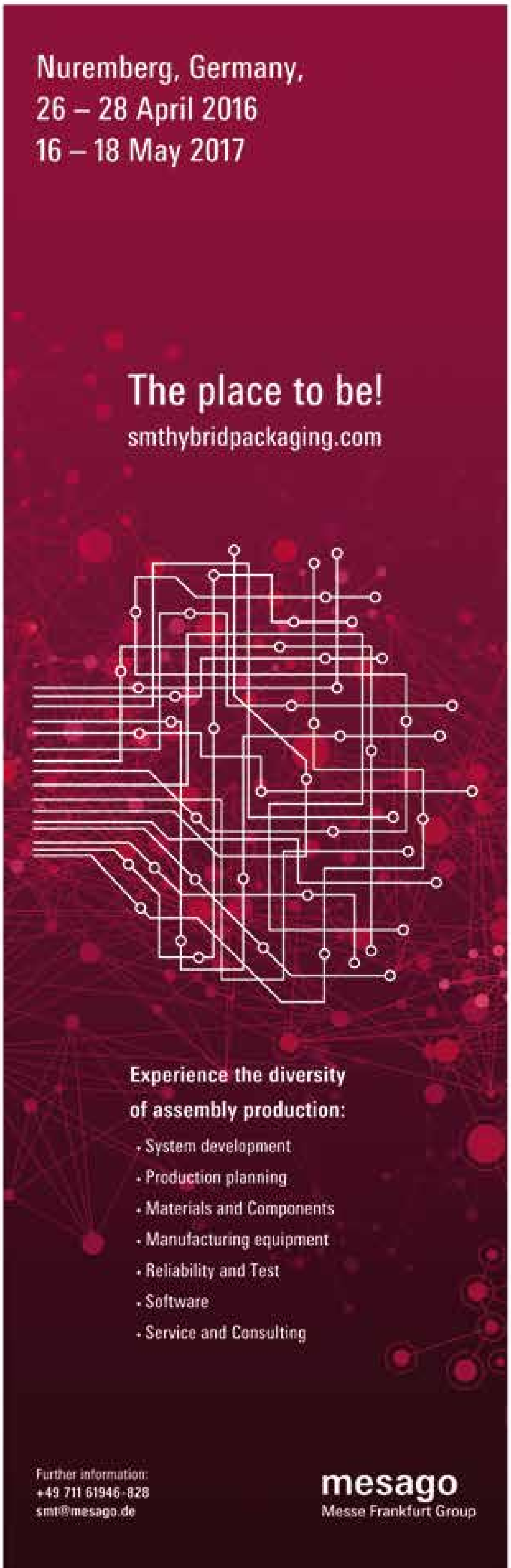
MICROSYSTEMS TECHNOLOGY IN GERMANY 2016

MIKROSYSTEMTECHNIK IN DEUTSCHLAND 2016



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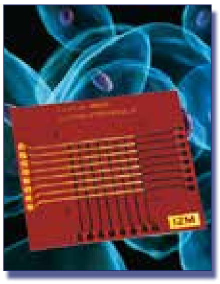

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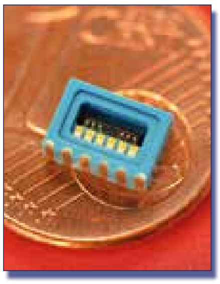


Microsystems: A Success Story with a Bright Future

Prof. Dr. Volker Saile
Chairman MST- Congress 2015
Karlsruhe Institute of Technology.

Microsystems or MEMS (Micro Electro Mechanical Systems) have changed our world in the past two decades. Cars wouldn't drive safely without them and smartphones wouldn't be smart at all. In a broader picture, microsystems technology has developed into a key technology for addressing challenges facing our society and providing solutions. Such challenges include secure energy production and supply, preservation of our environment and our health, development of our communication infrastructure, locally and around the globe, and support of our mobility. Novel concepts are currently being developed under the headlines of Cyber Physical Systems (CPS), TSensors, Internet of Things (IoT), Internet of Things and Services (IoTS) and Internet of Everything (IoE). The common feature of all of them is network connectivity of physical objects with electronics, processors and software and all of them rely on microsystems, in particular, on sensors. Such sensors first conquered the automotive sector in the 90's, then the consumer market since approximately ten years reaching an incredible annual volume production of several billion units mostly for smartphones. The next phase is already in sight with another dramatic jump in volume through IoTS. These new concepts impact the manufacturing sector and will lead to a next phase in industrialization. In Germany these developments are promoted under the headline Industrie 4.0 and major, often government supported, efforts aim at informing industry representatives and preparing them for the paradigm changes.

Germany is in an enviable situation of holding a worldwide top position in microsystems research and development and, most important, also in production. Big companies like Bosch and Roche are world-leaders, and numerous small and medium size companies support the microsystems manufacturing network, while universities and research organizations develop the field further and educate the work force. Germany's leading position is not an accident but rather the result of a deliberate long term strategy of all partners involved and, last but definitely not least, of a prudent support and guidance of the federal and state governments. The individuals in the ministries, who whole-heartedly supported the microsystems efforts from early on and over a significant number of years deserve our recognition and thanks.

Every other year the Mikrosystemtechnik-Kongress serves as showcase for Germany's strength in microsystems R&D and products. It started originally in Freiburg in 1995 and its sixth edition was held in Karlsruhe in October 2015 as a joint event of the Federal Ministry of Education and Research, the State of Baden-Württemberg and the VDE Association for Electrical, Electronic & Information Technologies. Approximately 1000 participants and 50 exhibitors demonstrated the vitality of the field and everywhere an upbeat mood could be sensed in view of the bright future.

I hope you will enjoy reading “Microsystems Technology in Germany” and find inspiring contributions with new ideas, results and concepts.

With best regards,

Prof. Dr. Volker Saile
Chairman MST Congress 2015
Karlsruhe Institute of Technology

Mikrosystemtechnik – eine Erfolgsgeschichte mit glänzender Zukunft

Mikrosysteme oder MEMS (Micro Electro Mechanical Systems) haben in den vergangenen zwei Jahrzehnten unsere Welt verändert. Autos würden ohne sie nicht sicher fahren und Smartphones wären keineswegs „smart“. Aus globaler Sicht hat sich die Mikrosystemtechnik zu einer Schlüsseltechnologie entwickelt, die ein wichtiger Baustein bei der Bewältigung der großen Herausforderungen, vor denen unsere Gesellschaft steht, geworden ist und dabei Lösungsvorschläge liefert. Zu solchen Herausforderungen zählen eine sichere Energieerzeugung und -Versorgung, der Erhalt unserer Umwelt und unserer Gesundheit, die Weiterentwicklung unserer Kommunikations-Infrastruktur lokal und rund um den Globus sowie die Unterstützung unsere Mobilität. Zurzeit werden neue Konzepte unter den Schlagworten Cyber-Physical Systems (CPS), TSensors, Internet der Dinge (IoT), Internet der Dinge und Dienste (IoTS) und Internet of Everything (IoE) entwickelt. Ihr gemeinsames Merkmal ist die Vernetzung von physischen Objekten mit Elektronik, Prozessoren und Software und alle stützen sich auf Mikrosysteme und dabei insbesondere auf Sensoren. Solche Sensoren eroberten zuerst den Automobilsektor in den 90er Jahren, dann in den letzten zehn Jahren den Consumer-Markt und erreichten dabei beeindruckende Volumina in der Massenproduktion von mehreren Milliarden Einheiten pro Jahr, hauptsächlich für Smartphones. Die nächste Phase dieser Entwicklung ist bereits in Sicht mit einem weiteren dramatischen Sprung im Volumen durch IoTS. Diese neuen Konzepte haben Auswirkungen auf die verarbeitende Industrie und leiten die nächste Phase der Industrialisierung ein. In Deutschland wird diese Entwicklung unter der Überschrift Industrie 4.0 vorangetrieben und erhebliche Anstrengungen, die oft mit öffentlichen Mittel unterstützt werden, zielen auf eine Information von Repräsentanten aus der Industrie ab, um sie auf den Paradigmenwechsel vorzubereiten.

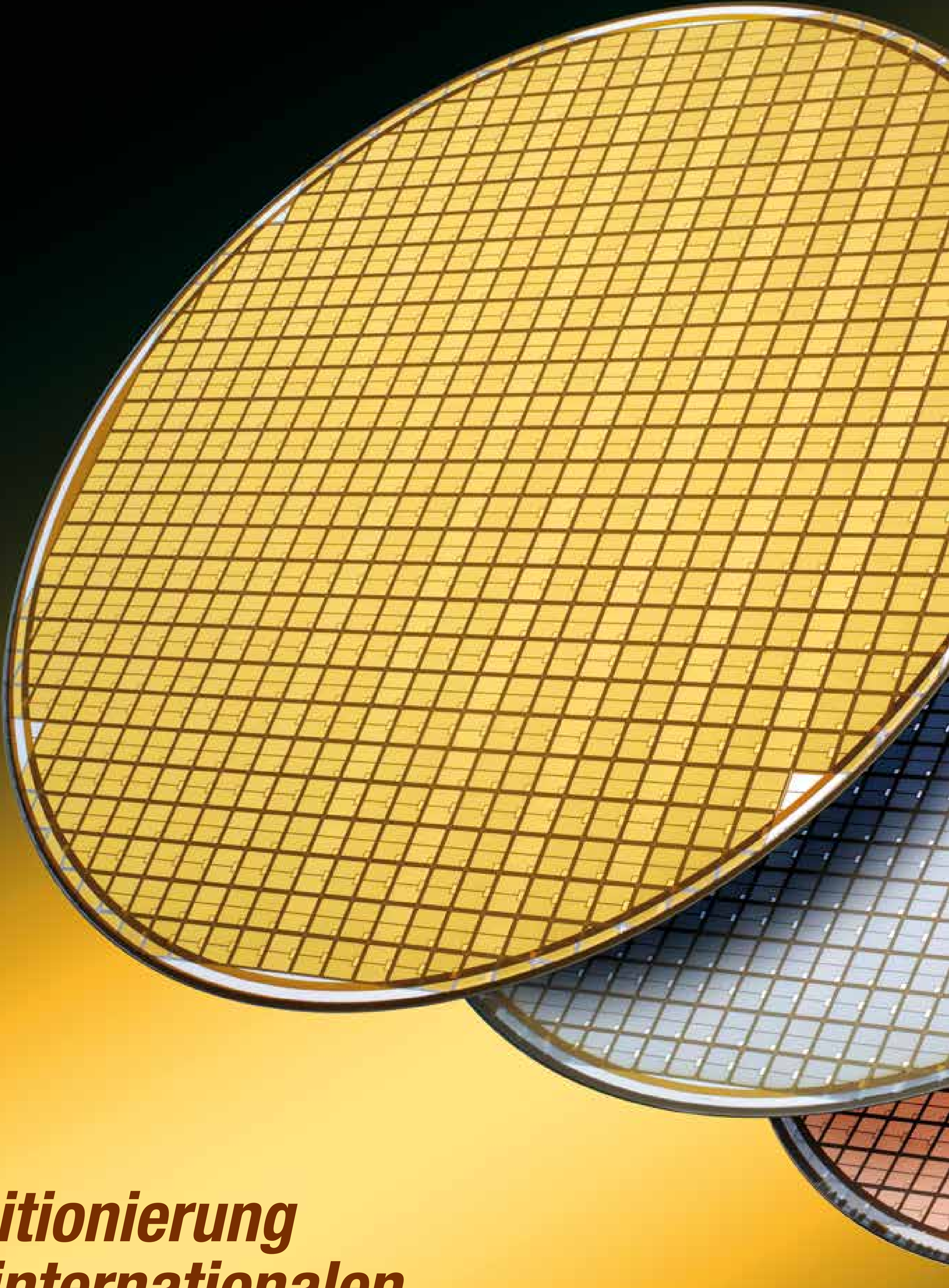
Deutschland ist in einer beneidenswerten Lage, eine weltweite Spitzenposition in Forschung und Entwicklung für die Mikrosystemtechnik und, das ist von größter Bedeutung, auch in ihrer Produktion innezuhaben. Große Unternehmen wie Bosch und Roche sind weltweit führend und zahlreiche Mittelständler unterstützen das Mikrosystem-Fertigungsnetzwerk während Universitäten und Forschungsinstitute das Feld weiterentwickeln und Mitarbeiter dafür ausbilden. Deutschlands führende Stellung ist kein Zufall, sondern das Ergebnis einer gezielten langfristigen Strategie aller beteiligten Partner, und dabei insbesondere auch einer umsichtigen Unterstützung und Begleitung durch die Bundes- und Landesregierungen. Die Mitarbeiter und Mitarbeiterinnen in den Ministerien, die engagiert die Anstrengungen in der Mikrosystemtechnik frühzeitig und über eine beträchtliche Anzahl von Jahren unterstützt haben, verdienen unsere Anerkennung und Dank.

Alle zwei Jahre dient der Mikrosystemtechnik-Kongress als Schaufenster für Deutschlands Stärke in FuE und Mikrosystemprodukten. Er fand erstmals im Jahre 1995 in Freiburg statt und wurde im Oktober 2015 zum sechsten Mal in Karlsruhe als gemeinsame Veranstaltung des Bundesministeriums für Bildung und Forschung, des Landes Baden-Württemberg und des Verbands der Elektrotechnik, Elektronik und Informationstechnik (VDE) durchgeführt. Etwa 1000 Teilnehmer und 50 Aussteller zeugten von der Vitalität des Feldes und überall herrschte Aufbruchstimmung angesichts der glänzenden Zukunftsperspektiven.

Ich hoffe, Ihnen gefällt die „Mikrosystemtechnik in Deutschland“ und Sie finden inspirierende Beiträge mit neuen Ideen, Ergebnissen und Konzepten.

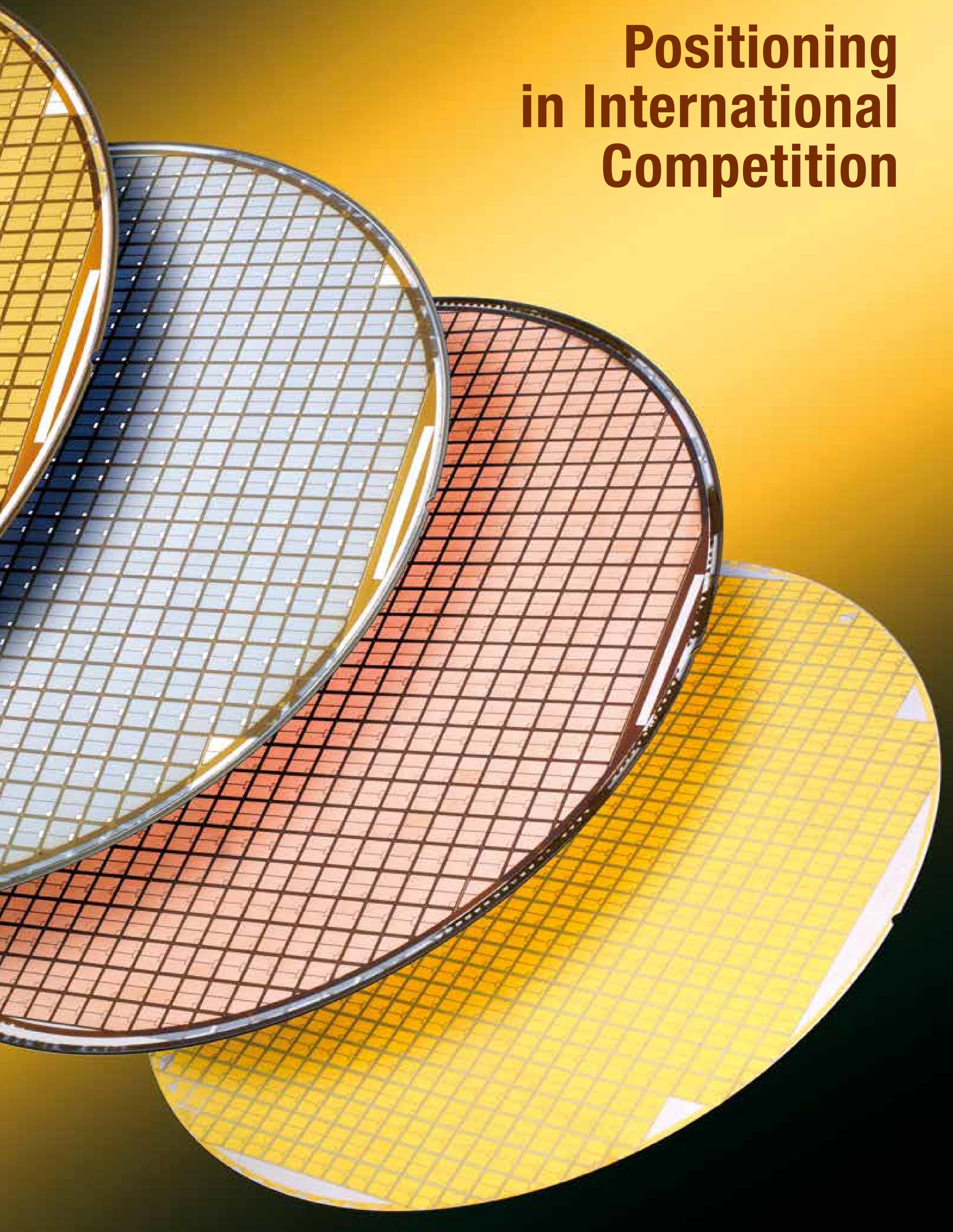
Mit besten Grüßen

Prof. Dr. Volker Saile
Tagungsleiter MST Kongress 2015
Karlsruher Institut für Technologie



Positionierung im internationalen Wettbewerb

Positioning in International Competition



Germany: The European MEMS Driver

Market developments

Recent years have seen much soul-searching in the European semiconductor and electronics communities. As Europe's share of the semiconductor market continues to ebb, there remains one European stronghold: More-than-Moore technology. Particularly important in this field is MEMS (known in Europe as microsystems technology). Europe as a whole is a world leader in this field and Germany is – like in so many other manufacturing-related fields – arguably Europe's engine.

2015 has seen reports of German giant Bosch taking the number 1 spot in the MEMS sensor market for the second year in a row. Together with STMicroelectronics, there are 2 European companies in the top 3 in terms of MEMS sales. In 2014, the gap between the two widened to more than $500 m.

The German MEMS industry enjoys a healthy competitive position. It supplies consumer markets, especially smartphones, with its sensors. This market offers large and growing volume, with total revenue increasing at an annualized 3% despite declining prices due to intense competition.

However, the German MEMS industry has a second pillar of growth within the strong domestic premium car industry. Here, demand for sensors and actuators is particularly strong and will continue to grow as cars that can sense their own environment become more important.

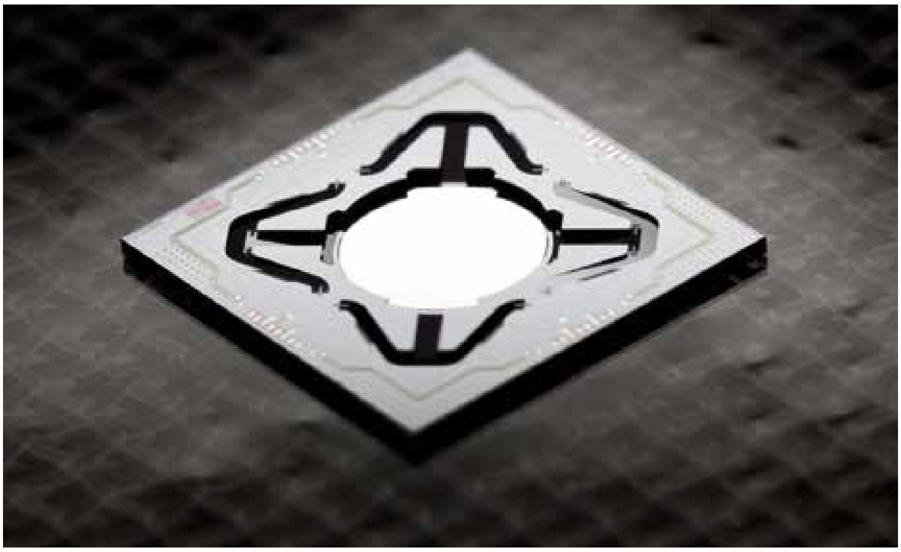


Fig. 1: Resonant translational mirror for industrial applications, © Fraunhofer IPMS

Investment

Not only is Germany very successful in the MEMS industry today but companies are investing heavily to stay ahead of the competition and conquer the markets of tomorrow. According to the German Association for Sensors and Measurement (AMA), German sensor industry companies are ramping up their investment into R&D and production capacity by an astonishing 24% in 2015. This increase comes after an already healthy increase of 5% in investment in 2014. This large-scale investment growth is driven by developments in the fields of the Internet of Things and Industry 4.0 / Smart Factories as well as autonomous driving. It is an encouraging sign that German companies are committed to staying ahead in this market.

		2013	2014
1	Bosch	$1,001.0	$1,167.0
2	Texas Instruments	$707.9	$805.0
3	STMicroelectronics	$777.0	$630.0
4	HP	$620.4	$560.0
5	Knowles	$505.0	$460.0
6	Avago	$358.2	$380.0
7	Canon	$367.8	$357.5
8	InvenSense	$248.2	$332.0
9	TriQuint (now Qorvo)	$265.8	$305.0
10	Freescale	$256.1	$271.4
	Others	$3,844.8	$4,190.4
	Total Top 10	$5,107.4	$5,267.9
	Total MEMS market	$8,952.2	$9,458.3
	Top 10 percentage of total	57%	56%

Source: IHS, March 2015

So all is well in Germany?

While Bosch enjoys a healthy position, it should not be forgotten that its top rank is largely dependent on Apple design contracts. Infineon is

Max Milbredt,
Manager
Electronics &
Microtechnology

also doing well in the MEMS market and has grown significantly over the past few years but is still a long way behind in terms of total sales in the market. Also, it should be noted that 7 out of the top 10 companies are US-based - although with NXP's recent acquisition of Freescale, we might count that as a third European MEMS company soon. Even so, the German industry needs to work on bringing more companies up to scale in this important market.

What about China?

China has not yet been able to penetrate MEMS markets significantly. However, there is significant interest from Chinese government, VCs and entrepreneurs. We are already seeing the rise of Chinese foundries. Thus far, the MEMS market has been characterized by long development cycles. According to Yole, the average R&D period is 10 years. Together with product and cost evolution, the total time from R&D to commercialization currently takes 27 years, so the efforts by Chinese start-ups could take more than a decade to show meaningful results. Nonetheless, these long product cycles are not law and it would not be the first time that a quicker rate of catch-up would surprise Western observers were China to get up to speed faster. If China puts its full weight of entrepreneurial spirit and easy access to capital behind its MEMS companies, it might surprise us all again.

The road ahead

That points to a threat to Germany's current competitive position. There is an ongoing discussion with regards to internet services companies and their need for easier access to capital markets. The German electronics industry should join that struggle to encourage getting innovation in MEMS up to scale. Otherwise the US and China, with their more efficient venture capital markets could again rise to dominate a new market. Looking at the lessons to be learned from traditional More-Moore technology and Europe's decline in that market, we now know we should aim to keep Europe and Germany strong in MEMS.

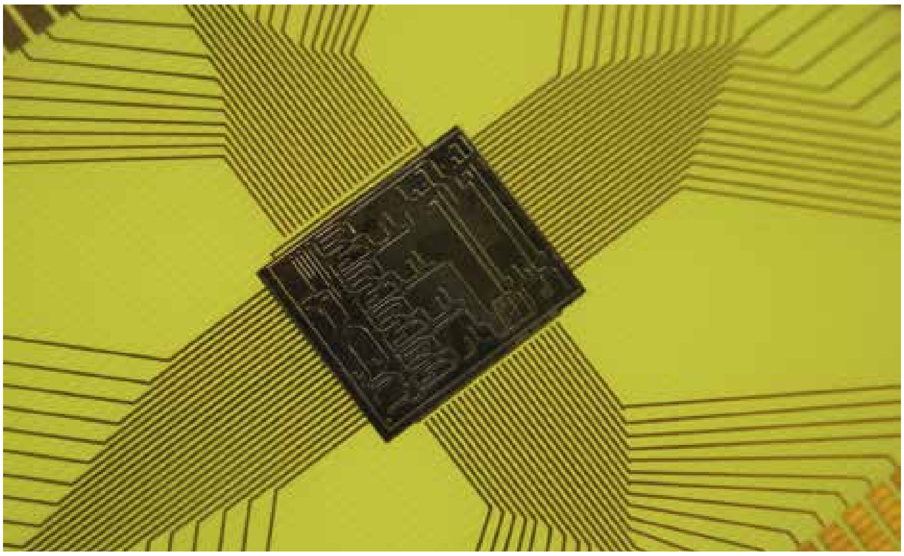


Fig. 2: Lab on a chip, © Henrik Ottoson

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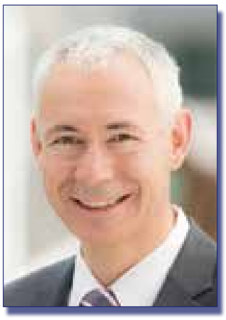
Microsystems Technology Meets Applications

Prof. Dr. Christoph Kutter,
Chairman VDE/VDI
Society of Microelectronics,
Microsystems and Precision
Engineering (GMM),
Fraunhofer EMFT,München



Germany and Europe enjoy outstanding strength in micro and nanotechnology research and applications. And we dare not give up this pole position. It is time to gather our forces and ensure a leading role in this new game. With double-digit growth rates, major leverage effects and steadily growing application potential, it numbers among the most important drivers of innovation and growth. Only those who master MST technologies and systems can prevail in global innovation competition, successfully develop new products for key markets of the future, and thus contribute to growth and employment in key industries.

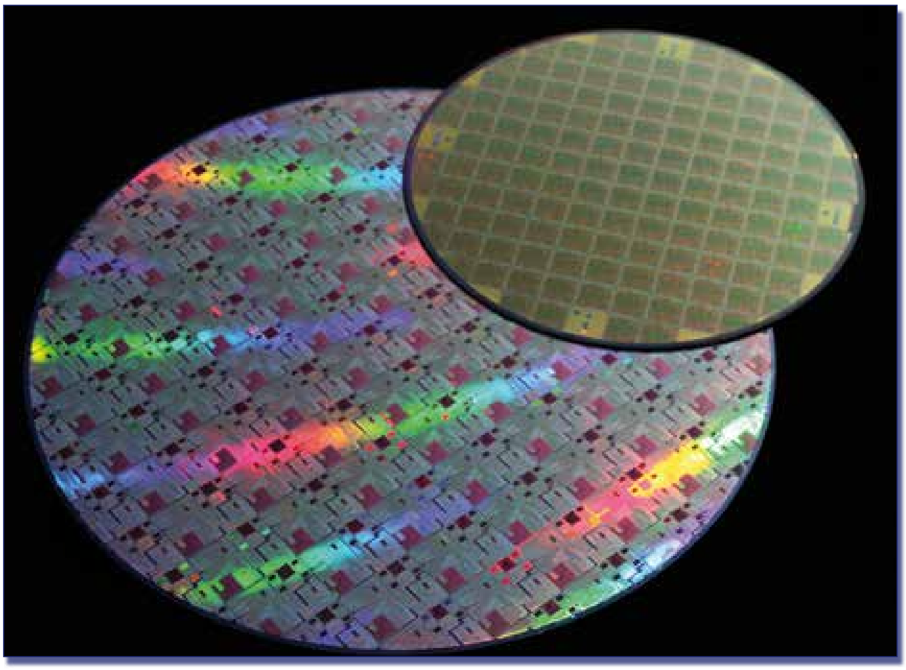


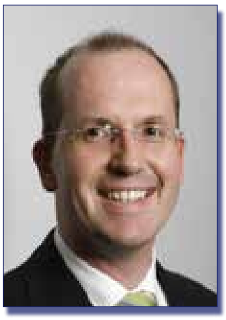
Fig.1: 300mm-wafer. Source: © ST-Leti

With its integration of sensor technology, evaluation electronics and actuation systems as well as miniaturization and software, microsystems technology (MST) makes possible innovative systems solutions for virtually all social, business and industrial applications. In particular, these include the key areas of energy/climate, mobility and communication, healthcare, safety, production and logistics.

In automotive electronics, MST contributes to the reduction of CO_2, increases safety and comfort with the help of innovative driver assistant systems, and supports the optimization of traffic flows through car-to-car communication. In medical engineering, MST solutions are becoming increasingly important for implants as well as for diagnostic and monitoring systems. In telecommunications, MST modules provide the basis for new functions and the development of 5 G future mobile communication. In industrial electronics, MST plays a growing role in wireless installation systems, building monitoring and the increasing use of sensor technology in machines and plants. The vision “Industry 4.0” cannot be realized without MST. In safety systems and logistics, countless MST-based solutions are being developed or are already in use, such as in smart cards, secure authentication systems. New MST applications are also opening up in micro-optics, the aerospace industry and in measuring and control systems.

Germany’s research and industry holds a very solid position in MST in international comparison. The fact that the importance of MST for German industry is growing is reflected by steadily increasing MST market volumes. By far the biggest customer industry here is automotive electronics, followed by industrial electronics, data processing and telecommunications as well as consumer electronics. The VDE believes the fields of energy efficiency and the internet of things, in particular, will be important MST growth drivers in the future. Important technology trends in coming years will be self-sufficient microsystems with their own energy supply and wireless communication.

We have to strengthen our microelectronics industry as part of an overall strategic EU innovation policy. Especially when it comes to system security – a vital issue – the message should be clear. We must eliminate so-called “chip backdoors” and find solutions for embedded end-to-end security. That’s why it is critically important to have the



Dr. Ronald Schnabel
VDE/VDI Society
of Microelectronics,
Microsystems and Precision
Engineering (GMM)

entire microelectronics innovation chain localized and under our own control. All the way from chip design to production, from microchips through embedded systems to entire cyber-physical systems. And what is the role of politics here? Our politicians must also provide attractive incentives for making the adequate investments needed for securing microelectronics and microsystems technologies and applications. Our political communities must create and maintain legal and regulatory framework conditions that ensure long-term planning security. Without this, developments will be hindered. The tasks lying ahead range from research in basic technologies to pilot projects and demonstrators in various technical fields.

The VDE and the German Federal Ministry of Education and Research (BMBF) are very successfully cooperating in the field of microsystems technology – both in the framework of the VDE/BMBF Microsystems Technology Congress as well as in network projects – to utilize the great innovation potential of MST in Germany for industry. Here, the VDE/VDI Society of Microelectronics, Microsystems and Precision Engineering (GMM) is playing an important role as a broadly-based expert platform for knowledge transfers, and is making major contributions to the strengthening of MST in Germany through position papers, workshops, conferences and initiatives.

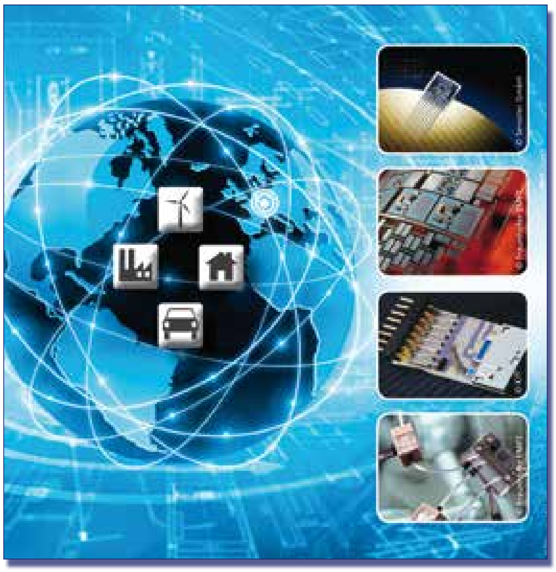


Fig.3: The world of microsystems ©VDE/VDI-GMM

The GMM believes one of the challenges in the future will be to support innovative small and mid-sized enterprises – that are shaping Germany's industrial structure in the field of MST and that contribute to Germany's leading position for innovation – in turning the results of their basic research into marketable products. Other challenges will be to reduce bureaucratic hurdles to innovation, expand knowledge networks and increase support for young talents and research. The VDE believes the goal of a far-sighted and future-oriented MST engagement is to rigorously utilize the great potential of MST and strategically strengthen Germany's competitive position in other key technologies and leading markets.

Fig.2: Chip-to-Wafer Stock for 3D Integration. Source: © Fraunhofer IZM

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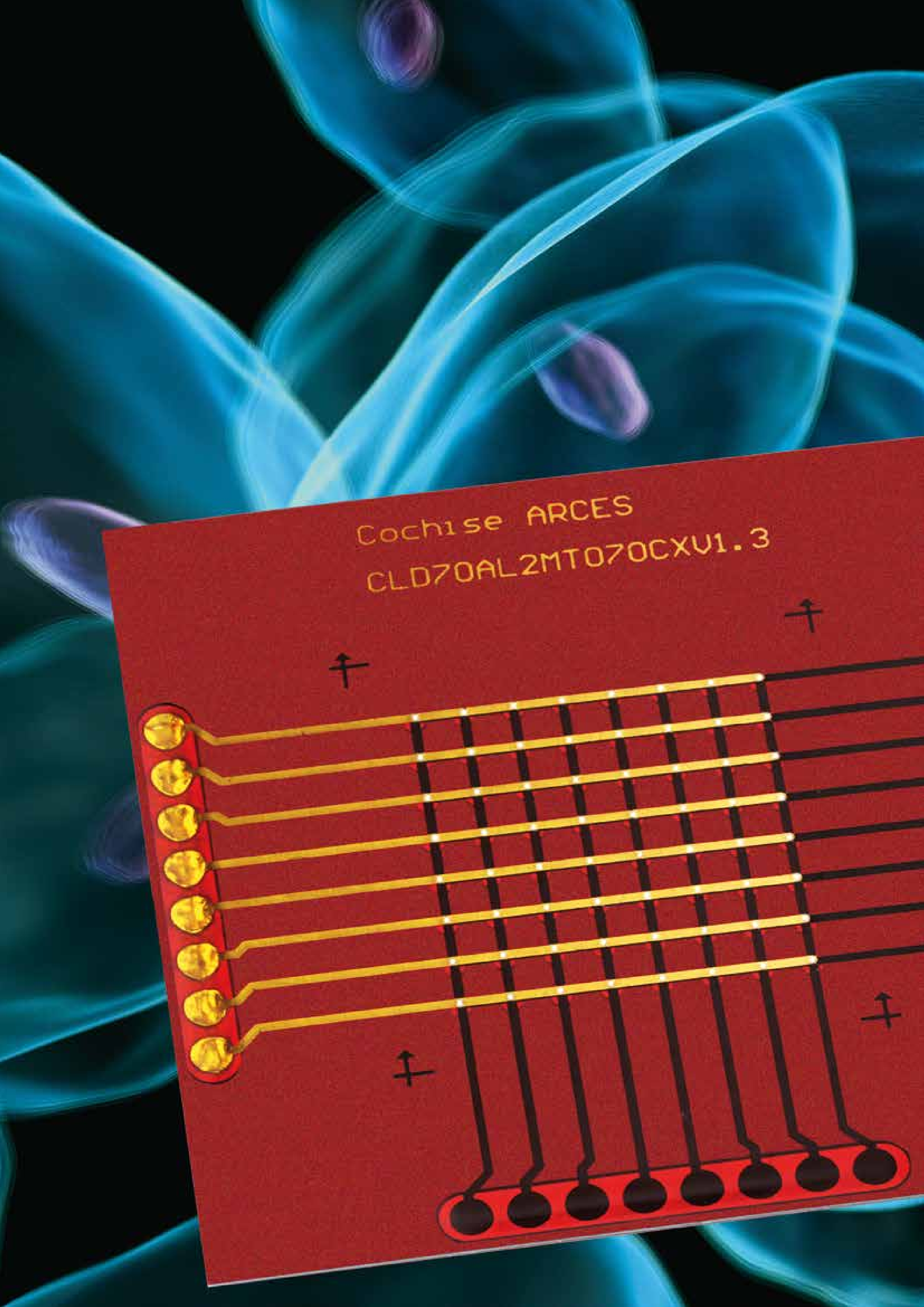
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Contributions to Topical Fields of Innovation

Beiträge zu aktuellen Innovationsfeldern

Smart Integrated Systems – hardware basis for the IoT

Prof. Dr. Thomas Gessner

Just several years ago Frost and Sullivan pointed out that smart is the new green. The concept of "Smart Earth" is, in fact, the in-depth application of a new generation of network and information technologies. Smart cities arise worldwide. Global concepts for smart production are under development. The Internet of Things - IoT - including smart grid, smart health, smart city, smart buildings, smart home, smart production and smart mobility provides not only big opportunities but is requesting more highly integrated smart systems from the hardware side. The total number of connected devices is expected to grow rapidly.

According to the strategic Research Agenda of the European Platform on Smart Systems Integration EPoSS smart systems are defined as self-sufficient intelligent technical systems or subsystems with advanced functionality, enabled by underlying micro- nano- and bio-systems and other components, Figure 1. They are able to sense, diagnose, describe, qualify and manage a given situation, their operation being further enhanced by their ability to mutually address, identify and work in consort with each other. They are highly reliable, often miniaturized, networked, predictive and energy autonomous.
Smart components and systems are a pervasive key enabling technology, impacting all industrial branches and almost all aspects of life. One of the most important applications is the smart factory or smart production. The international markets request new, high-quality products and individualized products in even shorter times. This can only be realized based on an increase of productivity minimizing resources and energy consumption.

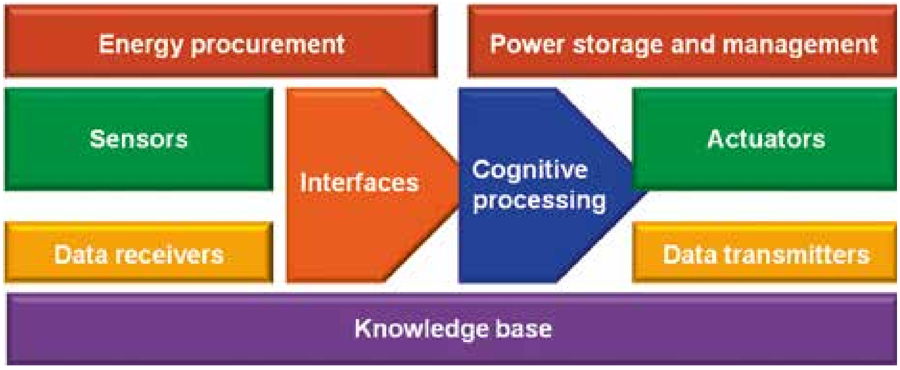

Figure 1: Smart Systems according to SRA of EPoSS, 2013 [1]

Therefore, the development of smart components and system for tomorrow's production is one of the keys of the current industrial revolution, in Germany called Industry 4.0. Germany's high-tech strategy provides good frame conditions to transfer excellent ideas into real products and services. Some of the clusters and aspects will be described below.

So the technology network "it's OWL" – Intelligent Technical Systems Ost-WestfalenLippe –, founded as one of Germany's leading edge clusters with 174 businesses, universities and other partners, is involved in 46 research projects to develop intelligent technical systems and make Industry 4.0 a reality. Looking at Industry 4.0 often cyberphysical systems are addressed. These are networked systems, their functionality is autonomously controlled by software. The hardware of cyberphysical systems are the smart systems. In order to make it easier if smart systems are exchanged as well as to reduce time and effort if new components are integrated in production units, the cluster aims to develop plug-and-play functionalities for intelligent devices, machinery and production units by devising hardware and software components and making them available on a platform. Thereby also interfaces for the integration of different sensors and actuators are established.

The vision of the Cluster of Excellence MERGE - Merge Technologies for Multifunctional Lightweight Structures - of Technische Universität Chemnitz is to tap into the joint resource potential of merged technologies and lightweight structures by adopting an integrated approach. The hybrid construction of multifunctional lightweight structures unites passive or active components, which must be combined to meet specific requirements. The fundamental production methods that form the basis for this research are textile, plastics and metal processing methods. Here active components such as sensors, actuators and generators in electronic modules can be integrated into the production process using in-line or in-situ procedures, thus adding a further stage of functional lightweight construction.

Current industrial trends in mechanical engineering and plant manufacturing address condition monitoring mainly to minimizing system failures as well as protection against plagiarism, Figure 2. The implementation of sensors, electronics for signal conditioning, wireless signal transmission (necessary due to rotating parts) and self-sustaining power supply allows an autonomous and efficient operation of such systems for various applications. For condition monitoring a smart system of second generation – a rotary shaft seal (Simmering®) with optical sealing function detection on air side - had been developed in a jointly cooperation of Freudenberg Dichtungs- und Schwingungstechnik GmbH & Co. KG, Weinheim, Fraunhofer ENAS Chemnitz and Fraunhofer IZM Berlin, Figure 3. The system contains sensors, electronics for signal conditioning, wireless signal transmission (necessary due to rotating parts) and self-sustaining power supply, which ensures the autonomous and efficient operation.

Looking at different markets it is clear to see that the smart systems have steadily evolved themselves in recent decades - and have to develop itself even further - in their variety of technologies, materials, used physical effects, application fields. With their offered variety of solution options they are adaptable for many different application fields as well – especially for the moment and even more in the future pending requirements from the grand challenges, mainly the climate change, a secure energy supply, the sustainable transport, the sustainable production, demographic change and securing of health and wellbeing. These capabilities of smart systems thus result in extremely high expectations; they are ultimately a key technology. These same claims generate a tremendous development pressure, by which the development will be further promoted and accelerated.

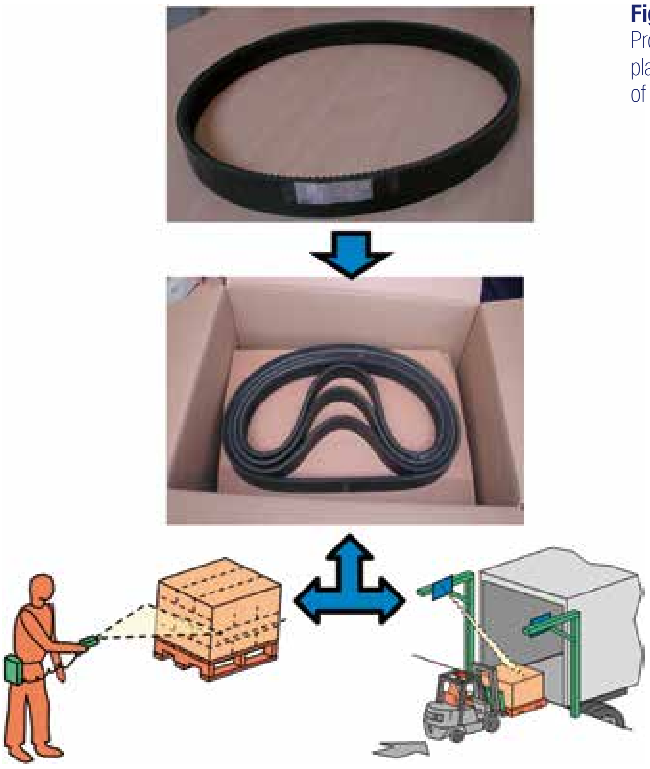

Figure 2: Protection against plagiarism in the case of a transmission belt

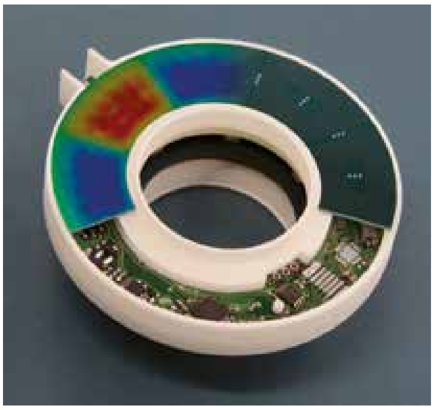

Figure 3: Rotary shaft seal (Simmering®) with optical sealing function detection on air side – Source: Fraunhofer ENAS

[1] Strategic research agenda of EPoSS 2013

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MEMS Micromirrors for Intelligent Headlamps

In the last decade automotive headlamps changed from simple dual lights with low beam and high beam to adaptive headlamps which are able to generate complex light distributions on the road. Today adaptive headlamps can be divided into two groups following the subtractive and the additive approach. In the subtractive principle, part of the generated flux is blanked out and dumped, e.g. by movable shutters. In contrast, the additive principle generates the light distribution by selectively switching on or off additional light sources.

Modern headlamps have several adaptive driving beam functions. One of them is the glare free high beam function which is based on an automotive camera system which is mounted in the rear view mirror. The camera detects and classifies besides their traffic participants on recognition of their tail lights and headlamps also unlighted pedestrians or game. Based on this information the light distribution is modified so that oncoming or drivers ahead are not blinded (see Figure 1).

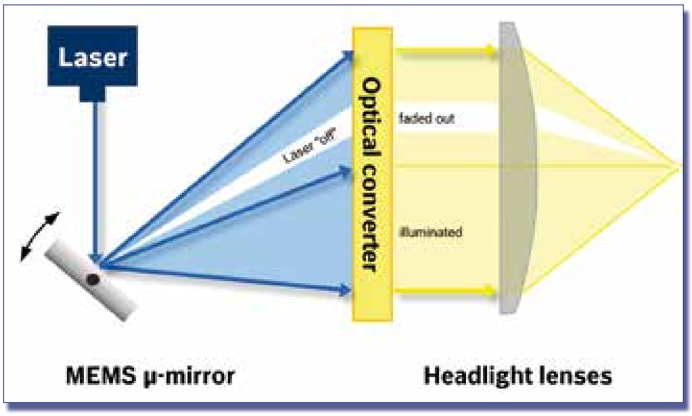

Figure 2: Principle setup of a headlight with a scanning MEMS micromirror

In order to realize new and innovative functions, a new technology will be developed in the course of the project iLaS ("intelligent laser based adaptive headlight system"), funded by the German Federal Ministry of Education and Research (BMBF), grant ID FKZ 13N13087. The project partners are Audi AG, Osram AG, Robert Bosch GmbH and Karlsruher Institut für Technologe (KIT). This technology uses a laser beam scanning unit and can neither be classified as a subtractive nor as an additive adaptive headlight. In this new headlight a laser beam is continuously scanned over a phosphor converter by a MEMS micro mirror. The so generated scan pattern is projected onto the road through secondary optics. For updating the pattern in time the system electronic must synchronize the deflection of the mirror and the power supply of the laser.

Figure 1: A glare free headlight

Figure 2 shows the principle setup. The beam of a laser diode with a wavelength of around 450 nm is directed onto a small MEMS micromirror, which deflects the light towards a phosphor converter. The converter contains conversion and scattering particles embedded in a matrix. The resulting mix of scattered blue light and converted light can be tuned to yield white light. With the synchronized combination of tilting the MEMS micromirror and controlling the laser power a desired light pattern can be produced on the converter and projected onto the road like a slide in a slide projector.

Dr. Frank Schäfer,
BOSCH

The light pattern will be modified according to information obtained by high performance driver assistance sensors (camera, LIDAR, RADAR, etc.) and merged by an ECU in order to calculate an adaptive and intelligent light distribution.

Today's most advanced adaptive headlamps are matrix LED headlights. Nearly 100 LEDs can be activated and deactivated or dimmed individually. This is a major drawback compared to headlights based on scanning micromirrors. Each LED is generating or modulating light and can be individually projected into a defined solid angle. This pixel structure could cause visible patterns and "jumping" boundaries of the illuminated area especially when single segments are switched on or off. In contrast, scanning micromirror based systems generate a continuous light distribution. The light masking can follow smoothly an oncoming vehicle without sudden jumps of the width of the masked area caused by activating or deactivating adjacent pixels.

Another advantage of headlights based on scanning micromirrors is their ability of a true redistribution of the available light. Subtractive lighting systems, e.g. systems based on DLP, LCD or LCOS imagers can only discard light after it is generated. This requires having more luminous power installed than needed on average and also supplying it with electrical power. An ideal scanning laser system is able to redistribute the light flux as required allowing for a high average utilization of the installed light sources and low energy consumption.

Figure 3 shows a micromirror suited for headlight applications. The mirror is made of silicon, manufactured with standard MEMS technologies. In our case the mirror is covered with a glass lid to allow optical access and offer protection against particles. The reflection properties of the MEMS element are very demanding for a headlight application. Based on typical system parameter values it can be derived that optical laser power of about 10W might be required. A typical metal coating for CE applications like, e.g. Ag is achieving about 95% reflection at 450nm. For minimizing the power deposited into the micro mirror, and hence to reduce the thermal load, a high reflection is necessary. We utilize an optimized dielectric multilayer stack. Depending on the polarization of the used laser beam a reflectivity close to 100% can be achieved.

This new application would enable a complete new market for MEMS products. Today the automotive MEMS market is dominated by acceleration sensors, gyroscopes and pressure sensors for airbag, ESP® and power train. Being one of the MEMS pioneers and by far the world's largest automotive MEMS supplier with the experience of more than 6 billion MEMS sensors (automotive and CE), Bosch fulfills all conditions to step successfully into this new application field: scanning micromirrors for adaptive headlights.

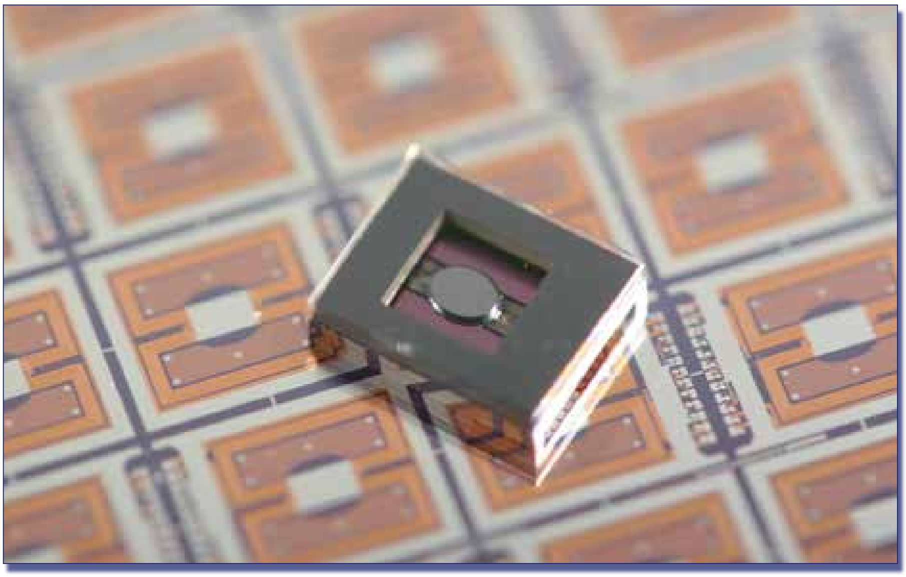

Figure 3: MEMS micromirror

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Smart Materials and Microsystems

Continuous development of functional materials, adequate structuring technologies and component manufacturing is the key to advances in micro-technology and systems integration and enables superior products and innovative applications. The "Smart Materials and Systems" department at Fraunhofer IKTS is specialized in developing dielectric functional ceramics and integrating them into devices, microsystems and active structures. Research covers all aspects of the value chain, ranging from materials synthesis to functional verification in prototype systems. Special materials expertise exists in the field of complex perovskites, which, as high-performance piezoceramic or dielectric ceramics, provide sensing, actuating, and electronic functions in monolithic components and composites with polymers, metals, glasses, and other ceramics. Thick film, multilayer, and piezocomposite technologies are available as complete technology chains. Functional optimization is accordingly performed on several scales, through utilization of property combinations of composites, functional consolidation in materials, and adaptation of components to the system environment. This is emphasized by the following examples.

Piezoceramic Thick Films

Piezoceramic thick films with typical thickness of 30 – 150 µm offer the opportunity of integrated solutions for smart electrical, optical and fluidic microsystems. Depending on layout and electrical activation they can be applied as sensors, actuators, ultrasonic transducers, transformers or energy harvesters. Using screen printing technology net-shaped structures can easily be fabricated on substrates like Low Temperature Cofired Ceramics (LTCC), Al_2O_3, ZrO_2, silicon and appropriate steel grades. Insulation and electrode layers compatible to the piezoceramic material enable a large variety of different designs with electrical connection to each single piezoceramic element. Thereby miniaturized devices which allow for a combination of piezoelectric function, multilayer technology and electronics packaging can be manufactured. Because the screen printing process is technologically established, monolithic and integrated piezoceramic solutions are feasible in batch production on wafer-level.

Figure 1 shows four PZT (lead zirconate titanate) thick film structures printed on a LTCC substrate. Finally, assembled in the system, each structure forms the rear side of a bimorph mirror enabling beam focusing in an optical system. Each single PZT thick film element is individually controllable and works as an actuator that can locally deform the mirror. By this, optical aberrations of e.g. high-energy lasers can be controlled.

Figure 2 contains an example similar to Figure 1 but in difference used for ultrasound generation. It shows a screen printed ultrasonic transducer array for particle manipulation. The principle of these so-called ultrasonic tweezers is based on the generation of standing ultrasound waves within a fluid channel between a transducer and a reflector layer. Particles with dimensions of less than 1 µm up to hundreds of microns can be trapped at the pressure node plane. Ultrasonic transducer arrays made of individually addressable elements enable for stepwise driving and thus for moving trapped particles along a microfluidic chamber which is of special interest in fields of biotechnology and life science like cell separation and sorting.

Figure 1:
Different layouts of PZT thick film actuators on LTCC substrate used as adaptive mirrors for laser beam shaping (FhG IKTS/IOF)

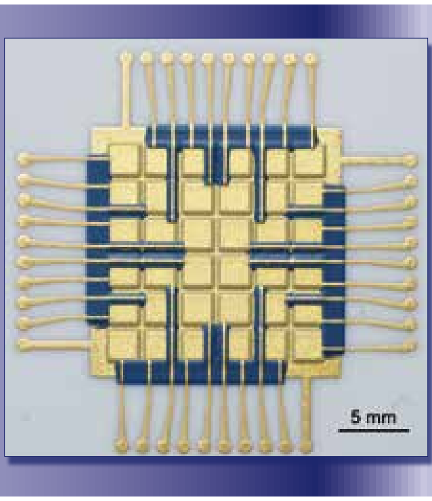

Figure 2:
2D ultrasonic transducer array on Al_2O_3 for particle manipulation, 6 x 6 PZT thick film elements with 2 mm feature width and 2.3 mm pitch

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Cross electrode designs, as shown in Figure 3, allow for 2D ultrasonic transducer arrays with even smaller pitches and larger numbers of elements. In those designs, a continuous PZT layer is printed between perpendicularly arranged bottom and top electrode lines. The example in Figure 3 comprises 900 elements with an electrode line width of 200 µm and a pitch of 500 µm.

Soft Mold Process

Screen printed structures are limited in height by technology. Fine scaled structures with larger aspect ratio between element height and width can be manufactured by the soft mold process. It uses master molds, which have been structured by microsystems technology like micromachining, chemical or plasma etching. The microstructured, e.g. silicon, master mold is transferred into the ceramic mold via a soft plastic template, which is reusable. The template, being the negative of the desired structure, is filled with a ceramic slurry. After drying, the ceramic green body is demolded and subsequently sintered. Figure 4 gives an example of such manufactured PZT array structures with cylindrical rods in a non-regular arrangement after sintering. Rod diameters are 65 and 48 µm, rod height is 325 µm in this case. These structures are further processed to 1-3 piezocomposites for ultrasonic transducer arrays. Currently, reduction of rod size down to 30 µm and lower is under investigation designed for frequency ranges up to 30 MHz.

The research activities of the “Smart Materials and Systems” department at IKTS are not restricted to the above described materials and processes. Current projects cover, for example, dielectric materials and component technology for capacitors in power electronics and high voltage applications, electro-caloric materials for innovative cooling systems, lead free and high temperature piezoceramic materials for sensor, actuator and ultrasound applications as well as piezoelectric fibers, pearls and composites thereof for adaptive functions.

We gratefully acknowledge cooperational research with the Institute for Medical Science and Technology of Dundee University, UK within the „Electronic Sonotweezers“ programme funded by the UK Engineering and Physical Sciences Research Council, and the Fraunhofer Institute for Applied Optics and Precision Engineering within the “Kompetenzdreieck Optische Mikrosysteme – KD Optimi” funded by the Federal Ministry of Education and Research (BMBF) FKZ: 16SV5473.

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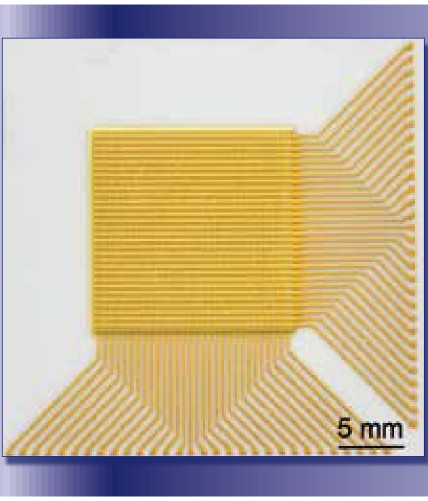
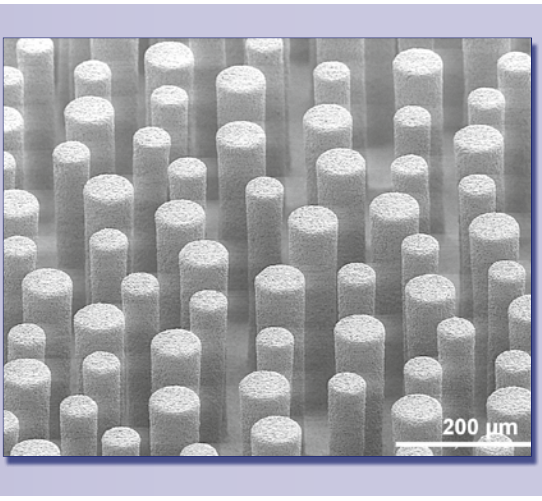


Figure 3:
Crossed electrode ultrasonic transducer array

Figure 4:
SEM micrograph of a sintered PZT array structure with cylindrical rods in a non-regular arrangement



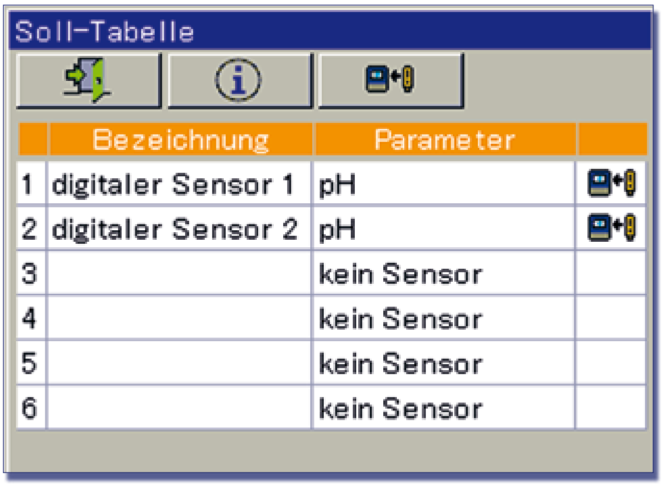
Smart Sensors for Industry 4.0

With digiLine, JUMO presents the first bus-capable connection system for digital liquid analysis sensors with Plug and Play functionality and an with integrated sensor management. The system enables the simple setup of sensor networks.

digiLine Pressefoto

The world is analog – our senses, as well as all natural, physical, and chemical processes, function according to this principle. Why then do we try to make everything digital?
For the technical world, the digitization of measurement signals represented an important step forward. Finally, it was possible to process measured values from the sensors in display units, controllers, or recorders without any loss, and to mathematically connect these with other signals.
The major trend in recent years has been not to first digitize the sensor signals in a measuring or control device, but instead to bring these as close as possible to the analog sensor element. This enables any signal changes or malfunctions on the way from the sensor to the downstream measuring device to be further minimized or prevented altogether.
Through the integration of microprocessors in the sensors, analog measuring sensors became so-called “smart sensors”, which carry their specifications with them at all times. From a technical point of view, this now simplifies startups, calibration processes, and parameter settings. The sensor has

digiLine Systemaufbau

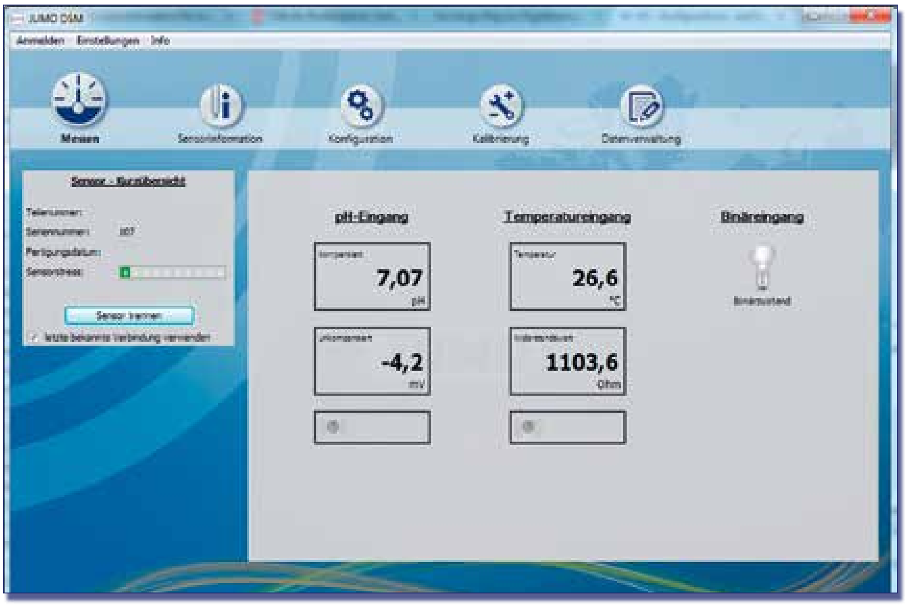


Soll-Tabelle

	Bezeichnung	Parameter	
1	digitaler Sensor 1	pH	
2	digitaler Sensor 2	pH	
3		kein Sensor	
4		kein Sensor	
5		kein Sensor	
6		kein Sensor	

digiLine Sensorerkennung

Reinhard Manns



DSM-Software (Digital Sensor Management)

everything on board to automatically provide the peripheral equipment with the option to retrieve measurement signals and further data. The often mentioned "Plug and Play" from the consumer sector has now finally found its practical use in the industrial and technical world.

In addition to the digital transfer of sensor signals, the smart sensors also enable the setup of sensor networks. An example of this type of intelligent network is the JUMO digiLine. A diverse range of sensors can be connected to each other in a star network or in series. Only a single digital signal cable then connects to the next evaluating unit or to the control. This enables more efficient and faster cable installation in plants in which several parameters need to be monitored simultaneously at a diverse range of locations.

A variety of liquid analysis parameters can now be measured using just one system. For the market launch, a digiLine component was developed for pH, redox, and temperature measurement. Furthermore, it is possible to connect with tried-and-tested JUMO products for turbidity and oxygen measurement. Digital versions of the conductivity and amperometric sensors for disinfection (free chlorine, total chlorine, ozone, hydrogen peroxide, etc.) are also in preparation.

The major benefit: the simple connection of various sensors to a bus opens up a range of new possibilities for industrial applications in the processing, food, pharmaceutical, and water industry. The JUMO digiLine sensor network also increases the number of sensors that can be connected to the JUMO AQUIS touch multichannel measuring and control devices. Furthermore, JUMO digiLine sensors can be integrated with the JUMO mTRON T automation system. This means that there is no need for an additional transmitter between the control and the digital sensor.

Alongside the Modbus-based digiLine protocol, most digiLine sensors are also available with an analog output of 4 to 20 mA. This allows the smart sensors to be integrated even in older systems. JUMO digiLine pH and redox sensors come as a single unit consisting of the sensor with the electronic system screwed onto it. Once the pH redox component has become completely worn, the screw connection is separated and electronic components can continue to be used with a new sensor. The system software is also completely new. The necessary parameterization and calibration of the pH or redox sensor can be carried out conveniently in the laboratory using a PC or laptop, a USB interface converter, and the JUMO digiLine software. Calibration data and the sensor status evaluation are stored directly in the sensor and enable seamless documentation over the entire sensor life cycle.

With this new technology, JUMO is bridging the gap between the world of sensor technology and Industry 4.0.

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Energy Efficient Magnetoresistive Sensors for Low-power and Wireless Applications

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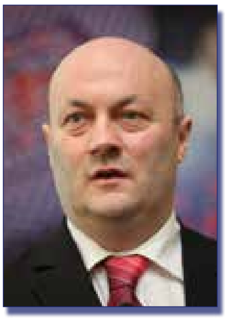

Magnetoresistive sensor technology

Magnetic microsystems in the form of magnetoresistive (MR) sensors are firmly established in automobiles, mobile telephones, medical devices, wind turbines, machine tools or industrial robots: be it for the measurement of path, angle or electrical current, or as an electronic compass. Originally developed for data storage applications, the different MR effects open up new measurement possibilities for sensors, not only in terrestrial applications, but also in space applications. MR sensors are robust, reliable, precise and miniaturized. This combination of features is leading to continuous growth in the application field of MR sensors. The extremely low power consumption of MR sensors makes them ideal for wireless, autonomous sensor applications. They present the developers of many different types of mechanism or instrument with completely new possibilities to measure angle, path, electrical currents or magnetic fields.

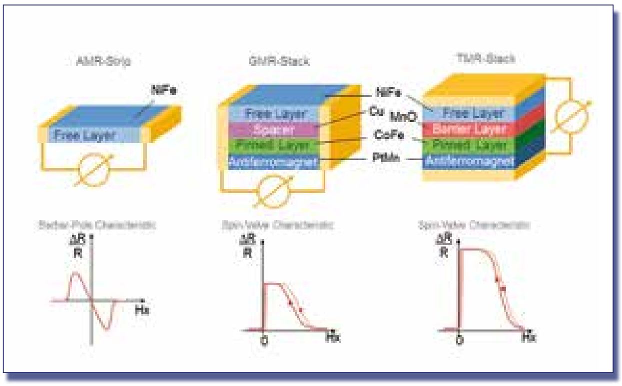

Fig. 1: Comparison of MR technologies. Source: Sensitec GmbH

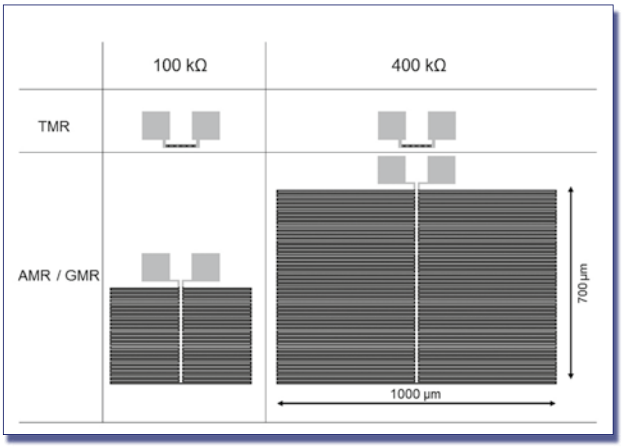

Fig. 2: Comparison of sensor area for different resistances. Source: Sensitec GmbH

The magnetoresistive effect has been known for more than 150 years. The British physicist William Thomson, later known as Lord Kelvin, discovered that the electrical resistance of a conductor changed under the influence of a magnetic field. However, this effect could first be used industrially more than 120 years later, during the late 1970s, in combination with thin-film technologies derived from the semiconductor industry. The intelligent arrangement of thin-film structures within a sensor enabled the development of many different sensor types for measuring the angle, strength or gradient of a magnetic field. The effect discovered by Thomson was named the “anisotropic magnetoresistive effect” (AMR) and resulted in a resistance change of just a few percent. Nevertheless this effect was used million-fold in the production of read-heads for hard discs. At the end of the 1980s the “giant magnetoresistive effect” (GMR) was discovered. Here the resistance change was more than 50 %, which opened up even more applications for MR sensors. In the meantime the read-heads of hard discs are almost exclusively based on the “tunnel magnetoresistive effect” (TMR), which can exhibit a resistance change of several hundred percent under laboratory conditions. This technology has additional features that

	AMR	GMR (Spin-Valve)	TMR
Signal strength (ΔR/R)	< 4 %	< 15 %	< 200 %
Direction of current flow	Parallel to layer plane	Parallel to layer plane	Perpendicular to layer plane
Topology	Meander	Meander	Point

Table 1: Differences between MR technologies

	Signal strength (ΔR/R)	Sensitivity	Detectivity (low frequency)	Detectivity (high frequency)	Bandwidth	Power consumption	Temperature stability	Hysteresis	Radiation hardness	Miniaturisation capability
AMR	o	+	++	++	++	o	+	++	++	o
GMR	+	+	o	++	+	+	++	o	+	+
TMR	++	+	o	++	+	++	++	o	+	++
Hall	-	-	-	-	-	-	-	++	-	-

Table 2: Comparison of magnetic sensor technologies

are not only interesting for storage technology, but also for sensors. For example, TMR-based sensors have an extremely high sensitivity and a very low power consumption. Fig. 1 shows a schematic comparison of the different MR layer structures and Table 1 compares their basic characteristics for commercially available products. For sensor applications the AMR, GMR and TMR effects are complementary, each offering specific advantages that can be of benefit in different applications.

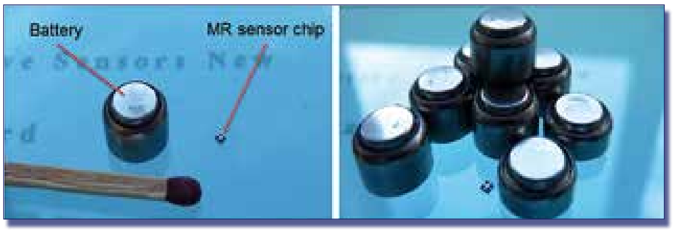

Fig. 3: Battery consumption after 6 months for typical TMR sensor (left) and AMR sensor (right) in continuous operation. Souce: Sensitec GmbH

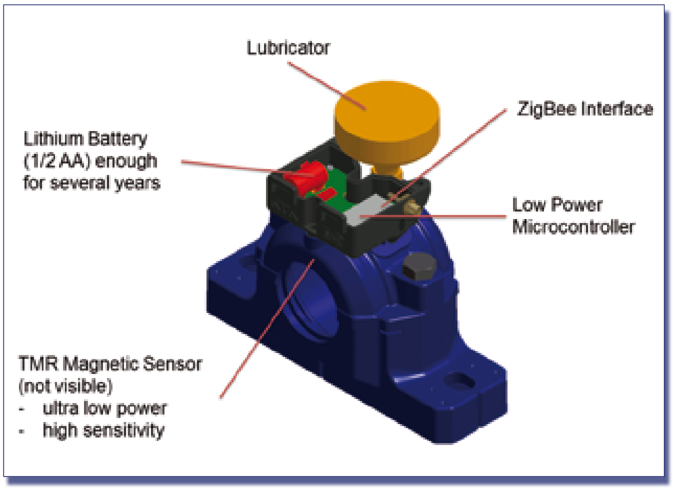

Fig. 4: Intelligent plummer block (left) and solar-powered demonstrator (right). Source: NTN-SNR Roulements S.A.

As indicated above the TMR effect not only offers a large signal strength, but also makes the realization of ultra-low power sensors possible. The AMR effect depends on the material volume of the MR material, with the consequence that a 4-fold increase in resistance to achieve a reduction in power consumption, leads to a 4-fold increase in the area of the active surface of the sensor chip, as shown in Fig. 2. For the TMR effect, on the other hand, the resistance of the sensor chip increases exponentially with the thickness of the barrier layer (see Fig. 1). In this case the power consumption of the sensor chip can be reduced significantly without any increase in chip area. Compared to an AMR sensor the power consumption can be reduced by a factor between ca. 10 and 100, compared to a Hall-effect sensor by a factor of up to 1000.

There is, however, a limit to how high the resistance of a TMR sensor can be increased. Thermal and shot noise increases with increasing resistance and 1/f noise increases as the sensor area gets smaller, with the result that the signal-to-noise ratio worsens. At low frequency (< 100 Hz) the detectivity of GMR and TMR sensors is in any case lower than for AMR sensors due to intrinsic 1/f noise. For this reason sensor nodes featuring magnetic field measurement, e.g. for vehicle detection, almost always feature AMR sensors to date. Table 2 summarizes the main properties of MR sensors, in comparison to other magnetic sensors, such as hall-effect sensors.

Application Example: Condition monitoring of bearings

Fig. 4 shows an intelligent plummer block developed by NTN-SNR in France. Also known as a pillow block, this is a pedestal for supporting rotating shafts in large machines. This application allows the remote monitoring of a bearing in terms of temperature, vibration, speed and number of turns. For saving battery life, the node is most of the time idle and wakes up from time to time for making the different measurements and sending them over a RF network using the IEEE 802.15.4 protocol. A TMR sensor is used here with a pole ring inside the housing for measuring the shaft speed.

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Wireless Sensors for Structural Health Monitoring

Methods und measurement systems of condition monitoring help to assure the availability of machines and plants as well as reliability and optimal functioning of critical components.
Integrated in the production, condition monitoring supports control and optimization of production processes within companies and along the value added chain.

Fraunhofer IKTS provides optical, acoustical and electromagnetic sensors, sensor systems and monitoring systems, which act as support for the erection and commissioning of plants as well as the ongoing operation by permanent condition diagnostics. They are designed for harsh operation conditions and provide advantages, like non-destructive defect detection, real-time monitoring and associated condition-based maintenance or plant optimization and lifetime prognosis.

Structural Health Monitoring (SHM) – as a part of condition monitoring – consists in the testing of (mostly) mechanical properties of technical structures with regard to their safety and proper function. Mostly, SHM requires a network of many sensor nodes to test large structures like bridges, pipelines, wind power plant rotors etc. Generally speaking, a SHM sensor network is some kind of a “sensing skin” of a technical device like the skin of an animal or human being. SHM applications have gained significant attention in many industrial fields. One of the most important physical methods to implement SHM is the detection of (material- inherent or stimulated) acoustical lamb waves in the frequency range of a few 100 kHz. To detect lamb waves in (mostly larger) technical structures, it is necessary to implement a sensor network on the skin of the structure or inside the structure. These sensor networks are often “in the field”, that means far away from any power supply. Furthermore, the usage of cabling is not desirable in many applications. Examples are the aircraft industry (each cable produces more weight) and rotor blades of wind energy plants (to avoid lightning flash damages). Sensor nodes completely embedded in carbon fiber reinforced plastics (CFRP) should also be wireless, because any additional cable could weak the stiffness of the structure (fig. 1). For this reason, there is a need for completely wireless, self-sufficient sensor nodes.

Along the project “CoolSensornet” partially initiated and led by my Fraunhofer group and based within the leading edge technology cluster named “Cool Silicon” Fraunhofer IZFP and IKTS have jointly developed energy autonomous and wireless sensor systems together with IMA GmbH Dresden, Technische Universität Dresden, ZMDi AG and RHe Microsystems GmbH. These sensor systems are ready-to-use for monitoring large sized aircraft structures and wind power rotor blades over long terms.
First project results revealed that by using wireless sensors that are based on acoustical lamb waves it is possible to detect damages after impacts in CFRP materials. To achieve this, a defect indicator is determined by the sensor node firmware with the help of data compression, environment influence compensation and feature extraction.

The hardware of the sensor node includes a 900 MHz IEEE 802.15.4 transceiver, which is a ZigBee derivate,

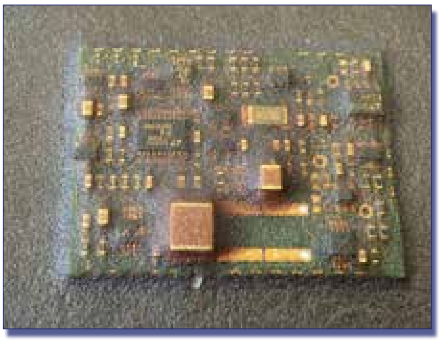


Fig. 1: Sensor Node Embedded in CFRP

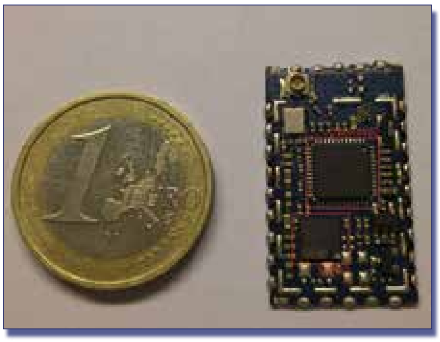


Fig. 2: Sensor Node Electronics

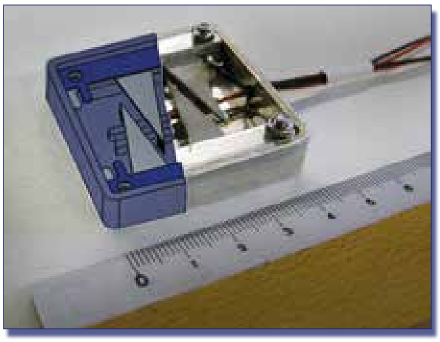
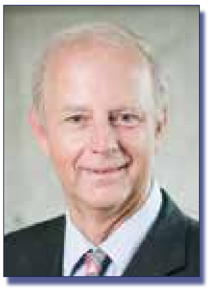


Fig. 3: Energy Harvesting System

Dr.-Ing. Dieter Hentschel



Dr. Lars Schubert

and an ARM 32-bit Cortex © -M3 as the central processor unit. The sensor input signals are filtered and amplified, and after this, converted by a 14bit 2MS/s analog/digital converter. The energy consumption of the sensor node hardware for a complete RX/TX cycle amounts to 1 mWs only. Figure 2 shows the complete sensor node electronics.

To provide the sensor node with the required energy, our group developed an energy harvesting system with four parallel piezoelectric transducers connected with a tip mass (fig. 3). The energy harvesting system gains its input energy from vibrations of an aircraft structure, which is resonant at about 500 Hz. These structure vibrations are on the one hand of high dynamics, but on the other hand they have small elongations of a few µm. Therefore, the electrical output of the energy harvesting system is only a little more than 100 µW. Nevertheless, an intermittent monitoring cycle is possible in case of continuous vibration. During a time span of 90 seconds, an amount of 1 mW electrical energy is collected in a storing capacitor of 47 µF. This is sufficient to achieve a complete RX/TX cycle of the sensor node.

The reliability of the SHM sensor is another very important question: The test system has to be more reliable than the structure to be tested. Therefore, the lifetime of the embedded sensor node according Figure 1 of up to 15 years was proved by accelerated aging. The whole system was damage free till

Fig. 4: Sensor Sleeve for Underwater Applications

1. 5000 hours at 85 % of relative humidity at a temperature of 85 °C
2. 4000 temperature cycles at -55/+85 °C
3. 24 hours at a temperature of 180 °C
4. 24 hours at a temperature of -70 °C
5. More than 3 million mechanical strain cycles.

Meanwhile, the SHM sensor nodes are used in many other technical fields too. One example is the detection of cracks in railway vehicle wheels by monitoring the three-dimensional acceleration signals with the help of a sensor system mounted inside the bearing cap besides the railway wheel set. In this special case, another type of energy harvesting system is necessary, dealing with heavy stochastical elongations.

Another example is the SHM of pipes by a sensor sleeve. In this case, the monitoring of local corrosion, cracks and integral wall abrasion is possible with the help of sensors in a special arrangement around the pipe. Monitoring of pipelines and base structures of off-shore wind energy plants is realized, even underwater, as shown in figure 4.

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smartWT – The intelligent Workpiece Carrier for Micro Production and more

Arnd Menschig, Carl ZEISS 3D Automation GmbH

A short throughput time, a secure part handling and traceable processes - these facts do essentially determine the quality and effectivity of production. Cyber physical systems are on the way to bring this benefit even to small and medium enterprises. According to fulfil the Industrie 4.0 requirement on real-time data processing a self-sufficient workpiece carrier with radio communication is needed.

Introduction

The independent smartWT helps to record and deliver continuously the relevant data of the fabrication process or the logistics supply chain. The communication partner can be a controller of a metal working machine, a micro production equipment or an enterprise resource planning system. With the help of the smartWT infrastructure the production scheduler can supervise and optimize selected processes permanently. Even so, if the smartWT is not coupled to a machinery.

The smartWT is not only a smart, but a real intelligent object. May be you will not name him intelligent only because of his brain – the micro controller with his data storage – and his senses – smart sensors for e.g. temperature, shock and vibration. Or because he also is possible to activate movements, to accumulate energy and to communicate with the production environment. But then he tells you that something will go wrong in your next fabrication step. Now you accept that he is an intelligent accessory for your production.

The electronic heart of the sensor and actor platform

A miniaturized electronic control unit – the smartWT miniECU – is the brain of the configurable sensor and actor platform. It supports the connection of I^2C-bus, Modbus and analog sensors and communicates with the environment by wire or wireless. For the radio communication a gateway for the industrial bus systems Modbus and I^2C was realized **[1]**. Built within the available ISM radio band (Industrial, Scientific and Medical) at 868 MHz it allows sending data to a receiver over at least 25 m in an in-door star topology at 0 dBm transmitting power. A software defined radio controller with a special wake-up technology developed by IMTEK **[2]** was used to save energy. The wake-up distance was measured to reach 15 m.

Figure 1: Smart sensors with miniaturized head for temperature measurements at workpieces adapted to a workpiece carrier system [Zeiss 3D Automation, 2015].

As energy storage an AAA-sized Li-ion accumulator with a capacity of 500 mAh at 3.6 V was chosen. Loading is done via inductive energy transfer with an air gap of up to 5 mm with a maximum transmission capacity of 7.5 Watt. On the secondary side a miniaturized single circuit board (54 mm x 8 mm) for the bridge rectifier together with the energy management and monitoring circuit with an I^2C-communication to the smartWT controller was developed. A charging current of 500 mA at a maximum voltage of 4.2 V can be realized. Towards the primary side a withstand voltage of maximum 76 V was implemented.
The inductive energy transfer unit on the primary side was integrated in loading stations for the three different applications metrology, assembly and manufacturing. The resonance frequency, the output voltage and power can be adapted by software. Also available are error messaging and configuration of control parameters for voltage, current and phase of the oscillator, and also for the temperature of the electronics. The software runs on the computer of the workstations to set-up the workpiece carriers.

Figure 2: Web-based operator interface for monitoring and analyzing of sensor networks across locations [Zeiss 3D Automation, 2015].

Miniaturized sensors and sensor networks

Low power miniaturized sensors for temperature measurement, 3D shock detection and 2D angle metering together with a M5 industrial connection environment were realized. Also a Modbus to I²C converter electronic is available to connect low-cost sensors of different type. The overall size of the injection molded electronics is 50 x 11 x 8 mm (Figure 1). The shielded cable has an outer diameter of 3 mm. As the communication protocol the industrial Modbus with a supply voltage of 5 V was chosen. The sensors can be used in classic wired networks or together with the smartWT miniECU in the new wireless Modbus/I²C network. The digital workpiece temperature sensors have spring-loaded single Pt100 heads of size 6.5 x 32 mm with a spring deflection of about 2 mm. The electronics use high precision analog to digital converter, a temperature accuracy of 50 mK can be specified. The sensor model and the calibration data is stored within the miniaturized electronics in Modbus register.

Besides the miniaturized sensors also a special 3D seismic detector with 200 µg accuracy was developed. The embedded module solution performs an on-board data processing of the output data from a sensitive acceleration sensor to supervise threshold values of vibration amplitudes in several ranges of frequency. Via Modbus communication the violations of up to six limits for each range of frequency can be transferred.

Both sensor network types were integrated into a local data collecting and analyzing controller with a web-based operator interface. The software infrastructure supports database synchronization to a cloud application in the local network or the internet. With this technology important information, e.g. temperature gradients or seismic events, are analyzed and visualized in real-time. As required for Industrie 4.0 applications the results can be viewed and compared to historical data on mobile devices locally or all over the world.

Figure 3: : Sensoric workpiece carrier on a coordinate measurement machine [Kugler, 2015].

Metrology applications

In production the carriers today are mainly pure mechanical fixtures to hold the workpiece sometimes combined with static identifiers or with memory accessed by RFID technology. Now a miniaturized self-sufficient solution is available with sensors detecting the condition of the workpiece or the environment.

The brain of the carrier can learn positions, set-point temperatures and successive process steps, as laser micromachining, cleaning, solder deposition, soldering and quality inspection, of different workpieces. The carrier can control measured values, determine and compare the process quality and communicate the information also to external equipment. A mile-stone is reached making Industrie 4.0 compatible real-time data available for production control.

In metrology the technology was used to realize a permanent shock and thermal control during transport and long term measurement. A shock event can be a signal, that parts are damaged. A temperature variation of the workpieces or of the carrier during measurement causes different elongations. Therefore shape and position tolerances can not be met. The smartWT informs the user when the set-point temperature is reached or a shock event occurred so that the following process step can be blocked or performed. One workpiece carrier (530 x 120 x 70 mm) was realized to perform batch measurement of 20 high precision mechanical parts used in wafer alignment within lithographic machines (Figure 2). Another one addresses further miniaturization. With a two-dimensional clamping system it is possible to fix 36 cylindrical shafts on minimal surface area (Figure 4). Although each single position can be addressed to load or unload the workpiece. On an open frame workpiece carrier with a dimension of 190 x 150 mm also a gripper interface for automation and the complete self-sufficient smartWT electronics together with two temperature, one tri-axial shock and one two-axial levelling sensors were arranged.

Applications assembly and manufacturing

In addition to the static solutions for metrology in these applications system integrated actors allow cooperation between the carrier and the production process. One carrier type was realized with integrated rotational elements (Figure 5). It is no longer necessary to rotate a dispenser tool or a camera by robot around the workpiece or reduce to one-piece flow technology. In an assembly application the carrier was used to deposit glue radially on metal shafts in a two-dimensional arrangement of 27 pieces without moving the tool tip.

For the manufacturing application the use case high precision diamond turning was chosen. A cylindrical workpiece (diameter 8 mm, height 90 mm) needs to be centered within a tolerance of ± 1 µm. In the past the part was centered on a palette of a zero point clamping system and fixed to the tool holder in the turning machine. A manual beating and inductive sensing operation needs 10 minutes per part to achieve a toler-

Figure 4:
Miniaturized modular workpiece carrier for automatic handling [Zeiss 3D Automation/Schunk, 2015].

Figure 5:
Highly modular carrier system [3] equipped with four units for workpiece rotation in a dispensing application [Fraunhofer IPA, 2015].

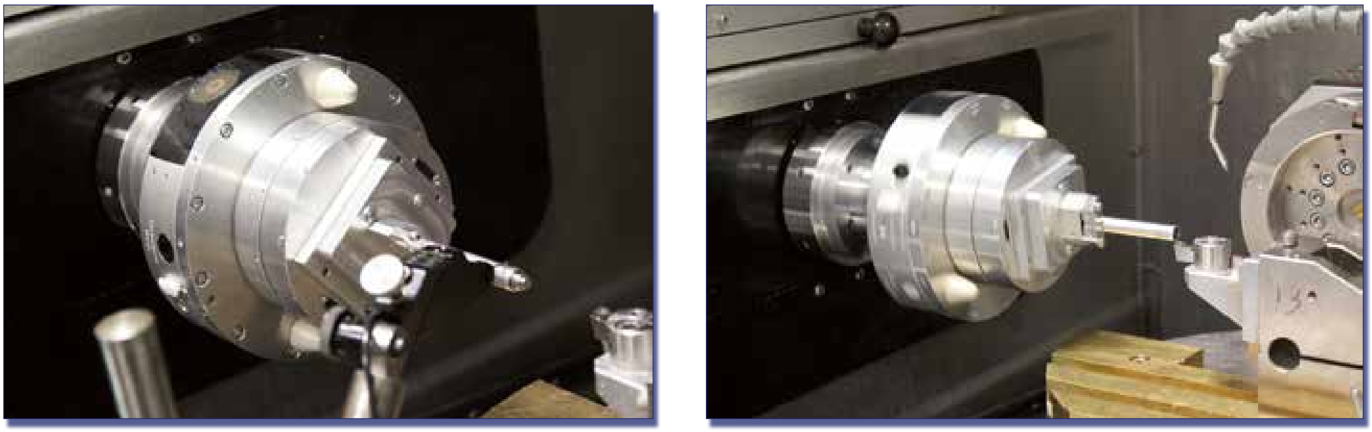

Figure 6: Centering unit in a high precision turning machine: measuring centricity (left), adjustment with actuator modules and turning (right) [Kugler, 2015].

ance better than 10 µm. To increase productivity this procedure should be automated.

Here the smartWT was set up as a centering unit with three cylindrical containers on top of each other with a total height of only 90 mm (Figure 6). In the base electronic unit the smartWT miniECU was combined with two motor controllers and two energy storages. On top two actor units each with 100 µm travel range were mounted. The axes move perpendicular to each other and therefore can center the workpiece. Now the centricity is measured on the machine. The correction values were transmitted wireless to the smartWT centering unit and corrected automatically in half of the time the operator needs using the manual procedure.

Conclusion

Eight partner worked together to achieve a common objective – CADwalk GmbH & Co. KG, Carl Zeiss 3D Automation GmbH, digiraster GmbH, Fraunhofer Institut für Produktionstechnik und Automatisierung (IPA), Universität Freiburg IMTEK Lehrstuhl EMP, Kugler GmbH, Schunk GmbH & Co. KG and WITTENSTEIN AG.

It is possible to build workpiece carriers suitable for production using the miniaturized electronic units of the sensor and actor platform. The development of the electronics was completed successfully and the demonstrators operate properly. The industrialization of the project results is on the way. Smart sensors, the electronic sensor and actor platform, intelligent workpiece carriers and the software infrastructure will become commercially available within the next twelve months.

Acknowledgements

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Intelligent Service Robotics for Production

The future of the production landscape is often put on a level with the term Industry 4.0. The ongoing discussion about possible upcoming transformations on the shopfloor is not only driven by technological innovation but also by fundamental changes in customer behaviour and future products. Firstly, individual products and personalization increasingly penetrate the consumer industry and B2C business, now carried forward to B2B business. Secondly, shorter product life cycles require a higher implementation rate and the speeding up of innovation processes. Thirdly, the ecological footprint of products is gaining importance. In this context, not only the environmental impacts of production have to be considered but also the use of new materials and technologies for sustainable production.

And fourthly, the increasing availability and use of social media triggers a fundamental change in customer 's behaviour and expectations on purchase and utilization of products.

It is these four trends that mainly influence the technological lines of action towards a future production landscape. The digitalization and interconnectedness of production facilities are a precondition for customer specific production in terms of mass customization, small lot sizes or one piece flow.

On the other side, sustainability has to be addressed by high efficiency, near-to-zero emission, re-use and a continous lean production approach. Furthermore, social aspects come to the fore when future working conditions, competence development and preservation, as well as learning and motivation strategies are discussed.

It is clear that the depicted changes in the production landscape will fundamentally change the role of human workforce on the shopfloor. The interaction of workers and intelligent service robotics will increase considerably to deal with low and varying production volumes and to allow quick up-scaling to large numbers at need. In excess of increased adaptivity, the use of intelligent service robotics on the shopfloor may also considerably improve the flexibility of production infrastructure by reducing complexity.

In this context, intelligent service robotics has to be regarded from an architectural perspective:

On the **component level**, intelligent microsystems integrate sensors and microcontrollers to provide a real-time image of the lateral working space and to handle process data in a decentralized way. In excess to sensor signals like position, acceleration, pressure or force, more complex and “smart” sensors like 3D vision systems or advanced proximity sensors (e.g. smart skin, systems in foil) will make their way to applications. On-board systems may be supported by external sensors which can provide an observer perspective to the scene and get integrated via intelligent communication interfaces. In doing so, intelligent service robotics may handle and

Pictures:
Gesture Control (left) and Brain-Machine-Interface in CogniGame (right) at Festo

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communicate with several decentralized on–board microsystems as well as with peripheral devices. Matching all necessary information on **platform level** and deriving a specific kinesic behaviour out of these information, intelligent service robotics may also be constituted as cyber physical systems (CPS). Due to the trailblazing development of processing power in microcontrollers, innovative approaches of artificial intelligence are supposed to facilitate a new generation of context-sensitive, intelligent service robotics. This example shows that intelligence is also needed in terms of a distinct and effective **human-machine-interaction** (MMI). While smart and responsive displays emerge at present, research and future technologies already focus on advanced MMIs like gesture control or brain-machine-interfaces.
Irrespective of the way of interaction between human beings and machines, safety and security represent a crucial pitfall for a commercial use. Technical specifications for engineering standards as well as legal guidelines have to be fulfilled.
The reliability of structural elements, components, materials and error free communication are typical measures to ensure the functional safety of technical systems. The aim is to avoid damage caused by the operation of technical systems and to prevent physical injury. Security can be seen as an important attribute of a safe system and primarily addresses the protection of technical facilities against manipulation or loss of sensible data. Security networks, authentification, cyber diodes, access restrictions, data encryption or security on a chip can be typical measures to achieve security. It is obvious that safety and security likewise are one of the major sticking points for a commercial use of intelligent service robotics.

The scenario of the digital (r)evolution in the future production landscape often conciliates a picture of a totally software driven environment. It is beyond dispute that software will play a crucial role in future production, but Microsystems Technology will still provide a major share of physical platforms to run future factories and enable new technologies like intelligent service robotics on the shopfloor.

Pictures:
Festo ExoHand (left) and Human-Machine-Interaction on the shopfloor at Festo production plant (right)

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Intelligent Implants in Neural Engineering: from tools in neuroscience to new treatment options in an ageing society

Thomas Stieglitz, IMTEK

Miniaturization, information and communication technologies have significantly contributed to many diagnosis and treatment options in the life sciences. Technical devices have been used in medicine in the context of diagnosis, therapy and rehabilitation for centuries but the microelectronic revolution brought developments to a new level. Since the human body works truly electric for many functions, neural engineering arose as a discipline to investigate the electrical activity and interactions in nerve cells and neural networks and invented new tools and methods to intervene with the brain and the peripheral nervous system. Different application areas and developments have been summarized in neural engineering: implants deliver electrical pulse trains in neuromodulation to overwrite electrical neural patterns and thereby treat symptoms of diseases and change functions in the body. Neural prostheses are intelligent implants that shall replace sensory functions or motor deficits with the help of electrical stimulation of existing nerves. The electrical modulation of internal organs as intervention instead of pharmaceutical treatment is the latest application field and has been introduced as “bioelectronics medicine”. Over the last decades, implantable neural interfaces served as fundamental tools in the neurosciences to investigate the electrical activity of single cells up to networks, correlate behavior to it and identify pathophysiological changes in disease models. A toolbox of devices is available for a large variety of questions in preclinical studies. If neural implants are transferred into clinical applications in humans, not only functionality has to be guaranteed but also strong safety aspects have to be considered. Even though many application scenarios have been proposed for neural implants from a research point of view only few success stories have been written with respect to economic success and market penetration (Stieglitz 2009). From an economical aspect, neural implant numbers are often compared with the cardiac pacemaker, which is sold for than 350,000 times per year. Cochlea implants restore hearing, spinal cord stimulators treat chronic pain and incontinence, deep brain stimulators modulate movement disorders in Parkinson's disease and vagal nerve stimulators decrease the seizure frequencies in epilepsy. Worldwide, less than a million patients benefit from neural implants in these most prominent applications, even though the costs of brain related diseases in Europe extends the cumulative costs of cancer and cardiovascular diseases (DiLuca & Olesen 2014). Academic and corporate research from start-up as well as large companies focused on the development of neural implants to intervene with the brain in the last decades. Different approaches are competing with each other. Laser technology allows the development of electrode arrays with large number of contact sites (Fig. 1) and overcomes the limits of integration density of precision mechanics approaches. These developments have to come with the development of hermetic packages with

Fig. 1: Some neural implants are placed on the surface of the brain, the cortex, to record electrical signals of the underlying areas and electrically stimulate the brain. Electrode sites are made out of thin metal foils and sandwiched between silicon rubber layers. Cables are used to connect the electrode sites with a control unit that transmits the signals wirelessly to an extracorporal receiver unit.
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Fig. 2: Electronic components and circuits are assembled on a ceramic-based substrate that serves as part of a hermetic package to protect them from water and salt ions. Many electrical feedthroughs have to be integrated to interconnect each and every site of the electrode array with the electronic circuitry inside the package. © Daimler-und-Benz-Stiftung / Oostergard

Fig. 3: Thomas Stieglitz is director of the Laboratory for Biomedical Micotechnology in the Department of Microsystems Engineering (IMTEK) at the University of Freiburg and PI in the cluster of excellence "BrainLinks-BrainTools". His teaching and research interests include neural interface and implant development, biocompatible packaging and assembly technologies and bioelectonic medicine. He combines expertise in fundamental and translational research. In this photograph he demonstrates where package and electrode arrays will be placed in neural implants for intervention with the brain. Dr. Stieglitz is co-founder of the start-up company CorTec (www.cortec-neuro.com) that commercializes neural interfaces and implants to investigate and treat brain disorders. © Daimler-und-Benz-Stiftung / Oostergard

a large number of electrical feedthroughs (Fig. 2). Implants exchange data with an extracorporal control unit and will be also powered or recharged via a wireless link. Microtechnical approaches with integrated thin-film electrodes are not yet established for reliability reasons. First interfaces have been recently successfully evaluated in a first-in-man study. Four implants with a total of 56 contact sites have been implanted in the arm nerves of one subject nine years after amputation trauma to reduce phantom limb pain and restore natural sensory feedback in bidirectional hand prosthesis control (Raspopovic 2014).

While approaches in neural prostheses often suffer from relatively small patient numbers that prevent investors to invest in these endeavors, neuromodulation and especially bioelectronics medicine target large patient groups that are currently treated with pharmaceuticals. Neural implants are often proposed as last resort treatment but opinions change. In the case of hypertension, a portion of about 30 % of all patients is medically refractory and desperately waiting for new treatment options. First studies proved the opportunity of a personalized closed-loop approach to lower blood pressure with a neural implant (Plachta 2014). Other applications in which the nerve signals from natural sensors of internal organs are recorded and overwritten include diabetes and other typical diseases of an ageing society.

Precision mechanics has been well established for decades in implant manufacturing but came to its scaling limitations. Microsystems engineering has been eventually identified by medical companies as enabling technology to bring neural implants to a new level and offer treatment options for larger patient groups. Future will tell the next success stories in the emerging field of neural implants hopefully soon.

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The Aesculap-Miethke SENSOR RESERVOIR®: on the way to becoming a telemetric intracranial pressure (ICP) measurement device

Approval of the first long-term-implantable pressure sensor for a non-invasive and radiation-free hydrocephalus-shunt function diagnosis.

The fundamental importance of ICP

The brain is the only human organ which is located in a hard and closed shell: the skull. Thereby it is optimally protected against shocks and injuries. „Cerebrospinal fluid“ (CSF) is produced in four compartments inside the brain - the so-called „ventricles“ - and circulates along thin channels („foraminae“) to the spine and the surrounding „subarachnoid space“, where it is absorbed again. The CSF circulation system serves as a shock absorber, nutrient supply and defence against infections. Due to the inflexibility of the skull, the pressure balance is very susceptible to disturbance. Space-demanding processes like the growth of cysts or tumours, internal bleedings, overproduction or reduced absorption of CSF, blockages of the flow channels, a reduced brain elasticity or also an abnormal high CO2 concentration in the blood can create a dangerous overpressure. This abnormal high intracranial pressure (ICP) can cause an irreversible destruction of brain tissue, and lead to death if remains untreated.

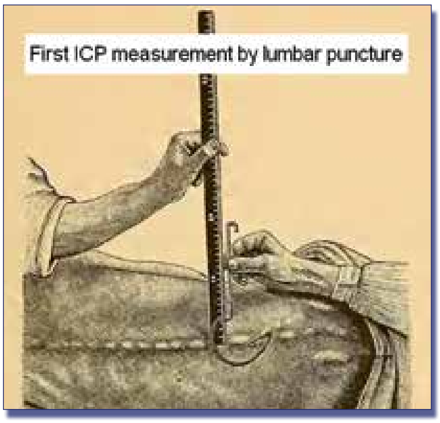

Fig.1

That is why there is great interest in a thorough knowledge of the real “in-situ” course of the ICP.
The first ex-situ pressure measurement, a short-term “lumbar (i.e. spine) puncture”, has been performed already in 1891 with a riser (see fig. 1). However, even with the first availability of sterile electro-mechanical sensors in the 1980th ICP measurement remained complicated, error-prone and dangerous. Today it is known, that many different normal and pathologic ICP waves with different amplitudes and frequencies superimpose with each other and form a complex pattern. Nevertheless, many questions remain unanswered because of the lack of truly long-term pressure measurements inside the closed skull.

Hydrocephalus

The clinical picture of CSF accumulation with too high ICP is called “Hydrocephalus”. Since the 1950th it is successfully treated mainly by the implantation of a permanent drainage system, a so-called “hydrocephalus shunt”. The overpressure is reduced by drainage of the excess CSF through a catheter implanted under the skin mainly into the abdominal cavity. An integrated differential pressure valve regulates the amount of CSF drained with the aim to control the ICP within the physiological range (see fig 2). Particles inside the CSF like clumped proteins, tissue cells or blood clots can lead to an occlusion of the shunt, so that the shunt must be explanted and exchanged. Such a shunt-failure cannot easily be diagnosed (e.g. with x-ray image), but only be derived with high uncertainty from clinical anomalies and patient’s behaviour. A reliable shunt-function-control is of utmost importance to avoid unnecessary burdensome shunt-revisions.

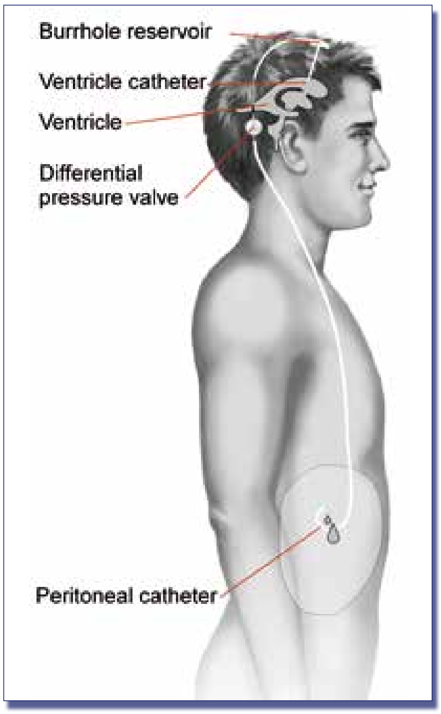

Fig.2

An appropriate way of a shunt-function-diagnosis is a pressure measurement within the shunt system. By manoeuvres with the patient (lying, getting up, pressing, coughing, sneezing, compression of the vena-jugularis etc.) the state of the shunt can be identified from the pressure readings. If for example the pulse-induced pressure waves are not detectable the ventricle catheter (see fig. 2) is probably occluded.

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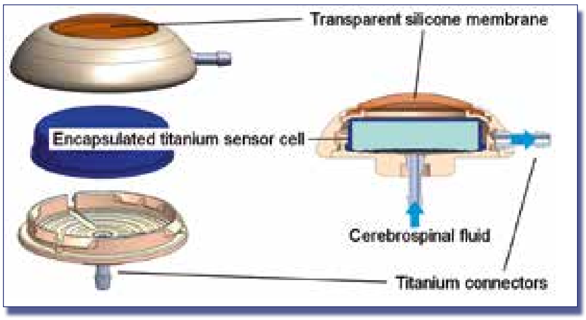

Fig.3

Telemetric shunt function control

Since decades there have been efforts to develop an implantable autonomous ICP or shunt-pressure sensor, which can be controlled in a non-invasive telemetric way. End of 2014 Aesculap-Miethke brought such a device onto the market: the SENSOR RESERVOIR®.

It consists of a capacitive pressure sensor with an integrated control unit for the measurement and the telemetric energy/data transmission (ASIC). The SENSOR RESERVOIR® is housed in a burrhole reservoir (see fig. 2 & 3). In the reservoir the drained CSF flows around the encapsulated sensor cell (see fig. 3) and the pressure within the shunt is effectively transmitted by a thin titanium membrane (see fig. 4). Beside its small diameter with the size of a thumbnail, the SENSOR RESERVOIR® offers eminent further advantages:

1. Integration in a shunt system. No additional operative step like a second burrhole in the skull for another separate implant is required.
2. The pressure is measured with a high precision of a few mbar relative to the outer atmospheric pressure.
3. The encapsulated titanium sensor is suitable for ETO sterilization, fulfils all electromagnetic-compatibility-requirements (EMC) and is MRI-compatible up to the common field strength of 3T.
4. The sensor is half-active, i.e. no battery is required. The necessary energy for the ASIC is transferred by the antenna of the reader unit (see fig. 5) through the titanium membrane by a 130 kHz-field and received by an induction-coil. The field is used at the same time for data transmission (by amplitude modulation). The reader unit is hold by the physician in a distance of 1–3 cm over the implanted SENSOR RESERVOIR® to activate the sensor and to measure the pressure. With two separate single measurements the pressure difference in recumbent and upright position or (if the valve is adjustable) for different differential pressure set points can be calculated. Alternatively a time-resolved measurement within several seconds should show the already mentioned pulse- synchronous pressure waves. By a more detailed evaluation of the measurement results, conclusions about the approximate location of a possibly present occlusion can be drawn.
5. In case of an outage of the SENSOR RESERVOIR® there is no need to explants the device. The sensor electronic is encapsulated in a robust biocompatible titanium shell and is approved for a long-term implantation with unlimited duration. The therapeutic function of the shunt is not affected by any sensor drop-out.

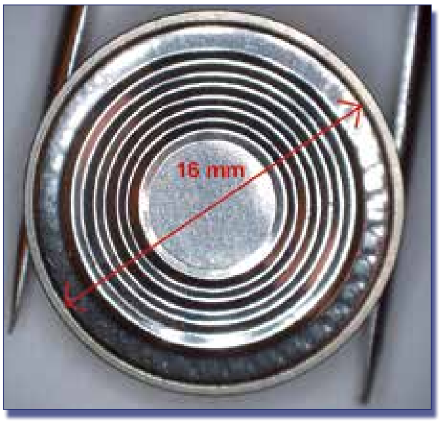

Fig.4

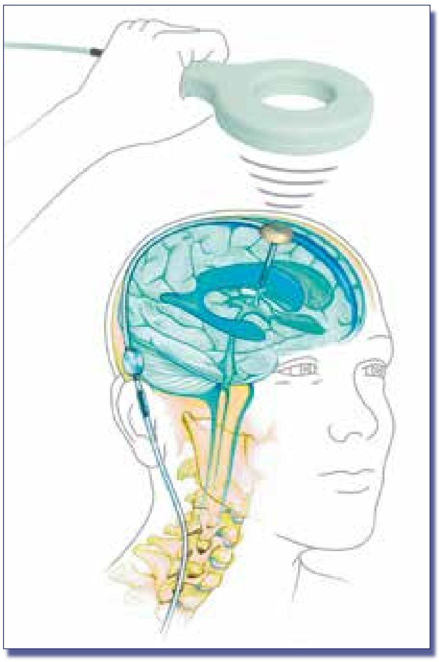

Fig.5

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Waver Level Packaging and System Integration

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WAVER LEVEL PACKAGING AND SYSTEM INTEGRATION

Microelectronic packaging and system integration is of main relevance for new application areas e. g. Cyber Physical Systems (CPS), Internet of Things (IoT), Ambient Assisted Living (AAL) as well as information & communication, logistics, security, automotive, health care and industrial electronics (Industry 4.0). Heterogeneous integration approaches following “More than Moore” are of high importance to address the needs of time to market and cost targets for future products.

System in Packages (SiPs) are driving today‘s packaging and heterogeneous system integration technologies. New technologies are emerging which specifically meet the requirements of the new product generations in a wireless connected world regarding e.g. miniaturization, high speed wireless data transmission, power delivery & management or multi-device integration. In this context, individual and different wafer level packaging and 3D system integration approaches are adapted to specific application scenarios.

3D WAFER LEVEL ARCHITECTURES

3D-SiPs involve a set of technologies including stacked packages, stacked devices with Through Silicon Vias (3D IC), silicon interposer (2,5D) and embedding technologies to integrate different devices e.g. ASICs, memories, passive devices, transceivers, sensors and MEMS into one package.
Vertical interconnects through devices or through packages e.g. Through Silicon Vias (TSVs), Through Glass Vias (TGVs), Through Package Vias (TPVs), Through Mold Vias (TMVs) are key elements for the three dimensional device or package architecture. During the last years, also the embedded wafer level ball grid array (eWLB) package has been introduced. The integration of vertical interconnects in the package and double-sided RDL extend the integration capabilities to the third dimension (3D).
The expansion to 3D architectures poses unique challenges that are not encountered in conventional 2D packaging. These include technical challenges e.g. via formation (TxV), wafer thinning and handling, 3D device stacking (die, wafer), thermal management, power delivery/management and testing of 3D structures. 3D integration also requires, beside the development of new technological approaches and the application of new materials, the consideration of reliability and design aspects.

THROUGH SILICON VIA (TSV) TECHNOLOGY

The Through Silicon Via (TSV) technology is a key element of 3D integration where electrical interconnects are formed from front side to the back side of active or passive silicon devices on wafer level. The TSV approach provides shortest vertical interconnects between devices or functional layers. There are

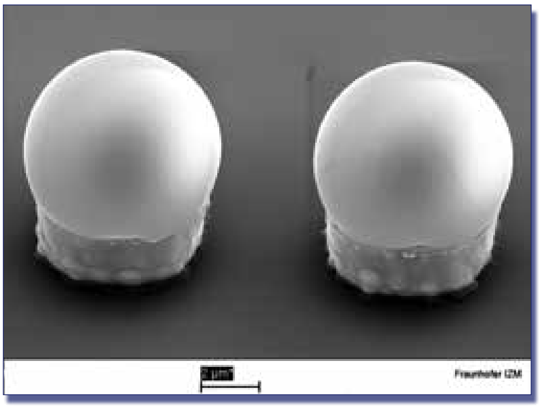

Figure 1: Fine pitch Interconnects: Indium Micro bumps (6 µm diameter, 10 µm pitch)

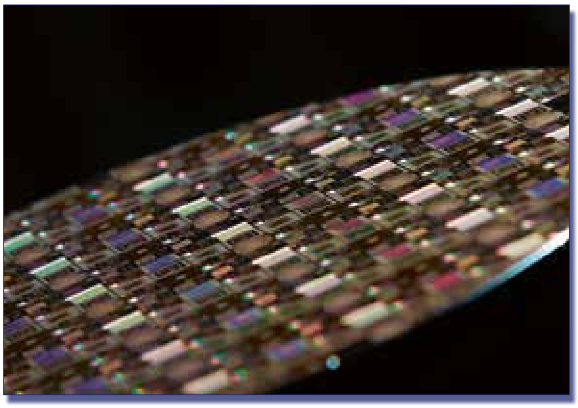

Figure 2: Silicon Interposer with Cu TSVs (10 µm/ASR >10)

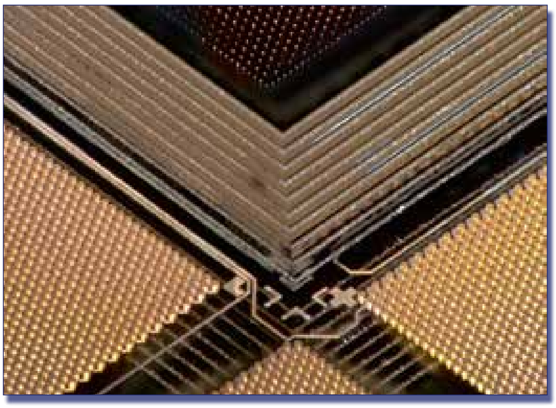

Figure 3:
3D multiple TSV device stack (10x)

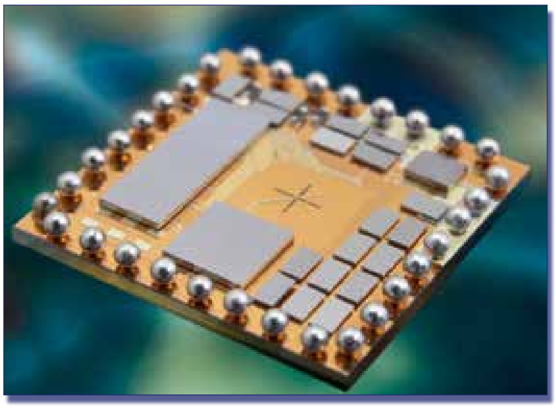

Figure 4:
Wafer level SiP

different TSV integration schemes such as via first, via last, via middle, or backside TSV. Cu-TSVs provide excellent electrical properties and are realized by using electro-deposition of copper with an appropriate seed layer deposition process. This allows the realization of different TSVs in silicon substrates and active devices with different integration schemes and different sizes.
Today, the TSV via middle approach is most commonly used for Cu-TSV integration in active circuits. Depending on the business model and supply chain, also other approaches e.g. via last TSV from backside are becoming important. Recent R&D especially focused on achieving a high TSV yield at reasonable processing cost. Beside optimization of process materials, also the TSV size has a great impact on process time and cost. For interposers, the full filled TSV has an aspect ratio of > 10 (10 µm diameter, 110-120 µm depth). With via-middle integration, the TSV size tends to be less than 5 µm diameter and less than 50 µm depth.

INTERCONNECT STRUCTURES – MICROBUMPS

Today, mostly flip chip with solder bumps are performed for 3D stack formation. New interconnection technologies, e. g. micro-solder bumps (SnAg) and Cu-Pillars, are used for the assembly and 3D stack formation of the devices to deal especially with the surface topography of the devices and the warpage of the board/substrate. Depending on the second level, interconnects for 3D systems or interposer are performed by larger bumps e.g. solder balls with typical feature sizes like micro-BGAs. For high density I/Os, also Cu-Pillar micro-bumps with or without solder cap with diameters of approx. 20 µm and pitches of approx. 50 µm are used.

SILICON INTERPOSER FOR 3D ARCHITECTURES

Silicon interposers (2,5D) with TSVs are an important element for combining different circuit devices into one miniaturized SiP with high functionality and to overcome current technical and financial issues regarding TSV integration into active circuit devices. In this way, 3D SiPs can be realized at reasonable costs with a short time to market. 3D WL-SiPs using TSVs and interposers are very product specific and require an overall understanding of design, technology and reliability.
Concerning technical features, interposers can handle multiple functions e.g. fan-out routing and providing high-dense, high-speed interconnects between circuits for digital applications. Future high-speed applications will also address, besides electrical interconnects, integrated optical waveguides. New interposer architectures are also dealing with integrated micro-fluidic channels to address cooling for performance applications and integrated active and passive device functions. And, last but not least, interposers are also acting as a complete package (housing) for sensor applications e.g. MEMS. Beside silicon interposer, also glass interposers with Through Glass Vias (TGV) are emerging substrates for specific applications e.g. RF modules and sensor.

OUTLOOK

Future Internet of Things (IoT) applications are driving the development of cost efficient, multifunctional, miniaturized system in packages (SiP). The use of the 3rd dimension in package architectures is an indispensable prerequisite to achieve better form factors and to increase performance at the same time. Different 3D integration approaches are used whereat 3D wafer level SiPs are very attractive since they can use existing manufacturing lines.
Fraunhofer IZMs research activities especially focus on technologies for wafer level system integration and packaging (6"-12") and offer a broad spectrum of R&D services including customer-specific SiP development, prototyping and pilot manufacturing at their two locations in Berlin and at ASSID in Dresden.

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MEMS: Trends and Challenges of Connected Sensor Systems

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With nearly seven billion MEMS sensors shipped since 1995, Bosch is one of the pioneers in microsystems technologies and the leading supplier of MEMS sensors. Mass production and industrialization of this technology was first driven by automotive applications such as airbag-systems, and ESP (Electronic Stability Program), as well as engine management and exhaust gas control. A modern car contains more than 50 MEMS sensors in different applications. Today's automotive MEMS sensor landscape is still dominated by pressure, mass flow, angular rate and acceleration sensors. One upcoming new application for MEMS in automotive is micro-mirror based intelligent head-lamps [1].

Since the beginning of this century, MEMS sensors have been penetrating the consumer market with applications such as gaming and smartphones. In 2015, roughly 1.4 bn smart phones have been shipped worldwide [2], each of them equipped with ~4-5 MEMS sensors, reflecting the high potential in this market. The market is far more dynamic and faster, in comparison to automotive – with speed and time-to-market being crucial success factors. Bosch successfully entered this market with the founding of Bosch Sensortec in 2005. Meanwhile 3 out of 4 smartphones are equipped with sensors from Bosch Sensortec.

In the initial phase of MEMS consumer applications, the existing sensor technologies from automotive (pressure, acceleration and angular rate) had been adapted to consumer requirements. In order to be "smartphone capable", MEMS sensors needed to become much cheaper and smaller. Energy efficiency became an important factor. Continuously, additional sensing technologies have been developed at Bosch for serving the CE market, such as magnetometers, humidity sensors and gas sensors for indoor air quality measurement trough the smartphone.

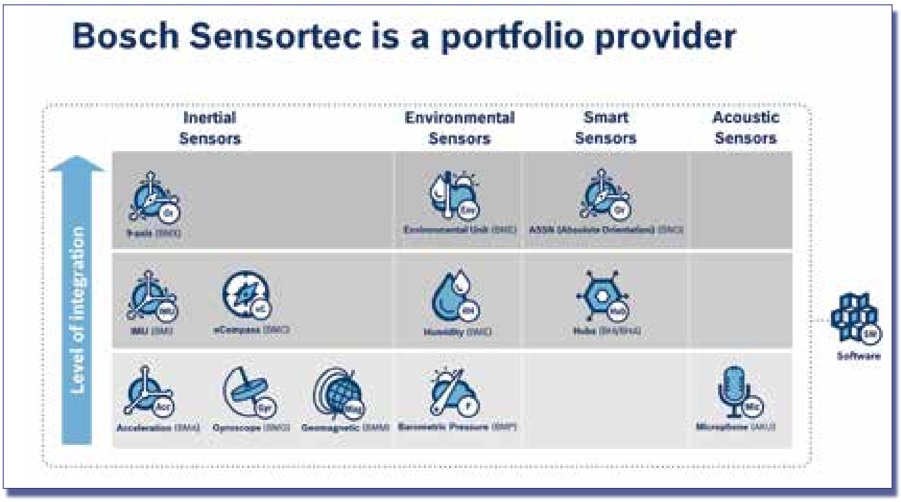

Figure1: Sensor portfolio Bosch Sensortec

Another trend is the integration of MEMS sensors into sensor clusters, so called "system-in-package" solutions. This allows for the creation of new complex functionalities, such as 9 degree of freedom (DOF) modules to measure "absolute orientation", or an environmental sensor cluster measuring gases, temperature, pressure, and humidity. In order to enable easy integration into the corresponding ecosystem and to create new functions and solutions, software and intelligence is directly integrated onto the sensor module. Moreover, software based solutions with intelligent algorithms and data fusion enable shorter time-to-market for new functionalities. An overview of Bosch Sensortec's product portfolio is shown in figure 1.

At a higher level of integration, the portfolio contains "sensor hubs" and "application specific sensor nodes" (ASSN) with software and intelligence on board. One recent example is the BHI160 containing a 3-axis gyro, 3-axis accelerometer, a magnetometer interface and an integrated sensor fusion core, which allows for 100Hz data fusion at less than 1.6 mA power consumption (figure 2). The MEMS core of the BHI160 is the BMI160 Inertial Measurement Unit which represents the world's first IMU for true always-on applications. The BMI160 integrates a 3-axis accelerometer and a 3-axis gyroscope into a single package with only 2.5 x 3 mm² footprint and features less than 1 mA current consumption in full operation mode.

Sensor hubs and ASSNs are building the bridge from consumer to IoT.

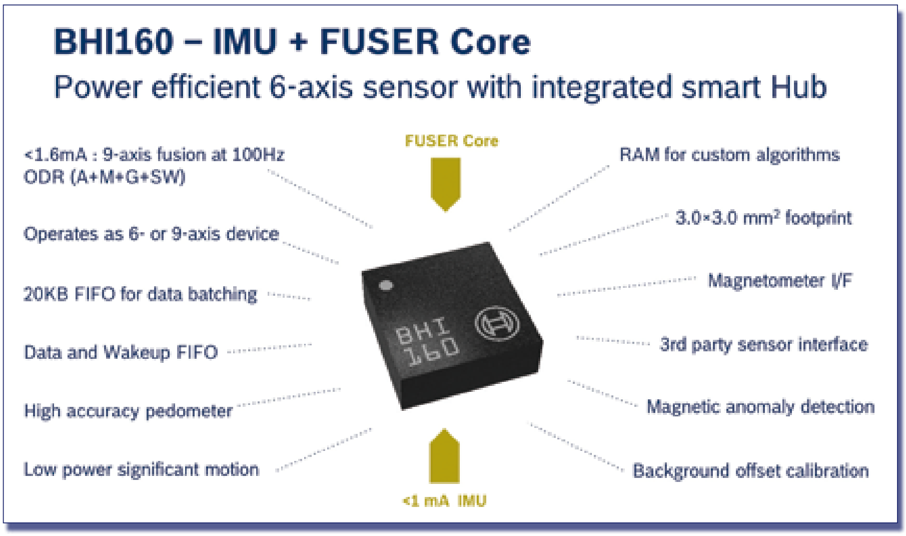

Figure 2: BHI160 – IMU + FUSER Core

They are key-building blocks for various IoT-applications in a sense that they can be easily integrated as well into the IoT-ecosystem over their built-in software interface. MEMS sensors are an important enabler and key-technology for the IoT, giving "our things a sense". With the increasing number of things being connected to the internet, this is opening up opportunities for various new solutions and applications in the fields of – for instance – smart home, industry 4.0, logistics, mobility, and health. Connected sensor systems will help to enhance our safety and health, to make our lives more convenient, to save resources, and to make industrial and logistic processes more efficient.
From the sensor technology point of view, the consequent further reduction in size and cost of the sensors, as well as the integration of different MEMS-chips into sensor clusters, is a strong trend. One decisive factor for smart connected sensor systems is energy efficiency. With ever increasing numbers of sensors, users will not accept limited energy availability causing system downtimes and maintenance efforts and cost. Use-cases will require more and more always-on applications. Energy lifetime can be increased by [1] a further reduction of power consumption and [2] by energy harvesting. Levers to reduce the power consumption are continuously improving MEMS technology, low-power ASICs and radio technologies, and intelligent operating strategies. Harvesting approaches are use-case specific, and for miniaturized systems, in general, the amount of energy earning is limited. However, with a further significant reduction of power consumption, harvesting might be appropriate for certain applications, i.e. thermal generators for industry 4.0.

With Bosch Connected Devices and Solutions (BCDS) founded in 2013, Bosch has combined the IoT sensor and service platform activities into a dedicated business unit. The BCDS sensor platform integrates different sensors, GPS, radio, power management, µ-controller and software. Primary application fields for Bosch (BCDS) are industry 4.0 & logistics, connected mobility and smart home & building (figure 3).

Furthermore, the success of an IoT-based solution requires the optimization of a complex and distributed ecosystem consisting of devices (sensors and actuators), communication and network layer, cloud infrastructure, an application-layer and a corresponding business model.

As market leader in MEMS sensors and a multi-market system supplier, Bosch is well positioned to shape the future with new connected solutions.

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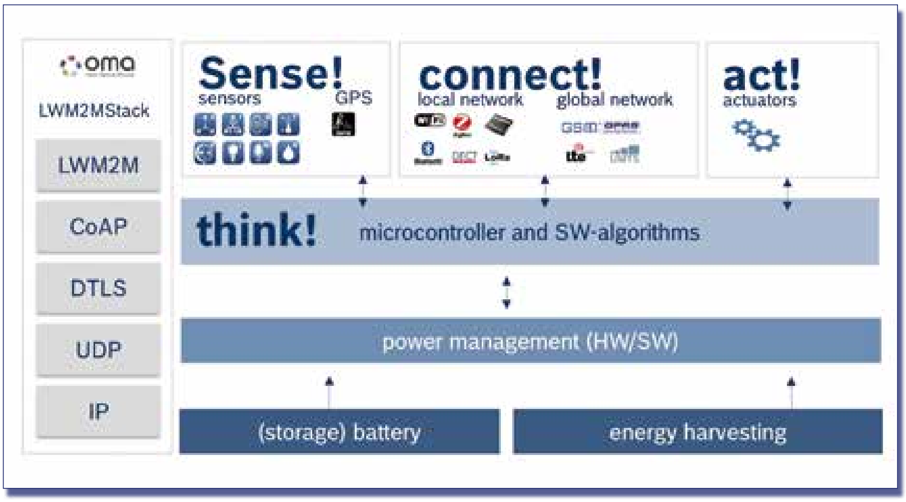

Figure 3: IoT sensor and service platform

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SmartSkin – An Intelligent Skin for Adaptive Bionic Grippers

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Introduction

Competitive automation solutions face the challenge of an advancing individualization. As a part of the automation chain handling systems play a key role in logistics and material flow. Thus a high degree of individualization in terms of positioning and gripping applications in the productive environment is needed. The adaptive Finray®-finger of the bionic handling assistant combined with an intelligent sensor system called SmartSkin meets these requirements and enables the possibility of an actively controlled gripping process [1,4].

SmartSkin – flexible sensor technology for adaptive grippers

SmartSkin is a customized system for the evaluation of stress and strain on the surface of the gripper finger (Figure 1). The sensor system consists of four equidistant distributed chips which employ stress sensitive PMOS- and NMOS-transistors. The Chips are embedded in a flexible multilayer composite of thin polyimide, forming the system-in-foil. The ultra-thin chips are mechanically flexible with a thickness of 20 µm and are manufactured using CMOS-technology. The integrated circuit packaging technology of the sensor system is realized by the ECT-µ-Via – CHIP+ process that will be enhanced further in this application for developing thin and steady flexible setups [5].

Due to the piezo-resistive effect, bending stress changes the transistor properties. As a result of bending measurable changes in the output current of the sensing transistors can be detected. The logical functionalities are designed to be stress independent, furthermore sensing elements are temperature-compensated due to the current mirror topology [3]. With an attached SmartSkin system the in-plane stress components σ_x, σ_y and σ_{xy} can be measured on the gripper surface during the gripping process.

Embedding of ultrathin chips by the ECT-µVia-Process

With novel processes the ultrathin silicon chips have been embedded in flexible polyimide circuit boards. Therefore ASICs have been positioned face down on a foil substrate with dispensed glue and a drying process. Subsequently the system is embedded in an acrylic matrix and pressed against a copper foil (Figure 3A–C). The electrical contacts have been realized by laser-drilled and electroplated microvias (Figure 3D–E). With the help of the ECT-Process (CHIP+, Embedded Component Technology) the embedding concept is demonstrated and first SmartSkin-systems have been realized successfully.

Simulations and measurements of SmartSkin

Depending on the object size and gripping position, the complex structure of the Finray®-finger shows distinctive stress- and strain patterns [2]. Purpose of the SmartSkin sensor system is to extract

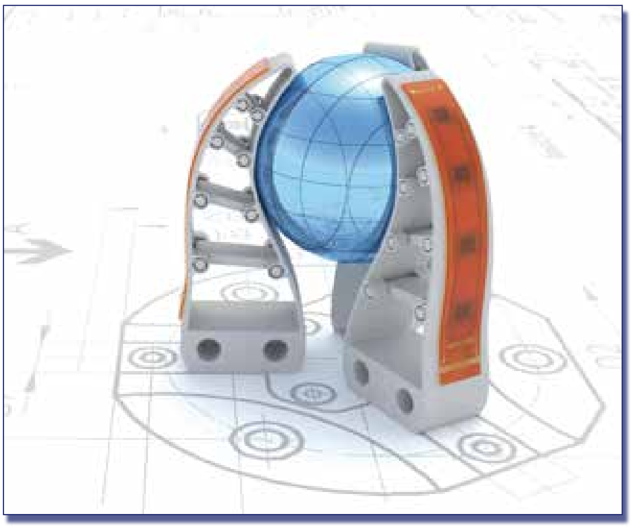

Figure 1: Adaptive gripper with SmartSkin

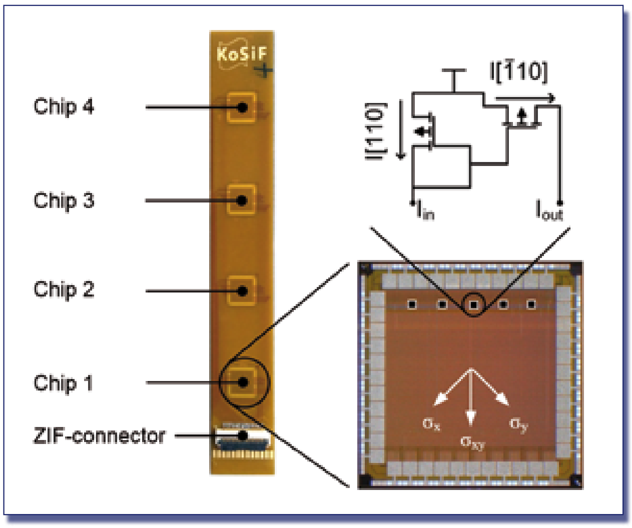

Figure 2: SmartSkin with four ultrathin chips

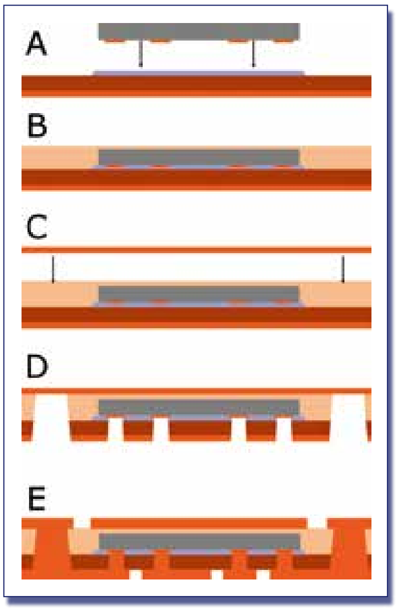

Figure 3: ECT-Process

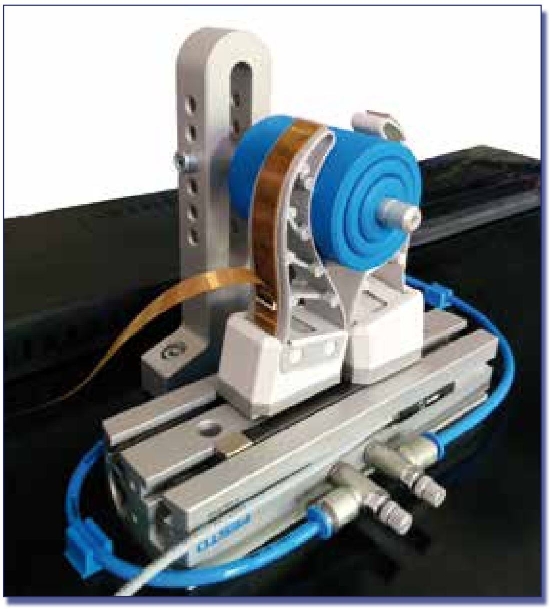

Figure 4: Application test rig

these characteristics from the sensor data to draw conclusions about the gripping state. For predicting and evaluating the stress levels of the transistors, a non-linear FEM-model of the system has been built. The stress levels in the chips have been simulated and verified by measurements, considering the 3D-printed gripper finger, an adhesive foam tape and SmartSkin. The adhesive foam tape serves as a compliant interface between the flexible gripper finger and the flexible multilayer circuit board preventing stress overload of the chips.

Figure 4 shows an application test rig with two Finray®-fingers mounted on a parallel gripper. Within this setup the output-signals of three functional chips have been measured whereas object sizes (ØD) and gripping positions H have been varied.

Depending on the application stress maxima σ_{max} (ØD) are linked to the object size whereas different stress gradients $\frac{\partial\sigma}{\partial H}$ indicate the gripping position whether the object has been clamped between the tips or is fully enclosed by the gripper fingers.

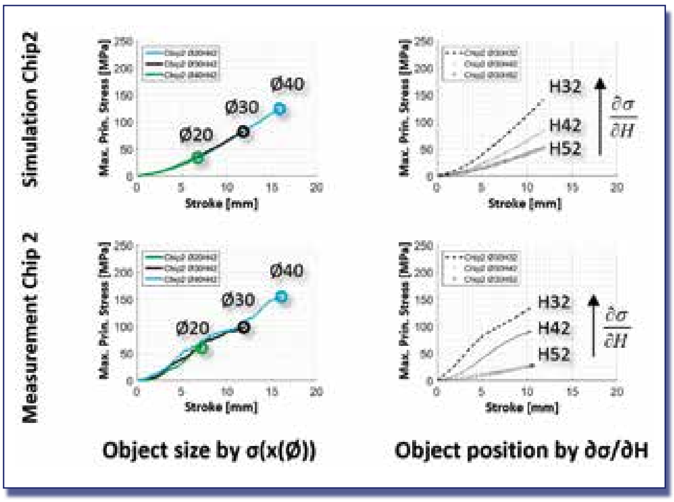

Figure 5: Comparison measurement and simulation (Chip 2)

Regarding the simulated PMOS-transistor signals of chip 2, good qualitative agreement between the measured output signal and the simulation results can be found (Figure 5). Moreover the object size and the gripping position can be distinguished.

Conclusions

With SmartSkin, the successful combination of flexible CMOS-technology and novel technologies of integration (ECT-μVIA) has been demonstrated. The distinct stress characteristics during the gripping process indicating object size and gripping position have been verified both in simulation and measurement of the system. SmartSkin enables the possibility of object recognition on adaptive grippers and enhancing the gripping process by ultrathin chips embedded in flexible multilayer circuit boards.

Acknowledgment

We gratefully acknowledge the support of our project partners working on the BMBF funded Project KoSiF (Project ID 161ES00015). Particularly we would like to thank the German Federal Ministry of Education and Research (BMBF) for funding and supporting the technologies presented.

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Different Force Sensor Approaches for Flexible Shoe Inlays in Acoustic Gait Analysis

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Abstract

Acoustic bio-feedback for improving body motion is actually discussed intensively since this kind of feedback is more intuitive than the widely used visual feedback alone, especially for learning new, more healthy motions e.g. after neurologic diseases or sports injuries [1]. Some of the gait parameters like the plantar pressure distribution and its time dependence can be measured by force or pressure sensors below the foot, thus different sensor approaches for their integration into a sensing shoe inlay are discussed.

Fig. 2: Color encoded planter pressure distributions measurements. Left: Flat Standing. Center: Heel standing. Right: Ball standing. Maximum forces are ~ 20 N/cm².

1 Introduction

Gait analysis is used in sports and medical rehabilitation for getting the actual status, its development over time and by installing visual or acoustic feedback an improvement of the gait behavior of a human. Different methods have been used in history for gait inspection, of which the most important ones are Kinematic methods, electromyographic (EMG) methods and kinetic methods. In this last method the plantar pressure distribution is directly measured, mostly by stand-alone pressure plates or by those integrated e.g. in treadmills, or, as described here, by pressure sensing shoe inlays.

2 General remarks

Gait analysis by the measurement of multiple gait parameters with different sensing methods has been discussed extensively in several studies during the past years [2,3,4].
From these studies the sensing positions for foot pressure distribution measurement are fixed on locations which may be denoted as “centers of gravity”. However, since feet from different people are also different, the measurement areas around these centers should be somewhat increased. A punctual sensing principle as for capacitive MEMS sensors [5] may require the usage of more sensors than areas. Integration of force sensors into a flexible and wireless shoe inlay require the fulfilling of some important specifications like robustness and reliability, low drift and low hysteresis, suited measurement ranges (force: 1 – 100 N/cm², sample rate at least 100 Hz), low energy consumption and low cost, thus in this project three sensing principles have been tested and evaluated: Commercially available resistive foil sensors, commercially available MEMS capacitive sensors, and ISIT printed piezoelectric and capacitive sensors, shown and described in more detail in [6].

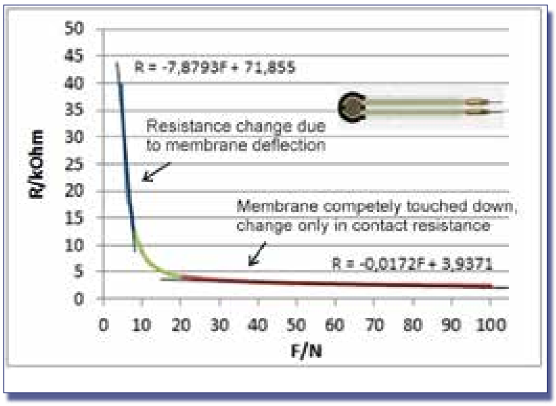

Fig. 1: R-F-Characteristics of the FSR 400TM resistive foil sensor with two linear parts. The inlet shows a photo of the foil sensor.

3 Experimental setup and results

As carrier substrates PET foil sheets (125 µm) have been used. On these substrates at first conductive lines and sensor attachment pads have been created by functional inkjet printing and sintering of silver nanoparticle ink. The printing layout depends on the used sensors or on the sensing principle, respectively.

3.1 Resistive foil sensors

For a first inlay prototype commercially available membrane force foil sensors have been used (Interlink, FSR-400™). The sensor output emits hysteresis effects and shows different linear characteristics for different force ranges, connected by a curved transition region, which makes calibration difficult (Fig. 1). Moreover different sensors show considerable variations in their output characteristics and also emit lowered repeatability. Since due to keep electronics and software simpler only one calibration curve for one inlay is used, the accuracy of the force output is lowered by at least 5-10%. The sensors where mounted onto a flexible PET substrate where already Ag conductive lines had been printed on. Sensor signals where thus led out to a plug which was connected to the electronics. Afterwards the whole sensor matrix was covered with a thin plastic / rubber foil. Moreover the whole stack was covered with textile for providing the user the impression of a conventional shoe inlay. Some measurements of plantar pressure distributions for different foot settings are shown in Fig. 2.

This setup appeared to be robust and accurate enough for first field test, e.g. on a treadmill.

3.2 MEMS capacitive sensors

Micro machined capacitive sensors designed for absolute pressure measurement (Protron™, series 09112012) have also been integrated into an inlay. The sensor itself was mounted and wire bonded on an interposer PCB.

This interposer was then fixed on a perforated PET foil, again containing printed lines and signal pads for contacting sensors. Another (upper) PET foil with printed lines and GND pads was then attached, yielding a two foil stack with embedded sensor modules.

The space between the two foils as well as the whole substrate pair was filled and encapsulated with PDMS. Measurements with embedded sensors are shown in Fig. 3. The signal is roughly linear but shows some drift and hysteresis.

3.3 Printed sensors

Free form factor, simple fabrication and integration as well as low price are the most important advantages of PPS. However, compared with the other mentioned principles, piezoelectric sensors will only yield direct results after dynamic, and not static, input.

Thus sensor printing technology was further developed and capacitive sensors with simple three layer setups and arbitrary shapes yielding a parallel plate capacitor structure were manufactured. In Fig. 4 the printing layout for one inlay is shown.

4 Conclusion and future work

It has been shown that various different sensing methods can be integrated into flexible substrates for gait analysis applications. Each sensing element has its own advantages and drawbacks. The next step will further development of capacitive printed sensor with sufficient shielding against external electrical fields and humidity.

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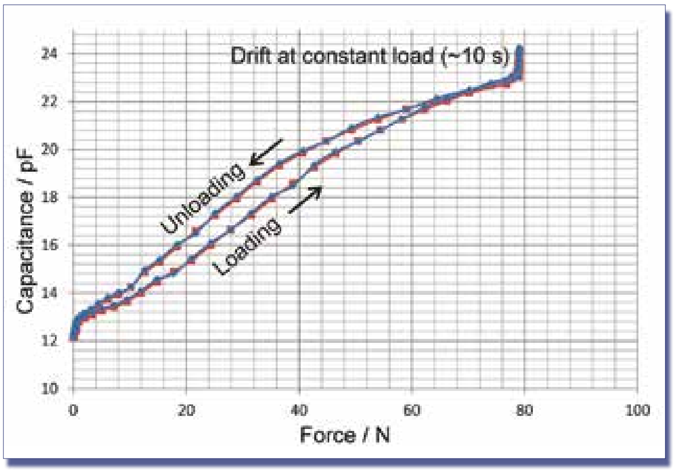

Fig. 3: Characteristics of capacitive MEMS sensors, embedded into a PET/PDMS inlay.

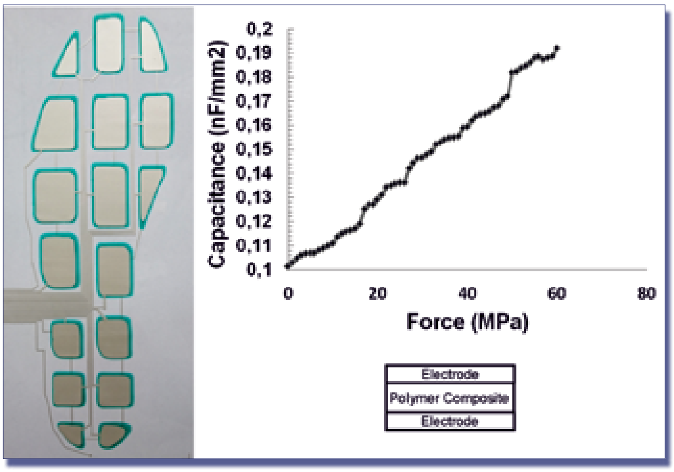

Fig. 4: Left: Printing layout for capacitive sensing inlays. Upper right: Sensor characteristics (area = 2 cm²). Lower right: Sensor construction.

Ultra-compact Adaptive High-speed Lenses with Large Aperture and Aspherical Correction

Abstract

Adaptive (varifocal) lenses give the possibility of changing the focal length or other properties of an optical system without actually moving any optical elements. This removes the complex and bulky lens translation mechanisms that may be costly and are often subject to wear. It may further reduce the number of necessary lenses, making the system lighter and smaller. We present a lens technology that advances the performance of adaptive lenses in three ways: Our lenses are more compact with up to 70% free aperture compared to the outer diameter, they are several times faster than existing adaptive lenses and also have a variable aspherical lens profile for aberration correction.

Background

There are three major types of adaptive lenses: Fluid-membrane lenses, electrowetting lenses and acoustic gradient index lenses – the latter ones being specialized lenses for high-frequency pulsed light. Electrowetting lenses use an electric field to control the size of a water-based drop in oil and hence the profile of the oil-water interface. They are inherently only suitable for small apertures (<4mm). Fluid-membrane lenses consist of a fluid-filled lens chamber that is covered with a lens membrane. A pump displaces the lens fluid into the lens chamber and hence causes the lens membrane to deflect. While they can have large apertures in the region of 10mm and a numerical aperture around 0.05, their speed is limited (around 10ms at 10mm aperture) and the pump makes them bulky, with at best 1/3 clear aperture, similar to electrowetting lenses.

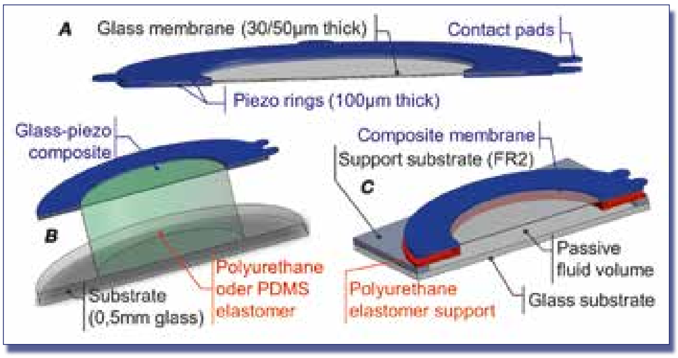

Fig. 1:
A) Active glass-piezo composite membrane.
B) Elastomer lens.
C) Fluid lens.

Working principle

The key component of our lenses is an active glass-piezo composite membrane (fig. 1a) consisting of a sheet of ultrathin glass (30-70µm thick) that is sandwiched between two piezo rings (~100µm thick). If we apply a `positive' voltage in the direction of the polarization to both piezo rings, they will contract – causing the membrane to buckle up or down. If we apply opposite or at least non-equal voltages, one ring may contract and one expand, giving a bending effect to the edge of the membrane. With these two degrees of freedom (fig. 2), we can control both the amplitude and the shape of the membrane profile, i.e. the aspherical behavior. As the PZT rings have a similar stiffness to the glass, they can be relatively narrow, depending on the glass thickness.

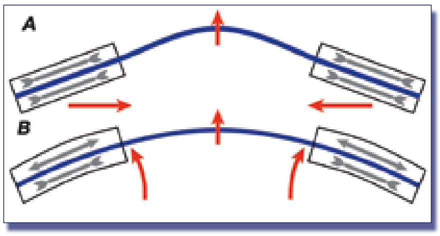

Fig. 2: Buckling and bending actuation modes.

To turn this membrane into a lens, we need a refractive medium. One possibility is to glue the membrane onto a soft cylindrical elastomer lens body as shown in fig. 1b. This system is straightforward to fabricate, in particular in small dimensions, but may suffer from birefringence in the deformed polymer. It has also a strong mechanical effect from the back pressure of the elastomer that needs an aspect ratio of at least around 0.5.

The other option (fig. 1c) is to use a fluid. We developed a thin lens chamber with an elastomer ring that acts as a hinge and support for the membrane and also allows for a vertical motion of the membrane to counteract the fluid displacement. This concept avoids birefringence as it comprises only a

Fig. 3: Images of elastomer and fluid lens.

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homogeneous and isotropic fluid and the glass surfaces in the lightpath. It is, however, less trivial to fabricate and to realize in small dimensions.

Realization

We investigated the elastomer concept with an ultra-compact lens with 6.25 mm aperture, using a 30 µm thin glass membrane and a narrow piezo ring with 7.9 mm outer diameter (fig. 3). For the 3.5 mm thick lens body, we tried a clear polyurethane with shore hardness A30 and a PDMS with shore hardness A25. These materials have a very different dynamic and mechanical behavior. The polyurethane further has a closer match in the refractive index to the glass while the PDMS has lower birefringence. The outer diameter of the package is 9 mm. A prototype of the fluid-based lens was developed to be used in an MR-compatible microscope, where we wanted to focus without moving parts and had to deal with an electromagnetically harsh environment. We designed the membrane with a 12.5 mm clear aperture to support the 8.5 mm aperture of the microscope and a dark field illumination. We chose a polyurethane with shore hardness A50 for the supporting ring, which is compatible with the paraffin oil that we used as an optical fluid. In this case, we did not package the lens, but mounted it directly on a PCB for integration into the microscope.

Results

We characterized the lenses primarily by measuring the membrane deformation, ignoring possible birefringence. The aspherical focusing behavior is indicated in fig. 4, where we show the quartic (i. e. fourth order fit) parameter α_4 of the lens profile as a function of the refractive power for voltage trajectories that roughly outline the operating region. $\alpha_4 = 0$ corresponds to a parabolic profile, $\alpha_4 > 0$ is hyperbolic and $\alpha_4 < 0$ elliptic. We see clearly that it is possible to achieve different aspherical profiles for a single focal power, with a focal range of ±5.8 dpt for the larger fluid lens (right) and ±11 dpt for the small polyurethane lens (left). The resonance frequencies (fig. 5) of the smaller lenses are in the kHz range, while the fluid lens has its first resonance around 500 Hz which can be suppressed with pre-deflections.

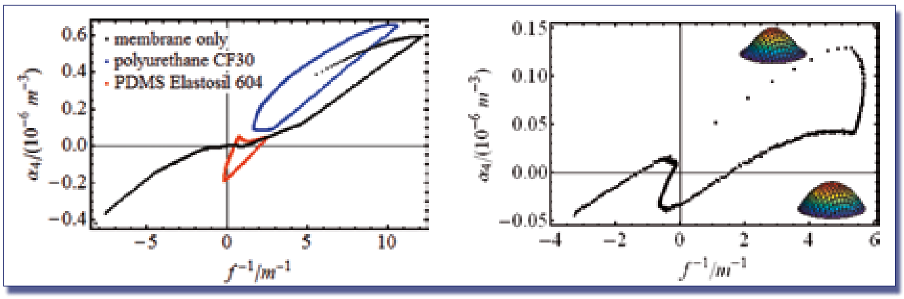

Fig. 4: Quartic parameter as a function of the focal power for voltage trajectories outlining the working range of the lenses on the 'positive branch'. The discontinuity corresponds to a jump between two (meta-)stable points.

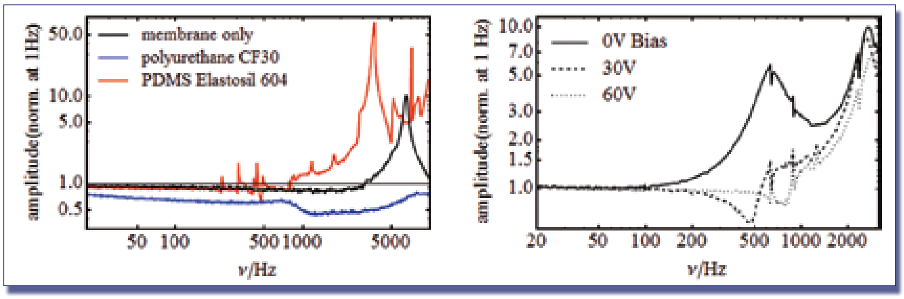

Fig. 5: Resonance spectrum of the elastomer (left) and fluid (right) lenses.

Comparing the different refractive media and the pure membrane assuming a fictive n = 1.49, we see that the polyurethane has a strong creeping behavior that makes it unsuitable for dynamic operation, but follows in the static behavior closely the membrane behavior. The PDMS highly affects the lens profile due to its cross-linked elasticity but has very low damping. The fluid lens seems to be a good compromise, as it combines low damping and a wide focal and aspherical tuning range.

We can conclude that this type of lens actuated by the piezo-glass-piezo sandwich offers a whole set of new opportunities for adaptive lenses with millisecond-scale response times, compact dimensions and aspherical correction.

Acknowledgments

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Thin Multi Aperture Microscope with High Resolution

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Abstract

Many applications in the field of point-of-care diagnostics call for the basic functionality of a microscope but in a much more compact format (e.g. size of a smartphone), with the possibility for rapid detection of several square millimeters object field, with high sensitivity but relatively little cost. One potential solution is provided by the approach of a parallel imaging through multiple lenslet channels in which each individual channel is miniaturized and thus transferring only a small part of the object field.
An array of (m x n) of these optical channels transmits an object field size that is (m x n)-times that of the single channel without increasing the system z-height.
For the production of the lenslet elements microoptical manufacturing processes are used which enable the achievement of the necessary tolerances for microscale imaging optics also in larger volume.
The feasibility of such an arrangement is demonstrated by an example system with a numerical aperture of 0.3 and an experimentally proven resolution of 1.1 µm at a z-height of less than 8 mm.

1 Introduction

Microscopes represent a versatile tool to inspect small structures within modern applications including biomedical imaging or machine-vision. However, analysing extended probes usually requires long image acquisitions due to the necessity to scan the entire object field, which limits the throughput and increases system size and costs. Here, we present the optical design as well as the technological implementation of a digital microscope, based on a multi-aperture, microoptical imaging approach. Initially, the utilization of two-dimensional lens arrays was proposed by Anderson [1] in order to image documents and displays onto a photographic film. Subsequently, the concept was successfully applied to project lithography masks [2]. Furthermore, microoptical solutions featuring 1:1 image projection based on this idea have been demonstrated [3, 4]. In contrast to these systems, the array microscope, presented here, enables to combine this principle with an optical magnification. It allows for the acquisition of an extended object field with a high resolution based on a parallelized imaging approach. At the same time, the multi-aperture configuration facilitates a compact and portable device with a reduced overall length of less than 8 mm. The respective optical system comprises a stack of refractive microlens arrays (MLAs), which are manufactured by cost-efficient, parallelized lithography and UV-imprint methods (Fig. 1).

2 Working principle and optical design

With the development of microelectronic image sensors, the necessity to see through a microscope with the human eye is eliminated – the inspection can be performed digitally on a PC. Without the requirement of a separate imaging track for the direct inspection with the eye, a significantly reduced system size can be achieved. In fact, the optical array module, presented here, can be tailored to specific requirements on the object field size as well as the image sensor by adapting the amount of imaging channels and without the need to increase the systems z-height.

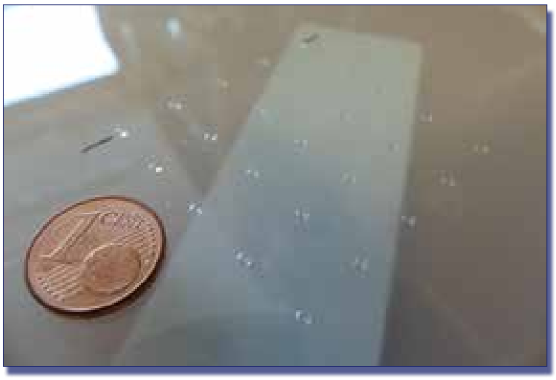

Fig. 1: Photograph of one microlens array of the system, manufactured by UV-imprinting.

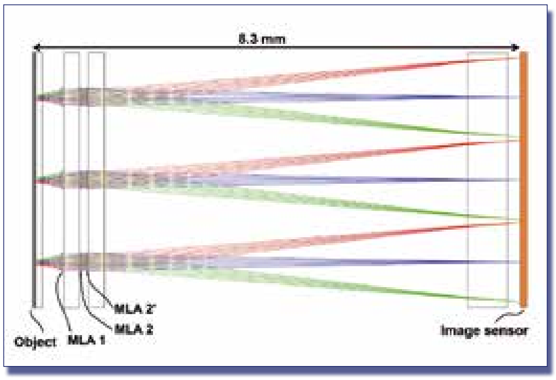

Fig. 2: Schematic design illustrating three optical channels that comprise three microlens surfaces.

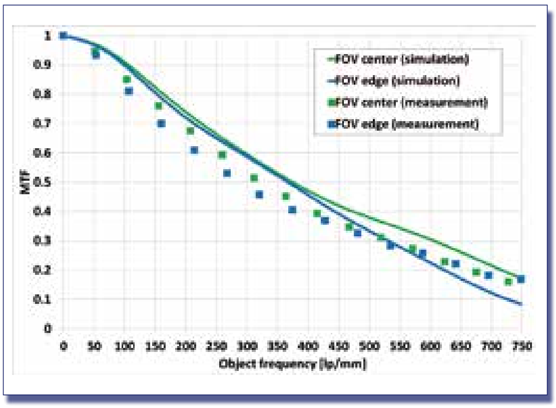

Fig. 3: Measured MTF (squares) at the center (green) and at the edge (blue, ca. 100 µm field position) of the single channel field of view (FOV). For comparison, the simulated MTF curves are plotted using straight lines.

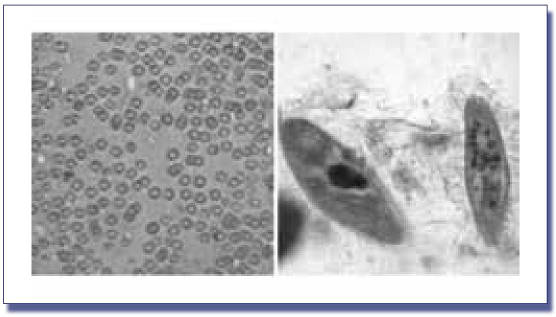

Fig. 4: Acquired images of red blood cells (left) with a diameter of 6-8 µm and two paramecium samples (right).

The resolution of previous systems was limited to about 6 µm [3,4]. In order to achieve a targeted object resolution of 1 µm, a numerical aperture of 0.3 is required for the imaging objective. In addition, the pixel pitch of current image sensors is in the order of a few micrometer and thus larger than the targeted resolution. Accordingly, resolving these features with the image sensor requires utilizing an optical magnification.

As shown in Fig. 2, the final design comprises three microlenses within each optical channel. It provides a close to diffraction limited performance for a small spectral bandwidth around 580 nm and features an optical magnification of 10 and a numerical aperture of 0.3. Due to the optical magnification, the image that is generated by an individual lenslet channel is larger than the corresponding subarea of the object. Accordingly, it is not possible to acquire the entire object field of interest by a single shot, even in case of 100 % fill factor at the image sensor. The system thus requires the acquisition of multiple, laterally shifted images, which can be combined subsequently using post processing software.

3 Experimental results

The microoptical components (see Fig. 1) are manufactured by imprinting a single lens master into a UV-polymer on top of a glass substrate (step & repeat process). This master is created using ultra-precision diamond turning. The analysis of the obtained microlens surface profile confirmed the suitability of the applied technology chain and their respective tolerances for cost-efficient fabrication of these complex optical elements.

In order to quantify the optical performance of the system, the modulation transfer function (MTF) is measured according to ISO 12233. The obtained results are plotted in Fig. 3 and show a nearly diffraction limited performance.

A resolution limit of 910 lp/mm was measured in the center of the lenslet's field of view (FOV), considering a minimum MTF requirement of 10 %. The corresponding minimum feature size of 1.1 µm agrees with the simulated results as well as the theoretical limit provided by the system's numerical aperture. The field of view of each lenslet channel is 200 x 200 µm² and the depth of focus is approximately 5 µm. The acquired exemplary images, presented in Fig. 4, demonstrate that the system performance is sufficient in order to resolve micro-biological structures such as the paramecium and its inner parts, as well as blood cells.

4 Future work

The limited spectral bandwidth of the current system is already sufficient for many applications, e. g. fluorescence microscopy. However, the optical design can be optimized further by incorporating multiple polymers (achromatic design) in order to be able to image the entire visual spectrum. In addition, an increased numerical aperture of 0.5 can be achieved by utilizing six microlens elements within each lenslet channel, which enables an enhanced optical resolution of 700 nm.

In summary, the concept of the presented array microscope provides a powerful, cost-efficient and compact optical solution for many bio-medical applications, e. g. the diagnosis of viral infections.

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Automated Microfluidic System with Optical Setup for the Investigation of Peptide-Antibody Interactions in an Array Format

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Abstract

Peptide arrays enable high throughput screening of antibody-protein interactions. Thousands of peptides can be screened simultaneously with a minimum of sample volume. Besides the information whether an antibody binds specifically to a peptide, it is of interest to characterize the peptide-antibody interaction. Therefore, we developed a microfluidic system for the automated incubation of peptide arrays with biological samples and for the optical characterisation of antibody-peptide interactions in the array format.

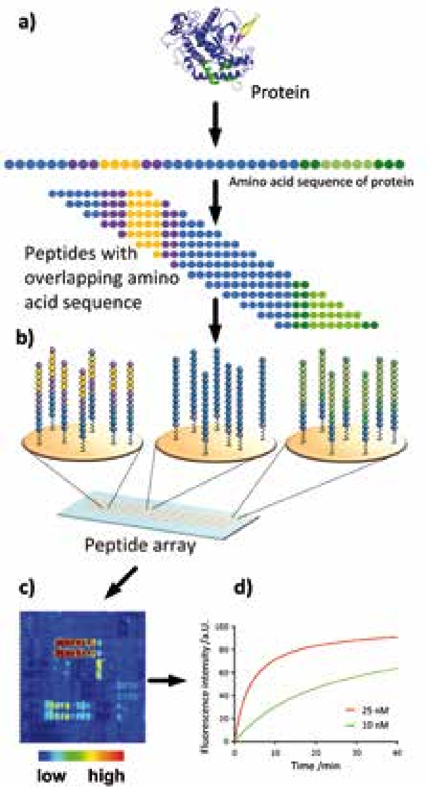

Figure 1:
a) The amino acid sequence of a protein is cut in silico into peptides with overlapping sequences.
b) These sequences are synthesized onto a peptide array. c) The peptide array is incubated with fluorescently labelled antibodies. d) The fluorescence signal is detected with a camera over time for different antibody concentrations. Example protein structure from [6], modeled with PyMOL

Introduction

The study of protein binding is the basis of fundamental research regarding cancer related signaling cascades as well as for diagnostics regarding detection of disease-related antibodies [1]. For the interrogation of protein binding events, peptide arrays are a well-established method [2]. They enable multiplexed high-throughput assays and require minimal sample volume. At the Institute of Microstructure Technology at KIT high-density peptide arrays and their applications are developed and optimized [3, 4]. Peptide arrays can be used to search for linear epitopes in the immune response to diseases or vaccines: displaying the whole amino acid sequence of a toxoid as overlapping peptides, the toxoid specific antibodies in a patient serum can be analyzed and characterized [5] (see fig. 1 a-c).

We were especially interested to set up a system that – in addition to mere antibody binding – would also deliver kinetic data in an array format, and for many different antibody-peptide pairs.

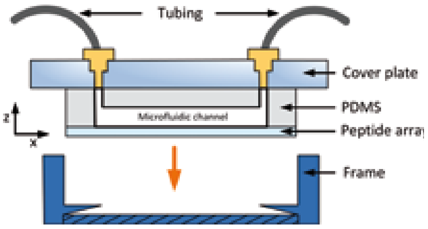

Figure 2: MicCell system by GeSiM.

Therefore, our experimental setup allows incubating 120 different peptides with different biological samples (e.g. sera or cell culture supernatant), while binding events are detected by time resolved fluorescence imaging.

Microfluidic system

All incubation steps are automatically performed in a microfluidic system.
A continuous, laminar flow allows the contact and interaction of the sample antibodies with the peptides, which are immobilized in array format.
The core part of the experimental setup is a microfluidic channel of the MicCell system by GeSiM (see fig. 2). The walls and the top of the channel are molded into Polydimethylsiloxane (PDMS). The actual channel is formed when the peptide array is attached to the PDMS.
A cover plate contains threads to connect the tubing. By screwing the cover plate onto the frame, a defined pressure is applied to the PDMS and the peptide array to seal the microfluidic channel.
There are two parallel channel molded into the PDMS, each 150 µm in height

and 3.5 mm in width. A continuous flow is realized by an automated peristaltic pump (Reglo ICC, Ismatec). All process relevant buffers are connected to the system via a motorized valve.

Optical Setup

For the detection of binding events, we chose fluorescence, due to the high sensitivity.

Fluorescence on the peptide array is excited by a high-power LED at 530 nm. A filter set (F41-007 HQ-Set, AHF Analysetechnik) separates excitation and emission. The signal is detected with a CCD-Camera (ProgRes C5, Jenoptik) (see fig. 3). Exposure times of up to 10 seconds are possible.

The fluorescence signal increases over time as more antibodies bind to the peptides.

Peptide arrays and antibodies

To establish the system, a monoclonal Anti-FLAG M1 antibody (Sigma-Aldrich) binding to the FLAG peptide (amino acid sequence DYKDDDDK) is used. The antibody is fluorescently labelled with a Lightning-Link™ Rapid conjugation kit (Innova Biosciences) with the fluorophore Dylight550 according to the instructions. Peptides were ordered from Peps4LS and spotted with a Spotting Roboter (MicroGrid II, Genomic Solutions) onto 3D-maleimide functionalized surfaces (PolyAn).

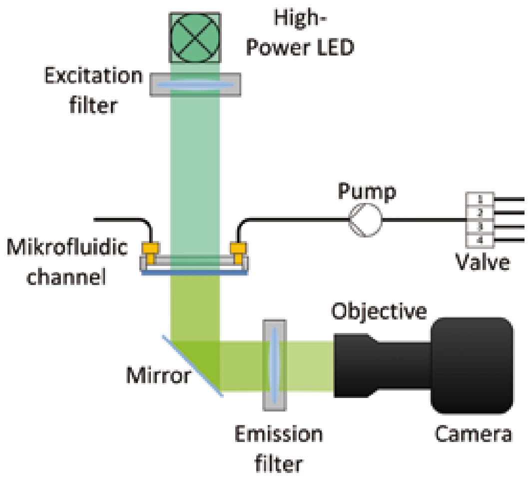

Figure 3: Schematic of experimental setup.

The peptides are functionalized with a C-terminal cysteine which contains a thiol in the side chain that binds to the maleimide. After the completion of the spotting procedure, unreacted maleimides on the surface are blocked by washing the surface with mercaptoethanol. Unbound peptides from the spotting process are removed by a washing step with 0.1% trifluoroacetic acid in acetonitrile.

Experiments

All buffers used for washing, blocking and incubation are degassed and filtered sterile. In the first step the microfluidic channel is filled with phosphate buffered saline with 0.05 % Tween20 (PBS-T, Sigma Aldrich) and the array is preswollen for 10 minutes under flow with a volume flow rate of 600 µl/min. Next, the system is blocked with Rockland buffer (Biotrend) for 30 minutes to prevent any unspecific binding of antibodies in the system. The incubation of the array with antibodies is realized at a flow velocity of 16.4 mm/s, resulting in a Reynolds number of 2.1 for the microfluidic channel. Every minute, the CCD camera takes an image with an exposure time of 8 seconds and a digital gain of 8. Bias and flat field correction is performed with ImageJ. The intensity of the signal is calculated as the average grey scale value of all pixels of one peptide spot.

Finally, the intensity of designated background control areas is subtracted from the intensity of the peptide spots. For the calculation of the equilibrium dissociation rate constant K_D, a pseudo-first-order model according to O'Shannassay and Winzor [7] is used.

Results and Outlook

With the above described system, we detected kinetic profiles of a monoclonal antibody (see fig. 4).

We calculated an equilibrium dissociation rate constant K_D of $6.1 \cdot 10^{-8}$ M.

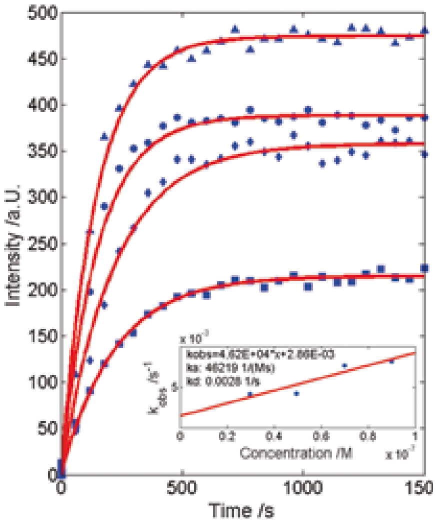

Figure 4: Fluorescence intensity detected over time for anti-FLAG antibodies labelled with Cy3 incubated in different concentrations on peptides: ■ 30 nM, ♦ 50 nM, • 70 nM, ▲ 90 nM. Fitting according to [7]. $I = I_{max}\,(1 - e^{-k_{obs}t})$ with I_{max} representing the fluorescence intensity at equilibrium and $k_{obs} = k_a c + k_d$. k_a and k_d are the respective association and dissociation rate constants.

In the future, we plan to investigate different peptide-antibody combinations with our system and establish reference measurements for validation. Potentially, our system will allow for obtaining dissociation rate constants for 120 different peptide spots simultaneously.

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Ultra-thin Silicon Chips and Printed Circuit Boards for Applications in Flexible Electronic Systems

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There is a growing demand for mechanically flexible electronic systems intended for various advanced applications. Therefore, hybrid systems with ultra-thin flexible silicon chips embedded in polymer substrates (System-in-Foil) are getting more and more attention. These systems require thin chips which maintain their proper functionality even in bent state. It should also be possible to reliably handle and assemble them on or inside foil carriers with available process technologies. A consortium of three companies and one research institute has been closely cooperating to tackle these problems within the framework of a leading-edge cluster called "MicroTEC Südwest" in Germany.

1. Introduction

The development of technologies for the fabrication of thin and flexible substrates offers the opportunity for new applications and innovative solutions for the entire system even with the existing concepts. Both the patented ChipFilm™ technology and wafer back grinding enable the fabrication of chips with thickness below 20 µm and 50 µm, respectively. Novel handling and assembly processes are used to mount these IC chips onto semi-manufactured substrates and to produce Systems-in-Foils.

2. Ultra-thin chips

As a part of the System-in-Foil, ultra-thin silicon dies are fabricated either through ChipFilm™ technology [1] or by a wafer back-grinding process, the so called Dicing-Before-Grinding (DBG) [2]. During the ChipFilm™ process buried cavities and anchor structures are defined on the silicon wafer before the CMOS integration process. After the CMOS process the chips are separated by trenching and then detached from the wafer by means of a pick & place tool. In the DBG process the CMOS wafers are first notched and then grinded down do the final thickness while being attached to a framed carrier foil. During the grinding process the chips are separated but still held in place by the carrier foil.

3. Assembly interconnection and embedding with the ThinECT-µVia technology

During the so called ThinECT (Embedded Component Technology)-µVia process the pads of the ultra-thin chip are interconnected by copper vias [3]. This process starts with a single-sided copper-clad liquid crystal polymer on which the ultra-thin die is assembled face down by a thermal compressive process. To realize a double-layer flexible substrate, a second single-sided copper-clad liquid crystal polymer substrate which melts at lower temperature is thermally pressed onto the chip assembled substrate. The

Fig. 1: Ultra-thin chips embedded in liquid crystal polymer

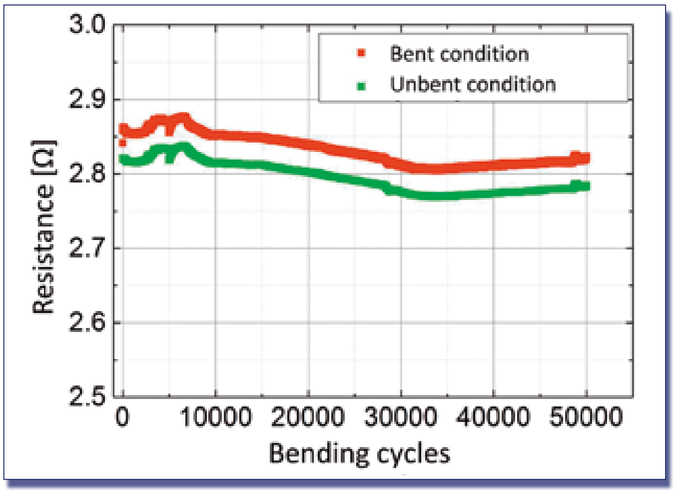

Fig. 2: Measured resistance of a daisy chain test device versus bending cycles

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pads are opened in a laser via drilling step and are connected through a copper plating process. As the last step, copper layers on both sides are structured by using a photolithography step (Fig. 1).

4. Electrical characterization of the ThinECT-µVia build-up

Characterization of the flexible circuit takes place in a special bending machine. This fully automated tool allows for in-situ electrical measurement of the foil during bending both in bent and unbent conditions. Different pre-set bending radii [4] can be used to qualify the bending behavior of the device under test. The measurement results presented in this paper are achieved from embedded daisy chain chips which have been bent to a radius of 10 mm.

To further analyse the daisy chain test device, resistance measurements have been carried out. Additionally lock-in-thermography before and after the bending cycles has been made to locate the failures or the vias with increased resistance in case that no electrical open occurs. For samples that did not exhibit any initial damages, it was found that the microvia connections were very stable and reliable. For the previously described bending setup, 50000 bending cycles could be achieved without any failure. The plot of the measured resistance values of a complete daisy chain is shown in Fig. 2. During the entire sequence, the change in resistance was below ±1.5% of the initial value, which is negligibly small.

Fig. 3: ULTIMUM demonstrator, Chip embedded in liquid crystal polymer

5. Mechanical Simulation of the ThinECT-µVia build-up

Based on the ThinECT-µVia process, different aspects have been examined through simulations. The data indicate high stress areas in the foil system close to the connection of thick copper vias. These results are confirmed by measurements.

Conclusions

Two different technologies to integrate ultra-thin chips into flexible substrates (Fig. 3) were presented. Accompanied by simulation, the electrical and mechanical characteristics of the flexible System-in-Foil were evaluated. It could be demonstrated that such Systems-in-Foil can sustain bending stress up to 50000 cycles.

Acknowledgements

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Sensor Capsule for Medical in Vivo Biosensors

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Microimplants for diagnosis and therapy

Electrically active medical implants are used for the diagnosis, monitoring and treatment of numerous diseases. The best known are pacemakers, cochlear implants and deep brain stimulators for the treatment of Parkinson's disease. Currently there are numerous dysfunctions of internal organs in the focus of new therapy approaches.

State-of-the-art active implants for long-term use basically consist of a solid metal housing protecting the electronics and the energy storage. For applications, where only a small volume is available for embedding of the implant into the body, and where large batteries and cabling are not applicable, miniaturized and compact system architectures are required. The devices must contain means for on-board data management and a wireless link with external devices for energy and data transmission. The SMART IMPLANT consortium in the Spitzencluster microTEC Südwest developed a highly-integrated system for in vivo biosensor applications. It contains amperometric, potentiometric and impedance sensors for measurement of the oxygen concentration, the pH value and the impedance in the immediate environment of the implant. The electronic circuits are designed for maximum energy efficiency to allow, together with the high integration density, as small as possible and wireless active implants.

Implantable biosensors allow the continuous detection of biomarkers that can be used for diagnosis and monitoring of neurological, cardiovascular and metabolic diseases, to monitor drug effects and vitality of tissue and organs in intensive care after transplantation.

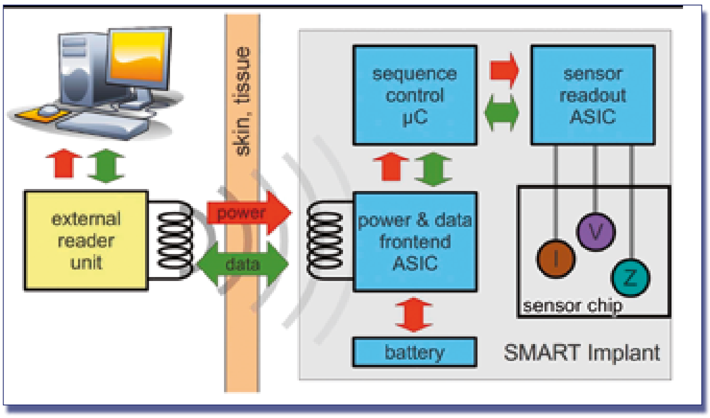


Fig. 1: Block diagram of the SMART implant system with a wireless link between an external reader unit and the implanted electronic circuit with ASICs and sensorchip.

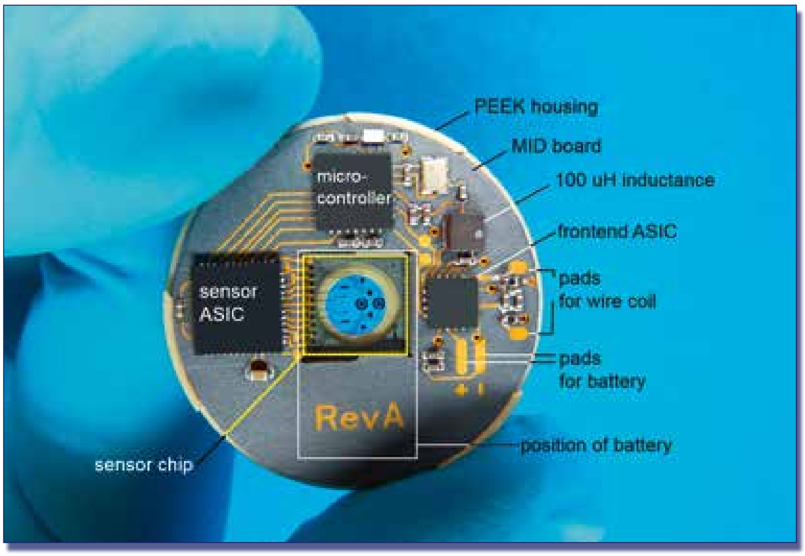
System architecture

The implant system consists of a sensor capsule and an external control and reading unit. ASICs (application specific integrated circuit) and a microcontroller enable the readout of sensors and inductive energy and bi-directional data transfer between the implant and an external unit via an inductive interface. The link enables data rates of 50 kbit/s for parametrization of the implant, uplink transmission of the sensor measurement data and the realization of a closed loop power control. The electronic components (2 ASICs, microcontroller, SMD components) and a separately produced sensor chip are assembled on a 3-dimensionally shaped MID (molded interconnect device) board. The board and a battery are housed for mechanical protection in a two-part, rigid capsule made of PEEK (polyetheretherketone). PEEK is suitable as a chemically resistant construction material. However, PEEK alone is not a sufficient barrier to water vapor and thus against moisture. To protect the MID board with the electronic parts against ingress of moisture, it is coated before being integrated into the capsule with Parylene C. The rechargeable battery allows autonomous operation of the implant.

Sensor Readout

Depending on the parametrization the microcontroller periodically wakes up

Fig. 3: MID board assembly of the SMART implant system.



the custom-made sensor readout ASIC which amplifies and digitizes the signals from the sensors and sends them back to the microcontroller, where they are stored in its internal memory. The connection to the microcontroller is established by a Serial Peripheral Interface (SPI) Bus. Biasing of the sensors is done by a digital to analogue converter (DAC) set by the microcontroller. The measurement circuits contain a charge integrator for current measurements and a high impedance amplifier for voltage measurement. All components are designed for low power operation, but still achieving an overall measurement rate of 1 kHz. The sensor readout ASIC is produced at IMS using the in-house Gate Forest architecture with 0.5µm CMOS processes. In the framework of this project 250 µm thick chips have been accommodated in a QFN48 (7x7mm) package.

Fig. 2: Implantable capsule for electrochemical biosensor applications. The sensors are located in the opening on the upper side of the PEEK housing.

Sensors

The microelectrodes for electrochemical monitoring are fabricated on a glass substrate by Ti/Pt sputtering and subsequent structuring of the connecting lanes and overlaying insulating layers (SiO_2, SU-8) by means of photolithography and dry etching processes. Each micro sensor array comprises the setup for two O_2-, two pH-value- and one impedance measurement. An amperometric sensor realized in a three electrode configuration with working, counter and reference electrode, is employed to measure oxygen concentration. A pH sensitive potentiometric sensor in a two electrode configuration comprising a working and reference electrode is fabricated by electroplating iridium dioxide and subsequent coating with a cation-selective polymer membrane (Nafion®). Amperometric and potentiometric sensors share a common on-chip reference electrode. This is realized as a quasi-reference electrode and fabricated by electroplating of Ag/AgCl. Impedance measurements as a parameter for tissue characterization are realized in a four electrode configuration with separated potential-pick up and current-carrying electrodes.

Conclusion

Miniaturization of active implants comprising high functionality and wireless links to external devices can be obtained by designing energy efficient electronic circuits and ASICs and their integration in compact substrates and housings. Those miniaturized implants will open up a whole new spectrum of health care applications, facilitating more specific diagnosis, more effective therapies and aids used on a daily basis by patients suffering e.g. from neurological or metabolic disorders.

Acknowledgement

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Micromechanical Binary Counter for Threshold Event Detection

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Introduction

For complex technical systems, the time periods between maintenance is often based on empirical data and not on measured information. Condition monitoring can be helpful to support maintenance and thus help to reduce costs and to use resources efficiently. For many applications, a summarized information of critical off-limit conditions after a preceding time of operation is sufficient to indicate the need of maintenance or the remaining life span. If sparse events that occur incidentally during long time spans of operation (years) have to be detected and need to be stored over arbitrary long time periods, non-electrical storage concepts are advantageous. Examples are known from acceleration sensors [1, 2] or from specialized applications such as measuring an integrated temperature-time load [3]. These systems are designed to detect a single or a few threshold events. Here, a micromechanical binary counter design is presented that enables detection and storing a large number of off-limit conditions as a binary code in a mechanical way.

An event to be detected is a physical parameter such as temperature, pressure, acceleration, etc., which is larger than a critical threshold and thus shall be counted. The counter mechanism shall be part of an autonomous sensor system that is shown in figure 1. Binary counting implements the analogue-digital conversion by the mechanical system itself so that a direct broadcast (e.g. by RFID) of the counter value is allowed.

Design

Adapting the idea of an electronic shift register, a micromechanical counter mechanism is designed. In figure 2 the system architecture and essential system components are presented. The switching energy at the entrance causes a movement of the mechanical coupled system components so that serial arranged bits are switched between two stable positions – referred to as the high (H) and the low or (L) state. The position of all bits represents the current counter value as a binary code.

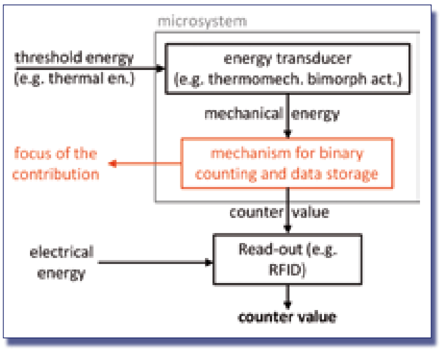

Figure 1: Autonomous microsystem containing a micromechanical binary counter mechanism

The switching energy acts always similarly on the entrance that forces the first bit to switch. In the low state the bit position is fixed by the ratchets that secure the bit against the spring force of its guiding springs. In the high state the bit guiding springs are relaxed or unstrained.

To achieve a binary counting, several switching rules have to be ensured:

If a bit n changes its state from low (L) to high (H), the next bit (n+1) state has to be unaffected by that movement which is implemented by a force rectifier. It is only capable of force forwarding to other system components in one x-direction. The change of a bit n from high to low has in contrast to this to cause the same switching for all serially following bits (n+m) with the same state high. This is realized utilizing two center arms that en-

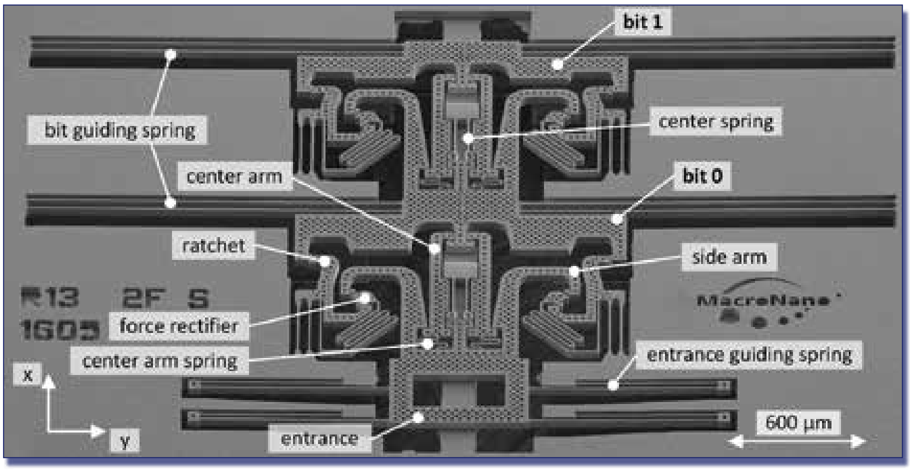

Figure 2: SEM picture (stack out of 10 single frames) of a fabricated 2-bit system – essential system components are shown – both bits are positioned in the high state

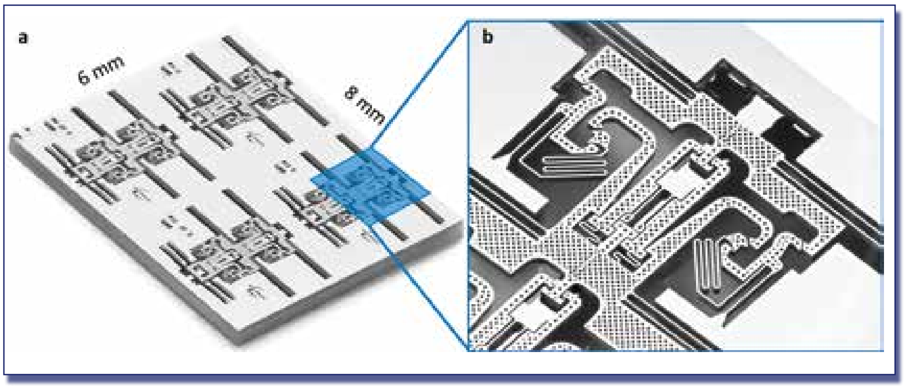

Figure 3: **a** Test chip containing four different 2-bit systems and (focus stacked photograph) **b** detailed view of a 2-bit system (focus stacked photograph)

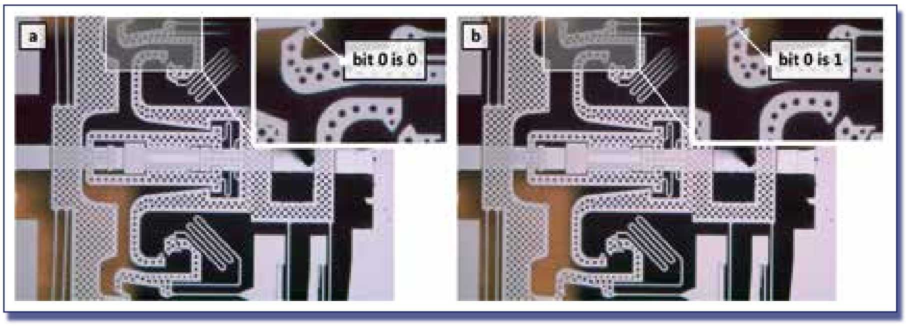

Figure 4: Photographs of the two different states for a 1-bit system demonstrator **a** shows the low (0) state of bit 0 and **b** shows the high (1) state of bit 0

able mechanical coupling between bits showing the state high. Additionally, the first serial following bit (n + m + 1) with the state low has to change from low to high which is realized by the ratchets that release this bit in case bit (n + m) switches from high to low. The system design is symmetric to suppress rotational movements. First demonstrator systems were fabricated using Silicon-on-Insulator (SOI) substrates with a device layer thickness of about 40 µm and standard microtechnology fabrication processes. A fabricated test chip with four 2-bit systems is presented in figure 3.

Measurements and Discussion

For system characterization a spring steel element is used as a force sensor. In the test setup, one end of the force sensor is connected with a two-axis stage (DC-motor with rotational encoder) that positions the force sensor with a precision of about 300 nm. The other end is coupled to the entrance of the demonstrator under test. Travel paths of several system components are video tracked in order to investigate their switching behavior.

For switching bit 0 from the high to the low state, the entrance has to be moved 69 µm and maximal input force of about 10.2 mN is needed. Here the bit guiding springs form the largest movement resistance. Their spring rate defines the necessary maximum switching force. In the end of the switching sequence bit 0 is fixed by the ratchets (see figure 4).

For switching bit 0 to the high state the entrance has to be moved 37 µm and a maximum force of about 8.2 mN has to be applied on the entrance. Bit 0 in its low state is held by the ratchets against the spring force of the bit guiding springs (see figure 4). Releasing the coupling between the ratchets and bit 0 is the main resistance for switching bit 0. The mechanical energy for both switch sequences is calculated using the tracked video paths of the entrance and the measured force values. It is found to be 0.1 µJ for switching bit 0 to the high state and 0.36 µJ for switching it back to the low state.

Conclusion

The micromechanical binary counter mechanism enables detection and quantified storage of off-limit conditions as a mechanical binary code without the need for electrical energy. The number of detectable threshold events is limited by the number of serially arranged bits, only. Expanding the design to up to ten bits would lead to a counter mechanism able to detect and store 1023 off-limit conditions. As the switching energy scales almost linearly with the number of bits, this system would need a peak energy of around 3.6 µJ at the system entrance. The system design can be expanded towards an electrical read-out of the bit positions by measuring whether the bit guiding springs are strained or un-strained. Consequently, the system represents a long time storage without self-discharge that enables e.g. non-electrical lifetime condition monitoring of critical physical quantities.

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Ergebnisse und Leistungen aus Forschungseinrichtungen

Results and Portfolios of Research Institutions

Mobile Telecommunications of Tomorrow: Aluminum Scandium Nitride (AlScN)

Fraunhofer
IAF

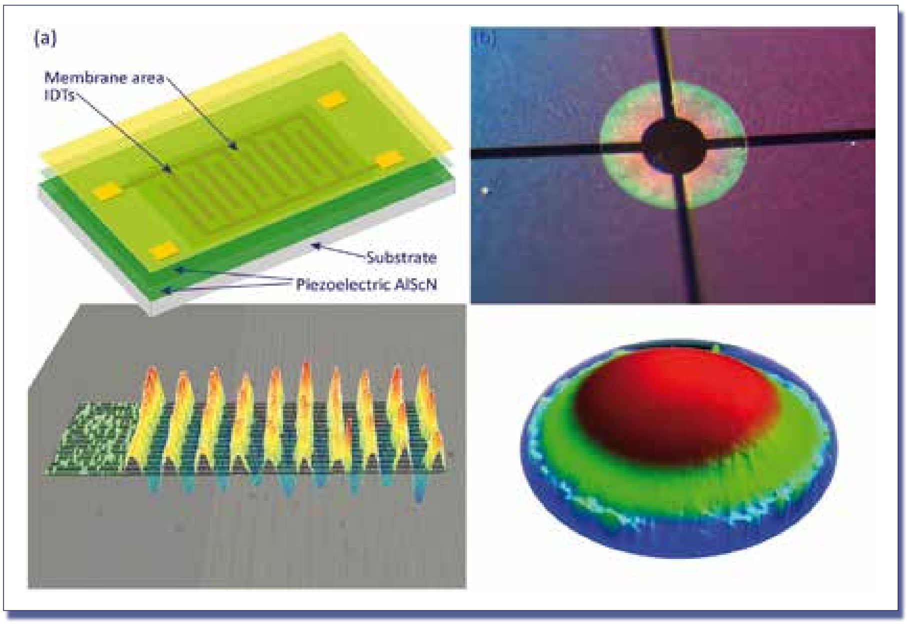

Figure 1
Examples of different structures with membranes produced at Fraunhofer IAF (a) top: Schematic drawing of Lamb mode wave resonator, bottom: membrane movement recorded using laser Doppler vibrometry (LDV); (b) top: piezoelectric microlense, bottom: lense movement recorded with white light interferrometry (WLI).

High frequency filters beyond AlN-based TFBAR

In today's fast pacing world, the ability to share large quantities of information becomes more and more important every day. We also have an increasing amount of different standards, for example 3G, 4G, Wi-Fi, GPS, and Bluetooth. Moreover, when we consider a smart phone, all of these different ways to communicate share the same limited space in one device, meaning that not only we require an efficient way to separate different, very narrow frequency bands, but we need to do it on a micro scale and with the power consumption as low as possible.

For that reason, compact microelectromechanical systems (MEMS) are a very attractive solution. By combining well established silicon (Si) micromachining technology with piezoelectric materials such as aluminum nitride (AlN), we can produce electroacoustic components for many different purposes, including radio frequency filter applications. However, even though AlN is a dominating choice for thin film bulk acoustic wave resonators (TFBAR) widely used in telecommunications, its piezoelectric properties and electromechanical coupling are limited. In order to produce AlN-based TFBARs suitable for higher frequencies (up to 5 GHz) the design of the components would become too complicated. So we need to change to a new type of structures, to replace the material itself, or, for the maximum effect – to do both.

MEMS technologies at Fraunhofer IAF

The Fraunhofer IAF and more than 250 of its employees focus on applied solid state physics – how to produce and use different compound semiconductors to create powerful electronics for many diverse applications. The institute is uniquely equipped to work on all levels – starting with basic material development and delivering a functioning device in the end. A part of the activities is directed towards developing various novel technologies for RF-MEMS devices based structures with AlN, AlScN, and diamond layers for applications in biomedicine, electronics, and optics. This is done by employing the most suitable material synthesis techniques, such as microwave chemical vapor deposition (CVD) for diamond growth, metal-organic CVD or dedicated reactive magnetron sputtering tools for nitride layers. Our extensive cleanroom facilities are well equipped for structuring material and to monolithically integrate the actuator layers into MEMS.

Aluminium scandium nitride

In a recent study it was shown that by alloying wurtzite AlN with cubic ScN we can form a metastable wurtzite aluminum scandium nitride (AlScN) with superior piezoelectric properties (up to 400% increase in piezoelectric coefficient d_{33}) and better electromechanical coupling k_t^2. Following the first report, numerous theoretical and experimental studies have been published to confirm and explain this phenomenon in more detail. The main reason for the enhanced piezoelectric response of AlScN is the ongoing competition between Al and Sc to bond with nitrogen in a different

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way, leading to internal softening of the material that improves the susceptibility for displacement. Only wurtzite Al$_{1-x}$Sc$_x$N shows enhanced piezoelectric properties, and according to theoretical predictions it is the most stable crystal phase when x<0.5. We at Fraunhofer IAF see this recent discovery as a potential key to high frequency filters for the next generation of mobile communications.

Lamb mode wave resonators

Surface acoustic wave (SAW) resonators have an advantage in comparison to TFBAR due to the comblike interdigital transducer (IDT) electrodes that make the devices less sensitive to fabrication uncertainties. However, the maximum frequency of operation for SAW devices on the market is limited to 2.5 GHz and the main drawback is incompatibility with Si integrated circuit (IC) technology. To combine the advantages of SAW and TFBAR we are currently investigating Lamb mode wave resonators (LWR), where a TFBAR-like membrane is produced with SAW-like IDT electrodes (Figure 1).

The application oriented research on thin-membrane LWR is on the rise, together with rapidly increasing number of reports on new suitable piezoelectric materials and functional devices operating in the lab environment. While the performance of conventional, AlN based LWRs is still limited by the moderate material constants, the recently reported AlScN-based structures show a great potential to overcome this limitation in the nearest future. Our main objective for current developments is to confirm that Al$_{1-x}$Sc$_x$N layers can improve the RF device performance and reliability. This demands a material with high piezoelectric constants (d_{33}>15 pC/N), improved electromechanical coupling (k_t^2>10%), excellent crystal quality, and homogeneous properties over 8” substrates. The current lack of commercial 8” sputter equipment capable of reliable deposition of Al$_{1-x}$Sc$_x$N with varying Sc concentration is a serious challenge hindering an application related development in this field.

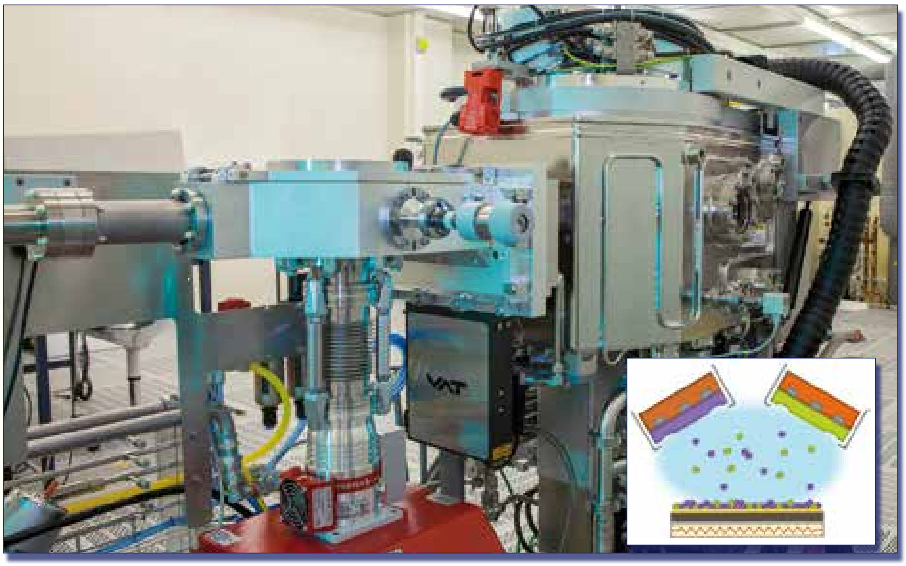

Figure 2

Multisource sputter tool by Evatec: 8” multi-target system used for growth of novel piezoelectric materials at Fraunhofer IAF. Inset (bottom right) – sputter process from two targets for growth of compounds, such as AlScN.

Outlook

Here at Fraunhofer IAF we currently aim for rapid development of Al$_{1-x}$Sc$_x$N thin film sputter deposition technique that is reliable and scalable up to 8”. We are focusing on “market-ready” conditions, cooperating with industrial partners in the field of multi-target sputter equipment (Figure 2) and RF-component producers. Current activities are mainly focused on prospective application fields for Al$_{1-x}$Sc$_x$N such as RF-electroacoustic (x>0.25) and piezo MEMS (x>0.4) devices (Figure 1), in order to test the first system prototypes within the next two years.

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Solutions with Light – Micro- and Nanooptical Systems and Technology

The Fraunhofer Institute for Applied Optics and Precision Engineering IOF develops innovative optical systems to control light from the generation to the application.

Our service range covers the entire photonic process chain from optomechanical and optoelectronical system design to the manufacturing of customized solutions and prototypes.

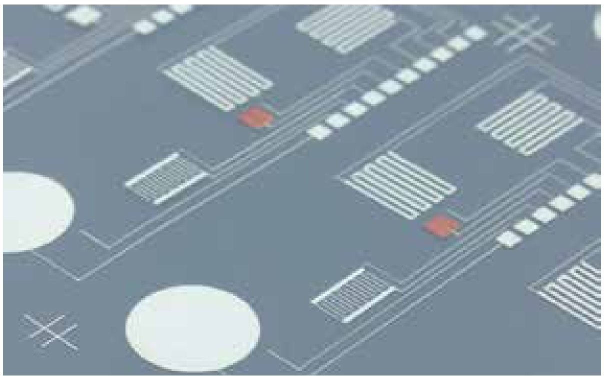
The institute works in the five business fields of Optical Components and Systems, Precision Engineering Components and Systems, Functional Surfaces and Layers, Photonic Sensors and Measuring Systems, and Laser Technology. Outstanding basic research results and strategic cooperation arrangements with various partners in the industry demonstrate the research strengths of the Fraunhofer IOF.

One of our core knowledge areas is microsystem technology, covering micro- and nanooptics, system integration technologies, printing of microsystems, and much more. The institute has extensive expertise in the development of micro- and nanooptical components and systems, as well as technologies for the hybrid integration of various components with high precision for the construction of complex optomechanical and optoelectronic micro- and macro systems. The Printing of microsystems as a new technology complements our portfolio. Within the following paragraphs, we want to show some actual examples of microsystem technology used at or realized by the Fraunhofer IOF.

Printed functional materials and structures for optofluidic Lab-on-a-Chip systems

Inkjet printing is an additive manufacturing technique suitable for depositing solutions or dispersions of different functional materials. Thanks to the additive approach, material consumption is low and no masking is required, which makes the process cost-effective and flexible. At Fraunhofer IOF, drop-on-demand inkjet printing is used to integrate functions in microfluidic Lab-on-a-Chip (LOC) systems. They carry out chemical or biological analyses on compact chips, which would typically require large laboratory infrastructure. LOC systems are often designed as single-use, disposable devices for point-of-care applications, and consist of a microstructured polymer chip and a cover foil that seals the channels on the chip. Current LOC systems feature complex fluidic structures, but require extensive external hardware, thus making the systems more bulky.

The goal at Fraunhofer IOF is to replace part of the external hardware with printed on-chip functions. Electrodes for resistive heating elements, capacitive fluid detectors or electrophoresis applications have been realized by printing metal nanoparticle dispersions or conductive polymers. Furthermore, membrane pumps based on fully printed, piezoelectric polymer actuators showed pump rates of more than 200 µL/min. Proof-of-concepts of on-chip optical excitation and detection by organic light sources and photodiodes were achieved. With these functions integrated on-chip, smarter LOC systems can be realized and less external equipment is required.



Example of printed silver electrodes and semiconducting polymers for photodiodes on the cover foil of a microfluidic chip

Direct writing grayscale lithography system for micro-optical fabrication

During the last two years, Fraunhofer IOF developed a novel direct writing grayscale lithography system for the fabrication of micro-optical freeform surfaces, micro-lenses, diffusors and diffractive optics. It incorporates an accurate and highly dynamic control system which provides a resolution better than 0.1% in the resulting height-profile. A highly precise substrate positioning and a demanding online data preparation software are used to suppress stitching effects of less than 0.1% RMS error within large patterned areas, also on curved substrates. Additionally, the exposure concept allows a high structure depth of

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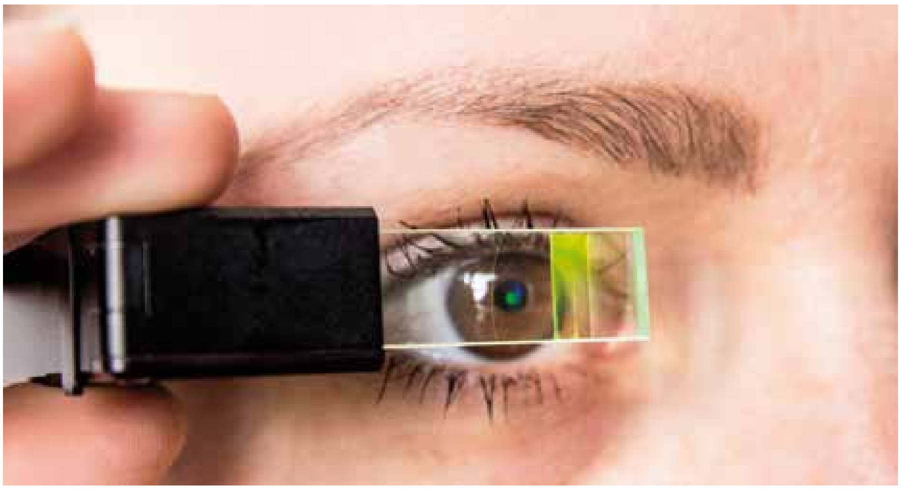
Near-to-eye display demonstrator.



more than 100µm and a spatial resolution below 1µm. At the same time, very steep edges of up to 80° have been achieved. The patterning speed of up to 100cm²/h makes the concept suitable for large-scale applications. The manufactured resist masters can be directly etched into the substrate or replicated with various molding methods. Recently, this technology has been used for the fabrication of micro-asphere-arrays with a superior low surface deviation below 0.2% RMS of the surface sag. This result demonstrates that the described novel fabrication concept is suitable for the realization of optical elements not only for illumination, but also for imaging and metrology applications.

Ultra slim multi-aperture near-to-eye see through display

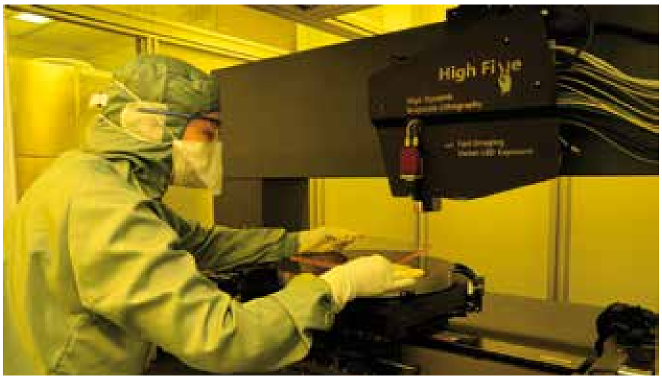
Wearable computer and communication devices such as smartphones or smart watches suffer from their limited space to visualize information. Near-to-eye displays offer information content comparable with common desktop monitors together with common desktop monitors while being much smaller and having see-through functionality.

The Realization requires the consistent miniaturization of the usual system components: a micro-imager, eye-piece optics, and a lightguide which shifts the image to the eye motion box and permits a see-through option.

The simplest realization is a plano-parallel lightguide with incoupling features to launch the image into the lightguide, and outcoupling features on its other end which direct the image to the user's eye and enable see-through functionality. This results in an extremely slim overall optical system layout.

The realized demonstrator system uses an LED-illuminated micro-imager model and a reflow lens array replicated as a polymer-on-glass element to form an multi-aperture eye-piece optics. The achieved 10° field of view image is launched into a 3.8 mm thick glass lightguide by a binary grating which is replicated into a thin polymer layer on top of the lightguide. After a 40 mm image shift through the lightguide, an identical outcoupling grating directs the image to the observer's eye.

Compared to single-aperture systems, the combination of multi-aperture eye-piece optics and a lightguide enables an extremely slim and unobtrusive system layout of see-through dataglasses.



High dynamic gray-scale lithography setup with fast imaging violet LED exposure.

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Fraunhofer ICT-IMM's Streamlined Portfolio

Continuous-flow photochemistry with the falling film microreactor: wavelength-specific irradiation of gas-liquid reactions using high-power LED arrays

For two years now we have been part of the Fraunhofer-Gesellschaft. An intense period of change, in which we were able to face new challenges. And, within that period, we have changed. As promised, we remain true to our high standards. It is still our mission to continually understand our customers' and partners' needs so that we are able to offer them application- and customer-oriented solutions to ensure their competitiveness. In doing so, we still always strive for the responsible handling of new technologies and for sustainable solutions for society and economy. This is reflected in two main pillars: Energy and Chemical Technology (Processes, Reactors and Plants) and Analysis Systems and Sensors (Methods, Components and Systems). And within these pillars we organize our competencies based upon the following priorities: Sustainable Economy and Energy, Healthy Living, Intelligent Mobility and Civil Security.

What is behind these priorities?
Keep on reading and find out:
Our competencies in the field **Sustainable Economy and Energy** include catalysis, hydrogen technology, biofuels, power to gas, heat and refrigeration management, energy storage, fusion energy, continuous synthesis, nanoparticles, photochemistry and electrochemistry. Let's have a closer look at ICT-IMM's approach to photochemistry: In the context of the Green Chemistry sustainability principles we implement photochemistry as an important synthesis route for future industrial applications. Photochemistry comprises a class of chemical reactions that are initiated by the interaction with light. Mostly, they take place at room temperature and normal pressure. Such sustainable and environmentally friendly conditions allow access to reagents and secondary products which can hardly be realized with thermal treatment. As such, photochemistry is a viable alternative to realize syntheses in a non-thermal way. Up to now, it is virtually impossible to perform photochemical reactions on a large industrial scale. A conventional "vessel" containing any kind of solution simply cannot be irradiated sufficiently uniformly so that a reasonably controlled process could be achieved. This is why ICT-IMM has brought its microreactor technology into play which allow the light to completely penetrate the formed thin layer of solution on its way through the reactor. Moreover, the precisely defined residence time enables more control over byproduct formation.

Back to the fields of competencies, let's zoom in onto **Healthy Living**. Our scientists perform research in point-of-care diagnostics, targeted drug delivery, active ingredient synthesis, functionalization, food safety, neurostimulation and implants. Point-of-care diagnostic is one of the most important future topics when it comes to the question of how to treat patients fast and individually. This is what triggered our scientists in the ERC Starting Grant Project PoCyton. Starting point in this case: How will a doctor know if a specific cancer therapy took effect? Flow cytometers measure the quantity of circulating tumor cells in blood. There's a snag: they usually cost up to 300TEUR and are as big as one or two washing machines. Moreover, the analysis takes many hours and the device can only be operated and calibrated by experts. All that makes it unaffordable for doctors' practices and hospitals. The scientists at ICT-IMM developed a flow cytometer which is able to do the analysis twenty times faster than the conventional large cytometer. An additional plus, the potential investment costs are on a very different scale with "only" a few thousand euros. And this is how the profitable flow cytometer works: A fluorescence dye is added to the blood sample. The dye molecules specifically target and

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attach to tumor cells while leaving all other cells untouched. So far, the laboratory technician had to add the dye to the blood sample by hand – PoCyton manages that automatically. The blood together with the dyed tumor cells then passes a narrow section where a laser spot lightens up all marked cells. The shining tumor cells can therewith be detected and counted. This procedure forms the highlight of PoCyton. The scientists have designed the narrow section in a way which also allows a twentyfold higher throughput as compared to conventional cytometry. Nevertheless, every passing object is recognized and no single cell can pass undetected. With one billion objects in only ten milliliters blood truly an art and of utmost importance: Even in the blood of severely sick patients only five of those cells are circulating tumor cells. The proverbial search for a needle in a haystack certainly applies for this procedure.

ICT-IMM's Bolometer chip

Intelligent Mobility deals with matters of reformer systems, exhaust gas cleaning, fuel supply, leakage tests and harsh environment. By the way, you can interpret harsh environment in many ways. Here, only one example out of our projects: ICT-IMM is part of a research and development consortium for specific plasma diagnostics at ITER (International Thermonuclear Experimental Reactor). The aim is to further develop so called bolometer cameras which shall monitor the plasma injection process, in the reaction vessel of ITER. ICT-IMM is working on the bolometer chip, the centerpiece of these cameras. With the help of this chip, the intensity of the photon flux from infrared to X-ray range, which is radiated by the ITER-plasma, can be measured. The material has to be highly radiation resistant while the detectors have to withstand impacting fusion neutrons and temperatures up to 450 °C. This is truly what you would call a harsh environment.

We conclude with the last field of competencies, **Civil Security**, which includes CBRN detection, water analysis and special sensor technology.

Moreover, the following **fundamentals** we know inside out and, thus, 25 years of success are built upon: process analytics, process control, simulation, reactor design and development, plant development, microfluidic components, sample preparation, assay development, spectral measurement methods, precision machining, surface modification, analytics, electronic engineering.

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Bridging the Gap between Macro and Nano

The Institute of Micro- and Nanotechnologies (IMN) MacroNano® is an interdisciplinary scientific institute of the Technische Universität Ilmenau dedicated to research in the areas Micro-Nano-Integration, Materials for Micro and Nanotechnologies, and 3D Biosystems. It comprises scientific competences of more than 38 research groups from fundamental to applied research. Since December 2013, its comprehensive technological infrastructure has been offered to internal and external users under the umbrella of the "DFG-Core Facility Micro-Nano-Integration".

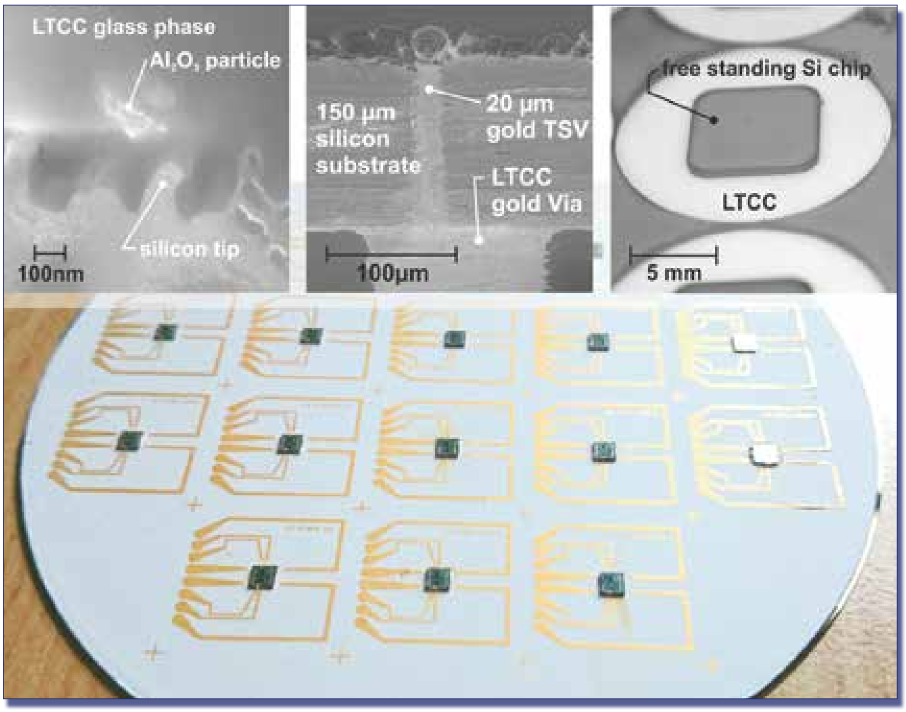

Fig. 1: Silicon-Ceramic-Composite substrate for MEMS and sensor applications

Micro-Nano-Integration enables a new substrate platform

A wafer-scale Silicon-Ceramic-Composite-Substrate (SiCer, Fig. 1) that allows the advantageous combination of MEMS and Low Temperature Cofired Ceramic (LTCC) technology was developed by a multidisciplinary group of scientist. The quasi-monolithic compound is fabricated by laminating a nano-patterned silicon wafer with a green silicon-matched LTCC layer stack and subsequent sintering. Due to the increased surface area with adapted wetting properties for the glass melt at the nanointerface (Fig. 1 inset left), the bond strength between the constituents is very high. SiCer is alkali-free and complies with typical wafer standards and is therefore suitable for MEMS processing. LTCC functionalities such as wiring, electrical and thermal vias, embedded passive components, fluidic channels, etc. can be included in the LTCC part. The silicon part of the substrate can be either used for MEMS processing or for depositing a thin film redistribution (e.g. for interposers). Through Silicon Vias (TSV) in the silicon layer allow the vertical interconnection to the vias in the LTCC (Fig. 1 inset middle). The silicon layer can be fabricated as thin as necessary for the desired function whereas the insulating LTCC layer ensures the mechanical stability. With deep reactive ion etching (DRIE), MEMS can be locally defined (Fig. 1 inset right). SiCer wafers can combine extremely different thermal, electrical and optical properties in one substrate, especially for a variety of RF-MEMS and sensor applications.

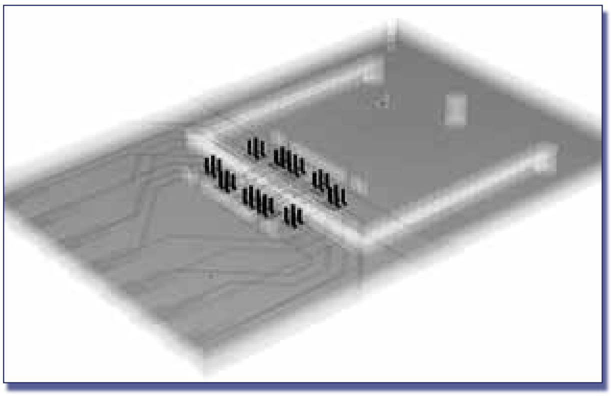

Fig. 2: X-ray view of a ceramic flow control unit comprising a heater and four temperature sensors

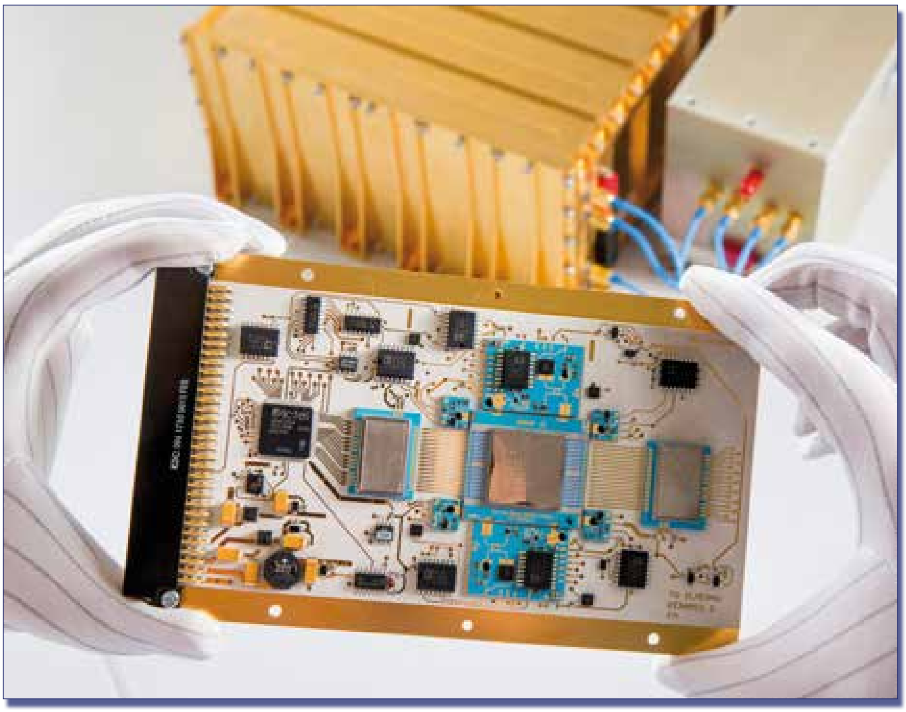

Fig. 3: Switch matrix and peripheral components mounted on a printed circuit board.
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3D-Biosystems for automated cell cultivation

Experts in optics, micromechanics and ceramics of IMN MacroNano® work together under the leadership of biomechatronics system designers and bio-material experts to create a bio-centered platform for the study of mechano-sensitive cells, that is, the cells and their extra cellular matrix are the core of the system and stay fixed. To provide in-vivo-like conditions, it is vital to enable stable growth conditions for 3D cell cultures. Miniaturized structures, e.g. microsystems, serve as housings and environmental conditioners. Furthermore they provide interfaces for a range of actuators to provoke mechanical, electrical or biochemical stimuli to control these cell cultures' fate. Sensors monitor metabolic processes as well as the impact of these stimuli, e.g. on cell differentiation. Due to interactions on molecular level, nanostructures offer a huge potential for innovative bio microsystems. The materials used for the microsystem components strongly depend on the requirements of the cell culture and the type of experiments whereas polymers, glass, silicon and ceramics are the main options.
Multilayer LTCC substrates provide various and flexible solutions for the integration of sensors and electronic components in microfluidic systems. Fluidic channels can have cross sections from millimeters down to a couple of 10 microns and enable thus nutrients supply for the 3D cell culture and the removal of metabolic residues. The ceramic reactor provides suitable interfaces for optical and MEMS sensors (Fig. 2).

Microsystems integration for miniaturized satellite components

A team of researchers developed and built a compact reconfigurable microwave switch matrix and peripheral components for the use in future communication satellites (Fig. 3). The applied design concept enables a tremendous reduction of weight and volume combined with faster switching speeds compared to currently used components. The technology passed a full space qualification and was successfully verified for low-earth orbits during a one year On-Orbit-Verification (OOV) mission aboard the German test satellite TET-1. The team is currently pursuing the space qualification for geostationary orbits in order to be part of the German Heinrich-Hertz-Mission.

More detailed information about ongoing research is provided in the scientific report which is available under www.macronano.de.

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Bridging the Gap from Nanoscience to Applications

Karlsruhe Institute of Technology

The research within the **Helmholtz Programme "Science and Technology of Nanosystems" (STN)** at the Karlsruhe Institute of Technology (KIT) takes on the challenge to discover fundamentally new scientific insights and to transfer these to industrially relevant nano- and microtechnology applications. It combines basic scientific research in the nanosciences, the application of tailor-made materials, the development of process technologies and the creation of systems ready for the market. Special focus is on nanocarbon devices based on carbon nanotubes and graphene, tuneable nanomaterials, printed electronics, and optics and photonics.

Energy harvesting is of increasing interest as a local energy source for sensors and sensor networks. A method for thermal energy harvesting at small temperature difference and high cycling frequency that exploits the unique magnetic properties and actuation capability of magnetic shape memory alloy films has been proven. Polycrystalline films of the Ni-Co-Mn-In alloy, were tailored to show a large abrupt change of magnetization and low thermal hysteresis well above room temperature. A free-standing film device, based on this alloy, has been demonstrated which exhibits thermomagnetically induced actuation between a heat source and sink with short heat transfer times (Fig. 1). [1]

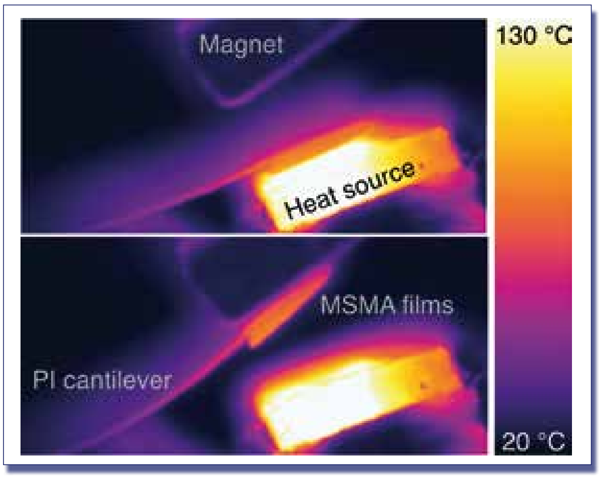

Fig. 1: Infrared image of the Ni-Co-Mn-In film actuator when in contact to the heat source (top) and to the magnet (bottom)

The first 3D invisibility cloak at visible wavelengths has been realized in our research area transformation optics and metamaterials. Metamaterials consist of homogeneous, regularly arranged elements that interact with electromagnetic waves. The breakthrough was based on the use of direct laser writing (DLW) to produce minute 3D structures with optical properties that do not exist in nature. Using 3D Stimulated Emission Depletion (STED) DLW, the STN scientists have succeeded in refining the metamaterial to produce the first 3D invisibility cloak for non-polarized visible light. [2] This invisibility cloak principle can be applied to increase the efficiency of solar cells. Up to one tenth of the surface area of solar cells is covered by so-called contact fingers that extract the generated current. This project did not focus on visually hiding the contact fingers, but rather on the deflected light that reaches the active surface area of the solar cell thanks to the invisibility cloak (Fig. 2). Prototypes show that the loss can be recovered completely. [3]

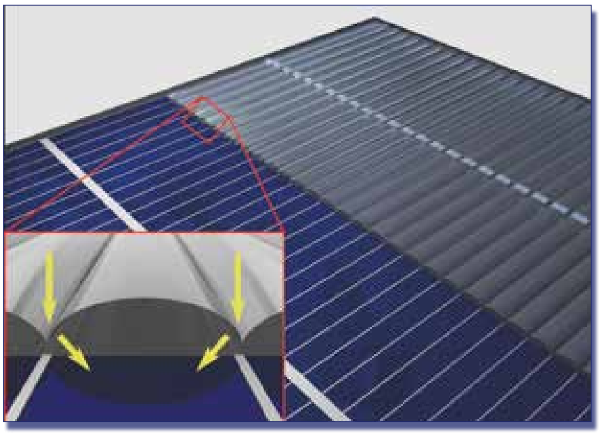

Fig 2: A special invisibility cloak (right) guides sunlight past the contacts for current removal to the active surface area of the solar cell

Compact optical transmission is of great interest in faster and more energy-efficient data exchange between electronic chips. A novel optical connection between semiconductor chips has been developed using a polymer-based optical waveguide. "Photonic wire bonding" reaches data transmission rates in the range of several terabits per second and is ideally suited for production on the industrial scale. [4] Another component serving fast data transmission is the Mach-Zehnder modulator (MZM) which is able to convert electronic signals into optical signals. Scientists of KIT and ETH Zurich have developed a plasmonic MZM of only 12.5 µm length which converts digital electrical signals into optical signals at a rate of up to 108 gigabit per second. [5]

The **Karlsruhe Nano Micro Facility (KNMF)** offers open access to a state-of-the-art portfolio of micro and nano structuring and characterisation technologies which can often be adapted to suit individual user needs. The close proximity of the in-house research at KIT ensures that the latest advances scientific knowledge and state-of-the-art the technology development are also available to our users. We are a collaboration-oriented facility, where our technology experts work together with our users to achieve the desired results.

In the Laboratory for Micro and Nano Structuring, a portfolio of technologies specialising in multimaterial structuring and replication of nano and micro-scale features may be combined in process chains as required. Technologies such as the above mentioned 3D-DLW enable users to create 3D structures with dimensions down to 200 nm, by 2 photon absorption of in a tightly focused laser spot in a resist. 3D-DLW may be used in combination with lithographic processes for multi-scale structuring and patterning on arbitrary shaped surfaces which are accessible by the laser beam. This is useful for producing e.g. novel auxetic structures (Fig. 3) or fluidic devices with surfaces functionalized by nano structures (Fig. 4) needed in biological analysis systems (lab-on-chip). [6, 7]

Atomic-layer-deposition is another recent addition to KNMF. The Picosun SUNALE R-200 Advanced system features a hot wall reactor for temperatures of up to 500 °C, an ozone generator, a plasma generator and has the capability to handle three liquid and three solid precursor materials at the same time.

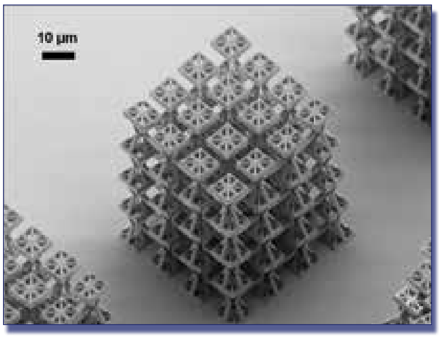

Fig 3: Polymeric auxetic structure with outer dimensions of 40 µm x 40 µm x 40 µm and a smallest feature size of 1,000 nm made with 3D-DLW

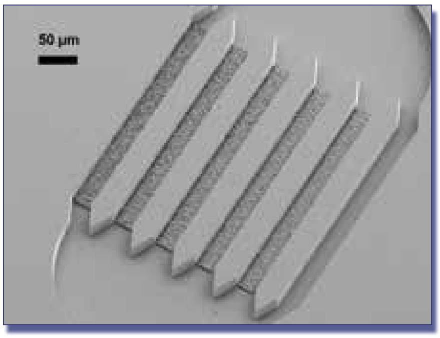

Fig. 4: Combination of 2D and 3D laser lithography to fabricate fractal surfaces in micro fluidic channels

The Laboratory for Microscopy and Spectroscopy offers a range of methods for the investigation of the microstructure and elemental and chemical composition of samples. 3D Atom Probe Tomography allows atom by atom, three-dimensional investigation of various types of samples such as metals, nanoglasses or even insulating materials with low conductivity. A recently installed helium ion microscope provides high-resolution imaging with high surface sensitivity and a depth-of-field 5-10 times higher than in a modern FE-SEM. Users from both industry and academia can access KNMF. No fee access, for work intended for publication is possible via a straightforward peer review process. Two calls per year are published and proposals are evaluated by an independent peer review board. Details of the full range of technologies and the contact data of the technology experts are available on www.knmf.kit.edu.

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From Microsystems to Nanosystems

M. Vogel, D. Reuter, S. Hermann, P. Matthes, C. Stöckel, S. Schulz, T. Otto, T. Gessner

The particular strength of the Fraunhofer Institute for Electronic Nano Systems ENAS lies in the development of smart integrated systems for different applications. Fraunhofer ENAS develops single components, technologies for their manufacturing as well as system concepts and system integration technologies and transfers them into production.

The product and service portfolio of Fraunhofer ENAS covers high-precision sensors for industrial applications, sensor and actuator systems with control units and evaluation electronics, printed functionalities as well as material and reliability research for microelectronics and microsystem technology. The development, the design and the test of MEMS/NEMS, methods and technologies for their encapsulation and integration with electronics as well as metallization and interconnect systems for micro- and nanoelectronics and 3D-integration are especially in the focus of the work. Application areas are semiconductor industry, communication technology, medical engineering, biotechnology, industry automation, mechanical engineering, automotive industry, environmental engineering, power engineering, logistics as well as aeronautics.
In order to increase the accuracy of sensors and actuators as well as to develop complete new systems, the application of nanomaterials and nanotechnologies are in the focus of the institute. Thereby Fraunhofer ENAS cooperates with the Center for Microtechnologies at Technische Universität Chemnitz. In the following four different topics are described in detail.

Starting in 2010, the design and fabrication of magnetic field sensors has been in the focus of the work, resulting ultimately in the development of 2D GMR spin valve sensors in an innovative and cost-effective monolithic integration. For this, the sensor devices are fabricated on wafer-level and subjected to specific laser-based post-processing steps for magnetic patterning. As sensor materials, we use partially exchange-coupled metallic nanolayers and structure them in the form of meanders integrated as double full Wheatstone bridges, see Figure 1. For a maximum signal-to-noise ratio, an antiparallel alignment (“pinning”) of the magnetic axes of neighbouring meanders is accomplished. In addition, the axes of the two nested bridges must be rotated by 90° relative to each other for providing 2D sensitivity, see Fig.1. The developed 2D sensors can readily be employed for determining the magnitude and the direction of small magnetic fields with high spatial (~1 mm) and temporal (~1 ms) resolution. The development of 3D sensors is currently undergoing as well as the implementation of TMR based technology.

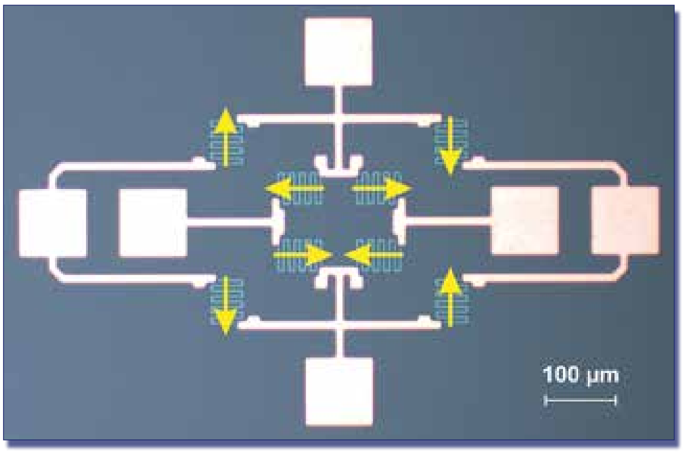
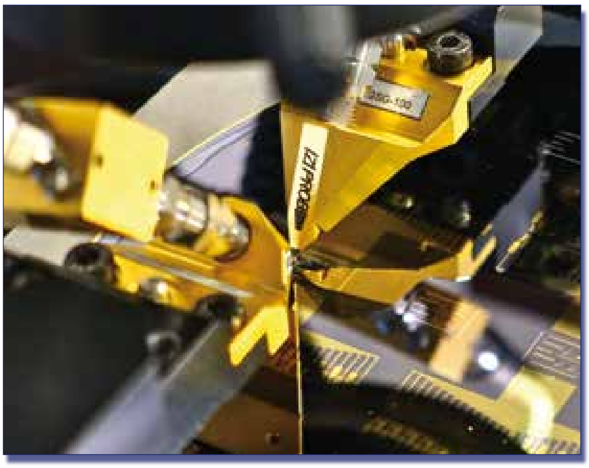


Fig. 1: Double Wheatstone bridge layout for a 2D GMR spin valve sensor in monolithic integration. The yellow arrows illustrate the locally set magnetization of the pinned layers.

Motivated by the outstanding properties of carbon nanotubes (CNT), the young research group Carbon Nano Devices aims to bridge the gap between science on CNTs and their application in electronics and NEMS by means of industrial compatible technologies. The group focuses in particular on a holistic wafer-level approach.

The technology team in Chemnitz in cooperation with cfaed (Center for Advancing Electronics Dresden) partners at TU Dresden already managed to fabricate CNT transistors on 6 inch wafers which operate already at a frequency of up to 3 GHz (Figure 2). Ongoing work is focusing on increasing of performance with respect to higher frequency and low-power consumption.
Moreover, the group applies its established nanotechnology platform for realizing a new generation of ultra-sensitive electromechanical sensors. Latest developments on CNT-strain sensors in-



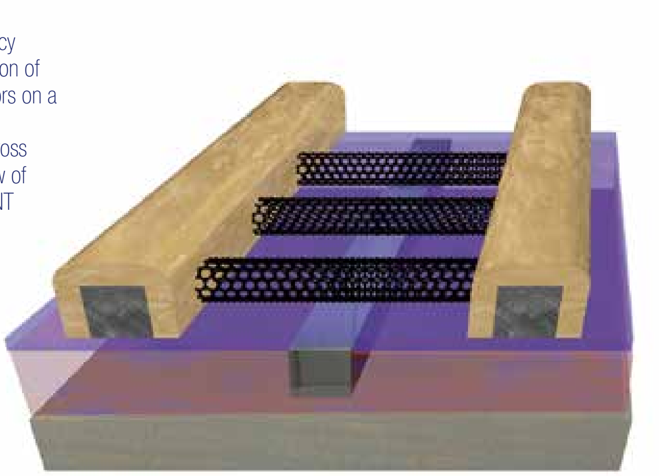


Fig. 2: High frequency characterization of CNT transistors on a wafer (left). Schematic cross sectional view of fabricated CNT transistors in bottom-gate configuration (right).

dicate a sensitivity significantly surpassing commercially available silicon-based strain gauges.

Aluminum nitride AlN is a seminal material for MEMS and NEMS sensors and actuators. The energy density for piezoelectric working principles is much higher compared to capacitive MEMS driving and sensing principles. This allows the shrinking of MEMS and NEMS, which reduces costs and energy consumption and increases the areas of application. Thereby, piezoelectric driven MEMS could be an alternative for actuators with smaller feature sizes. Furthermore, AlN is highly capable of being integrated into micromechanical and CMOS processes.

For measuring mechanical events like movement of objects, machines and bodies, shocks or impacts MEMS inertial sensors are the common solutions. In order to optimize the power consumption a wake-up generator (PDIG – Power Down Interrupt Generator) has been developed based on thin film aluminum nitride. If any mechanical event occurs, the PDIG generates electric energy by itself and "wakes up" any electric circuit, e.g. inertial sensors. This wake-up module with ASIC control requires less than 300 nA current consumption. In result, the lifetime of an independent battery-based system increases significantly.

Since 2015 Fraunhofer ENAS is running a nanolithography lab based on a variable shaped electron beam lithography system (model ID: SB254) from Vistec Electron Beam GmbH. By combining the proven technological competences in the field of micro- and nanosystems with the new nanolithography capabilities down to 20 nm and the great flexibility with respect to substrate dimension and materials, a unique research portfolio is created at one location in Saxony.
By the possibility of conducting advanced research in the whole process chain Fraunhofer ENAS is an interesting partner for the application fields of high-precision MEMS, nanosystem technologies as well as interconnect technologies for nanoelectronics and nanosystems.

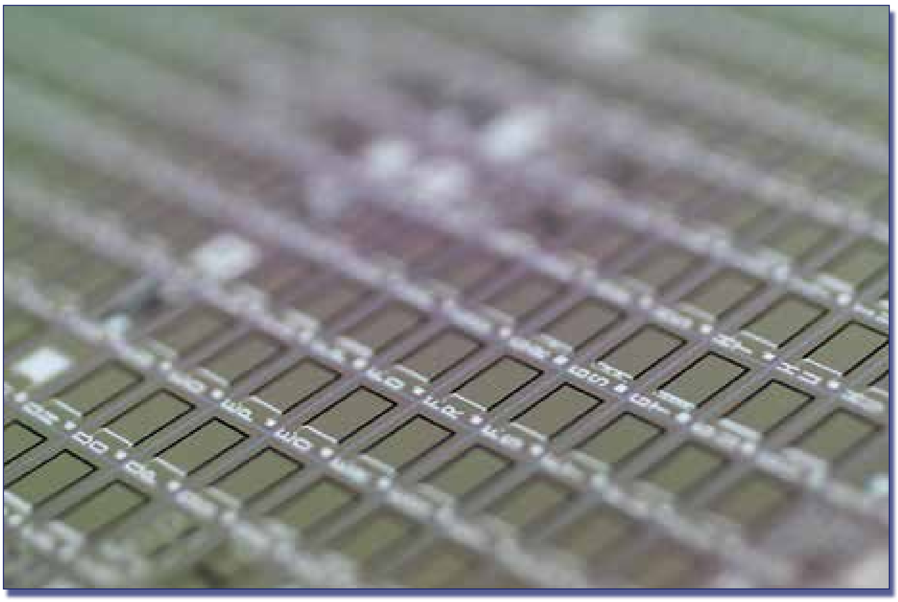


Fig. 3: PiezoMEMS at wafer-level, PDIGs with integrated piezoelectric aluminum nitride

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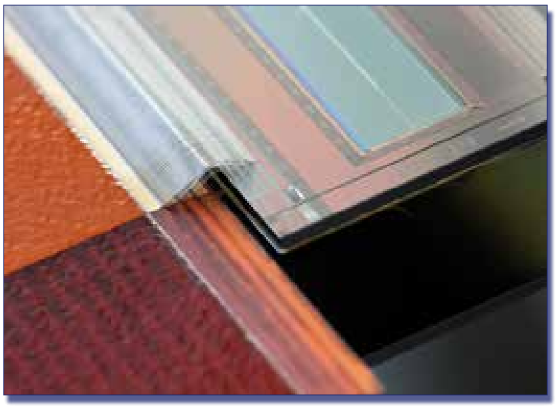
MEMS Technologies at the Fraunhofer Institute for Photonic Microsystems

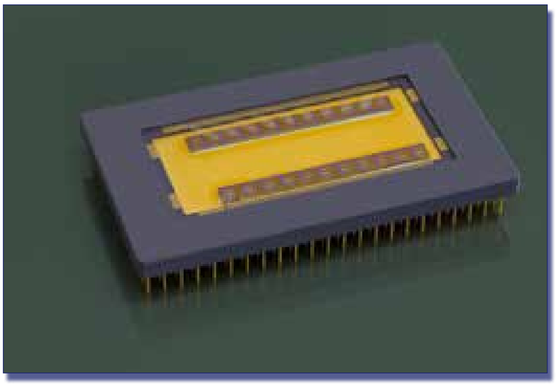
Fraunhofer IPMS offers its customers comprehensive services for the development of micro-electromechanical systems (MEMS) and micro-opto-electromechanical systems (MOEMS) on 150 mm wafers. Until 2017, the institute will upgrade its cleanroom to 200mm wafers. These services range from technology feasibility studies to process development all the way to complete fabrication processes including in-line process monitoring, post-process electrical characterization, and full process and device qualification. If desired, we will drive a process and device development through to pilot production in our own facility. Besides the development and production of complete MEMS technologies, we provide foundry services for individual process steps as well as technology modules.

We are able to offer these comprehensive services because of our deep technological expertise in the fields of surface and bulk micromachining. In addition, we have considerable experience combining these MEMS technologies with more conventional CMOS device and process technology. Our know-how in integrating MEMS and CMOS is used for the development of monolithic systems, where sensors and / or actuators are manufactured, together with the control electronics, in a single fabrication process.



One-dimensional SLM for Laser Direct Imaging

Wafer processing is carried out in a 15,000 square foot clean room, rated at Class 4 per ISO 14644-1, or Class 10 per U.S. Standard 209E. The clean room has been planned and built according to the latest industry standards. Its open and flexible architecture allows Fraunhofer IPMS to respond rapidly to future technological developments and innovations in fab equipment. Using this facility as a foundation, Fraunhofer IPMS is able to realize the widest range of customers' wishes: from analysis of initial ideas to full, high-yield pilot production.



Chip on carrier containing many CMUT arrays

MEMS devices developed and manufactured at Fraunhofer IPMS include among other components micro scanning mirrors manufactured by bulk micromachining as well as spatial light modulators and Capacitive Micromachined Ultrasonic Transducers (CMUTs), both done in surface micromachining. Applications for scanning mirrors range from reading barcode and data code, through 3D metrology, and right up to laser projection and spectroscopy. Spatial light modulators of Fraunhofer IPMS consist of arrays of up to several million micromirrors on semiconductor chips. In most cases this demands a highly integrated application specific electronic circuit (ASIC) as basis for the component architecture. CMUTs can send and receive ultrasound in an energy efficient manner, are environmentally friendly, provide miniaturization capabilities, and expand the applications of ultrasound beyond today's state of the art piezoelectric materials.

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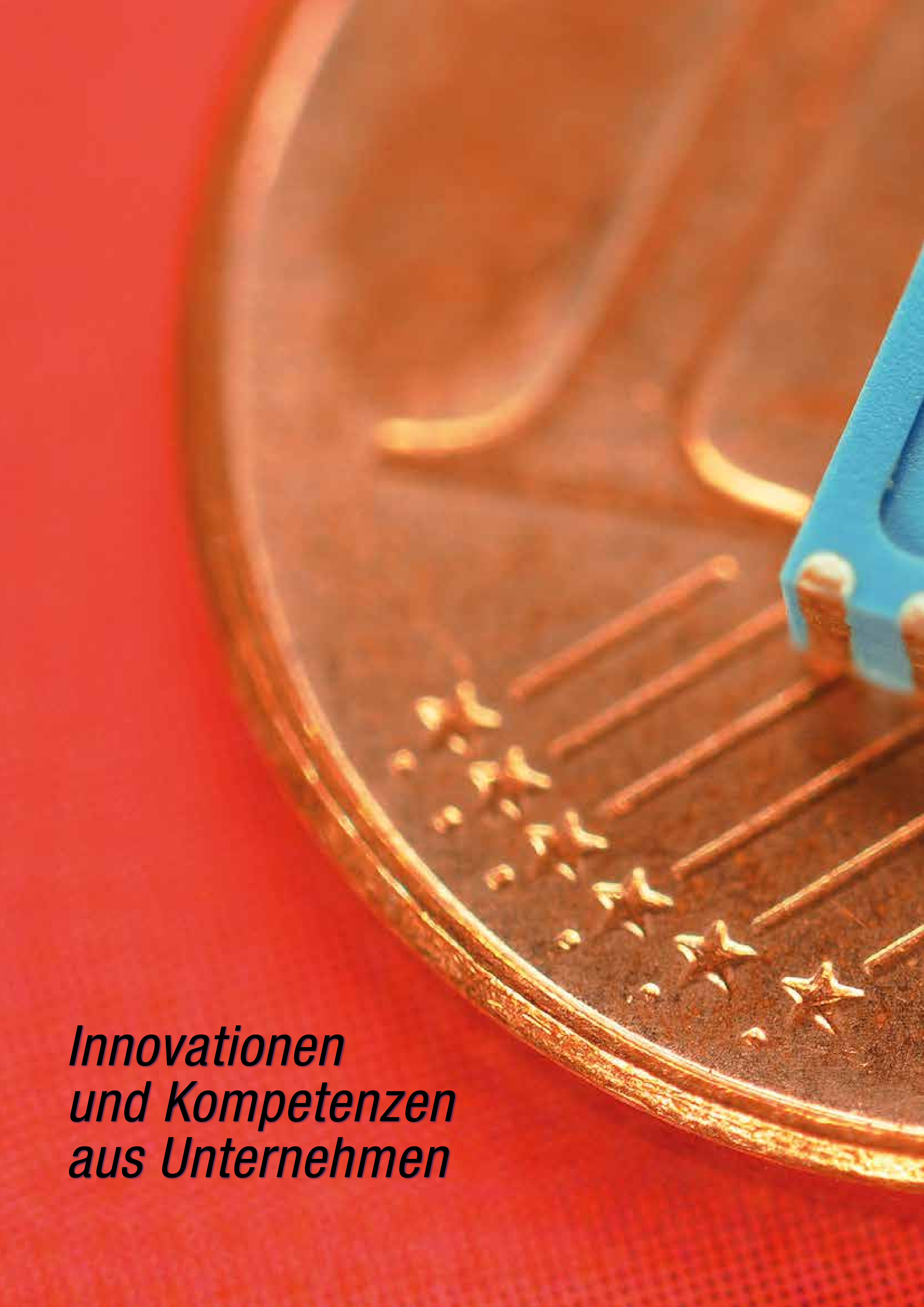
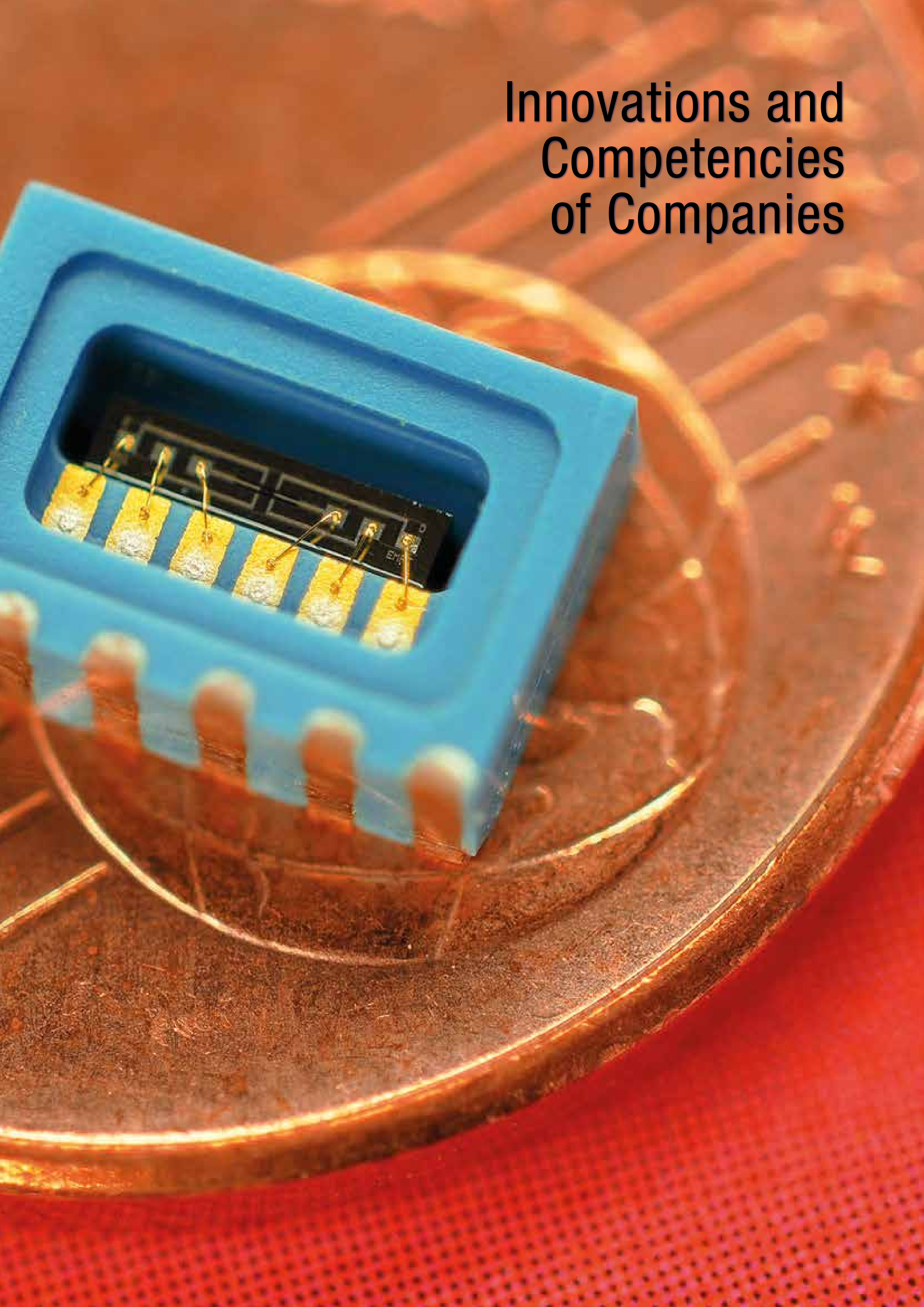


Innovationen und Kompetenzen aus Unternehmen

Innovations and Competencies of Companies



ADZ NAGANO GmbH

Gesellschaft für Sensortechnik

Dresden, Saxony's metropolis at the eastern end of the A 4 motorway, is said to be Europe's largest semiconductor centre and the world's fifth key semiconductor location. This is where ADZ Sensortechnik was founded in 1998 by Dietmar Arndt and Wolfgang Dürfeld, two former employees of Dresden's microelectronic research centre ZMD (Zentrum Mikroelektronik Dresden), together with two business friends.
The first products consisted of pressure transmitters for industrial applications. The technology that was used led to top quality products which soon made a name for themselves on the market. The so-called SML series is supplied with various output signals. The technically mature, robust sensors produced by ADZ NAGANO are used all over the world in many different industrial applications. Sensors are the sensory organs of automated plants and machinery. They play a crucial role when it comes to making top quality products or ensuring reliable, safe operation of machines. Development work in the young SME company focuses primarily on customised solutions for pressure measuring technology. Today, ADZ NAGANO GmbH has a workforce of nearly 100 employees at the company site in Ottendorf-Okrilla to the north of Dresden, including a development team of twelve. This is where not only individual customised solutions are produced, but where new standard products are also designed in accordance with state-of-the-art technology. Customers in process engineering, the automotive industry and all sectors using pneumatic and hydraulic systems have come to place their trust in solutions by ADZ NAGANO. The technologically challenging aerospace industry also advocates products by Saxony's sensory specialists. Every year, several hundred thousand pressure transmitters in 3,000 different variants are supplied to customers all over the world. From Asia via Europe to America, increasing numbers of users are convinced by the ADZ NAGANO products.

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AEMtec GmbH:
Electronics Development and Manufacture with Highest Precision

AEMtec GmbH based in the prestigious science and technology location of Berlin-Adlershof develops, qualifies and produces complex micro and optoelectronic modules through to complete systems for sophisticated applications in a wide range of industries. AEMtec is a member of exceet Group S.E. with excellent technology competence in the area of intelligent electronics and safety technology through to complete safety solutions.

Our customer-specific products are highly complex assemblies with precise placement. We therefore place great emphasis on the development work. However, product development does not mean merely creating a new product; the requirements for costs and high quality must be satisfied at the same time. A small design correction in advance is enough to avoid unnecessary follow-up costs. As such, diverse concept developments, exact specifications, feasibility and systematic risk analysis form the basis for safe and reliable results.

Precise placement “Made in Germany”

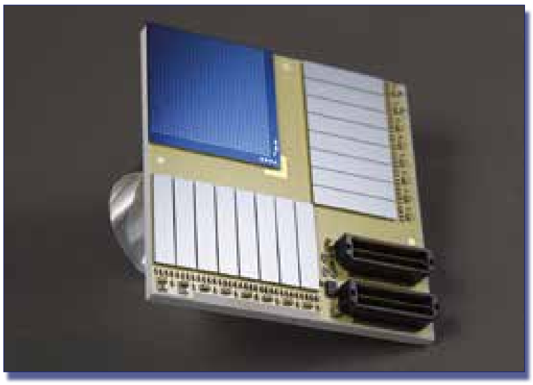
AEMtec produces medium to high quantities in a cleanroom environment. In our cleanrooms (ISO 5, 7, 8), we have broad technological diversity: chip-on-board, die bonding (with positioning accuracy up to +/- 1 µm), SMT, 3D integration, opto-packaging, SiP method, precision saws and X-rays. Ever since 2008, AEMtec has been active in the area of high-precision placement and it has continuously expanded its production capacities for this requirement and the necessary experience since that time. With an x-ray inspection system, complex requirements can be shown down to the smallest detail, particularly in the use of special soldering technologies.

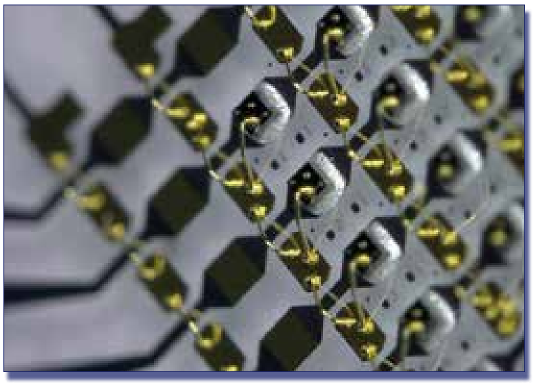
Positioning passive components quickly and cost-effectively

A scalable SMD placement platform with a modular structure and heads allows easy head replacement for construction elements of different sizes that are to be placed. The automatic correction technology and the image capture and processing guarantee high system accuracy. Our customers benefit from faster lead times and reduced unit costs as well as process setup that is reduced to a minimum with intelligent fully automated feeder units.

All common substrates are processed, for example such as standard circuit boards (rigid, rigid-flex), film, ceramic, silicon wafer, glass or IMS. The process ultimately selected is primarily dependent on the desired result and the complexity.

With longstanding experience in the product development and manufacture of sophisticated electronic components, in compliance with all the relevant quality standards (ISO 9001, ISO 13485, ISO 14001 and ISO/TS 16949), AEMtec has positioned itself as a reliable partner for the manufacture of products with a high level of integrity and reliability in recent years.


Picture 1: Micro-mirror assembly


Picture 2: High-precision placement (VCSEL array)

AEMtec

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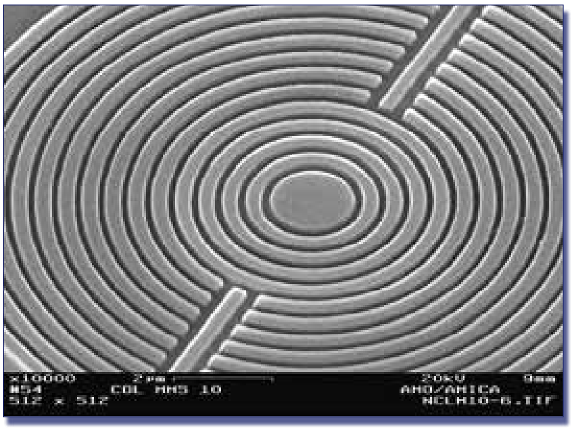
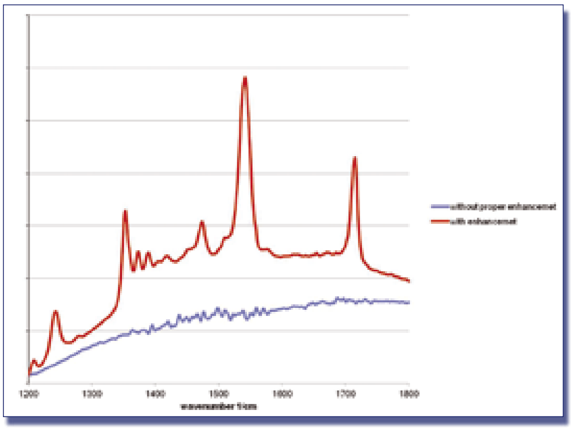
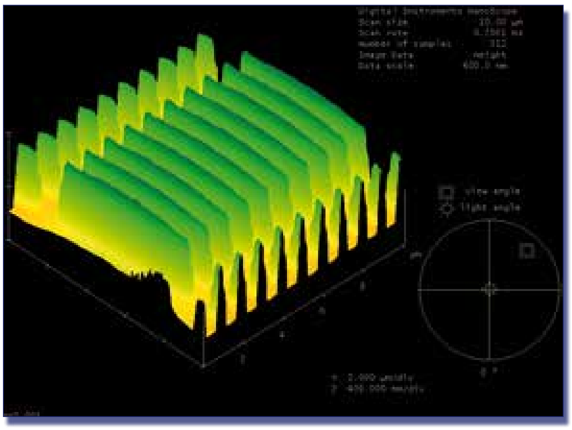
Diversification in CMOS-technology: Nano-Sensors using Photonics and Plasmonics

Nano-technology has already revolutionized the world of applied electronics in many fields beginning with data processing and storage up to the improvement of sensing devices for numerous applications. Especially here, deviating from the classical electronic approach, photonics and plasmonics are benefiting from the developing potentials in Nano-technology.

Integrated Nano-photonics have evolved on the basic fabrication schemes used in CMOS-technology.
Guiding and processing light in nanoscopic high refractive index materials has proven to be an asset for optical communication technology, yet the used fundamental devices, especially the ring resonator and Mach-Zehnder-interferometer have an even higher potential as ultra-sensitive elements especially for biotechnology and, depending on surface functionalization, as environmental sensors.







As the dimensions of device architectures shrink beneath the wavelength of light modern probe units can effectively boost selectivity and sensitivity of analytical procedures by implementing plasmonic reactions induced by light or THz exposure in the vicinity of an analyte. These so called plasmonic nano-antennas can be used to amplify spectroscopic detection systems to identify airborne explosives, hazardous components or pathogens. AMO offers activities in development and fabrication of sensor devices applying new materials and nanoscopic architectures using its state of the art CMOS-clean room, i. a. with special tools for nanolithography processes as Ebeam, deep UV interference lithography and UV (SCIL) nanoimprint. All processes are steadily refined and adapted to the demands of a permanently changing and challenging market.

Here AMO, being a technology venture with 20 years experience in nanotechnology, has accumulated knowhow in designing nanoscopic sensor surfaces also based on innovative materials as graphene with respect to the technical feasibility for a multitude of application fields.

We would be happy if we have piqued your interest and you intend to take advantage of the experience and technology of the AMO to explore new concepts and components in the field of MEMS-NEMS.

We place ourselves anytime at your disposal for requests.

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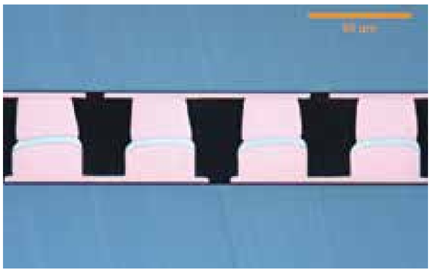
Finetech – Customized Sub-Micron Die Bonding Equipment

Today's advanced packaging and bonding technologies are characterized by rapid transformation and ever-more specific demands regarding the assembly equipment. Investing in a machine solution is not only about specs. Equally important is to rely on a solution which ensures maximum technological flexibility, compatibility with future technologies, longevity, and all-around economics.

With an industry-leading product line-up ranging from manual to fully-automated sub-micron bonding systems, Finetech from Berlin offers equipment for high-precision micro assembly challenges that ticks all the boxes. In the spirit of true developer's platforms, all FINEPLACER® sub-micron bonders can be configured to provide an optimal process environment for each application. Their modular system architecture allows highly-individualized machine configurations. Instead of acquiring another machine, new processes and technologies can be added by retrofitting the system with extension modules. This makes a FINEPLACER® system a long-standing and future-proof investment. Each FINEPLACER® system has been 100% designed and manufactured in Germany, with highest production standards being guaranteed through an ISO 9001 certified quality management.



Worldwide, more than 2.300 FINEPLACER® systems have been successfully installed in industries such as research departments of major OEMs, aerospace & defense, consumer electronics, medical technologies, telecommunication, government-funded labs and academic institutions, to support precise and complex applications: 3D/MEMS/MOEMS packaging, sensor assembly, photonics packaging, flip chip, laser bars, VCSELs, and many more. The entire spectrum of micro assembly and packaging technologies is supported, including thermocompression and ultrasonic bonding, adhesive technologies, curing, soldering, bump bonding, copper pillar bonding, precision vacuum die bonding or laser-assisted bonding.

FINEPLACER® sub micron die bonders mainly vary in their degree of automation, their optical resolution and supported substrate and component sizes. The portfolio includes highly flexible lab bonder, high bond force systems capable of bonding on chip and wafer level up to 300 mm as well as automated platforms for high-mix/high yield production environments.

For Finetech, a close partnership with the customer is paramount. With industrial grade cleanroom environments, extensive design and engineering resources and modern manufacturing facilities, Finetech can offer a consistent service chain from application evaluations to optimal customer-specific machine solutions to operator training.

To ensure quick response times anytime, Finetech maintains direct subsidiaries in the USA, China, Japan and Malaysia, providing consultation and service in global core markets.

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Competence in Micropositioning for more than 10 Years

Ultra-high precision spatial positioning of objects is of prime importance in the emerging field of nanotechnology. mechOnics patented new type of precision-positioning technology is based on an innovative concept that meets those market demands. The ultra-compact translation stages allow operation under ambient and extreme environmental conditions such as cryogenic temperatures (4 K) and ultra high vacuum environments (10^{-9} mbar). These features present a revolutionary advancement for the positioning market leading to new research in numerous areas.

Applications of these outstanding nanopositioning modules, well-known in many labs around the world, include open and closed loop nanopositioning stages with resolution up to 1 nm, ultra compact 3D-positioner with up to 10 mm in travel, or monomode coupler for fibres, to name just a few.

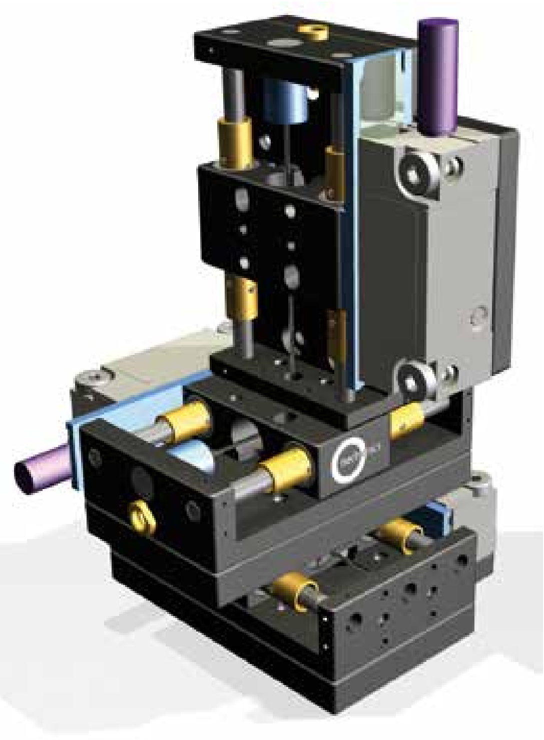
Furthermore, they are suitable for general beam manipulation applications involving optical fibers and solid state waveguides.

The product line of mechOnics ag ranges from these stand-alone simple positioning components for laboratory applications to complete automated and integrated solutions. The product range includes different sizes and travel of the stages for ambient temperature up to low temperature operation.

The product range is completed by innovative and highly flexible control systems for multiple axes operation.

As a market leader for micro-/nanopositioning devices we continuously work on supporting our customers to achieve reliable scientific results efficiently. Thus, our aim is to open up new possibilities ranging from scientific research to industrial applications.

Linear positioners are available with travel ranges up to 50 mm for ambient temperatures and UHV applications, for cryogenic application linear stages up to 20 mm can be delivered. Together with the open or closed loop controllers you can reach a repeatability up to 1 nm over the total travel range.



Range of standard products

- ✦ **New:** Multiphase Micropositioner DSP 50 with 1 nm resolution and 15 N driving force
- ✦ **New:** Nova Controller for mixing of open and closed loop stages (stepper motor driven and ultra-low temperature stages can be integrated as well)
- ✦ Linear stages up to 30 mm travel
- ✦ Ultra compact 3D-stages (travels 2 and 10 mm)
- ✦ Monomode coupler (travel 2 mm)
- ✦ Ultra low temperature stages (4 K)
- ✦ Ultra high vacuum stages (10^{-9} mbar)
- ✦ Mirror mounts for transmitting optics (tilt ± 3 deg.)
- ✦ Linear measuring systems (resolution up to 1 nm)
- ✦ Handheld battery driven controller
- ✦ USB-controller (open or closed loop)

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Two New Modalities in X-ray Imaging with microworks' TALINT System

Gratings of around 250 µm in height and 2.5 µm in width that use gold to absorb high-energy x-rays are the key components of microworks' TALINT system. Two new x-ray imaging modalities are now available to engineers and scientists: phase-contrast imaging and dark-field imaging.

Gratings based on x-ray phase-contrast imaging exploit the Talbot self-imaging effect to obtain information on the tiny angle deflections of x-rays which result from refraction and scattering. This has potential applications for a variety of fields, from medical imaging to materials research. Microworks' TALINT system is a compact, adaptable and inexpensive **TAL**bot **INT**erferometer designed for use.

The modular system is easily adjusted to many different specifications, including design energy, total setup length and sensitivity. A two-grating setup will serve for microfocus tubes, and a three-grating setup is used for standard x-ray tubes or rotating anode tubes.

The system can be directly installed in existing x-ray hutches or micro-CT machines. It is based on precision-aligned gratings and holders which can be moved with nanometer exactitude using piezoelectric actuators. The software is intuitive, producing radiographic images in three modes: classic absorption, phase contrast and dark field.

Microworks provides instructions which make installation straightforward and simple for experienced x-ray imaging users. Thanks to the quality control of the system at KIT/ANKA's Detector Lab, Moiré fringes are readily seen at first use, and only a fine-tuning of the alignment is required.

The key components of the system are x-ray absorbing gratings made by microworks using the LIGA process (LIthography, GAlvanisation [electroforming]).
This technique is the core competence of microworks, and the TALINT system's performance reflects the superior quality of these gratings.

The TALINT system's range of possible specifications:

- Energies from 8–50 keV; higher energies upon request
- Field of view: up to 10 cm Ø (using bent gratings)
- Phase-stepping visibility: typically >25%
- Minimum distance between source and detector: 50 cm
- Sensitivities ((G1–G2)/p2) can be customized to client's needs (as high as 250,000)
- Phase drift of the system: less than 3 rad/h (for a g2-period of 4.8 µm)
- Software: Python, to ensure easy adaptation by the user

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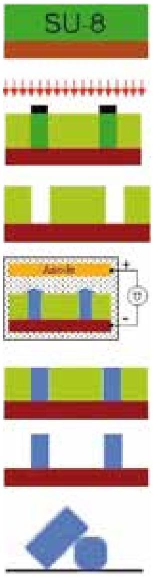
From microstructure to microsystem: 1-µm thin, 50-µm high gold lamellae absorb x-rays very well (left). An intensity image of a phase grating is projected onto this absorption grating, and Moiré patterns show the mismatch of the two gratings (center). Microworks' TALINT system provides the necessary actuators and software to use this configuration in x-ray phase-contrast and dark-field imaging.

MUEGGE-PLASMA SYSTEMS

Dr. Klaus Martin
Baumgärtner
CEO of MUEGGE

SU-8 stripping process

SU-8 stripping challenges



a. Deposition of an epoxy based negative resist (SU-8) up to 2 mm thick onto a carrier substrate with electrically conducting top layer

b. Lithographic exposure through a mask by parallel UV-light or X-ray from synchrotron

c. Dissolving away the unexposed parts of the resist by a suitable developer

d. Galvanic deposition (electroplating) of metal into open resist structures just above the resist height

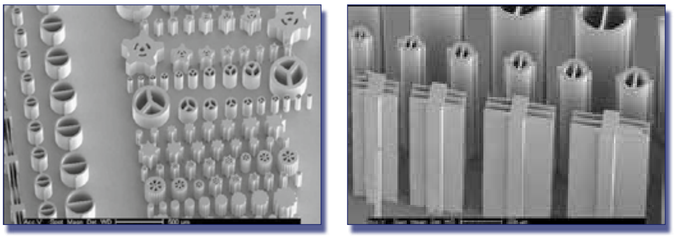
e. Uniformity after grinding and polishing to get uniform

f. Metal structure after removal (stripping) of the resist

g. Metal structures (microparts) after removal of the carrier substrate

Capability of SU-8 resist

SU-8 structures

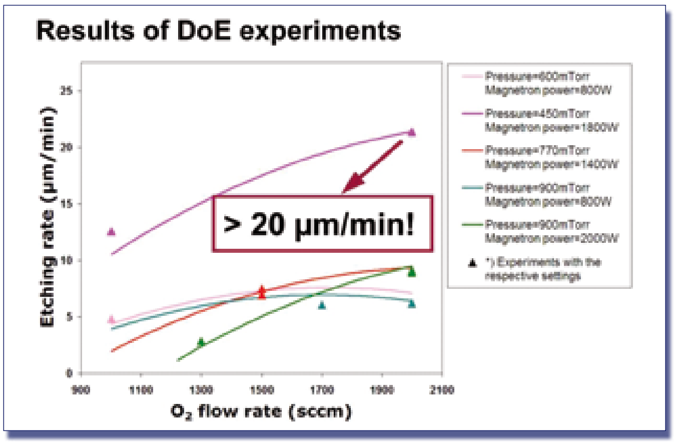


UV exposure (e. g. i-line 365 nm) up to 400 µm height, accuracy 3 - 5 µm
X-ray exposure (Synchrotron) up to > 2 mm height, accuracy 1 µm

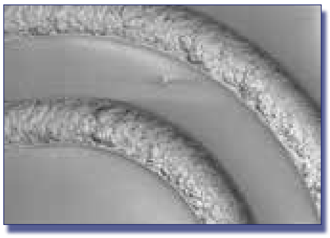
SU-8 Stripping requirements

- ✦ fast (i.e. economical) etch rates
- ✦ etch rate independent of layer thickness
- ✦ stripping of very thick resist layers possible (> 1 mm)
- ✦ no damage by ions (high selectivities achievable)
- ✦ no attack to metals
- ✦ high aspect ratios (> 100)
- ✦ no residues
- ✦ simultaneous etching of substrates with different resist thicknesses
- ✦ no overheating during stripping
- ✦ end point detection

SU-8 Stripping Experiments

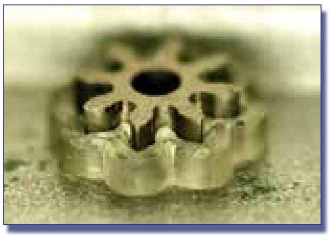


SU-8 Stripping Results



Before stripping

After stripping



Partial stripping of SU-8 resist after Ni galvanic; 50 % of the resist still present; faster resist etch rate near the Ni surface

Small gears after resist removal; Gear wheels ~250 um height, ~3 mm diameter

Combination of lithography and galvanizing using Muegge's Stripping Tool enables fast and precise production of microparts, e. g. for high end watch industries.

Industrial Microwave + Plasma Systems
MUEGGE

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SU-8 stripping technology

Technology for SU-8 stripping

Worldwide the new rapid reactive radicals technology shows for the first time the capability for stripping very thick layers of all kinds of organic materials, like SU-8 resist or other epoxy based materials, with excellent throughput and free of residues especially at structures with high aspect ratio (e. g. LIGA process). These materials are normally not strippable by wet chemicals or standard plasma etching/stripping equipment.

Remote Plasma Source (RPS)

Remote Plasma Source (RPS) means a plasma is only generated and exists in the RPS itself, not in the process chamber. The microwave energy is generated by a magnetron, coupled into the waveguide and transfered into the discharge system. The microwave energy is completely dissipated within the plasma zone of the pure alumina / sapphire / quartz chamber. No microwave radiation measurable on the radicals output. The all-side water cooled alumina / sapphire / quartz plasma chamber is the unique way to get contamination free radicals with highest efficiency.

Key Elements

- Remote microwave plasma source with unique water cooled plasma zone composed of alumina/sapphire/quartz guarantees outstanding lifetime of the plasma chamber
- Very high etch rate and low cost of ownership
- High environmental compliance due to very high dissociation of warming gases as CF4 and NF3.
- Pure chemical etching with no attack on the etching sample by ions; therefore high selectivity is achievable.
- Dense plasma excitation leads to high amount of radical generation which is necessary to start the stripping process
- Remote plasma for much less thermal load in the chamber than conventional plasma

SU-8 Stripping Tool STP 2020

The MUEGGE SU-8 Stripping Tool STP 2020 for MEMS- applications is the only tool in the market which enables fast dry etching of thick SU-8 resist. Unique features of the SU-8 Stripping Tool STP 2020 are providing leading edge technology for dry etching of SU-8 photoresist.

STP 2020 etch process - special features

- High etch rate (>200 um/h) on large areas (e.g. batch of 5 x 6" wafers) independent of thickness; more than 20 µm/min for small samples.
- Etch rates nearly independent of pretreatment like hard bake conditions: differences in etch rate smaller than 10 % between no HB and 200 °C HB.
- Stripping of very thick (>1 mm) SU-8 resist layers for MEMS is possible.
- Remote high oxygen radical output plasma source, no damage by ions, heat impact only by reaction energy.
- No attack to metals like Ni, Ni/Fe, Au, Cu etc.
- Minimal damage to Si and Si compounds like SiO2 or Si3N4.
- No organic residues; inorganic residues (i.e. decapsulation) removable by additional cleaning step.
- Simultaneous etching of substrates with different resist thicknesses possible.
- End point detection for each individual substrate.

MUEGGE STP Compact

The MUEGGE STP Compact microwave plasma system is the latest and most advanced generation of MW batch ashers offered today.

Optical 3D Surface Measuring Technology for Industry and Research: Accurate Profile Reproduction of the Finest Structures Thanks to Piezo Technology and Confocal Technology

NanoFocus AG, located in Oberhausen, Germany, has been considered for many years as a pioneer in optical-confocal 3D surface measuring technology. For rapid wide-area measurements the µsurf systems for example work with vertical resolutions up to 1 nm, laterally up to 300 nm. This means they are suitable both for the lab as well as for demanding industrial use (Fig. 1), such as three-dimensional surface measurements in medical technology, the semiconductor industry, forensics, electronics, the automobile industry, materials management and the steel industry.

Extremely Low-Scatter Signaling

The core of each of these µsurf systems is the integrated confocal-optical filter unit that is combined with a highly precise and fast focusing module. The patented multi-pinhole disc (MPD) is used as an optical filter of reflected light rays and distinguishes itself through extremely low scatter light intensity as well as robust signaling with a high light yield. The objective focuses light from a high-performance LED source through the multi-pinhole disc onto the surface. Only the portion of the light that is reflected from one point of the surface and which lies precisely in the focal distance of the objective can pass the point openings of the MPD. By rotating the MPD, the entire sample surface can be quickly and completely scanned.

Fig.1: The optical 3D surface inspection is ideal both for the lab as well as demanding industrial use, e.g. for checking paint appearance in the automotive industry. (Photo: NanoFocus)

By moving the objective vertical to the sample surface, all contour lines of the sample are focused one after the other. The CCD camera used stores the brightness values of the visual field for each objective position. Points with maximum brightness are located on one contour line. The 3D structure of the sample can be determined from the total number of images at different height intervals, this is called the image stack (Fig. 2).

Piezo Positioning System for the Objective

In order to achieve such a high measurement resolution, the objective must be moved in the direction of the z axis with great precision. “The positioning system for our objective is therefore based on piezo actuators. They work free of wear and friction with zero play and they are suitable for high recording frequencies due to their dynamics,” explains Dr. Georg Wiora, responsible for strategic development and innovation management at NanoFocus. Zero play and highly precise flexure guides together ensure high focus stability.

The piezo-based, single-axis positioning system used in the µsurf system originates from the comprehensive product portfolio of the Karlsruhe-based company PI (Physik Instrumente). It was adapted to precisely meet the application requirements, was able to be easily integrated into the objective holder thanks to its compact dimensions and moves the objective at a constant speed. The core requirement of the positioning system is a high velocity constancy in the nanometer range. This is the only way absolutely accurate (down to a few nanometers) roughness measurements can be taken that are compatible with tactile processes and meet the requirements of the corresponding industrial norms. Repeatability is just as important when positioning the objective, so as to prevent a height offset when assessing the stack of individual images.

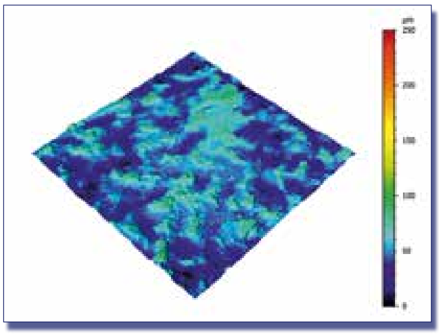

Fig.2: 200 to 400 individual 2D images are converted into a 3D image by the measurement software. (Photo: NanoFocus)

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Optical Measurement Tools for State-of-the-Art Microstructure Development and Testing

Precise experimental characterization of micro-devices such as MEMS is increasingly important in research and development as well as for routine measurements at wafer-level. Optical interferometric measurement systems are the tools of choice for determining properties as resonance frequencies, damping, transfer functions, deflection shapes, transient response and also static topography.
For dynamic measurements Laser Doppler Vibrometry is well established as the standard method because the entire frequency spectrum is obtained in real time, without contact, phase-resolved and with resolution down to the sub-pm-range for both OOP and IP motion. Therefore transient response, settling characteristics and indeed any vibration waveform, not just periodic motion, can be investigated very quickly and easily.

VALIDATION OF SIMULATION MODELS

MEMS researchers use various engineering tools to take a design from concept to simulation, prototyping and testing. Simulation models are validated and fine-tuned through comparisons with precise experimental data. By using light as the probe, the measurement procedure has virtually no influence on the MEMS device. Extensive data import and export functions in Polytec's Micro System Analyzers allow for an easy and highly productive data exchange with FEM systems.

IMPROVING MEMS RELIABILITY

It is very important to determine reliability under mechanical excitation, radiation, temperature, humidity and pressure stress by targeting the device inside an environmental or vacuum chamber. The Polytec MSA-500 Micro System Analyzer has a stand-off distance that allows the researcher to characterize static and dynamic behavior under specific environmental conditions and can be easily interfaced to vacuum or pressure chambers and probe stations.

FIND PARAMETERS RELEVANT TO MANUFACTURING

Information about current process parameters and their impact on dimensions and material parameters of the MEMS devices is needed to control the manufacturing process. For instance, when silicon-on-insulator technology is used to build three-dimensional micro-machined sensors and actuators, topographic analysis is critical to their development. White-light interferometry, available from Polytec as system option or stand-alone solution, provides these data quickly and reliably with high accuracy and precision.

WAFER-LEVEL PRODUCTION TESTING

Wafer-level testing can save money by the early characterization and separation of bad devices prior to packaging. For this task the MSA-500 can easily be integrated into automated and semi-automated probe stations. Fast measurement allows high throughput and is an important tool to monitor the manufacturing process.

STUDYING MICROACOUSTICS IN THE GHZ-REGIME

Combining micro- and nanotechnology with ultrasonic actuation, engineers need new methods and instruments for characterizing mechanical responses up to the GHz frequency regime and displacements in the pm range. Laser-based, non-contact optical testing is the best choice since it avoids mass loading from direct contact. Polytec's award-winning UHF-120 Vibrometer can characterize the out-of-plane vibrations at such ultra-high frequencies, featuring a measurement bandwidth up to 1.2 GHz.

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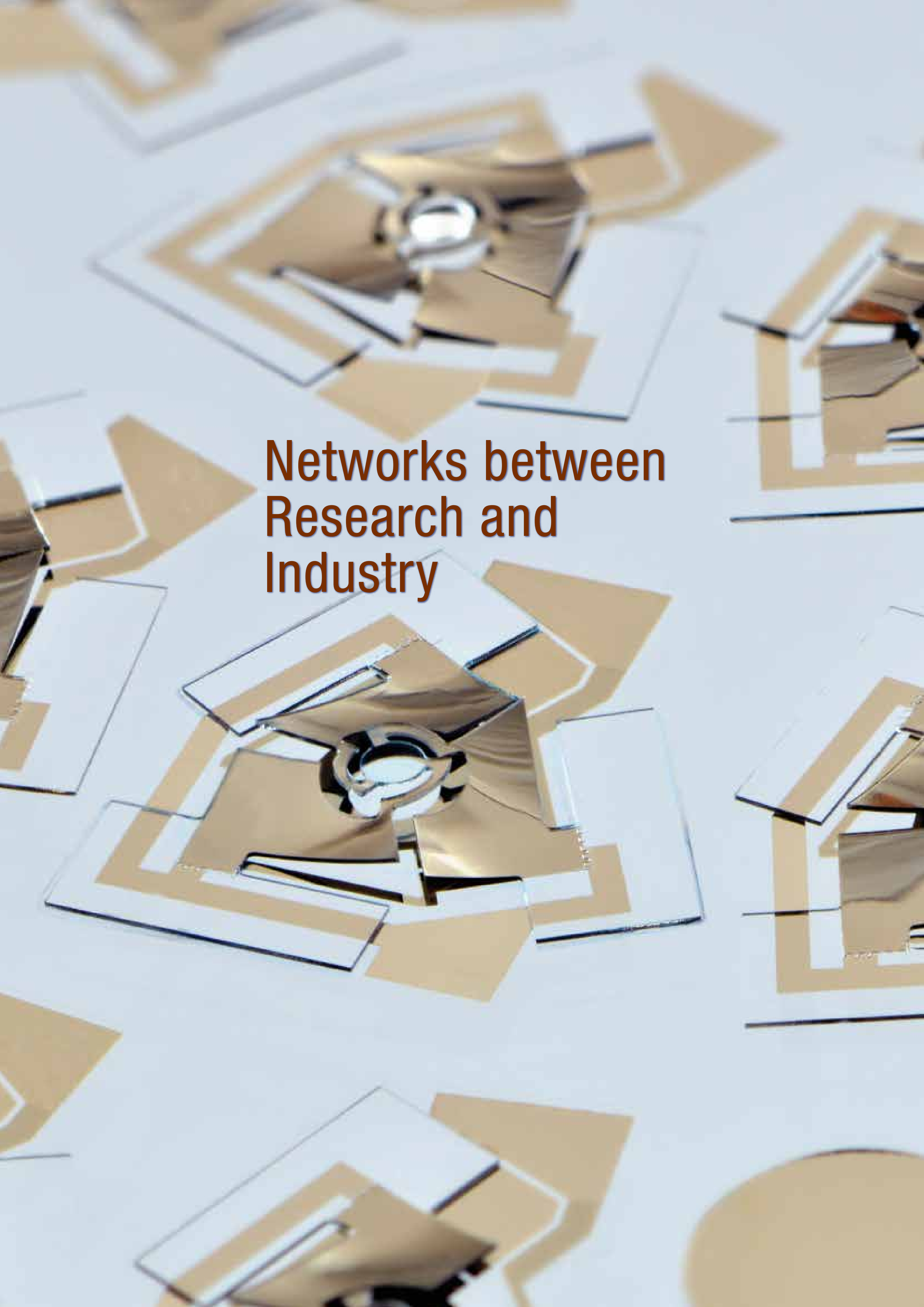
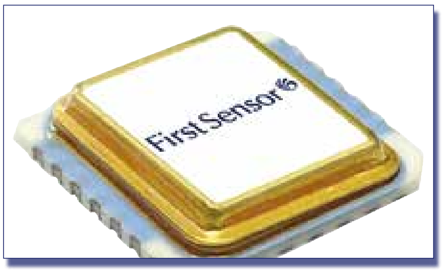


Networks between Research and Industry

Netzwerke zwischen Forschung und Industrie

ZVEI - German Electrical and Electronic Manufacturers´ Association

Micro-electro-mechanical systems (MEMS) are intelligent miniature products combining materials, components and functions. They are used for processing data and are also connected to their natural environment through sensors and actuators.



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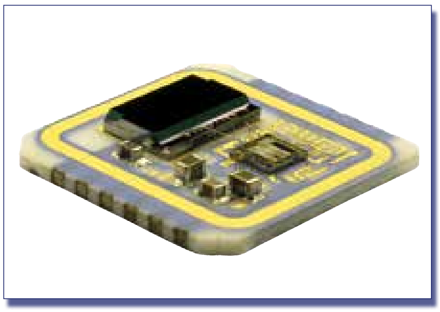

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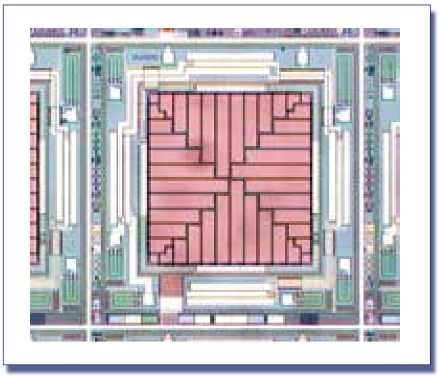

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Germany has a leading position in the MEMS world market. Control and automation requirements particularly with regard to the megaproject „Industrie 4.0“ and to automotive customers are steadily increasing and the intensified use of MEMS in medical applications will further foster this development. Also smart grids, smart buildings etc. are not imaginable without MEMS technology.

MEMS contribute significantly to the competitiveness of the German industry and enable and secure future-oriented jobs in Germany.

The MEMS companies within the ZVEI - German Electrical and Electronic Manufacturers´ Association confirm the positive outlook.

The group of companies represents leading automotive suppliers, semiconductor manufacturers, MEMS suppliers and small and medium sized companies.

The group activities of the ZVEI membership focus on the development of basic technologies and tools representing key drivers for innovation. The aim of these activities is to further strengthen microsystem technology in Germany and to facilitate a sustainable growth of this young technology by partnering in the pre-competitive phase.

The ZVEI - Electronic Components and Systems Division hosts an own industry group for MEMS technology which is an ideal platform for the representatives of the branch to share experience and to be kept up to date with the latest developments. Furthermore the group develops position papers in order to advise involved decision makers about the position of the industry. The efficiency of the ZVEI in this respect is indeed a valuable asset. The partner organisations AMA Association for Sensor Technology and IVAM Microtechnology Network further strengthen the cooperation of all companies related to MEMS.

Furthermore, this makes it possible to transport nationally generated content in a larger, international context through the pro-active input of our membership on European level.

The many success stories underline the strong activities of the association for and together with the member companies and show the great importance of the association for the industry.

ZVEI - Zentralverband Elektrotechnik- und Elektronikindustrie e.V.

Die Mikrosystemtechnik verknüpft Materialien, Komponenten und Funktionen zu intelligenten miniaturisierten Gesamtsystemen. Diese dienen der Informationsverarbeitung und sind zudem über Sensoren und Aktoren mit der natürlichen Umgebung verbunden.

Deutschland hat im Bereich der Mikrosysteme eine führende Position auf dem Weltmarkt. Der zunehmende Regelungs- und Automatisierungsbedarf, insbesondere angesichts des Megaprojekts Industrie 4.0 und in der Automobiltechnik sowie der vermehrte Einsatz von Mikrosystemen in der Medizintechnik wird diese Stellung weiter fördern. Auch Smart Grids, Smart Buildings etc. sind ohne Mikrosystemtechnik nicht vorstellbar.
Die Mikrosystemtechnik leistet somit einen wichtigen Beitrag zur Wettbewerbsfähigkeit der deutschen Industrie und ermöglicht die Schaffung und Sicherung zukunftsorientierter Arbeitsplätze in Deutschland.
Dieses positive Bild bestätigen die im ZVEI - Zentralverband Elektrotechnik- und Elektronikindustrie e. V. organisierten Mikrosystemtechnikunternehmen. Hierzu gehören neben großen Kfz-Zulieferern und Halbleiterunternehmen auch industrielle Mikrosystemtechnik-Anbieter bis hin zu hoch spezialisierten Klein- und Mittelstandsunternehmen (KMU).

Im Vordergrund des Verbandsengagements steht das Ziel, die Basistechnologien und Werkzeuge gemeinsam weiterzuentwickeln sowie Innovation zu unterstützen. Ziel ist es, eine weitere Stärkung der Mikrosystemtechnik in Deutschland und das langfristige Wachstum dieser noch jungen Technik im vorwettbewerblichen Umfeld partnerschaftlich zu fördern.
Der ZVEI bietet hierzu mit der Fachgruppe Mikrosystemtechnik im Fachverband Electronic Components and Systems eine geeignete Plattform, die den Vertretern der Branche einen intensiven Erfahrungsaustausch ermöglicht. Hier werden Positionspapiere erarbeitet, die wirkungsvoll bei politischen Entscheidungsträgern platziert werden. Hierbei konnte sich der ZVEI als Vertreter der Branche bewähren. Durch die Partner „AMA Fachverband für Sensorik e.V.“ und „IVAM e.V. Fachverband für Mikrotechnik“ wird die Zusammenarbeit aller in Deutschland an der Mikrosystemtechnik interessierten Unternehmen weiter gestärkt.
Darüber hinaus können national erarbeitete Verbandsthemen auch im internationalen Kontext durch die Aktivität der Mitgliedsfirmen auf europäischer Ebene verfolgt werden.
Die Erfolge engagierter Verbandsarbeit, welche zusammen mit und für die Mitgliedsunternehmen erzielt wurden, zeigen den Nutzen der Verbandsaktivität für die Industrie.

ZVEI:
Die Elektroindustrie

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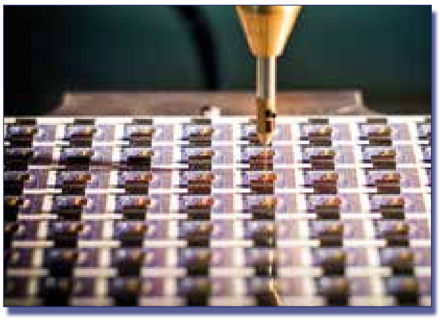

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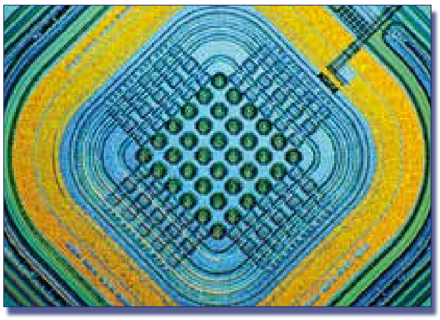

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VDMA
The German Engineering Federation

Micro Technology

Micro cameras in cell phones, magnetic field and location sensors in play stations, micro pumps for insulin and touch sensitive surfaces are available already today. The "Internet of Things", video contact lenses, nano robots, lab-on-a-chip, mentally operable prostheses, autonomous driving, and self-organizing production ("Industry 4.0") are demonstrated product developments with a high future market potential.

They all combine sensors, actuators and wireless connections with data processing, power supply, display systems and storage devices and appear in two high-tech sectors: micro and nano electronics as well as micro and nano technologies. In the past, those two sectors have developed side by side. In the meantime, however, they have merged increasingly. System integration is the magic word – it enables more miniaturization and creates higher product diversity.

Therefore, research and industry join forces in order to align the development of both sectors. In order to provide affordable products it is necessary that production technology takes those new markets into consideration and spurs development together with manufacturers and material suppliers.
In order to meet production requirements of the manufacturers in the future it was necessary to constantly take on new technological developments.
VDMA acted accordingly and founded new divisions: Displays in 2000, Organic Electronics in 2004, Photovoltaic Equipment in 2007 followed by Battery Production in 2011. Although VDMA Productronics and VDMA Micro Technology had occasionally cooperated in the past it became necessary to join forces for the benefit of our members and their customers.

In 2014 VDMA therefore founded the Sector Association "Electronics, Micro and Nano Technologies (EMINT)", gaining synergies from the Sector Groups Productronics (Electronics Production) and Micro Technologies (micro products and micro production technology). The Sector Groups define and realize custom-made activities for the respective sector industries. The association develops joint activities between both Sector Groups and with the Organic Electronics Association (OE-A), VDMA Photovoltaics Equipment as well as with VDMA Battery Production.

Productronics and Micro Technologies in Detail:

From highly specialized controllers in automotive applications to tablet PCs as a mass product: Electronics production equipment enables high-tech for everyone. "Productronics" is a common term for these machines, systems, materials and components used for electronics production. Semiconductor chips and highly integrated electronic assemblies are two main product categories.
As production processes in electronics manufacturing are becoming increasingly interchangeable all over the world, companies can maintain their competitive position only by enhancing their automation. Industry 4.0 – the intelligent, adaptable automation made in Europe – electronics enables it and benefits from it at the same time.

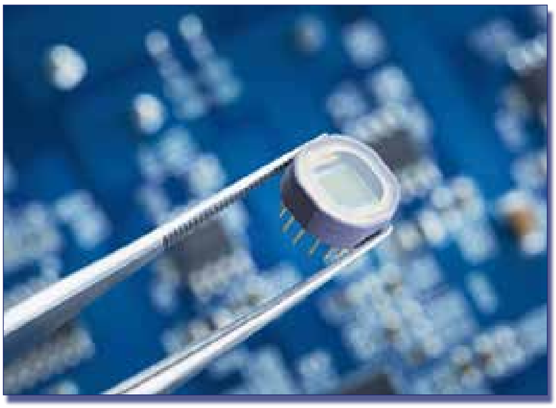

Fig.1: PCB with Camerasensor Source: Westend61 bei fotolia

Fig.2: Soldering machines finalize the assembly of components on printed circuit boards. Source: kurtz-ersa Group

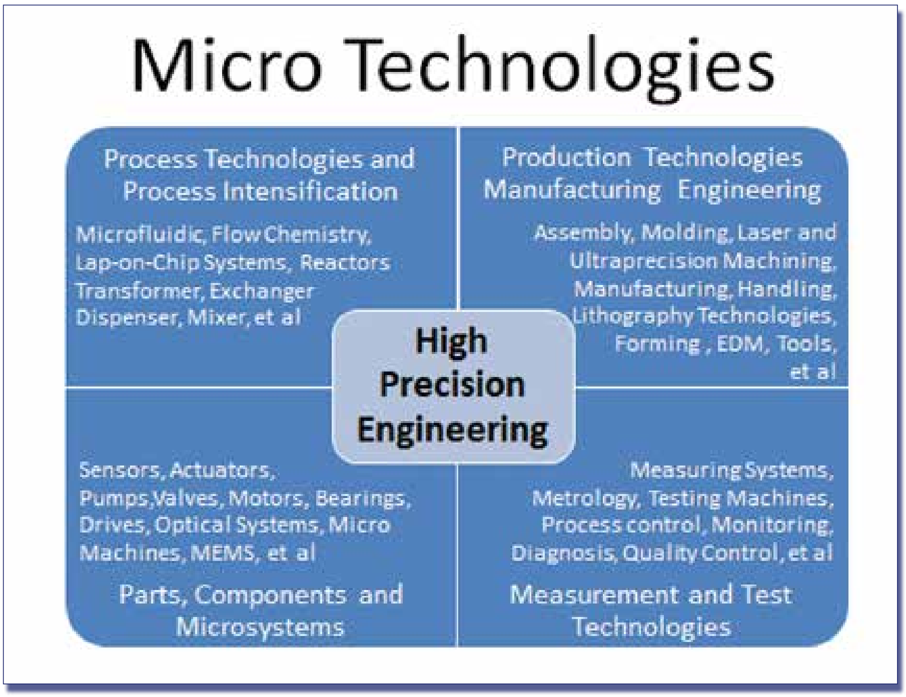

Fig.3: Source: VDMA Micro Technologies

Only innovative production technologies can ensure recyclable, eco-friendly and long lasting products. Machines and production equipment are pacemakers for both, ecology and economy. VDMA EMINT is member of “BlueCompetence” – the sustainability initiative of the German engineering industry.
The complexity of products and production processes in electronics has led to a strong specialization among the machine makers. Our small and medium sized member companies concentrate on specific types of machines covering a large scale of electronics’ segments and customers’ markets. In some areas even suppliers of turn-key factories have been established.

Micro Technologies - opportunities and potentials

The modern world was expanded by micro technologies which pave the way to new -hence unknown -realms of feasibility. Altogether new applications of existing products become possible in the capital goods, pharmaceutical, life science industries, medical technologies, precision engineering, automotive engineering, electrical and electronics industries, information and communication technology, to name only a few.

The usage of micro technologies is broadening every day: The technology gets a partner, the Market-Pull. This trend will continue, as more and more of the benefits and the potentials of micro technology is recognized from the different application fields. The wide-ranging usage of these components and subsystems in the different fields of the engineering sector, and this is true for many others technology sectors, is growing. A great potential of opportunities is offered by micro technologies. For small and medium sized companies. For large groups. For service providers. For manufacturers.

Benefits for users everywhere

Miniaturisation has gained its place as successful strategy for modern technologies. Developers all over the globe expect benefits in terms of energy, materials and space savings. As more and more the competence for solving problems, the suitability for industry, quality standards, the performance and creativity plays a important part, shows that the productronic and microtechnology industries contribute a growing share of value added.

Furthermore the nationally generated content of VDMA EMINT can be transferred via the VDMA network on the European level. The European and international activities of our member companies are supported by VDMA offices located in Japan, China, India, Russia , Brazil, Berlin and Brussels. VDMA Electronics, Micro and Nano Technologies (EMINT) is one of the 38 Sector Associations within VDMA.

Fig.4: Assembly of Micro Annular Gear Pumps Source: HNP Mikrosysteme GmbH

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Sensors and Measurement: Tiny Smart Devices Keep Up Big Advances

The demand for intelligent devices continues to grow worldwide. Production costs and energy consumption are supposed to drop, while product quality is to improve. Microsystem, sensor, and measuring technologies need to cope with this challenging demand. The AMA Association for Sensors and Measurement (AMA) reckons that the number of sensors applied in this area will double every five years.

Fig.1: ©AMA/B.Oertwig: Protecting what we hold dear – sensors see what we do no

Challenges and Opportunities

The Internet of Things, Industry 4.0, and the Digital Agenda can hardly be implemented without an intelligent microsystem technology, state-of-the art sensors, and capable measuring systems. Today's microsystems are smart, networked, and energy autonomous – and certainly more than just another component. In fact, they have transformed into independent nodes in intelligent systems, such as sensor networks. Thanks to continued miniaturization, ever new areas of application are being opened on the way to an intelligent environment. Smart sensors can perform self-diagnoses, they encapsulate the complexity of sophisticated systems, and are capable of a much improved level of communication. Thus the increased flexibility and autonomy attained, in turn enables autonomous machines to communicate with other machines. Hence, sensors and sensor systems can be considered as the sensory organs of industry: Without these sensors, machines would stay deaf and blind.

The AMA Association has noted that imaging technologies are on the rise, miniaturization is continuing its advance, and the importance of signal processing is ever-increasing. Measuring technology, as a facet of automation, must meet extremely high requirements, filter relevant data, and deliver results in real-time. Sensors are getting faster and faster and even have integrated system knowledge. Such sensors and measuring systems need to provide reliable data in real-time and without the need for maintenance, recalibration, or readjustment, and they must be capable of autodiagnosis.

Future-oriented projects, such as "Industry 4.0" and the "Internet of Things," let the traditional walls between the branches of industry crumble and considerably transform the value-chain processes. For developers and suppliers of sensors and measuring equipment, these changes offer infinite new challenges and opportunities to master the intrinsic complexities. This drives the demand for smart sensors.

Fig.2: ©AMA/B.Oertwig: Greater safety in traffic – sensors and measuring systems for intelligent driver assist and traffic control systems for safer travel

The Sensor and Measurement Industry is Growing and Investing

The AMA estimates that there are approximately 2,500 suppliers on the German sensor and measurement market. This segment of industry comprises suppliers, distributors, engineering consultants, specialized service providers, and research institutes. It has 250,000 employees – mostly highly qualified professionals – and a turnover of 35 billion euros per year.

According to a statistics poll among AMA members on the economic development, the sensor and measurement industry had a growth in revenue of eight percent in 2014. This result shows the increasing demand for sensor and measuring technology. Exemplary is the industry's research and development area. The mostly small and medium-sized enterprises are investing an average of ten percent of their revenue in research and development, making the sensor and measuring branch one of the most innovative industries.

Sensors and measurement technology from German-speaking countries are considered worldwide as leading with a share of just about thirty percent of the world market. The tiny smart devices are a German export success: Sixty percent of these sensors "made in Germany" are used domestically, 40 percent go to the rest of the world. However, if we include all the sensors that are already integrated in exported machines and systems, the export quota for sensors and measurement attains almost 80 percent.

Fig.3: ©AMA/B.Oertwig:
Sensors and measuring technology paves the way for electric cars and vehicle networks

Networking and Exchanging Information

The AMA Association for Sensors and Measurement is the network and representative of the interests of the key industry: sensor, measuring, and testing technology. The AMA can call on the know-how of its 480 members in industry and research. It cultivates an exchange of information among supplier, researcher, and user industries.
The AMA offers all participants a network with a broad communication platform: The AMA's annual SENSOR+TEST trade fair invites all to take part its Innovation Dialog. The AMA Centers for Sensors and Measurement represent the industry at other major fairs in Europe and overseas. Biannually, the AMA Science Board invites professionals from industry and research to discuss current topics and publishes its studies in SENSOR-TRENDS. The AMA also publishes the scientific Open Access Journal, the Journal of Sensors and Sensor Systems with the latest research results in sensor and measuring technology. Last not least, the Association sponsors the yearly AMA Innovation Award and offers comprehensive training opportunities in sensor, measuring, and microsystem technologies.

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IVAM Microtechnology – International High-tech Network

Hannover Messe fair

IVAM Microtechnology Network, being an international high-tech association, has been supporting companies and institutions from all around the world for more than 20 years. The central mission of the association is to create synergies and to support its members in exchanging knowledge, initiating joint projects and networking with each other and potential customers. IVAM uses targeted technology marketing activities to speed up the implementation of innovative ideas into marketable products. Further activities include lobbying, market analysis and the continuous development of international markets. Furthermore, IVAM strengthens cooperation between industry and research in order to promote the transfer of technology, to make the high-tech industries globally competitive and to create and secure jobs in the field of new technologies.

Microsystems technology in a state of transition – focus on application areas

Microtechnology and related technologies such as nanotechnology, advanced materials, optical technologies, organic electronics, systems integration or additive manufacturing are the so-called Key Enabling Technologies (KET) – essential cross-cutting technologies that are indispensable for the future implementation of innovations.
Since the 1990s, microtechnology has been transforming to become more and more application-oriented. The applications are as diverse as the technologies themselves. They include applications in the fields of logistics, transport or consumer goods, environmental and energy technology, mechanical and plant engineering as well as optimization of production processes for almost every industry.
IVAM promotes the dissemination of applications of KET e.g. by informing the public about the possibilities of new technologies. For this reason, IVAM observes developments and changes of technologies and markets and is thus able to adapt its activities to trends
In particular in the field of healthcare, biomedicine and the AAL technologies, many marketable products are already in use. The market for medical devices has experienced a rapid upswing in recent years. More than 70% of IVAM's members deal with this issue and are looking for appropriate marketplaces to sell their products.

Business platforms at medical technology trade fairs worldwide

High-tech solutions for the medical device industry are bundled on the IVAM Product Market "High-tech for Medical Devices" at the COMPAMED fair in Dusseldorf. The exhibition has constantly grown in recent years and became one of the leading international marketplaces for suppliers of medical manufacturing.

At the MD&M West, the world's largest trade fair for design and manufacturing in medical technology, held annually in February in California, IVAM organizes the special exhibition area MicroNanotech and is thereby offering an opportunity for its members to step into the US medical market.

Even Latin America offers great potential for medical technology manufacturers. Brazil, for example, is one of the largest economies in South America with the highest potential for companies in the healthcare market. In May 2016, São Paulo will once again host the HOSPITALAR, Latin America's largest and most important trade fair for medical technology. The main topics are medical devices, equipment, services and technologies for the health care sector. IVAM organizes a joint pavilion at HOSPITALAR as well.

Dr. Thomas R. Dietrich

COMPAMED fair

The range of technologies presented by IVAM's members at these medical technology fairs all over the world covers miniaturized components, functional materials and high-precision processes that will improve cost-effectiveness, safety and reliability of medical technology products in the future, e.g. in the manufacture of mobile analysis, treatment and monitoring devices. Manufacturing wearable devices requires miniaturized sensors that reliably and continuously deliver accurate readings. This way, vital signs can be monitored with devices directly on the body, e.g. in-ear or at the wrist.

Enabled by continuously increasing requirements for reliability and precision in medical diagnostic and therapeutic devices, the topics biophotonics, laser technology and micro-optics are also gaining a foothold in medical technology. Optical processes, e.g. in minimally invasive procedures or imaging, have proven to be particularly low-risk and patient-friendly. Miniaturized optical sensors make measuring and evaluating blood levels such as blood glucose pain free, laser beams reduce bleedings in surgical incisions and high-tech microscopes determine the perfect, personalized fit for implants.

Promising applications in industry and building technology

In addition to the already established applications in the field of medical technology, further application fields of micro- and nanotechnology are currently particularly promising. In the area of "smart homes", high efficiency in heating and power supply, autonomous energy production, increase of comfort and safety, information and entertainment are goals of current technical developments.

At the industrial fair HANNOVER MESSE the IVAM members present innovations that make it possible to greatly increase the efficiency and speed of industrial processes, enhance the reliability and quality of industry products while at the same time reducing costs. High-precision micro solutions already play an important role in industrial automation – a key aspect of automated and integrated industry.

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microTEC Südwest
The Cluster for Smart Solutions

Smart Production

Smart Health

The cluster microTEC Südwest is located in the state of Baden-Württemberg in the southwest of Germany, one of Europe's high-performance areas of science and industry. The cluster, with its over 380 cluster partners, is one of the largest technology networks in Europe. The microTEC Südwest cluster has won the Spitzencluster (leading-edge cluster) competition launched by the German Federal Ministry of Research and Eduction (BMBF) in 2010. In 2012 the quality label "Cluster-Exzellenz Baden-Württemberg" was given to microTEC Südwest for outstanding cluster management. This award officially includes the Gold Label on a European level.

Progress, trends and developments

The cluster microTEC Südwest focuses on the application areas of Smart Production, Smart Health, Smart Energy and Smart Mobility. These fields have special potential for microsystems technology and high potential with regard to world markets and innovation. Not only do new partnerships arise with a quicker exchange of knowledge, but a positive climate for company founding as well. Economic growth in the region is also further fostered. In our focus areas we present some samples as follows:

✦ Smart Production

Intelligent workpiece carriers

Carl Zeiss 3D Automation GmbH, along with a consortium of R&D partners, component manufacturers and system providers, has developed an intelligent workpiece carrier system equipped with its own intelligence and interfaces to the outside world.

Intelligent service robots

Festo AG & Co. KG has developed miniaturized 3D optics for a modular robot system. In the future, intelligent products and workpiece carriers will communicate with the machines in their vicinity as cyber-physical production systems (CPPS) and will partially control the manufacturing system autonomously. The ability of intelligent systems to communicate independently with a user, with other intelligent systems or even between functional groups within a single system will be a major contribution to realizing the vision of "Industry 4.0".

Cyber-physical production systems

Miniaturized sensors and actuators will play a central role in the development of cyber-physical production systems – which can be used as intelligent, networked and autonomous sub- or overall systems in manufacturing or in logistics ("Industry 4.0").

✦ Smart Health

Quick diagnostics

Roche Professional Diagnostics developed an "intelligent" in-vitro cartridge for better test efficiency in the field of in-vitro diagnostics. In addition, members of the cluster are working on detectors for viruses and metastasizing cancer cells.

Intelligent implants

The "CorTec Brain Interchange" of CorTec GmbH connects the human brain with an intelligent microsystem: a high-performance closed-loop technology can measure and influence brain activity in long-term service.
Retina Implant AG developed the retina chip "Alpha IMS", the first subretinal implant to receive marketing rights in Europe. Cicor has produced a flexible


Smart Mobility


Smart Energy

antenna coil for the sensor. It supports the transmission of the data and provides power to the micro sensor for the wireless intraocular pressure measuring.

✦ Smart Mobility

Mobility: resource-saving and low in emissions

Sensors that measure internal cylinder pressure promise more efficiency and therefore optimal combustion methods. These sensors must be robust as well as reasonably priced. And that is exactly what silicon carbide technology offers and it is being further developed for use in motor vehicles.

Safety in traffic

Bosch is involved in research of solutions which allow the generation of real-time maps that display vacant parking spaces to detect if a car is on a parking place or not.

✦ Smart Energy

Energy monitoring

SmartExergy WMS has developed radio modules for more efficient, decentralized cost-efficient monitoring and maintenance of photovoltaic power plants to monitor the functions of all photovoltaic modules in plants individually and economically.

Energy efficiency

Precision Motors Deutsche Minebea GmbH utilizes the difference in temperature between the heating element and the room to produce electrical energy and in this way can save 20% to 30% in energy.

microTEC Südwest in a Nutshell

The cluster microTEC Südwest brings together industry, research and politics. It connects experts to ensure the ongoing development of different technologies. Thus, innovations can be formulated and actioned. The microTEC Südwest cluster does this by promoting the transfer of technological and application-oriented know-how by special interest groups. These groups point out developments in microsystem technology and their effects on German industry and deal with the following thematic focal points: Printing technologies, energy supply, intelligent implants, in vitro diagnostics, cooperative innovation processes, surfaces and smart systems.

The cluster microTEC Südwest has also built up strategic partnerships across national borders to set-up research and innovation projects in Europe. Furthermore, the cluster offers various marketing and sales activities. The competencies in the region can be accessed on the “Kompetenzatlas”, a smart search engine that provides complete profiles of institutions, small and large companies, start-ups as well as institutions and universities that are working in the field of microsystem technology.

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The Stage is set for Micro Photonics 2016 in Berlin

micro photonics
International Congress Expo

Berlin, 11 – 13 October 2016

With the micro photonics the Berlin-Brandenburg Photonics Cluster has a new market place for its broad spectrum of innovative products at the interface of microsystems and optical technologies.

At the micro photonics preview event, which came to a close on 27 of November in Berlin, the focus was on the latest research findings in the field of microphotonics and biophotonics as well as their uses in industry and medicine. 250 specialists from 20 countries participated in the plenary sessions, poster sessions and networking events on the Berlin Exhibition Grounds. In addition to leading researchers, university lecturers and industry representatives from Europe, experts from Australia and Japan were also among the speakers.

Professor Dr. Popp, scientific chair of the micro photonics preview event: "The micro photonics preview event definitely more than fullfilled all our high expectations, and created a desire for more.
It means we are very much looking forward to the first regular micro photonics next year and will be doing our best to put together a comprehensive and fascinating biophotonics event in 2016." An internationally renowned scientist and university lecturer, Professor Popp is director of the Institute of Physical Chemistry at Friedrich Schiller University in Jena and the science head of the Leibniz Institute of Photonic Technology.


Source: Ferdinand Braun Institute


Source: TOPTICA Photonics


Source: Messe Berlin

Besides offering an outstanding programme of congress events the preview event was a marketplace with many opportunities for networking, where companies and institutes presented their latest research findings, projects, products and systems. Parallel with the micro photonics preview event the first Biophotonics Symposium, organised by the European Photonics Industry Consortium (EPIC), an important partner of micro photonics, took place in adjacent rooms.
Jose Pozo, director of EPIC, responsible for technology and innovation:
"This was a high-level exchange between members of industry and science, due to the EPIC Symposium and micro photonics preview event taking place at the same.

First micro photonics from 11 to 13 October 2016 in Berlin

The first edition of micro photonics will take place on 11 to 13 October 2016 at Berlin ExpoCenter City, after which this three-day trade fair and conference will take place annually. micro photonics is organised by Messe Berlin in association with Berlin Partner für Wirtschaft und Technologie GmbH, the K.I.T. Group and other partners.
www.micro-photonics.de

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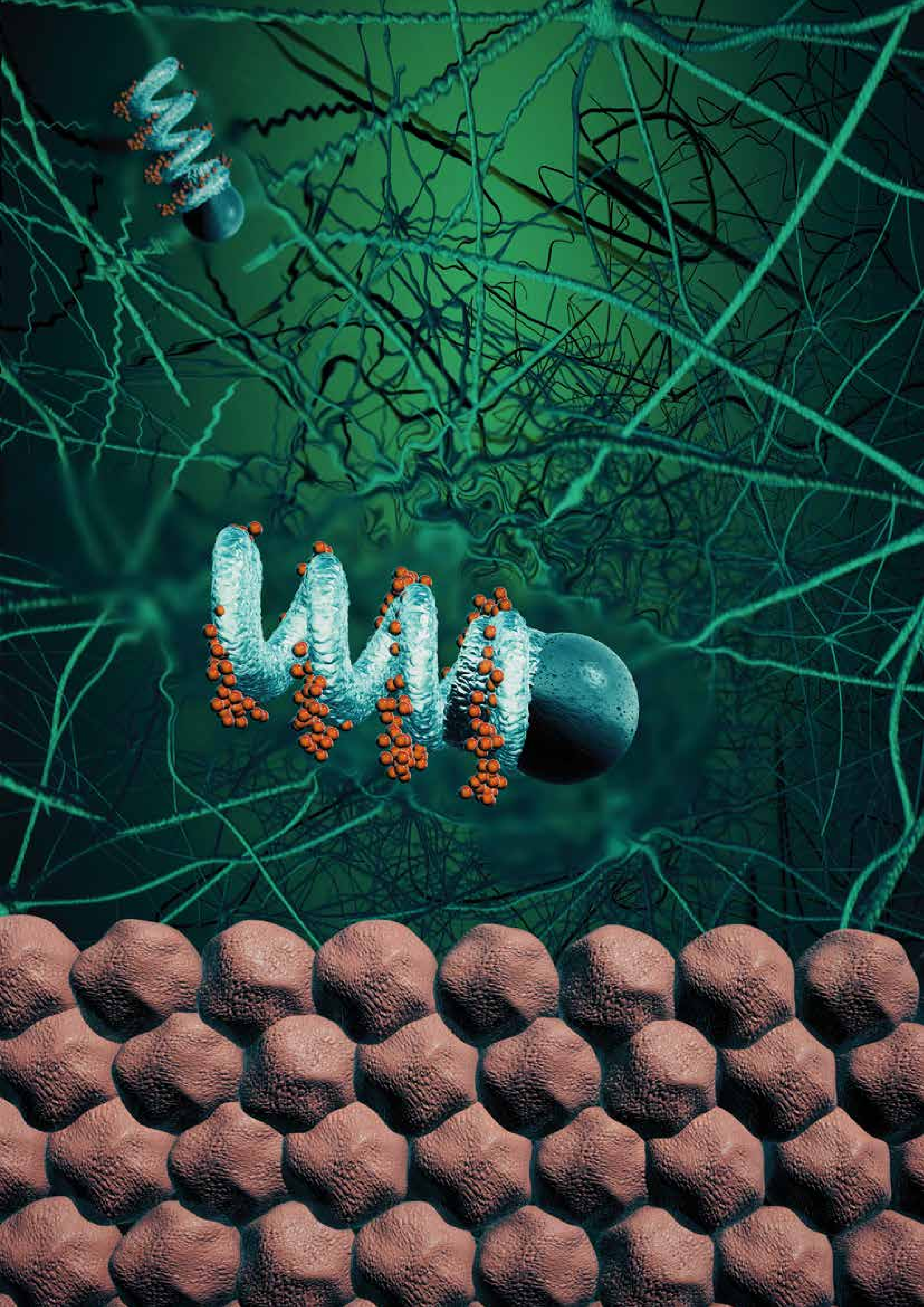

DORTMUND

Top Location for Micro- and Nanotechnology!

Stadt Dortmund
Wirtschaftsförderung

At the heart of it all:
Anyone looking to achieve big things with microtechnology is certainly at the right place in Dortmund. The city is leading the way across in Europe in the development and industrial use of micro- and nanotechnology, with its local cluster creating a unique environment for growth and settlement.

- 45 companies with approximately 2,600 employees and a skilled workforce rate quota of 85% - and rising.
- MST.factory dortmund - the competence center for micro- and nanotechnology is located here.
- Scientific expertise – thanks to the city's renowned research and development centers.
- Headquarters of the international IVAM Microtechnology Network.
- Well-qualified specialist staff through sector-specific training programs and university courses.

We are here to help:
As an industry expert for micro- and nanotechnology, I am your contact within the City of Dortmund Economic Development Agency. We combine urban, economic and scientific dynamics to form strong sectors. In addition to micro- and nanotechnology, this involves logistics, biotechnology, ICT, efficiency technology, production management, health care, creative industries and economic services.

Benefit from our industry expertise and diverse activities that promote Dortmund as a business location. This involves:

- Setting the stage for Dortmund's stakeholders to network on a local and regional level, as well as facilitating the close integration of neighbouring sectors.
- Presenting this location's technological expertise in specialist media, at congresses and at major international fairs Discover what the micro- and nanotechnology sector in Dortmund has to offer you! Talk to us!

Excellent prospects:
Micro- and nanotechnology is a key technology of the 21st century. Boasting technological diversity, it is making a significant contribution towards developing solutions for the future challenges facing society and towards continued growth. Be a part of this success story. And make full use of the advantages Dortmund has to offer you!

- Innovative technological location with many world market-leaders and specialist suppliers as well as strong networking for crosscutting issues.
- Support for technology transfer between scientific establishments and companies in the region.
- Effective network in the science and business communities to support both startups and established companies.
- Support from the City of Dortmund Economic Development Agency together with its partners from the worlds of science, business and economics.

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Wirtschaftsförderung

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Und vom Know-How-Transfer mit der Wirtschaft profitieren

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GMM VDE/VDI-GESELLSCHAFT
MIKROELEKTRONIK, MIKROSYSTEM-
UND FEINWERKTECHNIK

VDE

ZVEI:
Die Elektroindustrie

IVAM.

AMA
Fachverband für Sensorik e.V.
Innovatoren verbinden

VDMA
Micro Technology

trias
CONSULT

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