium-sized companies, often with a background in industrial automation. Typical vendors are Leuze electronic GmbH & Co. KG, Baumer Ident GmbH, Balluf GmbH & Co., ICT Integrated Control Technology GmbH, EUCHNER GmbH & Co. KG, and Pepperl+Fuchs GmbH. However, there is no clear distinction between equipment manufacturers and system integrators, since some equipment manufacturers also implement complete identification systems for their customers. The RFID system integrators originate at least from three different branches: vendors of process automation like MOBA Mobile Automation AG, providers of logistics systems like the Schreiner Group GmbH & Co. KG, and IT consulting firms like SAP AG. Although there are over ten German label printer manufacturers, only Feinwerk- und Drucktechnik GmbH has established itself as a vendor of smart label printers.

Scientific Activities in Germany
Overall, German scientific institutions are among the European top players in smart label development. Very many disciplines of microsystem technologies contribute to the development of smart labels: among others, packaging, sensor technology, autonomous power supply, and the integration of electronics in textiles and flexible substrates. Therefore, a great number of well-known microsystems technology research institutes therefore are involved.

The basic research project AVM (autarkic distributed microsystems), supported by the German Federal Ministry of Education and Research (BMBF) and coordinated by Fraunhofer IZM, aims to provide the technological foundations for the next-generation RFID systems, the sensor networks. An additional activity is based at the University of Bremen, described in the following article.

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Intelligent RFID in Logistics - Identification and Beyond

Walter Lang, Bernd Scholz-Reiter, Thorsten Philipp and Reiner Jedermann

Radio Frequency Identification Devices (RFID) have so far been deployed in many payment and security systems. In logistics applications, conventional identification systems like barcodes are now starting to be replaced by RFIDs as well.

The radio frequency of RFID procedure is based on resonant circuits adjusted to a defined resonant frequency. For communication, RFIDs use the principles of magnetic fields and electromagnetic waves. The range of communication depends on the frequency and on the RFID type (active or passive tags). Furthermore, it is a non-contact method that has a higher speed of identification and does not require an exact position of the object in comparison to traditional autoidentification technologies. RFIDs may also include the use of memory in the transponder (with read/write capabilities) and the simultaneous reading of multiple tags. Information can then be administered and stored directly on the transported object, which would lead to automation possibilities through the whole value added chain. Distribution is becoming decentralized and no longer coupled to merchandise management or inventory control.

The application of RFID in the identification of goods in logistics is not directly visible, compared to other applications of smart cards like bank cards, pay cards, etc. Logistic applications are often confined to the transportation industry. In a few years, however, RFID tags will be common in retail stores.

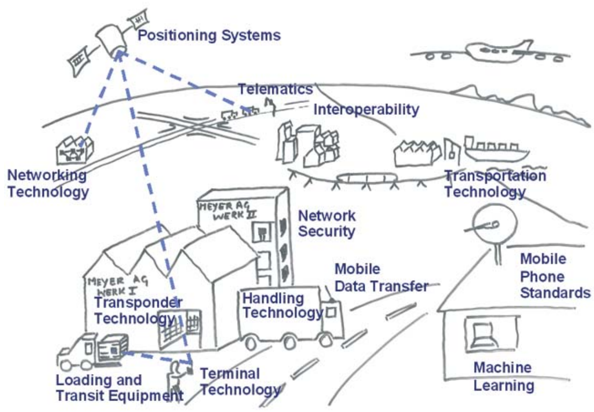

Figure 2: Technological Trends

An example of an RFID application in logistics was implemented by EURO I.D. Identifikationssysteme GmbH & Co. KG. for the administration of pallets for inventory control. The system was configured with tags that are detected by readers. These tags are, for example, integrated into delivery ramps. When the pallets are loaded they are analyzed and the delivery trucks are routed to the appropriate customer. This system allows not only inventory control, but also static analysis and capacity optimization. In the near future, the system will also be expanded and used for the planning and control of repairs.

One problem that is currently being examined by many research groups world-wide is the monitoring of containers. Intelligent RFID systems should monitor critical parameters during transport. However, this does not require the RFID system to be equipped with sensors. It could also be configured as a sensor system that is already in the container or directly on the goods, being queried in a wireless manner. In the future, a completely automated system that controls the transport process is imaginable. The container could sense the individual goods that are loaded, for example bags of coffee. From the internet or through a database, it loads information for the temperature and air humidity restrictions to be met. It then polls for sensors, to see what is available and constructs an ad-hoc network tailored to monitor the coffee (see Figure 1).

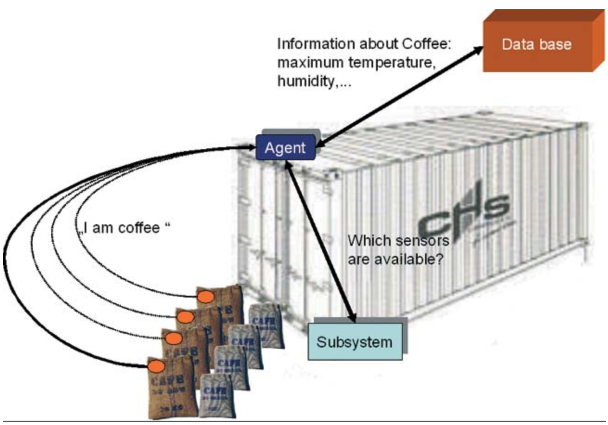

Figure 1: Monitoring of Containers with Sensor Technology

Such a system cannot only measure and store specific values, it can additionally comprehend critical situations. For example, it could notify "turn on humidifier" when the humidity drops below a critical level. It could also intervene and redirect the containers in real time.

The autonomy of the logistic goods (such as cargo, loading equipment, and transport systems) is made possible through new information and communication technology, such as RFID and other technological developments (compare to Figure 2).

This enables and demands new control strategies and autonomous, decentralized control systems for logistic processes. Advanced systems of this kind are investigated at the University of Bremen through the Collaborative Research Area "Autonomous Cooperating Logistic Processes: A Paradigm Shift and its Limitations" (Sonderforschungsbereich SFB 637) funded by the German Research Foundation (DFG).

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Microsystems in Communication Technology

Rainer Heinstein

The transmission of data and messages in the close-up range of persons gains more and more importance. WLAN technology is one of the most important network developments of the last few years. This is also true for the licensed ISM standards (2.4 GHz). Currently lots of research and development activities are going on to satisfy the different user requirements in terms of security, data rate, IP's, RF-power, etc. An increasingly important standard is WPAN (wireless personal area network), using technology for short range communication within 10 meters. A well-known example is Bluetooth (IEEE 802.15) with operating frequencies at around 2.4 GHz in digital modes. A WPAN connects all the ordinary computing and communicating devices that many people have on their desk or carry with them everyday - or it serves a more specific purpose such as allowing the surgeon and other team members to communicate during an operation.
WLAN- and WPAN-devices, miniaturized by MST, are easily integrated in system environments such as laptops, pagers, consumer electronics, PDA's, etc. These devices are highly integrated analogue and digital circuits, containing D/A-A/D converters, RF power-amplifiers, signal processing units and other components. New generations of WLAN / WPAN-devices are complete systems on a single silicon chip.
Beyond WPAN there are considerations that deal with networks even inside and on the human body (body area networks, BAN). The former serve primarily medical purposes (monitoring of patients). In the future, Body Area Networks (see the example in figure 1) will be increasingly important. Especially all types of monitoring of biometric data are relevant. Furthermore, the area of wearable computers, i.e., the integration of microelectronics and MST in textiles, will gain further significance. Thus, clothes (see jacket with integrated mp3-player by Infineon), home textiles (like the carpet with sensor technology, by Infineon) or linen (with embedded labels from Fraunhofer IZM) are moving into the centre of attention as new applications.
It can easily be understood that the challenging needs of WLAN-, WPAN- and BAN technology-based applications, in particular the high requirements concerning miniaturization, low power consumption, sufficient RF-power, high functionality etc., make the application of microsystem technology indispensable.
WLAN, WPAN and BAN technology and devices bear major market and growth potential for the German industry. Forecasts for the involved markets in Germany predict a growth of 2.5% for 2004 up to a total volume of approx. 131 billion. In all of Western Europe it is expected to increase by 3.1% up to 611 billion during the same period. The basic drivers of growth will be telecommunication services. Digital consumer electronics will be top-ranked with an assumed growth of approx. 16% up to 29 billion. Due to steady progression in the introduction of UMTS, mobile services will emerge.

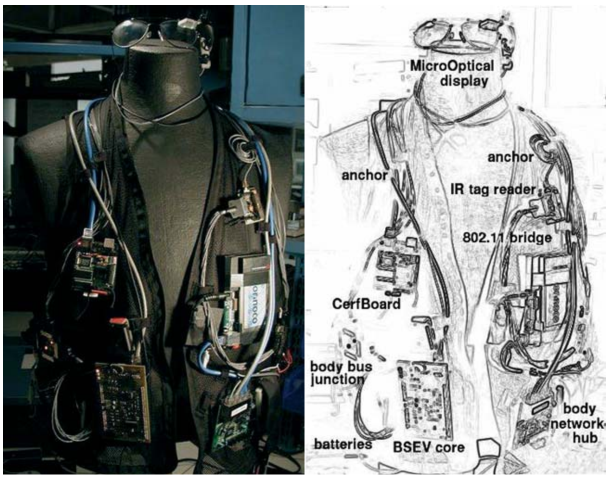

Figure 1a and b: Example of a Body Area Network with components; source: MIThrill at www.media.mit.edu/wearables/mithril/

Germany has a leading competitive role in the international fields of WLAN components and their applications. In 2003 the turnover of WLAN components increased by 70%. By the middle of 2004 the number of public "hotspots" in Germany had increased to more than 2,500. German enterprises are developing countless application-specific hardware and software solutions for industrial use with a steadily increasing share of bluetooth technology. In 2006 sales of bluetooth chips are expected to exceed the amount of 1 Mio, while - to mention this too - the chips are mainly manufactured in the U.S.

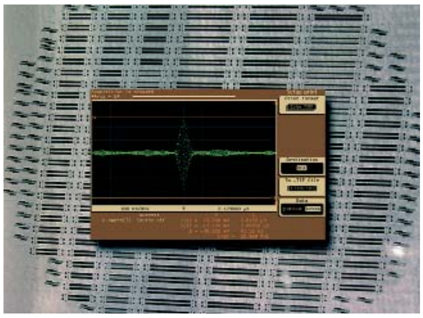

Figure 2: SAW chip as a basic component for spreading und dispreading of RF signals and the meas-ured autocorrelation function

In the development of wireless network components a great number of German small and medium-sized enterprises are involved, as well as renowned research institutes and universities. Quite often small firms especially show an excellent performance in developing and implementing new microsystems solutions for wireless applications. For example, the teleBITcom GmbH in Teltow near Berlin provides the market with its "SAWAS Technology" (Surface Acoustic Wave Autocorrelation Spread Spectrum) for disturbance-free transmission of data as well as video and audio signals in ISM band. Figure 2 shows the "core" of the system: A surface acoustic wave (SAW) filter implemented by a micro-structured ceramic body.
A particular feature of SAWAS is the ability of tap-proof transmission of high amounts of data at a low signal strength. More information is given at www.telebitcom.de

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Smart Home

Hartmut Strese

The "Smart Home" has been a dream for generations. Today features like an intelligent oven equipped with sensors monitoring the baking process, speech-controlled appliances, or an autonomous vacuum cleaner are, or at least could be, easily available. The intelligent devices used in such systems often utilize microsystems technology.

At first glance, it is not necessary to apply microsystems in this area, as there are not any restrictions as to size and weight like in the automotive sector. However, hidden in many (even small) appliances, there are (micro-)sensors integrated, measuring temperatures, gas concentrations, smoke, light, pressure, moisture, breaking of glass, etc. Small actuators can activate valves for optimized heating, switches for lights, and mechanisms to open and close windows depending of the weather. Besides sensors and actors, communication is an important part of the smart home. Today, cable-based communication is standard. However, radio-controlled solutions are emerging. It is expected that these solutions will increase exponentially (see Gabriel, page 14). Easy installation in an ambient network will allow nearly unlimited opportunities.

The market for smart homes or at least smart features in the home is not easy to determine. Frost & Sullivan publishes the following figures: The world market for intelligent home automation systems for the private home is estimated to reach 399 million US$ in 2009 (as against 173 million US$ in 2002). This is minor compared to the general market for Building Automation (USA and Canada: 12.4 billion US$ in 2003, estimated at 21.2 billion US$ in 2009). However, it should be realized that approximately 250 million home appliances are sold in Europe every year, which is equivalent to an annual turnover of 35 billion EUR, according to statistical data by the EU. These figures indicate the potential for smart solutions, offering new functionalities for energy conservation, safety, and comfort.

There are several companies in Germany dealing with the development of microsystems for the home; only some examples can be listed here. EnOcean GmbH, a small young spin-off company of Siemens AG, is developing light switches that use radio communication and can be installed at any location, not requiring any wiring. The switches generate the energy for sending a signal to the device to be switched by the mechanical pressure applied during the switching process. Busch-Jaeger Elektro GmbH developed a new and very flat generation of presence and movement sensors using new research results in micro-optics. Smart watering systems by Gardena AG support gardening. Miele & Cie KG integrates sensor devices into washing machines to increase the quality of the washing process. Infineon AG has introduced a prototype of a smart carpet, where pressure sensor arrays have been integrated into the fabric for identifying moving or lying individuals. A group of companies including Siemens AG is developing a smart window. This window is able to close automatically when rain is detected. It opens, however, when detecting an elevated CO_2 concentration. The small company, Robowatch technologies GmbH, sells a robot to be used for the automatic detection and identification of individuals in a building. Fraunhofer IPA has developed a prototype of a window-cleaning robot and is planning a production in the near future.

"Ambient Assisted Living", an initiative of VDI/VDE-IT and others, aims for concepts for the introduction of a smart home environment, supporting especially elderly and disabled people to maintain their autonomy of living in a safe and secure way. Ambient in this context should be understood as hidden complex technology, assisted expresses assistance, by technical devices as well as by technical or human services.

Several research institutes in Germany, universities and institutes of the Fraunhofer-Gesellschaft and others are active in developing and presenting technological advancements in this area. Some of them demonstrated their results within "smart homes" open for a visit, for example: inHaus in Duisburg (inhaus GmbH, Fraunhofer IMS), tele-haus (University of Munich), and FutureLife in Hünenberg, Switzerland.

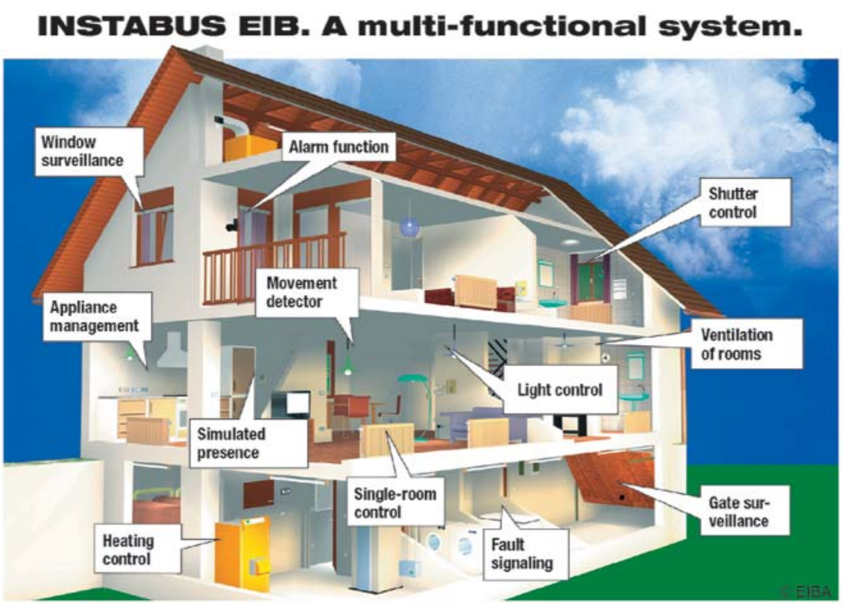

Figure 1: INSTABUS EIB application model

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Microsystems in Environmental Technology Applications

Marc Bovenschulte and Helmut Kergel

Environmental technology is concerned with all technical means that reduce adverse environmental impacts in industry, trade, private households and public institutions. Important goals are sustainable production, preservation of resources (material and energy) and decrease in and/or avoidance of pollution. The protection of life and nature from the harmful and negative side effects of industrial production is a key element of environmental technology. In this area, sensing and regulation technologies are found as well as filtering and re-creation techniques. Especially the concept of integrated environment protection outlines the aim to avoid pollution instead of using end of pipe technology to collect and handle toxic and hazardous waste. Microsystems technology can contribute at many points of this broad industrial sector.

Germany is a worldwide leading player in environmental technology, ranging from integrated environment protection via analysis to recycling technologies. Based on a national system of rigid regulation policy with low threshold values and tolerance, the need for advanced technology in this field is "traditionally" high. Combined with an outstanding capability in microsystems technology, Germany's research units and companies are strong, innovative and reliable partners when it comes to protecting our environment and providing sustainable development.

The effort to protect the environment and to avoid serious damage needs reliable means to monitor and measure a variety of critical parameters that are used as direct or indirect indicators of a harmful shift. Using metal-oxide based sensors as offered by UST Umweltsensortechnik GmbH and Paragon AG and advanced microspectrometers as sold by Boehringer Ingelheim microParts GmbH, microsystems technology offers a broad platform to detect distinctive substances in gas, liquids or solid state material. The development of multisensor-array systems like Webnose® (Fraunhofer-Institut Physikalische Messtechnik) or KAMINA® (Forschungszentrum Karlsruhe) made it possible to monitor complex processes resulting in a complex and variable signal pattern that represents characteristic phases. An example of the application of such a multisensor array using a microstructured quartz-surface is given in the corresponding article on the next page. Water quality control is another issue, where microsystems can make a contribution. As early as 2000, Laser-Laboratorium Goettingen e.V. introduced a prototype of sensor system based on fluorescence spectroscopy for in-situ measurements in ground water. Further developments are ongoing today and Analytik Jena AG is planning to introduce such a system into the market.

Figure: Battery operated tubular KAMINA module (diameter 32 mm, lenght 650 mm) for subsurface soil analysis integrated in electric hammer driven percussion probe, development funded by the Deutsche Bundesstiftung Umwelt (DBU, www.dbu.de) (source: Forschungszentrum Karlsruhe GmbH)

Another field for the use of microsystems technology for environmental analysis and monitoring, in relation to biomedical diagnostics, is the use of biohybrid systems, which combine bioactive components like enzymes or antibodies for specific detection with microstructured devices for signal processing: Making use of the fact that it is possible to raise antibodies against more or less every solid antigen, no matter whether it is of a biological, chemical or other origin, nearly any solid substance can be detected on the level of a macro molecule. The resulting binding process of antibody-antigen can be monitored and analysed. Such biohybrid systems as developed by ICB - Institut für Chemo- und Biosensorik GmbH - offer the advantage of an all-time sensitive and specific detection in complex liquid mixtures for low cost. This rather new area of bio-microtechnology will be discussed in two specific articles (page 22 - 23) in this issue.

Another example of microsystems technology that contributes to environmental issues is the area of chemical engineering. On the one hand, a large number of process and environmental parameters have to be controlled within a chemical plant to maintain stable and safe processes. On the other hand, microsystems technology itself can be used to set up a chemical micro plant, allowing totally new processes (for instance allowing extremely exothermic processes in a controlled matter). This rather new field of micro process engineering is described in the article by Ute Ackermann (page 20).

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Continuous On-line Odour Measurements

G. Horner and P. Boeker

In a significant number of municipal and rural areas of Europe (and all over the world), the quality of living suffers due to odour nuisances from the sewer system. According to practical experience, efficient countermeasures are associated with high costs, which can add up to 50% the proportional sewage tax budget. The identification of problem areas, as well as the optimisation and preservation of evidence of countermeasures is a specific goal of the current development.

Until now, from a methodological viewpoint, the state of the art has been too simply structured around the supposed analogy to the sense of smell, with an array of gas sensors and electronic pattern recognition. The conditions in odour monitoring, however, are different from the conditions in chemical monitoring. Odour sensing is less a chemically induced measurement process than it is a complicated, filtered information process via specific conditions of the atmospheric air. Chemically very similar substances can differ totally in their odour impression, but are recorded similarly by chemical measurement systems.

Frequent attempts were made to perform true odour measurements with 'electronic nose' type measurement systems. In doing so, either the basic methodological conditions were not complied with, or the constraints were not defined carefully. The described methodological defects can be attributed to the fact that the measurement systems have not, as yet, been suitable for long-term use, because for the investigation and mapping of different odour states, long measurement sequences are required in any case. In laboratory operation of sensor systems, satisfactorily stable performance can be achieved with reference measurements and recalibrations. In continuous measuring operation under harsh conditions, other methods must be used. The various different sensor types have different degrees of susceptibility to drift and ageing.

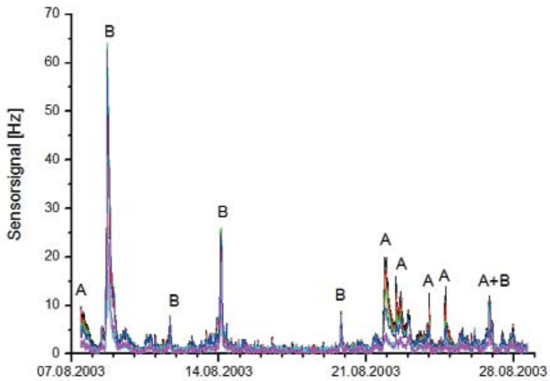

Figure 2: Time slice of three weeks (out of three months) of sewage canal measurements in Vienna. High emission peaks could be assigned to certain odour patterns.

The fact that odours, particularly in complex and highly variable sewer systems, cannot be detected exhaustively by the measurement of leading parameters (e.g., H2S) has led to the development of Quartz Microbalance Sensor (QMB) arrays by specific sensitive polymer phase coatings and an integrated sample preparation. In this sensor type, instead of a chemical reaction, only a physical absorption of gases into the sensitive layer occurs, which does not cause any irreversible changes. The long-term stability over months and years is therefore assured. For odour measurements, the preferential measurement of higher molecular weight substances is also important. Most odours fall into this region, up to 300 daltons, while some odourless low molecular weight components, such as methane and other hydrocarbons, cannot be measured by QMB devices, in contrast to other technologies. By using an unique integrated array of QMB sensors the actual sensor cell has a very small volume, which is ideal for the combination with thermal desorption. In this way, an expansion of the measuring capabilities can also be achieved, which can be used in the environmental measurement field to filter undesired components.

Figure 1: On-line odour measurements with OdourVector. The measurement system comprises a gas conditioning unit, a preconcentration device, the measuring cell and a signal evaluation unit.

Supported by the German Federal Ministry of Education and Science (BMBF), the odour measurement system OdourVector was developed by HKR Sensorsysteme GmbH (Fig. 1). Such system has already been used for several months in the city of Vienna. Fig. 2 shows the results of a long term measurement campaign monitoring sewage canal emissions. The measurement system will make a technical and economic contribution to odour control thanks to the following new possibilities:

- Objective identification and evaluation of problem areas
- Preservation of evidence of odour control measures
- Technical and economic optimisation of odour control measures
- Supervision of odour control facilities

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New Chemistry with Micro Process Engineering

Ute Ackermann

Introduction

Process Engineering is the industrial technology for the fabrication and treatment of solid, liquid or gaseous materials. Process Engineering combines unit operations like mixing, separation, heating, cooling and reaction in complex production facilities. For Micro process engineering unit operations are realized in structures having the range of microns. In these dimensions the coefficients of heat exchange and mass transfer are very high. Because of the small dimensions inside these structures, fluids can be heated or cooled very quickly or mixed very intensively. That means reactions can be controlled strictly and undesirable side reactions can be suppressed. Explosive and toxic substances can be controlled in a safer way. Microstructured equipment can be used as powerful tool for process development. New innovative process managements are possible.

The miniaturization of chemical processes means a paradigm shift. While established process engineering tends towards bigger and bigger plants because of the economy of scale, micro process engineering sets the trend to miniaturization in order to save cost by increasing efficiency.

Relevant areas of application are chemistry, pharmaceuticals, plastics, pigments, cosmetics, biotechnology and others. With chemistry, especially exothermic reactions are in the focus. First of all, expensive fine chemicals with small production rates (under 1000 t/a) are relevant. But there are also approaches for bulk chemicals where the impact of increased efficiency is high. With pharmaceuticals, especially the management of very small and costly quantities is the interesting point. For cosmetics, excellent mixing performance could lead to stable emulsions.

Presenting meaningful market data is not easy considering the emerging situation in this field. There is the PAMIR study, estimating sales for microreaction technology within the chemical industry at 40 million Euros in 2002.

Industry Platform and the Backbone Concept

In Germany there is already a lively community. Most of the players exchange experience via the industry platform micro process engineering at DECHEMA (www.microchemtec.de).

The industry platform has supervised the strategic project "Modular Micro Process Engineering". One of the results of this project is the so-called "backbone", a comprehensive modular construction kit for chemical processes.

Figure 1: The backbone system of the industry platform of DECHEMA

Micro process engineering in Germany

There are research institutes covering the entire range from fundamental to applied research with the option to establish start-ups. Some of the universities active in this field are the Technical University of Darmstadt, the University of Erlangen-Nürnberg, the RWTH Aachen, Technical University of Chemnitz, and others. Leading independent research institutes are the Institut für Mikrotechnik Mainz and the Forschungszentrum Karlsruhe with emphasis on hardware components and the Institute for Applied Chemistry Berlin-Adlershof and the Fraunhofer Institute for Chemical Technology in Pfinztal with emphasis on chemical reaction technology.

The capabilities for manufacturing microstructured components for process engineering can be found in research institutes and in a couple of enterprises with know-how in microsystem technology. Most of these enterprises are small- or medium-sized. Examples are mikroglas chemtech, CPC System, Little Things Factory and Ehrfeld Mikrotechnik BTS. Besides Atotech, a big company, offers an innovative soldering technology for CPU Cooler, which is also interesting for micro process engineering.

The business of plant engineering and construction is done by stronger companies like Siemens (formerly Siemens Axiva), Uhde and Lurgi, as examples.

Most of the users of micro process engineering belong to the process industries. It is assumed that nearly all big chemical companies in Germany are engaged in micro process engineering already, but most of them do not show that publicly. It looks like there is a silent race in integrating micro process operations. Prominent players are Clariant, Degussa, Merck, BASF, Bayer, and Schering, big players who are going ahead. Beyond them there is a big potential of medium sized-chemical industry still untouched by microtechnology.

Public promotion and funding

In spite of the evident advantages of micro process engineering, there are still innovation barriers. A crucial innovation barrier is the lack of acceptance by decision-makers. This lack of acceptance may be due to the short experience with realized plants in an industrial environment and corresponding economic considerations. At this point public assistance comes in. The Federal Ministry of Education and Research has emphasized micro process engineering in the framework of the "Microsystems" programme. In this context a couple of industrial projects are being prepared at present. These projects will realize model processes.

The following article from industry gives a short survey of the application field and some exemplary developments.

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Micro Process Engineering in Germany

Thomas Bayer

MST in Germany
Over the last 15 years, substantial research on microstructured devices for chemical applications on lab and pilot plant scale has been undertaken in Germany and established a solid scientific basis for the fabrication and analysis of individual units.
Components with structural features in the range of microns to millimetres ("microstructured objects") are now readily available in a wide variety of chemically resistant materials, such as glass, stainless steel, ceramics, polymers, alloys and graphite (and no longer only silicon). These new microstructured objects offer stimulating prospects for the development of a new generation of highly original process components and systems for chemical application, which can be exploited to significantly improve the quality, safety and effectiveness of industrial production. But until today these devices have rather been of a prototype character than having the status of a commercial product.
Despite all these efforts, developments have been dominated by a "technology push", and, on the part of chemical producers, there has, so far, not been any significant or systematic "market pull" worth mentioning. Within the last few years R&D work by the chemical companies Degussa and Clariant has slightly changed this view.

Figure 1: Pilot plant reactor DEMiSTM, DEGUSSA, Hanau-Wolfgang

Degussa, together with the engineering company Uhde and several partners from academia, are running the Demonstration Project for the Evaluation of Micro reaction Technology in Industrial Systems or DEMiSTM for short. With a pilot-scale micro reactor (see figure 1) they determined the gas-phase epoxidation of propene using vaporous hydrogen peroxide as a model reaction. Their aim is to use micro reaction technologies for the production of commodities.
Clariant reported a successful start of a continuous pilot plant micro reactor for the synthesis of azo-pigments (see figure 2) with a production capacity of several ten tons per year and a higher product quality compared to the conventional batch synthesis in a stirred vessel.
The former Axiva (today Siemens, BU Solutions Process Industries) developed a process for a continuous radical polymerisation of acrylates some years ago. Using a micro mixer for the immediate mixing of the starting materials, fouling could successfully be prevented. The pilot plant was operated with a throughput of about 8 kg/h, corresponding to an annual capacity of about 60 tons. A pre-basic engineering study demonstrated that by "numbering-up" a capacity of about 1,500 tons per year could be achieved as a result of operating with 28 micro mixers in parallel. With the micro mixers available today for production purposes, one micro mixer unit is suitable to attain an even higher capacity.
Microstructured devices and process components are setting the stage for a true paradigm shift in the principles of chemical process engineering. Rather than adapting operating conditions and chemistry to available equipment, the process structure, architecture and equipment can now be adapted to the physico-chemical transformation. Production units can be created by integration and interconnection of diverse, small-scale structured units into large-scale macro-production devices. A key feature of the resulting structured chemical devices is local process control (through integrated sensors and actuators), leading to enhanced global process performance.

Figure 2: Pigment synthesis pilot plant set-up, CLARIANT, Frankfurt-Höchst

Micro reaction technology allows switching from batch operation to continuous processing with great increase in process control, process stability and product quality. This is especially suited for products with small and medium capacities. For both ways of proceeding it is always important to keep in mind consequences for the whole process, i.e. what effects the higher conversion in the reaction may have on subsequent work-up steps like rectification, crystallisation, recycle streams, etc.
In order to advance the development of methodology on structured multiscale design, an industrial-academic consortium IMPULSE (an acronym for "Integrated Multiscale Process Units with Locally Structured Elements") has been created in the framework of the SUSTECH initiative of CEFIC, the European Chemical Industry Council (see www.cefic-sustech.org). The objective of the consortium research is enhanced performance through targeted, localized intensification. IMPULSE aims at effective, targeted integration of innovative process equipment (such as micro reactors and other micro and/or meso-structured components) to attain radical performance enhancement for whole processes. The consortium was selected for an Integrated Project within the 6th EU framework programme.
A lot of further collaborative effort of industrial and academic partners is needed to make micro reaction technology an economic and not only a scientific success. The premises exist. Let's sort things out.

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Microsystems in Biotechnology

Frank Bier

Biotechnology has become an interesting and economically significant field of application for microsystems in Germany. Perhaps the most prominent example is the "biochip", which is basically an umbrella term for various miniaturized bioanalytical concepts like microarrays, lab-on-a-chip or miniaturized biosensors. Microsystems in biotechnology are used for in-vitro applications, to date almost exclusively in the biomedical and pharmaceutical fields. Bioanalytics like determination of nucleic acids, peptides, proteins, biochemicals or cellular components currently play a major role in bioMST. But also other processes like cultivation, syntheses or handling/processing using microsystems are increasingly gaining in importance. In future, bioMST based devices will be used for environmental, food and warfare analytics as well.

In what way are microsystems entering Biotechnology? Modern Biotech benefits at various levels from miniaturizing and minimizing: Small-volume sample consumption and probe delivery are crucial to many applications, and microdispensing and microfluidic handling are key technologies of microsystems to foster the development of biotechnology at the small scale. Miniaturizing in Biotechnology at first means minimizing sample volume and fluid handling at the small scale - this is a requirement for both screening tasks in pharmaceutical industries and medical diagnostics. Microdispensing tools are mainly based on piezo-driven droplet forming in small nozzles, allowing droplets down to a few hundred picolitres (1 picolitre = 10^{-12} liter). Several developments have been made - all in Germany - to transfer the ink-jet principle to biotechnological applications. Glass-silicon hybrid materials (GeSiM, Großerkmannsdorf) or whole-glass pipettes actuated from outside (Scienion AG, Berlin; Fig. 1) are versatile dispensing tools that may be used with high-density microtitre or microwell plates (MTP, 1586 wells and more). Microdispensing and microfluidics are of great interest for library technologies and high-throughput screening (HTS) in the drug development process. HTS costs scale with volume and number of compounds to be investigated in a given time. Using miniaturized assay formats, this number can be increased by several orders of magnitudes.

Today the most prominent application of microdispensing techniques is the production of microarrays for genome and transcriptome analysis. The concurrency of contacting print methods using needles may be easily left behind when all advantages of the contact-free, microsystem-based methods are taken into account: (1) they are more flexible in terms of volume that may be released, (2) the reproducibility of the dispensing volume is higher, and (3) they provide more flexibility in the chemistry used. This latter feature is especially true of the whole-glass pipette based systems. For mass production of larger series of fixed format arrays, a microfluidic device has been developed by a research institute, the HSG-IMIT, together with the University of Freiburg - the so-called TopSpot method. The print head is formed as a nozzle array; once filled with 24 or 96 probes, the print head releases a single droplet from each nozzle simultaneously - the 384-print head has recently been under development. The reproducibility and homogeneity of such arrays is high enough to allow industrial application and mass production. Combination of these technologies has recently been demonstrated to form a production line for series production of low-density biochips (Fraunhofer IBMT, Potsdam-Nuthetal).

But deposition of molecules on a surface is only one step in the complicated bio-analysis process: Sample pretreatment, addition of reagents etc. call for microfluidic devices that work like a "lab-on-the-chip". This notion has been followed by many groups around the world, but many problems still have to be solved, one of these is packaging and contacting, gluing together different materials that have to be biocompatible. Several companies serve this demand (e.g. microfluidic ChipShop, Jena; Bartels

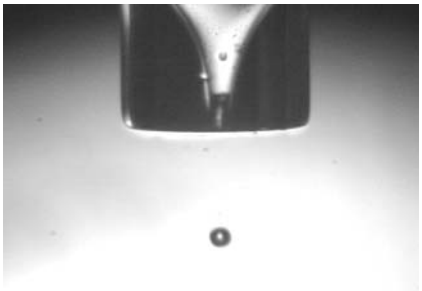

Figure 1: Flying drop of Scienion's FLEXARRAYER Piezo Dispenser.

Mikrotechnik, Dortmund) by providing rapid prototyping and micromoulding techniques.

Ultrasound actuation of fluidics overcomes some of the limitations that are inherent in microfluidics. While many mixers have been developed to overcome laminar flow limitations, this task can easily be fulfilled by ultrasound. Moreover, Advalytix showed the moving of droplets of some microlitres by surface acoustic wave (SAW) actuating. The same result can be achieved by electro-induced hydrophilic/hydrophobic switching of a surface. Still in its infancy, this technique may has the potential for further downscaling.

The combination of microfluidics with electroactuation is also used for cell manipulation. By alternating electric fields, electrophoresis may be suppressed and forces acting on induced dipoles can be employed by virtue of a field gradient, an effect known as dielectrophoresis. This effect has been developed by Evotec Technologies (Hamburg) into a complete microfluidic and electronically controlled cell handling system.

In summary, there are many opportunities provided by microsystems to strengthen biotechnology developments and products; many technology and engineering innovations have already been developed (and are still in process) at German universities, research institutes and industries.

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Microsystems for Biotech Benefit from Excellent Technologies "Made in Germany"

Cord Schlötelburg

Biotechnology is a relatively new field of microsystems application. Currently, it is focused on in-vitro analytical applications mainly in biomedicine and drug development. German companies and research institutes play a significant role in the development of microsystems for biotechnology (bioMST).

Technological strengths in Germany and model examples

From a technological point of view, Germany has an excellent position within the global competition of bioMST. German companies, research institutes and universities have developed a broad base of miniaturized technological solutions that can be applied for different biotechnological purposes. Germany possesses particular technological strengths in the areas of microfluidics, polymer-based microsystems, miniaturized detection technologies (mainly optical but also others) and microsystems for cell handling. A showcase is the thinXXs GmbH, a SME located in Mainz and Zweibrücken (Rhineland-Palatinate), that develops microstructured components and systems mainly made of plastics or respective combinations with silicon, glass or metal. ThinXXs sells micro diaphragm pumps, micromixers, lab-on-a-chip solutions, microslides and microplates. The company has specific expertise in active or passive fluid handling on the pico-, nano-, or microlitre scale (Fig. 1) and also in micro optical systems. Due to a specific approach of interface standardization, the broad range of solutions can be flexibly used for various biotechnological applications. Another example is the directif GmbH that belongs to the november AG, located in Erlangen (Bavaria). Directif is a specialist in the field of lab-on-a-chip technology with integrated electrochemical detection. The company develops a device that can be used for fast and decentralized diagnostics of infectious diseases based on molecular recognition of pathogen DNA. The technological basis for directif lab-on-a-chip is its credit card sized micro-channel structure, the carbon-plastic electrodes for electrochemical detection and also novel evaluation electronics. Unlike normally used optical detection technology, the electrochemical concept does not require additional biochemical labelling steps, which significantly simplifies the detection process. The third showcase is the non-university research facility IPHT e.V., the Institute for Physical High Technology in Jena (Thuringia). The IPHT applies state-of-the-art micro- and nanostructure technology in various subject areas. One particular topic of IPHT's bioMST is the development of miniaturized modules for detection, characterization and manipulation of cells. The work is focused on the development of micro compartments within a microfluidic environment (Fig. 2). Such systems can be used for applications where living cells have to be handled, cultivated or screened. An example is a microcultivation system for bacteria or for mammalian cells that is currently being developed by IPHT together with other German partners.

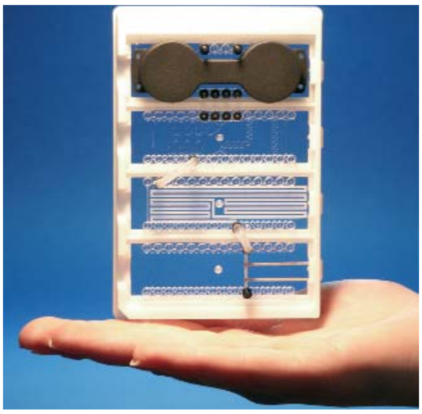

Figure 1: Microfluidic components by thinXXs

Commercialisation of bioMST in Germany:

Microsystems for biotechnology are relatively new and, therefore, no exact market data are available to date. Since the technology is still in its infancy, the market penetration of bioMST products in Germany is still low. An exception is the DNA array, including peripheral and spotting

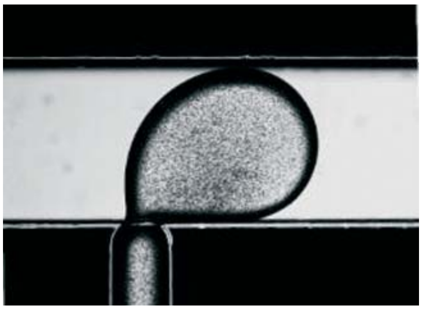

Figure 2: Injection of a droplet into a microchannel (IPHT)

technology, which is the only bioMST product with a billion Euro revenue each year. However, the whole market segment is clearly dominated by US companies.

The German bioMST location is characterized by highly innovative SMEs (e.g. Advalytix, thinXXs, november AG, greiner bio-one, Scienion, GeSIM, Evotec) and various research institutes. Only a small number of bigger companies (e.g. Siemens, Infineon, Boehringer Ingelheim) are active in this field. Furthermore, a lot of SMEs developing optical systems deal with bioMST as well (e.g. LaVision BioTec, Lambda Physik). As pointed out earlier, the technological base of German bioMST can be considered as strong, but the transfer of single technological solutions into products ready for marketing turns out to be suboptimal. In general, potential users and investors of bioMST like pharma or biotechnology industry are conservative at this time thus hampering the development of new bioMST products. Nevertheless, in the next years various new products and devices like lab-on-a-chips for biological, medical and pharmaceutical analyses, technical platforms for cell analysis and cell handling, micro cultivation systems, stand-alone devices for molecular diagnostics or biodetection systems for contaminated sites or bioterrorism will be commercially available from German companies.

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Microsystems for Medical Technology

Christine Weiss

Social demand is the driving force for new developments in miniaturised medical technology. Well-informed patients have high requirements in terms of improving the quality and safety of their lives. That can be achieved by a marked miniaturisation of medical devices, instruments and sensors that ensure that patients have less traumatic operations or can benefit from mobile monitoring systems. Microsystem technology provides potentials that meet those new social and medical requirements to the point. Major applications of microsystems are, for example, intelligent implants, patient monitoring and minimally invasive technology.

Intelligent Implants
A very important field in medicine is the development of intelligent implants based on microsystems technology. The pacemaker is a well-known example. The new generation of devices do no longer stimulate the heart by inflexible, constant impulses only, but collect data like heart rhythm and react self-sufficiently with variable adjustments. In this way, this therapy is becoming more flexible and physiological. Meanwhile these systems can absolutely hold their own on the market. Implanted defibrillators that stimulate the heart directly in case of cardiac arrest have also been developed. A strong electric impulse restores the heart function. These devices are also successfully being introduced into the market. The leading German supplier in that field is the company Biotronik GmbH & Co.

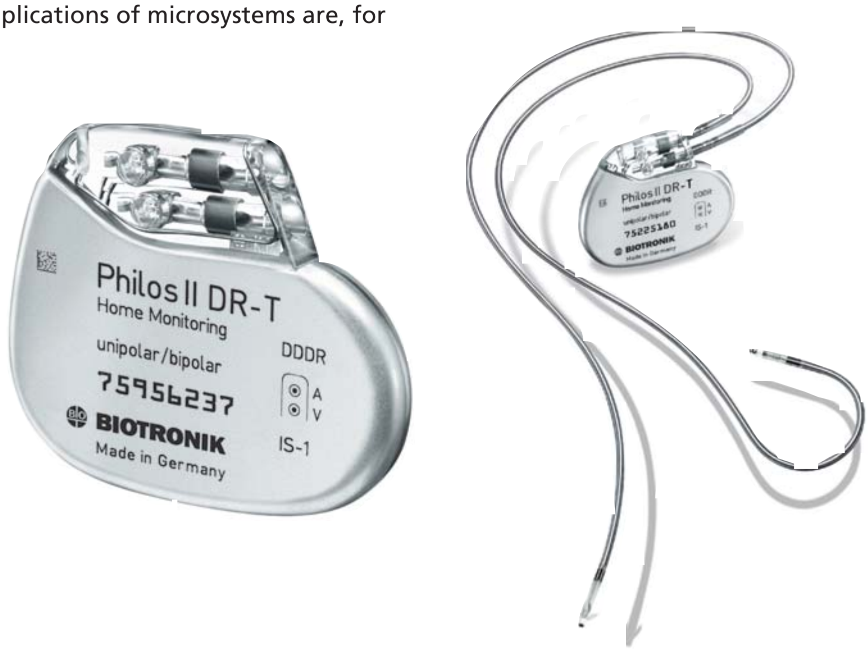

Figure 1a and 1b: Pacemaker of the medical device supplier Biotronik

Patient monitoring
A second very interesting application for microsystems is the continuous monitoring of physiological patient data. Therefore sensor systems inside or outside the body are needed. Up to now only stand-alone solutions are available, that means data remain stored in the device. Examples for ambulant devices with limited storing potential are 24-hour-blood-pressure measurement or 72-hours-blood sugar measurement. Using miniaturised sensors future systems in domestic surroundings should measure continuously and precisely blood pressure, intraocular pressure, electrocardiogram (ECG), level of blood sugar or respiratory sounds. The collected data will be wireless transmitted to the physicians. In this application field German companies like Siemens AG Medical Solutions, Dräger Medizintechnik GmbH,

Philips Medical Systems, Weinmann GmbH, Fresenius Medical Care AG und B. Braun Melsungen AG play an important role.

Minimally Invasive Technology
Minimal invasive operation techniques would be unthinkable without microsystems technology. In this field microsystems in terms of miniaturised mechanical and optical systems were introduced to the operating rooms already 15 years ago. German companies like KARL STORZ GmbH & Co. KG, AESCULAP AG & Co. KG und Richard Wolf GmbH are international leading players in this market with endoscopes and intelligent instruments. In future miniaturised instrument systems will be improved by sensors generating tactile feedback to the operating surgeon. Based on this tactile feedback, navigation systems can support the surgeon in planning and operating.

German medical technology is in a good position internationally
Internationally, German companies rank among the leading suppliers of microsystems in medical technology. They play an important part in the worldwide turnover in this market segment (12 billion in 2002) [1]. Microsystem technology is a key technology for the development of innovative medical products. Its great importance helps to strengthen the medical technology industry in Germany. In 2004 the total turnover of this industry sector was 18 billion Euros, employing 100,000 people in 1,200 companies [2]. Because of highly increasing exports, a turnover of 25 billion Euros is expected in 2010 [3]. "Made in Germany" is still a good reputation for medical products. The share of the turnover in foreign countries is almost 55% and it is expected to rise steadily until 2010 [4]. This underlines the international competitiveness of the German medical technology industry. With 38% of all exports, the EU states are the main customers of medical technology from Germany, followed by the US with 20% [4]. Two German companies belong to the worldwide top ten: Siemens Medical Systems ranks fifth and Fresenius Medical Care AG seventh [4].

Beside industry, national research institutes are a guarantee for success. More and more of them are combining R&D in microsystem technology with biomedical engineering. Well-known representatives are IMTEK, Prof. Stieglitz, University of Freiburg, ITIV, Dr. Stork, University of Karlsruhe, IWE, Prof. Mokwa, RWTH of Aachen, and Fraunhofer IBMT, Prof. Fuhr, St. Ingbert. University hospitals like the Charité in Berlin, Erlangen-Nürnberg and others apply biomicrotechnologies for innovative solutions in diagnostics and therapy.

Future developments will imply new challenges
The main challenge to be coped with in the field of microsystem technology is the connection of technological components with the biological surroundings. In future, top innovations can be achieved in the following applications:

- Enhancement of active implants by biocompatible coating
- Intelligent drug targeting according to data determined by microsystems
- Linking of data for complex diagnostics in an environment close to the patient without necessarily consulting a physician or going to hospital
- More complex and individual analysis of biological, chemical, pharmacological, toxicological and medical data
- Continuous advancement of imaging systems for instrument navigation and better acquisition of parameters relevant to therapy

The next article will focus on the challenges and opportunities of the use of microsystems in endoscopes for minimally invasive surgery.

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Endoscopes - Potential for Microsystem Technology

Klaus-Martin Irion

Over the last 15 years endoscopy has considerably gained in importance. The reason for this is a shift from the open surgical technique to Minimally Invasive Surgery (MIS). This technique, also known as 'keyhole' surgery, enables procedures to be carried out via the smallest artificial openings using remote-controlled instruments and small-caliber viewing systems, known as endoscopes. MIS is carried out primarily using rigid endoscopes - on the other hand, purely diagnostic procedures are generally carried out using flexible endoscopes. The global market leaders for rigid endoscopes are in Germany, whereas Japan dominates the flexible endoscope market.

An endoscope consists basically of the following micro-components: lens, image transfer element and light transfer element (optical fibers).

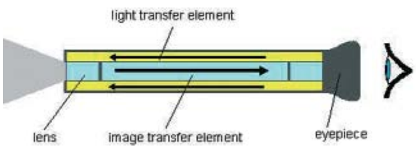

Figure 1: Basic structure of an endoscope

The thinnest endoscopes have a diameter of less than 500 µm. The maximum length is approx. 2 m - special systems can also be much longer. The aim for the future is to develop endoscopes or endoscopic image transfer elements with even smaller diameters and with no reduction in image quality.

Medical and industrial application for endoscopes

Endoscopes are used in medicine and technology wherever cavities are involved that cannot be visualized directly. Their main area of application is in medicine - besides surgery (MIS), urology, gastroenterology, gynecology, neurosurgery, ENT, orthopedics and veterinary medicine. But endoscopes are also used in other industrial settings, e.g. to examine drive units, motors, pipe systems, in architecture and in environmental protection. In addition, endoscopes are increasingly being used alongside microscopes for the inspection of microsystems.

Depending upon the application, there is a wide selection of different endoscopes that can be used. This selection comes back basically to the two types of endoscope - rigid and flexible. In addition, endoscopes are distinguished according to the method by which they transmit images. Image transmission from the distal endoscope section to the end of the instrument is done by rod lens systems in rigid endoscopes. In the case of flexible or semi-flexible endoscopes, the image is transmitted either via fiber bundles (image conductors) or in the case of endoscopes with optical-electronic imaging - known as 'video endoscopes' - via electrical signals. The following table gives an overview of the characteristics of the various types of endoscopes.

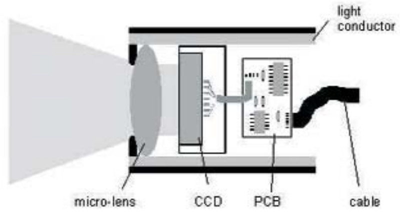

Figure 2: Diagram of a video endoscope

Characteristic / Type	rigid	flexible	video
Image transmission	optical lens system	fiber bundle	electrical
Image quality	++	-	+
Minimum diameter	+	++	-
Brightness	++	+	++
Flexibility	-	++	+
Price	++	+	-

Tab.: Characteristics of various types of endoscope (evaluation ++, +, -)

Video-endoscopes are only realizable with microsystems

Video-endoscopes transfer the image directly from the lens to a light-sensitive chip (CCD). This micro-camera - a complete microsystem with micro-optic, microelectronic and micro-mechanical components - is integrated into the distal end of the endoscope. It converts the image information into electrical signals that are transmitted via a system of cables within the shaft of the endoscope. The diameter of the endoscope is thus determined primarily by the size of the image sensor.

The use of image conversion chips means that the image shows no pixel-structure. This results in a higher image resolution. Moreover, there is a directly accessible video signal. The disadvantage is the fact that the electronic imaging chip is relatively large and the electronics involved in conditioning and processing the image signals is relatively complex.

Innovations assure market shares

Being one of the international top players, KARL STORZ achieves a significant amount of its business volume with high-quality endoscopes both in medical and in industrial application. To improve their position in the future the following fields of application for microsystem technology in endoscopy have to be addressed:

- Micro-assembly of endoscope components
- Miniaturization of endoscopes and video endoscopes
- Integration of new functions into endoscopes (measuring functions, additional imaging features such as OCT (**o**ptical **c**oherence **t**omography), ultrasound, confocal microscopy, molecular imaging)

Therefore, microsystem technology will not only help to keep the leadership of German medical companies but will also increase the high potential of innovation.

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Polytronics - an Emerging Technology with High Potentials in Germany

Yvette Kaminorz and Wolfgang Clemens

Polymer electronics or Polytronics comprehend the development, system integration and application of passive and active electronic and photonic devices, based on organic materials. Organic materials means either low molecular mass compounds, like small molecules or oligomers, or high molecular mass semiconductors, called polymers, which both require different technologies for the preparation of thin, homogeneous films. Small molecules are processed mainly with vacuum evaporation techniques, polymers are mainly processed from solution (printing, spin or dip coating, spraying or blading).

Although the performance of organic materials and devices was improved significantly during the last 10 to 15 years, on one point the experts in organic semiconductors agree upon: polymer electronics will not and can not compete with silicon technology. Nevertheless, organic semiconductors (OSC) are very attractive for low-cost applications, which require only low-performance.

Today, several application areas are intensively investigated. The development of organic integrated circuits (IC), radio frequency identification devices (RFID) and smart transponder cards, organic light emitting diodes (OLEDs) and displays, sensors and actuators, storage media and memories are under investigation for information and communication systems. Additionally, the performance of organic photovoltaic devices and solar cells as well as polymer batteries has been significantly improved during the last few years, in such a way that organic semiconductors (OSCs) will also influence energy systems. Due to their market relevance for German players, OLEDs and displays as well as RFID tags and smart labels should be discussed further.

OLED and Displays
According to iSupply (2002), a total market for flat panel displays of 57 billion US$ in 2006 was forecasted, which will mainly be shared by TFT-LCD (75%), plasma displays (12%), passive matrix LCD (6%) and OLED displays (4%). The advantages of OLED displays in comparison to LCD are significant, for instance higher luminance, large-area fabrication with potential low-cost technologies, and the potential usage of flexible substrates.

Today, the OLED display market, mainly based on licences of Kodak or Cambridge Display Technology, is dominated by Asian and US companies, a few European players are active as well.

In Germany, OSRAM Opto Semiconductors GmbH is very active in this field. OSRAM already has a monochrome OLED display in their product portfolio called Pictiva™ (PM, 128x64 pixels), which for instance is used in professional audio mixing consoles by Fairlight (www.fairlightau.com).

Although not many companies are fabricating organic displays in Germany, this application field is important, because companies are very active as technology providers like Novaled GmbH, materials providers like Covion Organic Semiconductors GmbH, Merck KGaA, and SCHOTT AG, as well as potential equipment providers like AIXTRON AG, Applied Films GmbH & Co. KG, MAN Roland Druckmaschinen AG, and others. For instance, the latest activities of AIXTRON together with RWTH Aachen and Philips (The Netherlands) focus on the development of large-area white OLEDs. A recently announced project plans to develop OLEDs for lighting applications and to establish new manufacturing processes using AIXTRONs organic vapour phase deposition technology.
Main research players in Germany are for instance: University of Braunschweig and Fraunhofer IPMS, both working on OLEDs and displays based on evaporated small molecules, University of Potsdam, working on OLEDs based on solution processed polymers, and Bergische Universität Wuppertal, developing OSC materials.

Organic displays today are already incorporated into products like car radios and mobile phones. Future trends point into two directions:

- larger area displays for televisions and computer screens
- high-resolution micro-displays

Although several products incorpo-

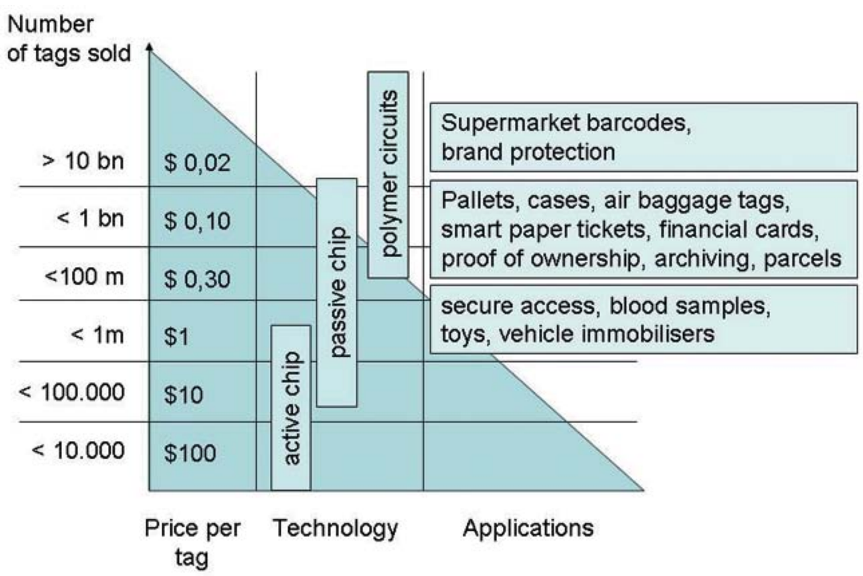

Figure 1: Relation between price of RFID tags and market (source: IDTEchEx)

rating small OLED displays are commercially available, the move to mass production has not been made yet. The main reasons are still limited lifetime as well as the complex industrial production process that negatively influences the cost-performance ratio in comparison to other display technologies. Amongst other things like improvement of luminance and pure colours for white emission, recent R&D efforts are focusing on these problems.

RFID Tags and Smart Labels
One of the most attractive applications for organic materials is RFID tags, which are foreseen to replace bar codes. The chances of success of OSCs are mainly due to the application of in-line, i.e. low-cost, manufacturing techniques, for instance Reel-to-Reel. Such techniques allow extremely low prices, required for the above-mentioned application (figure 1). Even if the size and the price of a silicon chip can be decreased significantly, such conventional construction still requires expensive assembling techniques, which are completely avoided for completely organic RFID tags.
In the Netherlands Philips successfully demonstrated a 64bit organic RFID transponder chip. Infineon AG verified ring oscillators based on small molecules, like pentacene.

PolyIC GmbH & Co. KG, a German joint venture between Siemens AG, and Leonhard Kurz GmbH&Co. KG, recently presented the fastest polymer based IC in form of a ring oscillator with a switching frequency of 600 kHz and also the first fully functional polymer based RFID tag working at 125 kHz. This set-up is still handmade in a hybrid laboratory set-up and just gives out a "1bit" signal. The next step will be the development of tags for the 13.56 MHz, usable for high-volume products. In parallel, the printing will be developed in such a way that these tags can be manufactured in a continuous process.

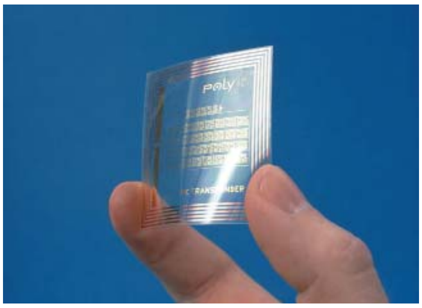
Figure 2: Poly IC RFID demonstrator

First products based on OSCs are planned to be available in the next 2 to 4 years. For instance, PolyIC plans to have first products of RFID tags in 2006. They will be working in the 13.56 MHz range and will have just one or a few bits of ROM information that can be used for brand protection or marketing purposes. In a next step, higher performance, especially in the form of a larger memory (still ROM), will be developed. The longer-term goal (not before 2008) is to have a printed EPC tag (EPC = electronic product code) for item level tagging.

Another potential market for printed electronics is "smart objects", where different devices like polymer chips, memory, display, battery, antenna or sensors can be combined. Several companies are already working on printed smart active labels, for instance KSW Microtec AG in Germany. KSW already provides a non-organic, but partially printed smart card with integrated temperature sensor, time monitoring and data tracking for less than one Euro. Nevertheless, recent trends already point to all-printed "smart objects" with significantly reduced prices and flexible substrates. PolyIC is already active in using the printed electronics platform for such kinds of products. An interesting application would be single-use smart cards with sensor, small display and polymer chip that can be combined with different energy sources like an antenna for RF-use, printed batteries or solar cells. There are many possible application areas for such products, like smart labels for logistics (e.g. temperature control of a transported good), intelligent consumer goods labels (e.g. expiration of milk products) or single-use medical sensors (e.g. alcohol tester). But also marketing labels or games and gimmicks can be imagined, as these smart labels will be very cost-efficient.

Main research institutes in Germany are for instance Fraunhofer IZM Munich, focusing on Reel-to-Reel technology as well as reliability, Technical University of Chemnitz, developing printing technologies for electronic devices, and TITK e. V., concentrating on laser structuring techniques. Materials research, besides other things, is done at Fraunhofer IAP for providing OSC as well as at Fraunhofer ISC for providing dielectrics and encapsulation.

In addition to the further improvement of tag performance, there are still demands for continued R&D work. First of all, materials have to be improved regarding increased charge carrier mobility, stability and processability as well as availability of n-type semiconductors. Further on, the conductivity of low-cost printing pastes for antennas has to be improved to compete with metallic materials or metal based-pastes that are used today. The R&D effort also focuses on the development of a chip design enabling highly efficient ICs with available materials and processes, for instance a CMOS - like printed electronics instead of a p-MOS-type one, that is the status today. Moreover, the improvement of high-volume low-cost printing processes is necessary in terms of high resolution, high performance multilayer designs, high accuracy for the alignment of layers, as well as the optimization of the right print formulations with the right printing methods.

In summary, polymer electronics is an emerging technology with high potentials for Germany. Up to now, the field is still mainly on a level that requires a lot of research. Based on this, Germany has a strong international position, which will lead to further innovative developments, applications and start-up companies. As the first products are now on the horizon, several aspects of the integration of printed labels into products, infrastructure and product logistics, as well as requirements asked for and quality assurance have to be addressed by the R&D effort.

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Energy Self-sufficient Microsystems - Trends and Opportunities

Marco Voigt

Today's portable electronic devices and various types of microsystems are typically powered by Li-Ion batteries which to some extent limit the functionality and the operation time of such devices and systems. The world-wide market of portable electronic devices is about 10 million units in 2004 and is believed to increase by 1 to 2 orders of magnitude over the next 5 years ("Fuel Cells for Portable Power", Darnell Group Inc., U.S.A., 2003). These figures show the potential and the necessity for generating new solutions to ensure the power supply for such systems.

Since it is not expected that improvements in Li-Ion battery chemistry will lead to a significant increase in energy density, other alternatives of energy storage and generation have to be investigated.

Miniaturised fuel cells are one promising alternative for this purpose, in particular polymer electrolyte membrane fuel cells. The energy density of this type of fuel cell in the oxygen operation mode is roughly 6 times the energy per unit mass of Li-Ion batteries and time-consuming recharging cycles are eliminated. However, some critical issues of existing fuel cell systems have to be solved, where micro- and nanotechnologies can contribute considerably: cost of production, volume reduction and efficiency of the system. Several research groups (Fraunhofer IKTS, ISE, IZM, IMM Mainz GmbH, and others) and research departments of enterprises (Smart Fuel Cell AG, Heliocentris Energiesysteme GmbH, and others) are evaluating this approach. One very interesting example is described more in detail in the article by L. Mex, page 30.

Other functional principles for solving the energy problem are imaginable. If one tries to categorize the field of energy self-sufficient microsystems, a distinction between general areas of research aiming for this goal can be made:

- energy sources (solar energy, mechanical energy, thermal energy, biochemical energy, chemical energy, high-frequency radiant energy),
- energy transfer (electromagnetic assignment, DC/DC transducer),
- energy storage (fuel cells, batteries, condensers),
- energy management.

Research and development is carried out in all of these areas.

Potentially, small amounts of available energy can by siphoned off from common ambient environments, an approach that is followed in various ways:

Since the human body emits energy as heat, a logical consequence could be to try utilising this energy for technical purposes. Although work on new materials and new approaches to devices based on the thermoelectric effect promise an improvement in conversion efficiencies, the efficiency of today's standard thermopiles is only between 0.2% and 0.8% for temperature differences of 5-20°C. However, such a temperature difference can be expected for a wearable system in moderate environments. In Germany, KUNDO SystemTechnik GmbH has entered the market as the first supplier of a sensor solution powered by a system based on the thermoelectric effect.

Smart labels (see pages 14-15) generate their energy from the ambient electromagnetic environment, an effect already applied by detector radio systems in the early days.

Transducers convert one form of energy to another. Junghans Uhren GmbH has been manufacturing and selling radio-controlled and solar cell powered wristwatches for many years. Piezoelectric materials, arranged as stacks of many single sheets, create an electrical voltage when mechanically stressed. Integrated into shoes, it might be designed as a manually powered battery charger for example.

In summary, not many energy self-sufficient microsystems are known to date. The increasing trend towards miniaturisation and functionality and increasing environmental concerns will be drivers for further developments though.

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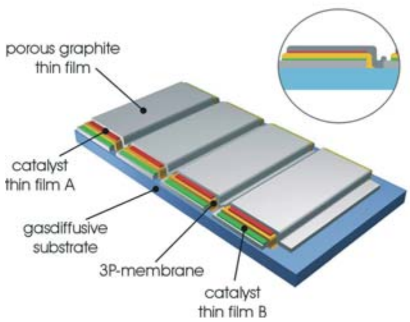

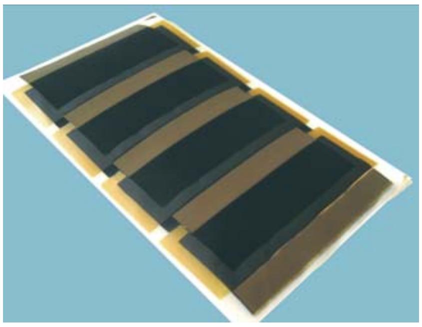

Figure 1: Scheme of a planar fuel cell arrangement on a partially gas-diffusive substrate and photograph of a prototype thin-film MEA (source: 3P-Energy GmbH)

Thin-film Technology for Miniaturised Fuel Cells

Laurent Mex

The set-up of a polymer electrolyte membrane fuel cell consists of two electrodes with gas diffusion capabilities and a built-in catalyst layer, both separated by an ion-conductive membrane, the polymer electrolyte. The reactant gases, for instance hydrogen and oxygen, are supplied through the gas diffusion enabling electrodes, and undergo electrochemical reactions at the catalyst layer. In this way the hydrogen gas molecules are split up into protons and electrons. The protons reach the opposite electrode through the ion-conductive membrane, while the electrons are conducted by an electric circuit. At the catalyst layer of the electrode where oxygen is supplied, protons, electrons and oxygen react to water. Under these circumstances a voltage drop of approximately 0.7 V occurs at the electrodes and a current of several hundreds mA/cm² can be provided depending on the operation conditions. Stacking and cascading a larger number of such membrane-electrode assemblies (MEAs), each requiring a controlled gas supply and complex sealings, builds up a conventional PEM fuel cell set-up.

Typically, miniaturised fuel cells, fabricated by micro technologies, show a planar design of several MEAs connected in series. By depositing the MEAs on a substrate, the fuel supply is kept very simple. Oxygen reaches every MEA from the top over the substrate and the fuel (hydrogen) is guided through a porous area of the substrate to the bottom electrodes.
To build up the MEAs on a substrate, deposition processes and structuring procedures are required for the bottom electrode and its catalyst layer, the ion-conductive membrane, and the counter electrode with its catalyst layer. While structuring can be done easily by lift-off procedures or even in situ by using shadow masks, the deposition processes for the MEAs have to be developed and well-suited to each other.

Technologies for Electrodes
Conventional electrodes for fuel cells are made of porous graphite that shows excellent long-term stability in the harsh environment of a fuel cell. Thin-film graphite layers can be deposited by plasma enhanced chemical vapour deposition processes in an acetylene atmosphere.
More favourable is the deposition of carbon nanotubes, which yields an increased surface area on which catalyst particles can be deposited, generating a high catalytic activity. Both process techniques, however, require a deposition temperature of more than 200°C, having a damaging impact on the ion-conductive membrane.

Furthermore, porous graphite layers can be obtained by spray coating at room temperature. Graphite inks can be used that are well-known in the preparation of catalyst layers for common fuel cell electrodes. These inks consist of graphite particles, catalyst clusters and additions of an ion-conductive polymer solution. In contact with a conventional ion-conductive membrane, this composition guarantees a high contact area between catalyst particles, the electron conductor graphite and the ion-conductive membrane, which is essential for high efficiency. On the other hand, not all off the catalyst particles in this ink are in direct contact with the ion-conductive membrane and the graphite simultaneously, so that efficiency gets lost.

Therefore, the electrodes for miniaturised fuel cells are made by inks containing graphite only. The catalyst is added as a thin layer on the rough and porous surface of the graphite by sputtering technique. A reduction in catalyst loading by one order of magnitude compared to conventional electrodes is typical and leads to a tremendous cost reduction in the fabrication of fuel cells.

Ion-conductive membranes
In the following step the ion-conductive membrane is grown directly on the first electrode/catalyst layer. Thereby, the 3-phase contact in between graphite, catalyst particles and ion-conductive membrane is excellently formed. Conventional PEM fuel cells require a critical hot pressing procedure to build the MEA.
Based on research at the Technical University of Hamburg-Harburg, Germany, 3P-Energy GmbH has developed a unique thin-film deposition process for ion-conductive membranes. An exceptional quality of these membranes is their low methanol permeability. This allows using methanol/water solutions with high methanol concentration as fuel instead of hydrogen. Therefore, relatively small and light fuel cartridges can be used in lieu of of heavy and voluminous hydrogen storage devices.

Micro fuel cell assembly
To complete the MEAs, the counter electrode with its catalyst layer is deposited on the ion-conductive membrane. Thereby, the structuring of the top-electrodes ensures a serial connection between neighbouring MEAs through an overlap with the bottom electrodes. To improve the planar conductivity of the graphite layers between the MEAs, additional metallic layers, e.g. gold, can be deposited in this area (see figure 1, photograph on the preceding page).

In addition to the MEA arrangement and a methanol/water fuel cartridge, the housing including an air supply and an electronic control unit completes the miniaturised fuel cell system. Depending on the specific application, the design of the thin-film MEAs can be varied widely and the appropriate choice of a substrate allows a planar as well as a rolled or folded 3-dimensional orientation. These features enable the fabrication of a completely miniaturised 3P-micro fuel cell that can be integrated into portable electronic devices.

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Production of Microsystems

Gabi Fernholz

Processes and Facilities
Germany has a leading position in the manufacturing of microsystems. Several major important industrial players produce sensors and actuators using silicon related processes, or offer related foundry services: HL-Planartechnik GmbH, microFAB Bremen GmbH, naomi technologies AG (a company of the LUST group), Robert Bosch GmbH, X-FAB Semiconductor Foundries AG, and others. Additionally, a number of precision mechanics based micro-production technologies have left the status of academic research and are facing implementation into industrial application. Among these technologies are (laser) ablation, mechanical micro-cutting, micro-erosion. All are being developed for 3-D structures from less than 1.0 mm down to 10 µm and smaller. Promising new replication technologies for mechanical micro-parts and microstructures are available as well, featuring processes like micro powder injection moulding and micro hot embossing. Boehringer Ingelheim microParts, mikroglas chemtech GmbH, thinXXS GmbH, and others are companies which have successfully introduced these techniques into industrial mass production.
There are several analysts who have generated forecasts for the development of the microsystems markets. This information has to be considered very carefully though, when looking from a German viewpoint. All the generated statistics consider silicon MEMS manufacturers only. When all technologies are included, and especially when polymer microsystems technology to replace silicon technology is considered, German microsystems manufacturers as a whole can be seen more in a leading role than such market studies suggest.

Providing Equipment for Manufacturing
During the production of microsystems, bonded or double side wafers and miniaturised singular 3D parts have to be processed and handled. This requires specific equipment. Some equipment providers in Germany supply such dedicated machinery: double side lithographic printers (SUSS MicroTec AG), micromoulding equipment (ARBURG GmbH + Co KG, JENOPTIK Mikrotechnik GmbH, and others) and specific manufacturing environments (M+W Zander Facility Engineering GmbH). Handling, picking, and assembly of miniaturised components and micro-devices is the domain of some equipment providers like Grohmann Engineering GmbH, IEF Werner GmbH, and others, while many kinds of grippers required for such tasks are provided by suppliers like GERWAH Mikrotechnik GmbH, Klocke Nanotechnik, MiLaSys technologies GmbH, SCHUNK GmbH & Co. KG, and others.

Quality Control and Functional Test
Test and quality control are steps within the microsystems production chain, where new solutions are still

Figure 1: Test of pressure sensors (source: Süss MicroTec)

required. Semiconductor related measurement methods and equipment have been adopted for some applications. They are limited to two-dimensional resolutions, however. Wafer level testing is one example where new equipment is under development, addressed by Polytec GmbH and SUSS MicroTec AG. During the production process of microsystems, parts with 3D topology have to be characterised. Therefore, it is not only a challenge to handle parts smaller than 1 mm, but also to determine their geometry, stability, and mechanical behaviour. The measurement of such micro-mechanical characteristics as strain distribution, hardness, or wear is sophisticated. Dedicated new measurement methods and tools have to be developed. This specific target will be addressed with a cluster of research projects during the next three years, supported within one technical focus topic of the "Microsystems" framework programme of the German Federal Ministry of Education and Research (BMBF). In this context, suppliers of measuring instruments like Carl Zeiss AG, Mahr GmbH, Werth Messtechnik GmbH, and others will develop measurement tools for microsystems production.

Production Models

The complete production process chain of microsystems and the construction of microsystems factory is a very complex matter due to the numerous processes and approaches whereby classical precision mechanics procedures cannot be scaled down further. Additionally, technologies such as LIGA, IC fabrication-related techniques, or optical, chemical, and physical processes have been developed under other circumstances. Standardised dedicated microsystems-related production steps or process flows hardly exist. Therefore, new manufacturing and production strategies always have to be developed.

Solutions have to be introduced that enable manufacturers of microsystems to produce cost-efficient micro components, even by only participating in a very small share of the value chain. An initiative to bundle the know-how and manufacturing capabilities of SMEs has been launched under the research project "MikroWebFab", originally initiated by BMBF support and now transformed into a commercial activity. The organisation of the virtual enterprise and its business model have been established, as well as access to internal and external processes, liability and legal aspects, financing, and infrastructure. A knowledge-based process library allows the design of new micro products and microsystems.

Strong micro production research base

Microsystems manufacturing and production is evaluated by an enormous variety of research institutes in Germany. (Technical) universities, institutes of the Fraunhofer-Gesellschaft, but also other public and semi-public laboratories are active, carrying out basic and applied research on materials, components, and processes in the context of the production process: Forschungszentrum Karlsruhe GmbH, Fraunhofer IPA, IPT, ISIT, IZM, HSG-IMAT, HSG - IMIT, IMM GmbH, several universities like Aachen, Braunschweig, Chemnitz, Hanover, and many other facilities.

Modularisation and Standardisation

Since microsystems technology and its applications are heterogeneous areas, where electrical and non-electrical features have to be integrated, manufactured, and tested, the definition of standards and scaling up/down approaches are not straight-forward processes. This will be one of the major challenges in the future. However, the definition of building blocks, and the modularisation of components and manufacturing processes are a necessity which is already being addressed and should be achieved in the near future. Recently, a handful of BMBF supported collaborative projects have generated solutions for some of the said tasks.

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From the Idea to the Successful Microsystem

Stefan Kreuzberger

For the development of a successful microsystem, several factors have to be considered, including the design, the prototype development, and the quality surveillance of serial production. Additionally, the process chain has to be managed well, as the example of the microParts spectrometer demonstrates.

Production Requirements

The combination of different microtechnical methods like micromilling, discharge machining, laser structuring, lithography and etching processes enable the production of complex geometries used for moulding tools (figure 1). Such structures, possibly in combination with electroforming processes, build the basis for the subsequent cost-efficient mass production with replicated plastic microproducts by moulding (figure 2). It is of great importance that the manufacturer of the microproducts is able to control the whole

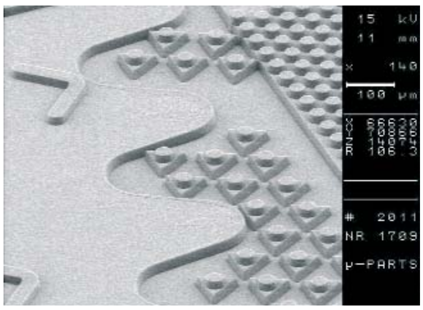

Figure 1: Microstructures manufactured by laser ablation (source: microParts)

process chain, from the design phase of the components to the final system integration.

For medical products, certifications and admissions of public authorities have to be considered in the phase of research and development. Of importance is the fast verification of the product features of prototypes. An additional effort concerns the certification and validation of the machines and the production environment under clean room conditions.

Surface treatments, such as hydrophobisation and hydrophilisation, are important for the defined handling of bio-molecules and for fluidic control. For optical products, reflective coatings are of particular importance. Other treatments are necessary to guarantee the operation of the micro product over its lifetime.

The assembly of microparts and their integration into a macroscopic system is the next challenge. Bonding and assembly techniques that allow product-specific material bonding without damaging microstructures or do not influence their functions have to be selected. For plastic components, technologies like ultrasonic or laser welding and thermal or adhesive bonding are considered, depending on the materials that are to be joined or depending on the tolerances to be achieved.

The microParts Microspectrometer
At the end of the 1980's, there was a strong demand to realize higher data rates in information technology. The idea to transfer a light signal simultaneously in different wavelengths and the requirements for qualified wavelength multiplexer and demultiplexer systems, was the starting point for

Figure 2: Injection moulding of microcomponents in a clean room (source: microParts)

the Forschungszentrum Karlsruhe GmbH (FZK) to develop a miniaturized planar microspectrophotometer with a self-focusing reflection grating made by LIGA-technology. The technological challenge was the optimization of the X-ray lithography process to precisely fabricate minute structures with resolutions of about a few tenths of micrometres with a depth of a few hundred micrometres.

microParts anticipated the high potential of the microspectrometer as a cost-effective alternative to rather expensive laboratory spectrometers. Particularly miniaturization and the industrial serial production of such a microspectrometer module would be the enabler of a development of new high performance hand-held devices.

Efficient industrial production is identified as basic to market success. This task was addressed in co-operation with FZK and qualified production process for the microspectrometer component was established. The required tooling technology and moulding machines were developed. Finally a production line integrating the entire process chain was set up by microParts. Initially the spectrometer components were produced as three-layer polymer waveguide by hot embossing. Increasing sales figures and the optimization of materials allowed the enhancement of production methods. The moulding process of the spectrometer component was changed from hot embossing to the more efficient injection moulding. The components are now produced as hollow cavity waveguide spectrometer (figure 3).

With the reduction of cycle times it was possible to increase the efficiency of the production. Additionally, the change to the hollow cavity waveguide design increased the performance of the microspectrometer significantly. Stray light attenuation was improved by approx. 40%. Furthermore, sensitivity was improved by a factor of 3. The improved stray light conditions and the higher sensitivity enable the microspectrometer to be used in various new applications, especially in Life Sciences. Current applications include colour measurement with hand-held devices, accurate quality determination of diamonds, measurement of fluorescence-based assays in medical diagnostic systems, a tooth shade colorimeter, or a Bilirubin Analyzer for Newborn Jaundice.

The hollow cavity waveguide principle now being utilized can measure the spectral range up to the near-infrared (NIR) and infrared wavelengths. Therefore an efficient and inexpensive NIR spectrometer module was developed as well. These NIR spectrometers are used for process monitoring in the food industry, for the high-throughput sorting of polymers, or in pharmaceutical applications.

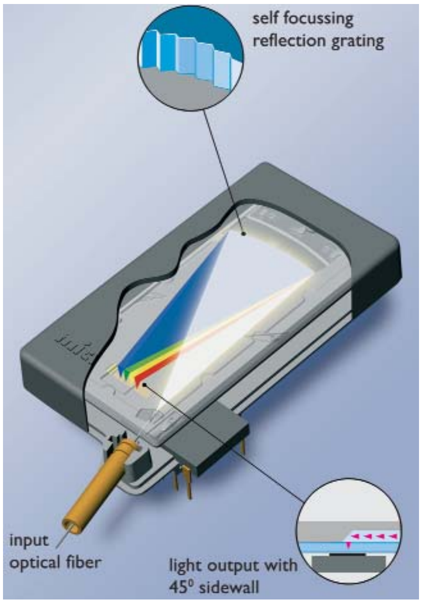

Figure 3: Design principle of the hollow cavity waveguide microspectrometer (source. microParts)

The microspectrophotometers are mass-fabricated according to well-established assembling techniques and according to requirements of the QM Systems DIN ISO 9001, EN ISO 13485 or GMP (Good Manufacturing Practice) standards. A stable and economical production was assured by the utilization of statistical quality management systems such as machine and process stability analysis in combination with optical performance tests.

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Strengthening Research and Industry - MST Innovation Policy in Germany

Lars Heinze

Innovation in the microsystems industry and in research departments is backed up by public policy. The current framework programme of the Federal Ministry of Education and Research is characterized by strong industry participation. In particular small and medium-sized enterprises benefit from this policy. The focus of the programme is on topics which particularly strengthen the German economy's innovative ability.

The development of Microsystems Technology (MST) in Germany has been supported by the Federal Ministry of Education and Research since 1990. Since then, the emphasis of the programmes has changed according to the specific requirements of the innovation system. At the outset, it was necessary to build up a sustainable research base that was able to co-operate with industry. Further programmes supported the orientation of research and development towards specific application fields and the development of marketable products. The current programme offers instruments that can respond to a highly dynamic technology and market development in MST. In the following, we will present a short outline of the MST programmes in force since 2000.

The German federal funding programme "Microsystems technology 2000+"
In the framework of "Microsystems technology 2000+" (2000 - 2003), a total of 114 collaborative projects, composed of 525 granted subprojects, were approved. Overall expenditure from the budget was 170.2 million . The additional financial contribution by the industrial participants led to a total project volume of 330.3 million for all collaborative projects. This means an average sponsorship rate of 51% for all participants.

111 million out of a total funding volume of 170.2 million (65%) was allocated to subprojects with industry participation. About 38% of the total funding budget was set aside for small- and medium-sized enterprises (SME) with an annual turnover of up to 100 million , so funding of SMEs corresponds to a share of 59% of the total budget granted to industrial participants.

From the academic world 36 universities, 12 Fraunhofer Institutes and 28 other research institutions with a total of 155 subprojects participated in the collaborative projects. The total budget for these different types of research was 59.2 million (35% of the total funding volume).

On the regional level projects are spread all over Germany. The largest group of participants is located in Baden-Württemberg (119 subprojects), followed by participants from Bavaria (70 subprojects), Thuringia (80 subprojects), North Rhine-Westphalia (65 subprojects) and Saxony (41 subprojects). About one out of three subprojects (32%) is run by participants from Eastern Germany.

If one looks at the application sectors of the projects between 2000 and 2003, one sees that a considerable part of the collaborative projects is located in the medical and pharmaceutical sector, machine and equipment construction, production technology, or is concerned with communication technology. From a technological perspective, a considerable group of collaborative projects is concentrating on assembly and packaging technologies, actuator technology, production technology and signal processing.

Results of the "Microsystems technology 2000+" programme evaluation
The progress made so far in microsystems technology in Germany has been remarkable. An international evaluation team that analyzed funding by the Ministry, the current stage of development as well as future prospects in MST confirmed that support for MST was highly effective. However, they also found that there are still many obstacles to the innovation process that require a continuing national effort. Further challenges are:

- Improvement of the networking between R&D facilities, MST manufacturers and users, with special regard to the requirements and interests of medium-sized enterprises
- Enhancement of the technological and structural base for development and production services to manufacture MST products and components efficiently and cost-effectively
- Development of modular MST relying on practical and tested interfaces and standards
- Securing future technological options of system integration through the well-timed development of new technologies
- Further development of the education and training system for MST
- Stimulating innovation financing in the MST area and their applications

The analysis of these obstacles defined key action fields for German research policy and strongly influenced the "Microsystems" framework programme, which is the follow-up to the "Microsystems technology 2000+" programme that ended in 2003.

I would like to highlight some further results of the evaluation:

1. *Microsystems technologies act as intermediary between technologies and applications*
   It turned out that the definition of MST as integration of sensors, signal processing and actors on a miniaturised scale is too narrow. On the other hand, it is becoming more and more clear that MST acts as an integration technology between the nano, the micro and the macro world or between the organic and the inorganic world.

2. *In the MST area co-operative industrial projects are a successful funding instrument*
   Due to MST funding R&D resources were permanently bundled. The number of MST manufacturers and users was extended simultaneously. The funded collaborative industrial projects initiated and fostered the co-operation of small and medium enterprises, large enterprises and R&D institutes. More than 40% of enterprises start new co-operations in the projects.

3. *Microsystems technologies do have a big innovation leverage effect*
   The relevance of MST for the German economy is already considerable: an estimated turnover of about 4.2 billion   was realized with MST components in 2003. In addition the turnover of products with integrated MST components was about 277 billion . This is a very remarkable leverage effect.

4. *Broad spectrum of "future areas" has been identified*
   The future potentials of MST were evaluated in a multi-step process relying on worldwide expert discussions. Very important trends are system integration, applications in the field of life sciences, the convergence of micro- and nanotechnologies, the development of new materials, the implementation of new fabrication concepts, smart energy and ubiquitous computing, just to name a few.

Microsystems Framework Programme (2004 - 2009)

The Federal Ministry of Education and Research is aiming for the maximum economic and societal leverage effect with the current "Microsystems" framework programme. Funding will therefore concentrate on topics which particularly strengthen the innovative power of the German economy.

The basic "design rules" for the new Microsystems framework programme are:

- Improvement of the networking between research institutions, suppliers and users, with special regard to the needs and interests of SMEs
- Improvement of the technological and structural basis for services in development, design, and manufacturing
- Further development of strategies for modularity of microsystems
- Developing and maintaining future technological options for system integration
- Further improvement of MST-relevant qualifications and skills
- Easier access to sources for financing innovation in the area of microsystems implementation
- Identification of focus topics in discussion with stakeholders from industry and research

To control the thematic focuses found for the programme criteria were applied as follows:

- Potential for application and stage of maturity of the topic
- Resources and structural premises in Germany
- Societal relevance of the development, production, and application of the specific microsystems
- Potentials for job creation

The success of the measures will continuously be monitored in an accompanying evaluation of the Framework Programme.

Until today six thematic calls have been launched:

1) Measuring and testing for the manufacturing of microsystems
2) Micro reaction technology, novel chemistry
3) First use of simulation and design tools by SMEs
4) Smart label, (production-)logistics
5) Driver assistance systems
6) Preventive Micromedicine

The focus of the programme is still on collaborative projects between industry and research. Collaborative projects under industrial guidance have proven especially well suited for application- and industry-oriented funding. Specifically, the involvement of small- and medium-sized enterprises will thereby be supported.

In addition to the funding of direct R&D projects and infrastructural measures, information services and communication processes with innovation-assisting measures are supported. That involves strategic measures for an ongoing development of the framework programme, like "trend scouting" for new technologies and applications. Apart from that, further measures can enhance the international position of German MST manufacturers and users, for example by providing target group-oriented information or by realizing benchmark and networking activities. Finally, innovation policy aims at a better public understanding of science (PUS), an improved education and training in MST and further extension of the results of the individual projects beyond their duration. Accounting for the high dynamics in the field of MST, public programmes open new potentials and can make a significant contribution to the identification of new technological fields and the development of innovative applications.

More information

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Expanding the Knowledge Base - Education and Training in Germany

Sabine Globisch

Microsystem Research and Industry can rely on a unique education system in Germany. There is a large number of education facilities and universities that organise courses for a wide range of qualifications. The education system has adjusted to the new challenges of Microsystem Technologies. Germany offers attractive places to study and graduates from Germany have a unique profile and are highly appreciated.

New challenges for the educational system

The success of industrial innovation depends on persons mastering knowledge of emerging technologies that is of current relevance. The development of microsystem technologies was at the forefront of changes in the engineering professions due to the application of new materials, techniques, methods and of course various combinations of all that. This caused new demands for qualifications and skills. A broad scientific and technological background is required that enables engineers to solve future technological problems. For this reason, it is necessary to merge scientific and engineering competences. Since MST is an interdisciplinary technology, courses embrace various technical subjects. Finally, MST calls for close relations with industry and emerging markets on an international level.
Following these new qualification requirements, all players from industry, education, research and politics joined in order to ensure that young professionals are taught in high technology, but also with industrial substance. In consequence, an outstanding education system covering the entire range of academic and non-academic qualifications for MST was established.

Centres of excellent research, teaching and training

The MST qualification system is based on three segments: non-academic training, academic studies and further education. More than 60 universities and technical colleges offer courses and degrees related to microsystem technologies. In many cases, the studies are integrated into existing majors like micromechanics, electrical engineering, physical technologies, information and communication technologies, and informatics. A number of universities offer courses with a specific MST profile. The next article will give an outline of the course at the Institute of Microsystem Technology at the University of Freiburg. The University of Applied Sciences Furtwangen offers a Master's Program in Microsystems Engineering that is focused on the growing market of MST and related areas. The FH Aachen and the FH Kaiserslautern/Zweibrücken have established a Virtual Clean Room - a new tool in teaching MST process technologies, just to name a few examples of major education facilities. In order to meet the international structure of MST research, a growing number of universities and technical colleges offer international degrees.

Furthermore, the technological dissemination into application fields and mass production calls for employees with an equivalent qualification profile beside the academic level: the Microtechnologist apprenticeship. The apprentices learn basic natural science, especially physics, chemistry and mathematics. Microtechnologists know how to drive the whole production process from the preparation to the controlling stage. Hence they often work in the production area to assist engineers.

To assist the industry in gaining highly qualified employees for Microsystems technology the Federal Ministry of Education and Research promotes six training and education networks throughout Germany. These networks aim to build up training courses and materials where employees can improve their knowledge work base oriented. Furthermore the networks aim to encourage cooperation between research area, industry and educational institutions, given that cooperation between these players supports the dissemination of relevant training concepts for the industry. For further information see www.mst-ausbildung.de.

Education for new labour markets

The chosen strategy, i.e. handling MST as a multidisciplinary key qualification for new technologies, led to good results. This is shown by a survey carried out on behalf of the German Ministry of Education and Research (BMBF) in 2002. Since the time the new studies were introduced at the beginning of the nineties about 2,000 graduates finished university or technical college with a MST degree. These graduates are highly welcome in industry. One fifth of them are already in employment while writing their diploma thesis and 84% of them are engaged during the first three months after their graduation. Within other subjects only 53% of graduates are engaged within this time period.

As the main MST companies are small- or medium-sized, they are in need of engineers with a general technological background ready to work in various functions. The MST graduates deliver this profile and work in the production area as well as in the research area. They are responsible for research and development, create production lines and they organise distribution and marketing as a result of their general competencies.

Graduates from new MST programs have a highly appreciated profile, and their broad and thorough education allows them to accommodate fast to the requirements in an industrial setting. MST programs stimulate the graduates towards life-long learning, which enables them to work at the edge of technological development.

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Educating Microsystem Technologists: New Technologies, New Engineers, New Approaches

Hans Zappe

Microsystem technology (MST), micro-electro-mechanical systems (MEMS) or micro-machines: three expressions for a single engineering discipline which has grown rapidly in the last two decades but whose origins still strongly affect the way the field is taught to young engineers. As MST matures, these traditional educational approaches will no longer suffice to train engineers whose capabilities are sufficiently broad to allow them to make important contributions to the advancement of the field.

Limited learning lacks luster
Far from its origins as a sub-discipline of electrical or mechanical engineering which employed semiconductor clean rooms for the fabrication of clever structures of unclear utility, microsystem technology has blossomed into a highly interdisciplinary field with a truly astonishingly broad range of industrial and, increasingly, commercial applications. MST now comprises a large variety of sub-disciplines of its own: we have optical, biological, mechanical, fluidic, electrical, chemical or medical microsystems, and many applications require combination and integration of more than one of these.

For this reason, young engineering graduates who intend to work in microsystem technology need to have a correspondingly broad engineering education. While no one expects a budding MST engineer to obtain simultaneous degrees in electrical, chemical and mechanical engineering, a bachelor's in phys-ics, a master's in optics and an MD to boot, productive workers in MST do need to have a working knowledge of at least some aspects of all of these fields. It is rapidly becoming clear that learning MST merely as a minor or as a concentration area in an engineering syllabus is no longer sufficient.

Innovative IMTEK
In 1996, the University of Freiburg in Germany grasped the opportunity to redefine MST education by founding the Institute of Microsystem Technology (IMTEK), an independent university department in the Faculty of Applied Sciences dedicated wholly to education and research in MST. The educational program was developed from scratch, allowing the founders to establish a finely tuned curriculum which addressed as many aspects of microsystem technology as possible. Depth and breadth, two opposing constraints, were balanced in an effort to educate engineering students with the range of capabilities required to engage in advanced MST research and development.

An IMTEK student begins her or his education with the basics required of all engineers (math, physics, chemistry) but the syllabus then expands to include electrical and mechanical engineering. Specialized classes, of which almost 20% are hands-on laboratory courses, then present topics as varied as microfabrication technology, system integration, simulation, micro-optics, sensors and actuators. In the last two years, students may then choose one of three concentration areas, in which courses dedicated to life sciences, system technology or materials are offered, permitting each student to fulfill personal technical interests in greater depth. A six-month diploma thesis, finally, requires of the student that she or he apply this knowledge by addressing an advanced research topic in some aspect of MST.

Graduates leave IMTEK with a Diploma degree in Microsystem Technology and most have firm job offers before they file their diploma thesis. Once prospective employers realize the far-reaching range of talents which the MST graduate has to offer, a wide range of employment opportunities presents itself. IMTEK graduates may be found in a broad spectrum of industrial employers, large and small, who benefit from the interdisciplinary technical abilities, the hands-on competence and, not least of all, the communication skills of those who have successfully completed the MST programme.

Degree development
Starting in 2005, the MST Diploma will be supplanted by a Bachelor's and Master's of Science program in microsystem technology. The added flexibility which this new program promises will allow, on the one hand, students to complete a five-year (BS and MS) education focused expressly on MST, but on the other hand also permit students with Bachelor's degrees in related disciplines to complement their previous training with a MS in microsystems. The latter alternative will most likely lead to significant numbers of graduates with an even more interdisciplinary education than heretofore.

Engineering evolves
IMTEK has played a pioneering role in MST education, allowing students for the first time to obtain a basic engineering degree focused wholly in microsystem technology. Whether one prefers MST, MEMS or micro-machines, this educational approach is now increasing in popularity, as universities realize that engineering disciplines change and evolve with time. We will likely see an increasing number of degree programs and engineering syllabi wholly dedicated to microsystem technology, yielding graduates who will take the field in innovative and stimulating directions.

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Networks and Associations - Initial Contact Points in Germany

A number of industrial associations support the application of microsystems technologies in Germany. Furthermore, these industrial associations can offer international MST producers and users an efficient "gateway" to find partners for co-operative projects or other joint action.

The AMA Association for Sensor Technology - a Mirror Image of Microtechnological Applications

In the mid-seventies the utilization of semiconductor effects started gaining significance for measuring applications. On the one hand, we had a technological transition from electromechanical to electronic measuring systems; on the other hand, first steps were being taken to miniaturize these systems. At the same time, an economic boom took place in the sensor industry which is still continuing today, with increases in turnover of about 8 to 10 percent a year and a continuous job growth.

By maintaining corporate structures from the era of electromechanical measuring techniques and thanks to the high concentration of customers and their diversity, the orientation in present-day Central Europe is still towards application niches and has thus re-tained the clear SMB structure in the industry. This diversity and structuring led to the founding of the AMA Arbeitsgemeinschaft Messwertaufnehmer (Working Group for Transducer Technology), now called AMA Fachverband für Sensorik e.V. (Association for Sensor Technology), as early as 1980. Today the AMA has more than 400 members and represents the entire value-added chain in sensorics and measuring technology with its researchers, developers, manufacturers, suppliers, retailers and service providers. As early as 1982, the AMA organised the SENSOR trade fair, reflecting the value-added chain as well as the broad range of applications. Especially through its parallel conferences, AMA has always retained its application orientation, as opposed to numerous other fairs for fundamental sciences.

In view of the increasing significance of microtechnologies for measuring applications, AMA offered a Microsystem Technology Forum in co-operation with the VDI/VDE-IT as a special application-oriented SENSOR event in 1988 - before all the other events were launched.

Today, microtechnology is an inherent part of sensor and measuring technology; the transition to microsystems technology is blurred. The AMA Association for Sensor Technology and its SENSOR+TEST trade fair (10-12 May 2005 in Nuremberg) are among the biggest platforms for microtechnology - not as an end in itself, but as a means for optimal products in sensor, measuring and testing technology.

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GMM Promotes Scientific and Technological Development and Industrialization

The society GMM (Gesellschaft für Mikroelektronik, Mikro- und Feinwerktechnik) is backed jointly by the two engineers' associations, VDE (Association for Electrical, Electronic & Information Technologies) and VDI (Association of German Engineers). Its ambit covers technical and scientific aspects of development and production, issues surrounding technology transfer, education and training, the job market as well as PR.

GMM is responsible for promoting the scientific and technological development of microelectronics, micro and precision engineering and its applications. It initiates the necessary dialogue between manufacturers, users, authorities and scientists in the various constituent fields and provides a forum for public discussion on the progress and opportunities presented by the growth of microtechnologies and for evaluating their consequences. It represents the professional interests of micro(electronics) engineers by providing up-to-date information, training, scientific support and work guidelines.

Many of them work on an honorary basis, carrying out their technical work within the seven different specialist divisions subdivided into about 35 committees.

The work done in the specialist division "Microsystems and Nanotechnology Engineering" is carried out in eight committees covering all MST aspects:

- Basic aspects of microsystems and nanotechnology
- Micro-optics
- Micro-sensors
- Micro-actuators
- Mask technology
- Microsystems for medical application
- Information technologies for microsystems
- Micro fabrication and materials for microsystems

Each committee has up to twenty members from the manufacturing and applied industry (small and medium enterprises and large-scale industry), universities and research institutions and in some cases official authorities. Technological progress and aspects of commercialization are intensely discussed in meetings, and necessary action is taken. GMM organizes conferences, discussions and workshops. The main orientation of the funding pro-

grammes is discussed with the German authorities responsible for funding joint MST projects,. GMM also publishes journals and papers dealing with technological development as well as the general aspects of the role of Microsystems Technologies in Germany.
On the international level GMM is cooperating with SPIE, IPC, EUREL and MANCEF.

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IVAM - Microtechnology Network

IVAM is an international, industry-orientated microtechnology association. Its mission is to bring together suppliers of microtechnology and users from all industry sectors. Founded in 1993, it had 138 members from eleven nations as of June 30, 2004. IVAM focuses on:

- Technology marketing and public relations
- International cooperation and networking
- Lobbying

IVAM organizes joint pavilions at fairs and workshops at highlights like the Hanover Fair, the Sensor Exhibition in Nuremberg and the Medica / ComPaMED in Dusseldorf. The e-mail newsletter MikroMedia and the magazine Inno keep microtechnology suppliers and users up to date on current developments and technological trends.

IVAM communicates the economic benefits of microtechnology applications to policy-making bodies and consumers and, consequently, supports the industrial application of microtechnology products and services. The association provides professional training and qualification in cooperation with educational organizations, universities, enterprises and governments.

IVAM cooperates with national partners like AMA, ZVEI, SPECTARIS and MeTNet, international MEMS organizations like NEXUS and international organizations like the MEMS Industry Group.

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NC-Gesellschaft e.V. - Application of New Technologies -

In 1975 a group of NC pioneers asked the VDI in vain to integrate the innovation known as "Numeric Control". Thus, the decision to found an association was taken quickly.

Registered as an association in Munich, the office settled in Switzerland (Biberist) and technology-transfer positioned in the German-speaking market - these were the starting signals of the NC-Gesellschaft e.V. The first ten to twelve years were mainly dedicated to the topics NC, CAM, CNC. When the management changed and the office moved to Germany in 1987, further topics developed: CAD, rapid prototyping, mould and tool making, HSC, PKM and MST/UPF are in the center of the current technology transfer.
Today, about 130 companies with more than 280 experts from five European countries are affiliated to the NC-Gesellschaft e.V. Right from the beginning, manufacturer and user of new technologies are organized in a unique way. This is complemented by the third member group, the education institutions, the frame for introduction and application of innovative processes and procedures of production engineering.

Visit us at the Hanover Fair (April 11 - 15, 2005) in hall 15 and at the 2. Microsys Fair (April 26. - 29, 2005) in Sinsheim in hall 5.

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VDMA - Micro Technology

Potentials and challenges
For some years now, microtechnologies have no longer been used for microelectronics alone: besides mechanical, fluid or optical components, sensor technologies are undergoing a profound change. Yet the far-ranging usage of these components and subsystems has just begun to penetrate the engineering sector. Microtechnologies are profoundly changing the landscape of products and the development & production process of all key industries.

Benefits for users everywhere
In order to follow the road of success, the use of microtechnologies is a must in areas such as micromechanics, microoptics, micro-fluidics, microacoustics, micro assembly, micro valves or micro pumps. Therefore, a key task of the VDMA Micro Technology As-sociation is to closely monitor all international developments in the relevant fields of technology and provide its membership with the very essence of its findings.

The Micro Technology Association
The Micro Technology Association intends to analyze markets of specific importance, tap them jointly and use the VDMA network (38 trade associations, 33 technical committees and working groups and 42 international industry committees) as a fo-

rum for a mutually beneficial dialogue between the players of the industry. The Association will offer technology road maps to its members, in particular to small companies and start-ups, helping them to make the right choices to find their way into the future.

Members
The Micro Technology Association is composed of industrial enterprises and financed solely by membership dues. The member companies' activities extend to the various micro product markets and the specific markets for micro production engineering.

What do these highly diverse member companies have in common? They are companies with the courage to venture out, companies with a vision. Their technological implementation will have a positive effect on our future, the future of user requirements. the future of the demands of markets.

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ZVEI - Micro System Technologies

Although there are several mass markets for microsystem technologies like the automotive and computer industries, micro technology is still facing the elementary challenge of large investments in R&D combined with production of small and medium quantities. It is thus very difficult for small to mid-sized enterprises to enter this market.

The Electronic Components and Systems Association within the German Electrical and Electronic Manufacturer´s Association (ZVEI - Zentralverband der Elektrotechnik- und Elektronikindustrie e.V.) has started in 1999 to address this issue by providing coordination, information, and support for microsystem technology suppliers and users. Since ZVEI represents 90 percent of the German electrical and electronic industries in terms of revenue and employees, the ZVEI avails its unique position to conduct this initiative. A variety of technologies used in microsystem technology are derived from semiconductor manufacturing and sensors, while the majority of sensors and actuators are controlled by electronic systems. Many companies that benefit from a diversification into microsystem technology are represented in ZVEI.

In order to evaluate the specific needs of market participants and to derive specific activities, the ZVEI MST Group first focused on the elucidation of the supply chain and the market opportunities - involving both large companies as well as small to mid-sized enterprises.
The obvious complexity of the technology including microelectronics, sensors, micro-optics, automation and production equipment as well as the different needs and demands have been in the spotlight. Several factors, which are still responsible for the unsatisfying market penetration of microsystem technology, have been figured out from the industrial point of view.

In its distinguished position paper the ZVEI identifies the challenges of transforming a successful R&D technology into a profitable industrial production.

Thus, we are very confident to help launch the wider use of microsystem technology that promises advances in resource conservation, environmental protection, the standard of living and create highly qualified job opportunities.

Currently, the group has been enlarged more and more by small and mid-size enterprises. With this enlargement, subjects such as design tools, control- and testing-equipment and especially the complete packaging technology come into focus. The packaging technology, one of most prospering MST sectors, shows its potential in the activities of the sub-groups "Wafer Level Packaging", "Multifunctional Packages" and "Stacked Chips".

The ZVEI MST Network comprises nearly 40 companies and ten representatives of institutes. This is valorized by the close collaboration with our partners AMA and IVAM. The ZVEI Group addresses all companies with products combining microelectronics with micro-mechanical, micro-chemical or micro-biological technologies into a system.

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MST - Industry Structure in Germany

Patric Salomon, Henne van Heeren, Lia Paschalidou and Ayman El-Fatatry

This article gives an outline of the role of German MST companies compared to the rest of the world. The authors have recently carried out extensive research into the supply chain of Micro Nano Technologies (MNT), which culminated in the publication of a number of industry reviews. The data used for this article has been derived from a selection of these enablingMNT reports and several bespoke projects.

The lifecycle of a Micro Nano Technology (MNT)-based component is, in general, similar to that of most complex products, which rely on multi-disciplinary engineering. In essence, the realisation of a multi-functional MNT component will undergo an engineering design process aimed at transferring the technical concept from the 'idea' phase to a commercialised product. However, with the convergence of disciplines such as physics, biology, and chemistry into MNT development and manufacturing steps, a novel approach to interdisciplinary engineering, partnerships and co-operation is inevitable.
The prime differentiators for countries/regions to be innovative and successful in establishing new technologies in their industries will be the quality and availability of specific networks of partners, service suppliers and infrastructure. Only with such services and infrastructure available, companies (especially SMEs) can successfully make use of MNT for the product creation process and create wealth.
A comparison of the number of companies that are strongly involved in the MNT supply chain shows that the USA are by far the strongest country, followed by Germany and the UK (see Figure 1).

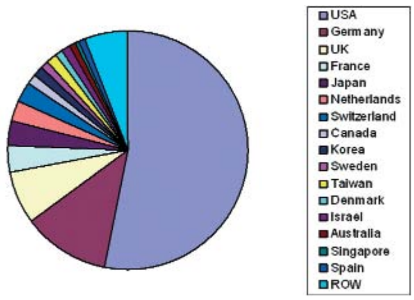

Figure 1: Companies involved in the MNT supply chain - world-wide (total number: 1090)

As shown in Figure 2, the distribution of the number of MNT service suppliers over the countries is similar to the whole number of companies. In this category, we investigated foundries, design houses, packaging, assembly

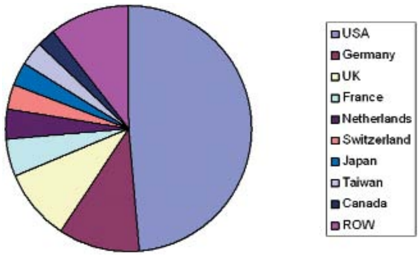

Figure 2: Commercial MNT service suppliers - world-wide (total number: 306)

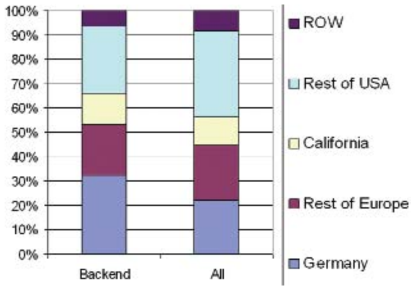

Figure 3: Regional distribution of back end MNT equipment suppliers and suppliers of all kinds of MNT equipment - world-wide

and test services, and other processing services and concluded that 32 out of a total of 306 commercial MNT service suppliers are based in Germany.
In the equipment sector for MNT production, German companies play an even stronger role. German companies make up more than 20% of the total companies world-wide (see Figure 3). Out of the 64 back-end equipment providers, there are nearly a third from Germany - only slightly less than from the USA. This German strength in back-end processing is not only evident in the equipment sector, but also in the number of providers of MST/MEMS packaging and assembly services.

While the German and European companies are supplying a large number of equipment products and back-end services at lower volume, the US-based companies are supplying the higher volume markets.

The distribution of the design houses across the industrialised world is reasonably even with a few exceptions such as the USA (an industrial culture promoting spin-offs and start-up companies) and a few European countries (see Figure 4). In Europe, the UK, Germany, Switzerland, Sweden and the Netherlands are dominating.
With regard to Nanotechnology, the MANCEF Roadmap compares the number of patents that have been granted to companies of different regions. Within the top ten, Germany is also well represented - there are two German companies and one French. The other seven are either US or Japanese.

Summary of observations
Overall, German companies are ranked second (after the USA) in services and equipment infrastructure along the supply chain of MNT. German suppliers are often serving niche markets, while the US companies concentrate on the higher volume areas. In addition to the availability of a services infrastructure, the availability of

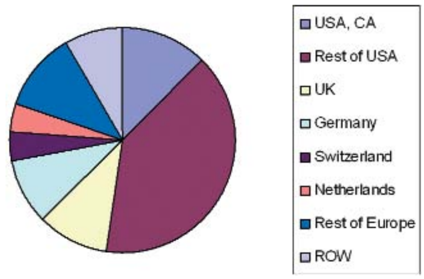

Figure 4: Regional distribution of "Design and Engineering Companies" - world-wide

a wide ranging, and current, industry-based intelligence information is of vital importance in order to optimally select from this array of enabling capabilities. This array of information is provided through the enablingMNT Industry Review series. Customised research and consulting services offered by enablingMNT range from market research, business development support and partner search for industrial customers to benchmarking and exploitation strategy development for public bodies.

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MST in Germany - Regarded with the Eyes of International Experts

Microsystems Technology (MST) - as other high-tech sectors as well - is characterized by a high degree of internationalization. Germany offers a good environment for R&D and applications of MST. But as MST is a very complex and challenging technology German companies regard in-ternational co-operation as precondition to meet the requirements of the customers abroad and as a means to exchange knowledge with international partners for mutual benefit. The following statements of well-renowned international MST-experts will give you an impression how the German as partners and "MST - made in Germany" are regarded by the international MST community.

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Germany, as leading industrial country, plays certainly a spearhead in the promotion of the MST research and industry. It has a very sound infrastructure in the MST networks in all levels. From the Federal project management VDI/VDE-IT and research institutes e.g. FZK, Fraunhofer institutes, down to State-level institutions such as Associations IVAM, and research institutes, IMM. In the industry side there are key players like Bosch, microParts, Jenoptik, Microfab and Ehrfeld. Good publications, good products and excellent human resources. After years of strong competition and cooperation winners and niche product providers have been crystallized. Except few integrated product providers where MST becomes a power tools for reducing costs, enhancing reliability, simplifying process, miniaturizing components or facilitating new functions, SME have generally difficulties overcoming the break-even barrier and justifying their existence and wide-spreading acceptance. This is also true for almost all geographical regions. MST is only one technology option of realizing customer needs. Volume (killer applications!!) still plays a crucial feature for industrial applications, however microelectronics rules and practice could not apply without modifications. Only when large amount of companies use the same inter-face or even dimensional standards, could MST experiences break-through. Courses like "Design for MST" would also help the acceptability. This has been properly addressed by German federal MST program. An even wider international cooperation, or task distribution seems to be inevitable.

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I am currently in charge of long-termed National microsystem R & D program in Korea, in that sense I am continually in contact with European microsystem research teams.
Since last couple of years large parts of MST research activities have been changed merely with the keyword of Nano instead of Micro, especially in government-funded research programs in USA, Japan and also in Korea. But it is clear to all of us that MST has its own specific role, impor-tance and fields besides the sharing field with Nano. From such aspect I regard meaningful that German federal government further continues to support MST research program since long.
There are relatively many small companies in Germany in the field of micro parts manufacturing. The technical level seems to be market leading in the world, I guess. I feel German situation much better than Korean situation, even though reliable profit cannot be expected at all yet. Traditionally strong point of German way is very practical and reliable rather than futuristic and fantastic in the viewpoint of market approach.
There seem to be several industry consortiums for mutual role collaboration, in Germany as well as in Europe, for example, IVAM, where we are involved with the purpose of information sharing. German MST activities seem to get more response from the customers, for example they expand the space at the Hanover industry fair.
I expect that German MST sector leads world market with the strong points of precision expertise and practicality. German products have the reputation of high reliability in Korea, I hope German micro products show the same reputation and customers.

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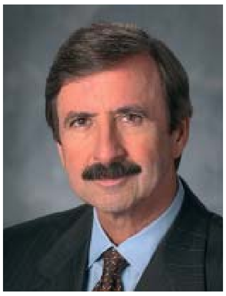
Germany has led the world on two fronts; firstly, through a creative impetus that has given rise to a multitude of MST-based novel devices and concepts and secondly, through an impressive array of successful commercial products. Underpinning this remarkable achievement is a national programme that provides support and strategic guidance - a programme that is now being emulated by other European nations including the UK.
Personally, I have many years of experience collaborating with many different organisations and individuals where the inventiveness of the researchers from institutions such as the FhG and the commercial pull-through of companies such as Siemens, microParts and Bosch have been both impressive and educational.
I now see a concerted shift by those organisations towards developing increasingly complex multifunctional and integrated microsystems for such applications as medical, automotive and life-style - a shift that is also, currently, key to the UK's strategy for a national micro and nanotechnology (MNT) initiative. I am certain that we in the UK will continue to learn from our German colleagues and I hope to see many more collaborative research projects flourish between German and British institutions particularly as the UK's centres of excellence begin to emerge (CEMMNT, in metrology and characterisation for MNT and the SEIC in systems engineering to name but two)."



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The contributions of Germany to the commercialization of worldwide MEMS/MST is truly significant. In using my popular "Commercialization Report Card" format which has been published in mstnews 3/02 and presented at the annual Commercialization of Micro and Nanosystems (COMS) Conferences, Germany and its organizations scores high grades. I consider the single most significant contribution of Germany to the commercialization of MEMS/MST to be the creation of the Dortmund MST cluster in 1989 which marked the beginning of the development of micro/nano technology clusters. Since that time, well over 20 other clusters have been or are in the process of being developed worldwide. It is said that imitation is the greatest form of flattery! Clusters historically have been key to the successful development of all industries and especially in the Microsystems/semiconductor areas e.g. Route 128 (Boston) and Silicon Valley California. The IVAM organization has played a major role in the development and support of the Dortmund cluster. Most notable about the success of this cluster has been the creation of two very success-ful companies: HL Planartechnik and STEAG microParts…, both of them producing high volumes of Microsystems yearly. The underlying success of this cluster as well as others is attributed to the financial support of the regional government, a source of well educated engineers and technical people and a strong infrastructure including the availability of research organizations (e.g. Fraunhofer Gesellschaft) and manufacturing/foundry facilities. Fortunately, Germany has been able to successfully fulfil all of these requirements in the past and I expect it will continue to do so in the future. As a final note, Germany hosted the first COMS conference in the mid of the nineties in Dortmund and will again host COMS 2005 in Baden Baden.

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During the latest market research for the enablingMNT Industry Review series, we investigated many areas of the MNT supply chain and we came to the conclusion that in several important area German companies are the market leader and in many others only second to the United States. Examples for these German strengths are the various commercial services in packaging and assembly and the supply of equipment for micro and nano technologies (MNT).
We think this good position has a relation with the systematic, engineering approach to R&D in Germany, but also with the early launch of the first Microsystems funding initiative in 1990 and its special focus on SMEs.

Another factor is the successful cluster formation in the regions that we can see especially in the Dortmund region. For the Netherlands it is very stimulating to have such a neighbour.

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As usually in R&D our cooperation with German MST teams has begun from personal relation-ships. It has to be acknowledged with gratitude, that after first works undertaken in Poland on pressure and acceleration sensors in the middle 80-ties, the important impulse to enter fascinating world of advanced microsystems came from Uni-Kassel, where Dr. Ivo Rangelow was work-ing on application of advanced plasma etching processes in MST. Starting from simple structures, this cooperation has developed into work on variety of sophisticated micro- and nanoprobes. We have formed a good international team sharing CMOS facility potential of Inst. of Electron Technology, Warsaw, the micro- and nanometrology skill of Dr. T.Gotszalk from Wroclaw, and the deep expertise in etching, knowledge in physics and good contacts in the research and industrial communities of Dr. Rangelow from Kassel. The co-operation was supported by DAAD and by Copernicus projects, however it has to be said, that this support didn't allow for full exploitation of existing possibilities.
Opening Framework V programs for Polish researchers was the turning point in our research co-operation with Germany. Now we have projects also with teams from IMM-Mainz, Uni-Oldenburg and Uni-Karlsruhe. What is extremely important, we have faced a German hi-tech industry, seeking innovative technologies and products. It is very challenging but also exciting. The change within last few years was enormous, however there is still room for improvement (certainly, lack of satisfaction is an attribute of a researcher). As an example, we have faced a situation where German SME were interested in our R&D work, however our research couldn't be financed from German national sources. Thus, a need exists for support programs oriented into facilitation of bilateral (across the border) R&D projects with clear industrial application perspective. Such a system would help considerably in development of the R&D cooperation within the ERA.

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At the beginning of the "Initiative Mikrotechnik Österreich" in 2000 we carefully checked the experiences of the already long running programme in that field of VDI/VDE-IT in Germany. There is not only a long lasting funding history in Germany but also much experience in research and development in different institutions e.g. various Fraunhofer Institutes and the Forschungszentrum Karlsruhe. That's why Austrian companies were also working together with R&D-partners in Germany. Austria and Germany are closely linked in cooperation on all levels of microtechnology in the past. This was a motivation in 2004 to co-operate on European level in a European Research Area network (ERA-Net) together with different other countries in the so called MNT ERA-Net project where both countries are in a leading position. We will find harmonized funding rules and in the end an easier cooperation between research and development institutions and companies across the countries borders.

MST - Events in Germany

Germany has a renowned tradition of international trade fairs, not only for established industry branches but also for high-tech fields and emerging technologies. A number of events have evolved into internationally recognized meetings on business communication in the field of microsystem technologies. Several trade fairs are accompanied by a conference that allows discussion of current R&D questions and hot topics for industry. The following remarks give just a brief impression of the wide variety of fairs that are held on a regular basis.

The Hanover Fair remains the world's leading showcase for industrial technology. The MicroTechnology at the Hanover Fair is the leading trade fair for applied microsystems technology and nanotechnology. Of particular interest is the integration of microsystems technology into other areas of technology and industrial applications. The exhibitors present innovations disseminating into industrial production, thereby covering crucial sectors like automation, communications, mobility, energy and the life sciences.

The Nuremberg trade fair centre hosts a number of specialized fairs that are highly relevant to microsystems technology. SENSOR+TEST, for example, presents the whole spectrum of measuring system competence, from microsensors to complex test systems. This international trade fair is considered to be the world's leading forum on sensors and measuring and testing technology.

The Munich Fair GmbH has set up MicroNanoWorld, a new brand encompassing all activities in the fields of micro- and nanotechnologies. The MicroNanoWorld at Productronica 2005 will focus on solutions for micro and nano production. MicroNanoWorld at electronica 2006 will be the industry platform for micro- and nanotechnical products and their applications. Munich also hosts the SEMICON Europa that serves as a gateway to the global semiconductor industry. Industry exhibits, user-supplier meetings, the SEMI International Standards meetings, conferences and seminars turn this event into a prime access point for industry information.

A unique opportunity to get further information on German microsystem industry and research and new international trends is the Mikrosystemtechnik Kongress, a new biannual platform that is organized by major associations and networks. The next event will take place in Freiburg in October 2005.

There is a large number of trade fairs whose focus is not on microsystem technologies per se, but on related technological fields. These fairs have also evolved into important events for presenting microsystems within specialized areas of application. The following are a few examples: The Biotechnica in Hanover (www.biotechnica.de) has become one of Europe's leading biotechnology events. The Medica and ComPaMED in Düsseldorf (www.messe-duesseldorf.de/compamed) offer an ideal environment for suppliers and trade partners in the medical industry. The Analytica, Munich (www.analytica-world.com), SMT/Hybrid/Packaging, Nuremberg (www.smt-exhibition.com), LASER, Munich (www.laser.de), Optatec, Frankfurt (www.optatec-messe.de) and many other trade fairs reflect the successful development of important sectors of the future with high relevance to microystem technologies.

Many trade fairs rely on a strong local research base and modern technology companies that have settled in the region. These trade fairs in Germany serve as a meeting place. An international audience from Europe, the USA and Asia provides an excellent basis for exchanging know-how and establishing new international partnerships.

The following list summarizes relevant key dates for 2005 and 2006. There are many additional events and conferences that deal with new research topics or with measures accompanying research and innovation, like education, commercialisation or research policies. For further up-to-date information, please refer to:
www.mstonline.de/news/events

SEMICON Europa, Munich - Semiconductor Equipment and Materials, 12-14 April 2005
www.semi.org

Hanover Fair MicroTechnology - showcase for innovations in microsystems technology and nanotechnology
11-15 April 2005, 24-28 April 2006, www.hannovermesse.de

Microsys, Sinsheim - convention trade fair for microsystems technology and ultra-precision manufacturing
26 to 29 April 2005, www.microsys-messe.de

Sensor + Test, Nuremberg - International trade fair for sensorics, measuring and testing technologies
10-12 May 2005, www.sensor-test.com

Mikrosystemtechnik Kongress 2005, Freiburg International conference on German microsystem industry and research
10 -12. October 2005, www.mstonline.de

Productronica, Munich - International fair for electronic production technology
15-18. November 2005, www.productronica.de

Actuator, Bremen - International conference on new actuators and international exhibition on smart actuators and drive systems, June 2006, www.actuator.de

Electronica, Munich - Trade fair for manufacturers and designers of electronic assemblies, equipment and machinery
14 -17 November 2006, www.electronica.de

Index of German Companies and Research Institutes

For further information see the enclosed booklet.