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Prof. Dr. Christoph Kutter
Chairman MST-Congress 2017
Fraunhofer Research Institution
for Microsystems and Solid State
Technologies EMFT

Not long since the PC was the central computing unit and interface to the internet – but the rapid technological development lets it appear as a different era. In particular, the trend 'Ubiquitous Computing' renders the PC more and more meaningless. Instead, our commodity items themselves get 'smart'.

This development would not have been possible without microsystems: they can be integrated in small and mobile commodity items, taking on tasks like sampling data or control functions. Often they allow new functionalities, representing the actual innovation of the overall systems. An everyday life example is the smartphone: every average smartphone nowadays includes microsystems with diverse functions, such as acceleration, gyro and magnetic field sensors. In the recent years, pressure sensors were added, at present the application of gas sensors is discussed and tested. Last but not least, filter banks, again of great importance in the next generation of the mobile telephone system 5G, will be manufactured using microsystem technology.

However, the possibilities for microsystems are not comprehensively described with those ‚standard' applications. In particular, the Internet of Things (IoT) opens up innumerable possible applications for microsystems: after all, 'things' want to 'talk about' something in the net, i.e. collect data on their surroundings and transmit it in the web to another network and higher hierarchy levels. Here, sensors are the mediators between the analog and digital world – they collect and convert data into electrical signals. Thus, we have come full circle: only thanks to the immense progress in microelectronics in general and microsystem technology in particular, such sensor systems can meanwhile boast very low manufacturing costs, low power consumption, small footprint, miniaturization and multifunctionality – and the limits of the realms of possibility have not been reached yet. For example, flexible electronics - printed on foils - could be established as an important key technology, offering several decisive advantages: extremely low height, high form flexibility, robustness and relatively low production costs, especially in mass production. Also the ability to combine most varied components and materials in one system will gain importance over the upcoming years. Hetero-integration-technologies allow combining the advantages of the different worlds of technologies, such as classic silicon technology and foil technology.

Not least, microsystem technology will have new answers to how electronic systems can be protected from manipulation in the IoT: there are many exciting approaches to implement security already on chip level.

In this context, it is not presumptuous to claim that microsystem technology is an essential supporting pillar for Germany's innovation power. The orientation of several funding programs towards microelectronics and microsystems mirrors this fact. Especially positive is the strategic farreaching decision of the 'Bundesministerium für Bildung und Forschung' to support the 'Forschungsfabrik Mikroelektronik Deutschland', for sustainable reinforcement and development of the research infrastructures of Fraunhofer- and Leibnitz-Institutes.

With best regards,

Prof. Dr. Christoph Kutter
Chairman MST-Congress 2017
Fraunhofer Research Institution
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Mikrosysteme – die heimlichen Stars im IoT

So lange ist es noch gar nicht her, dass der PC die zentrale Rechnereinheit und Schnittstelle zum Internet war – doch die rasante technologische Weiterentwicklung lässt uns das wie ein anderes Zeitalter erscheinen. Damit meine ich vor allem das „Ubiquitous Computing", den Trend, dass der PC immer mehr an Bedeutung verliert. Stattdessen werden unsere Alltagsgegenstände selbst „smart".

Diese Entwicklung wäre ohne Mikrosysteme gar nicht umsetzbar gewesen: Sie lassen sich in kleinen, mobilen Alltagsgegenständen integrieren, wo sie beispielsweise Daten aufnehmen oder Steuerungsaufgaben übernehmen. In vielen Fällen ermöglichen sie neue Funktionen und stehen damit für die eigentliche Innovation der Gesamtsysteme. Ein allgegenwärtiges Beispiel ist das Smartphone: Mikrosysteme finden sich heute in unterschiedlichen Funktionen in jedem durchschnittlichen Handy, zum Beispiel als Beschleunigungs-, Drehraten- oder Magnetfeldsensoren. In den letzten Jahren kamen Drucksensoren dazu und aktuell wird der Einsatz von Gassensoren diskutiert und erprobt. Aber auch Filterbänke, die in der nächsten Generation des Mobilfunks 5G wieder eine sehr wichtige Rolle spielen werden, werden in Mikrosystemtechnik hergestellt.

Dabei sind mit solchen „klassischen" Anwendungen die Möglichkeiten für Mikrosysteme noch lange nicht erschöpft. Vor allem das Internet of Things (IoT) eröffnet ungezählte weitere Einsatzszenarien für Mikrosysteme: Schließlich wollen die „Dinge" etwas im Netz erzählen können, d.h. Daten aus ihrer Umgebung erfassen und diese im Netz an ein Netzwerk oder eine höhere Ebene weitersenden. Sensoren sind hier die Mittler zwischen der analogen und digitalen Welt – sie nehmen Daten auf und wandeln sie in elektrische Signale um. Genau hier schließt sich der Kreis: Nur dank der immensen Fortschritte in der Mikroelektronik allgemein und der Mikrosystemtechnik im Speziellen lassen sich solche Sensorsysteme mittlerweile zu sehr niedrigen Kosten, mit sehr niedrigem Energieverbrauch, kleinem Footprint und miniaturisiert und multifunktional herstellen. Und die Grenzen des Möglichen sind noch nicht erreicht. So könnte sich etwa flexible, also auf Folie gedruckte Elektronik künftig als wichtige Schlüsseltechnologie etablieren, da sie gleich mehrere entscheidende Vorteile bietet: Eine extrem niedrige Bauhöhe, die hohe Formflexibilität und Robustheit und relativ geringe Herstellungskosten gerade in großen Stückzahlen. Auch die Fähigkeit, unterschiedlichste Bauteile und Materialien in einem System zu zusammenzubringen, dürfte in den kommenden Jahren noch einmal an Bedeutung gewinnen: Mit Heterointegrationstechnologien lassen sich die Vorteile verschiedener Technologiewelten vereinen, beispielsweise von klassischer Siliziumtechnologie und Folientechnologie. Nicht zuletzt wird die Mikrosystemtechnik auch neue Antworten auf die Frage geben können, wie mikroelektronische Systeme im IoT manipulationssicher gemacht werden können: Es gibt eine Reihe spannender Ansätze, die Sicherheit schon auf Chip-Ebene zu implementieren.

Vor diesem Hintergrund ist es nicht vermessen, festzustellen: Mikrosystemtechnik ist eine zentrale Säule für die Innovationskraft Deutschlands. Dies spiegelt sich auch in der Ausrichtung mehrerer Förderprogramme auf die Bereiche Mikroelektronik und Mikrosysteme wieder. Besonders erfreulich ist in diesem Zusammenhang die strategisch weitreichende Entscheidung des Bundesministeriums für Bildung und Forschung, die Forschungsfabrik Mikroelektronik Deutschland zu fördern und damit die Forschungsinfrastruktur von Fraunhofer- und Leibnitz-Instituten nachhaltig zu stärken und auszubauen.

Mit besten Grüßen

Prof. Dr. Christoph Kutter
Chairman des MST-Kongresses 2017
Fraunhofer EMFT

Positioning in International Competition

Positionierung im internationalen Wettbewerb

Germany: The European MST Driver

Jérôme Hull

Europe's MST Leader

Microsystems Technology (MST) counts as one of the most important key technology sectors driving global innovation. Europe is a world leader in this field and Germany is – like in so many other manufacturing-related fields – arguably Europe's engine; accounting for more than half of European microelectronics production. One in three chips produced in Europe is German-made and with international competition heating up in the global MST market, Germany is investing significantly in next-generation micro-electro mechanical systems (MEMS) innovation, as it seeks to extend the CMOS and More-than-Moore technologies required to develop the next generation components for application in the Internet of Things and the booming automotive, industry and health markets.

Fig. 1: Electronic components held in hand in laboratory, close up|© Monty Rakusen/Getty Images

Market Drivers and Applications

Increased levels of automation in passenger vehicles, the ongoing digitalization of industry, and a burgeoning mobile health sector are creating increased demand for advanced electronics and sensor technologies.

Automotive

MST is revolutionizing mobility, in Germany and elsewhere. Sensors and actuators account for around 80 percent of innovations in modern vehicles. Mobile internet access, digital operating controls and electronic assistance systems are slowly finding their way into all vehicle segments. The sector is driving increased chip demand, with digitalization and electrification fueling semiconductor growth of 103 percent for the period 2000 to 2016. It is also the semiconductor sector's main industry sector client, accounting for around 44 percent of domestic industry demand.

Industry

MST has also a decisive role to play in the ongoing digitalization of industrial production. As key enablers in industrial automation, electronics and sensors help transform production systems and products into cyber-physical systems (CPS). Embedded system production technologies and intelligent production processes show the way forward for peerless ICT-based integration making vertically integrated and networked manufacturing a reality. The industry sector is the second largest semiconductor segment, with a 24 percent semiconductor share. German industry plans to invest in the region of EUR 40 billion annually in Industrie 4.0 applications through to 2020.

Medical

Germany being Europe's biggest healthcare market and the world's third largest medical technology producer, digital transformation and cost pressure in the health care sector are also considered to be major driving forces behind innovation in the industry. Mobile health solutions are the main driver of the significant growth recorded in the growing digital health market which is currently worth around EUR 3 billion (recording a CAGR of around 22 percent since 2012).

Global investment

Germany is home to more than 40 semiconductor fabs run by diverse local and international players (among them Dutch group NXP Semiconductors, US

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company Texas Instruments, Abu Dhabi-owned GlobalFoundries and Belgium's X-Fab) and boasts an unparalleled density of world-leading device manufacturers and suppliers for materials, components, and equipment across the MST value chain.
To ensure that Germany continues to play a leading role and remains attractive to international players, the German government announced under the aegis of a European Commission instrument called IPCEI for Important Project of Common European Interest, a EUR 1 billion investment program aimed at promoting investment in the country's chip industry through to 2020. Additional industry investment of around EUR 3 billion should also be generated over the same period as part of efforts to strengthen Germany's already thriving semiconductor sector.

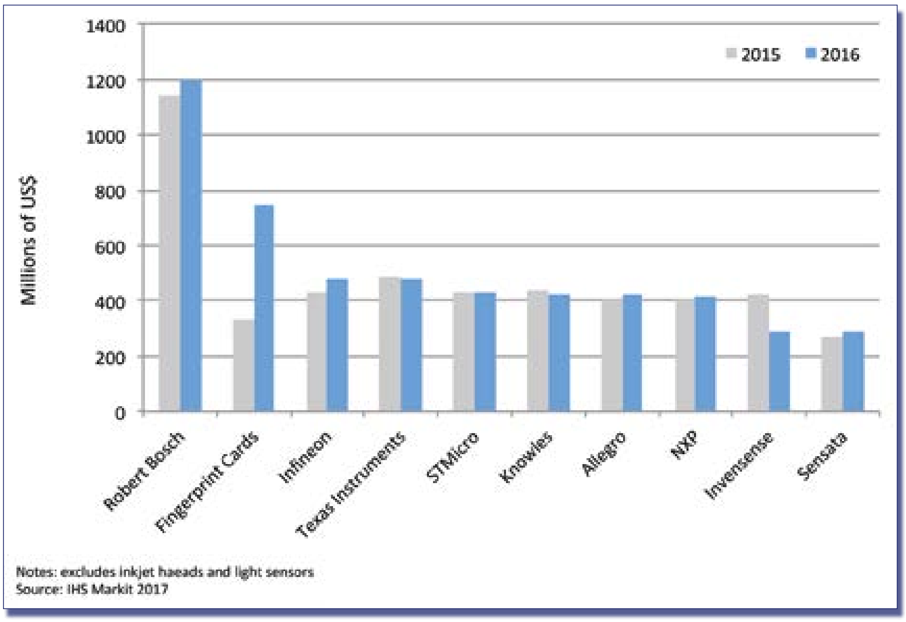

Fig. 3: Top 10 Semiconductor Sensor and Actuator Manufacturers|© HIS Markit

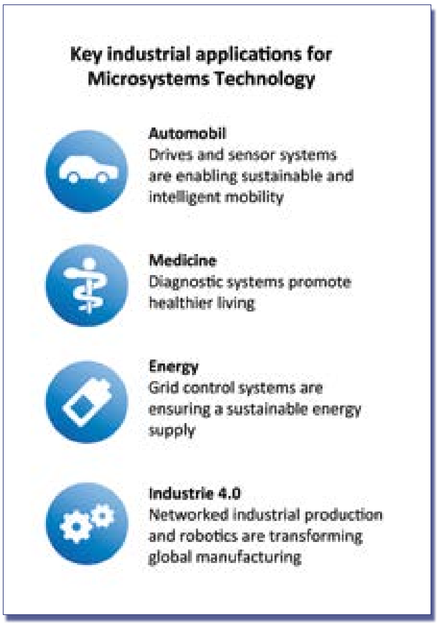

Fig. 2: Key industrial applications for Microsystems Technology|© Germany Trade & Invest

The subsidy activity is already reaping dividends with MEMS sensor market leader Bosch having announced planned investment of EUR 1 billion in a new 15,000 m² wafer fab in Dresden. The new wafer fab, necessary to meet growing Internet of Things (IoT) and mobility applications demand, represents the single biggest investment in Bosch's 130-year plus history. Globalfoundries has also announced planned investment of more than EUR 1.5 billion in Saxony, where it plans to produce next-generation FDX chips used in automotive and IoT applications.

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Microsystems Technology Meets Applications

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.

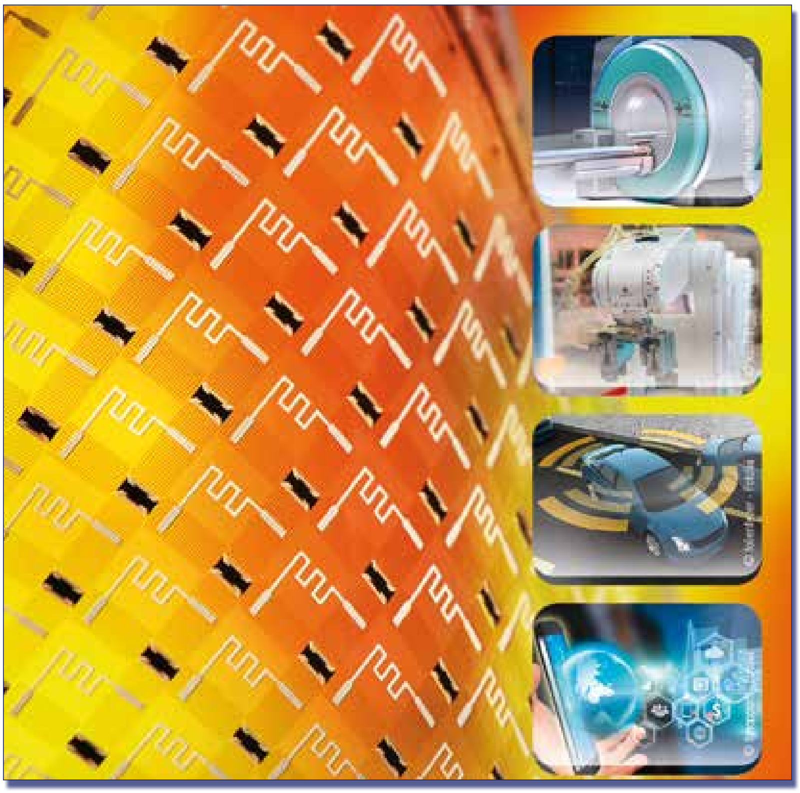

Fig. 1: Title German Congress on Microsystems Technology 2017 Copyright Fraunhofer EMFT

After the automotive electronics and smartphone boom, we are facing completely new challenges today. Microsystems go online, into the Internet of Things, into new applications: health, living, industry 4.0, smart energy. MST sensors are among the most important enablers of the IoT. Forecasts predict an increase in global demand from 1 billion in 2007 and 10 billion in 2014 to 100 trillion by 2030. This is an enormous economic potential for the MST pioneers Germany and Europe. Example Industry 4.0: The first major task here is to turn the sensor from a measuring instrument into a data generator that provides data for all possible business layers. This can only be achieved by networking, horizontally, vertically and along the life cycle.

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. Microelectronics creates the basis for reliable and secure communication – for example with chips without backdoors as well as cryptographic chips and mod-

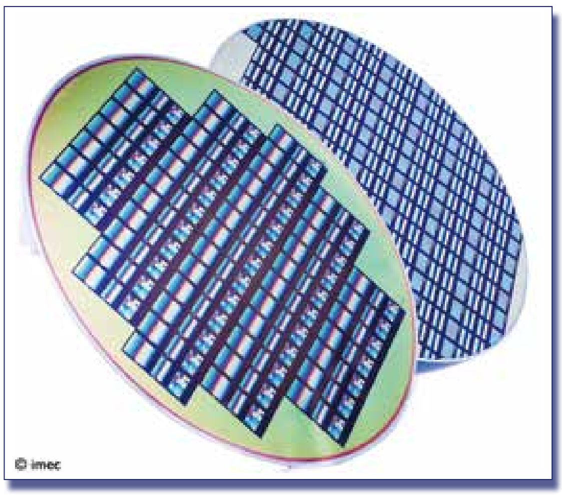

Fig. 2: ICPT 2017 Copyright imec, Belgium

Dr. Tim Gutheit
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Executive Director, VDE/VDI
Society Microelectronics,
Microsystems and Precision
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ules for securing data communication and end-to-end security. In combination with smart microsystems technology, microelectronics is the key enabler for industry 4.0, autonomous driving, smart cities and smart energy – and an essential key to digital sovereignty.
At the same time, Cyber Security can become an export hit if we manage to generate and market business models based on our critical approach to data protection. That's why it is critically important to have the 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? In spite of important and correct subsidy programs, Germany and Europe continue to lose market shares in microelectronics in Asia. If we do not focus our present actions consistently on the future, we are also risking our position as an industrial location in the face of global competition. Therefore, we need a comprehensive industrialization and digitization strategy with microelectronics at its heart. High tech and innovation have to be promoted more strongly, the ICT infrastructure and 5G as a communication standard have to be expanded.
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.
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. 3: Reliability Copyright Fraunhofer IZM

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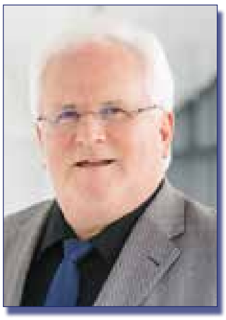
Research Fab Microelectronics Germany (FMD)

The Virtual Institute for Combined Microsystem Research and Development



Prof. Dr. Hubert Karl Lakner
Fraunhofer-Institute
for Photonic Microsystems (IPMS)

The microelectronic market is in transition. Based on mobile sensing and internet-of-things market trends, microsystem technologies are more and more important for product innovations. The research and development institutes have to follow these trends to strengthen the German industry with application-oriented research and development for high-tech products. In order to be able to offer technology under optimum conditions, eleven Fraunhofer institutes within the Fraunhofer Group for Microelectronics as well as the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) in Berlin and the Leibniz Institute for Innovations for High Performance Microelectronics (IHP) in Frankfurt/Oder, will combine their technology research into a joint, cross-location technology pool called the "Research Fab Microelectronics Germany" (FMD), and expand it.

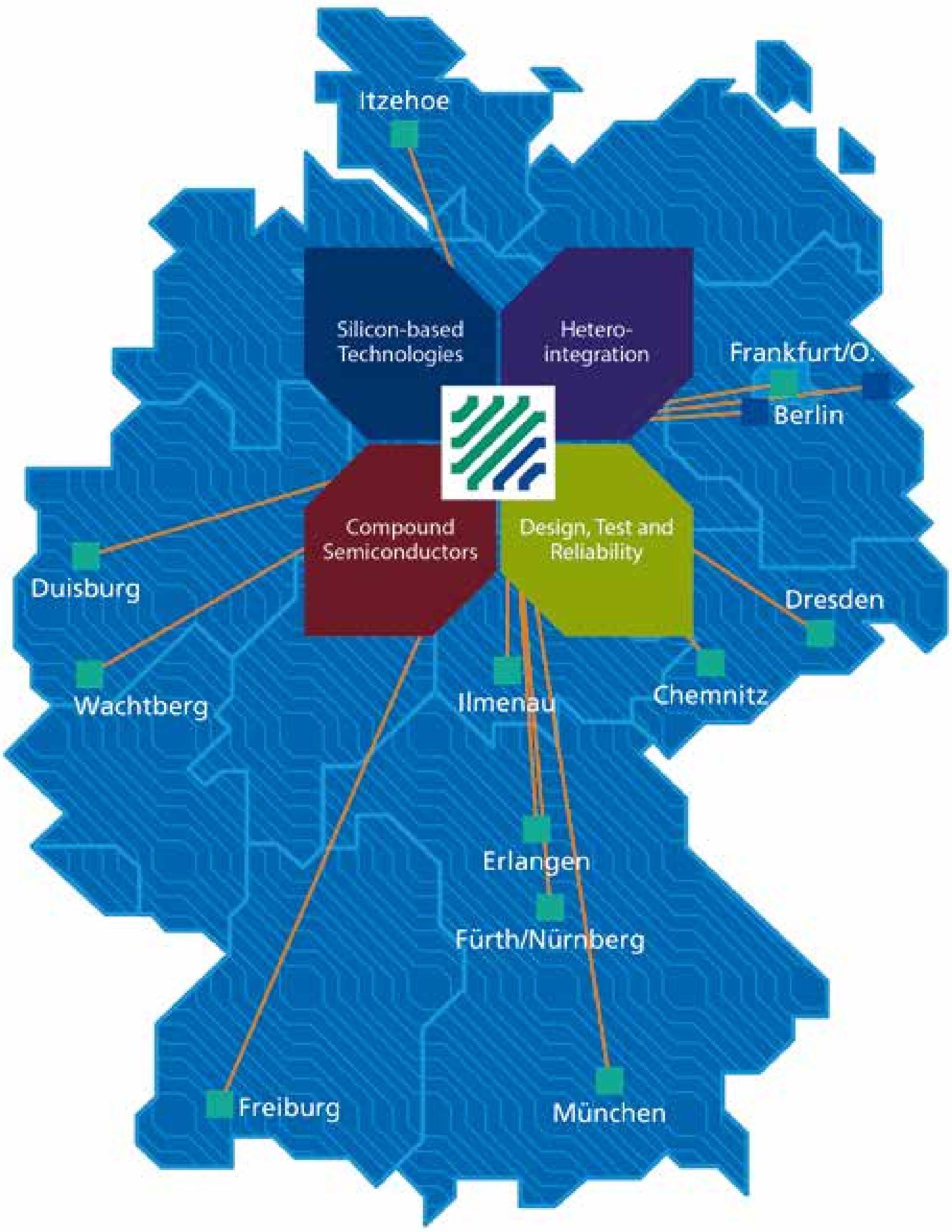
Overview and topics

In the Research Fab Microelectronics Germany, the institutes' existing locations will be retained, while expansion and operation will be coordinated and organized in a shared business office in Berlin. The aim is to be able to offer customers from large industry, small and medium enterprises and universities the entire value chain for microelectronics, microsystems and nanoelectronics in an uncomplicated manner and from a single supplier. The cooperation of a total of 13 research institutes and more than 2000 scientists is already the world's largest pool for technologies and intellectual property rights within the area of smart systems. For the modernization and expansion of their research facilities in order to keep up with technical developments, the founding participants will receive around 350 million euros from Germany's Federal Ministry of Education and Research to invest till the year 2020.
In order to advance future-relevant research topics as efficiently and quickly as possible, the FMD is organized into four technology parks – "Silicon-based Technologies", "Compound Semiconductors", "Heterointegration" and "Design, Test and Reliability".

Technology park "Silicon-based Technologies"

The technology park covers the area of silicon-based microelectronics and microsystem technology.
Integrating new material systems for MEMS and NEMS sensors and actuators and combining them with CMOS processes is one of the technology park's main focuses.
These technologies allow, in particular, the development and pilot manufacture of intelligent sensor nodes, cyber-physical systems, and hardware-oriented Industrial Internet-of-Things solutions. The range of technologies is complemented with high-frequency-capable MEMS and SiGe elements.

Fig. 1: Cleanroom inside the FMD cooperation. © Fraunhofer IPMS



Technology park "Compound semiconductors"

Compound semiconductors are – with the exceptions of silicon carbide (SiC) and gallium nitride on silicon (GaN-on-Si) – not compatible with silicon-based technologies when it comes to wafer diameter and process control. One important role of the technology park "Compound Semiconductors" will therefore be the provision of III-V wafers and chips for heterointegration with silicon electronics. This will allow customers to make practical use of the advantages offered by devices and circuits based on compound semiconductors.

Technology park "Heterointegration"

Heterointegration is the bonding of all parts and components of a system into a single functional unit - either as prototype or as finished product. The technology park develops and harmonizes all processing steps relevant to functional integration, which is then made available to our project partners in the form of transparent integration lines.
The technology park works closely with the processes of the external project partners to advance product ideas, implement production chains and, where necessary, facilitate cooperation with the other technology parks.

Research Fab Microelectronics Germany founding institutes

- Fraunhofer Institute for Applied Solid State Physics IAF
- Fraunhofer Institute for Electronic Nano Systems ENAS
- Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR
- Fraunhofer Institute for Integrated Circuits IIS
- Fraunhofer Institute for Integrated Systems and Device Technology IISB
- Fraunhofer Institute for Microelectronic Circuits and Systems IMS
- Fraunhofer Institute for Microsystems and Solid State Technologies EMFT
- Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute HHI
- Fraunhofer Institute for Photonic Microsystems IPMS
- Fraunhofer Institute for Silicon Technology ISIT
- Fraunhofer Institute for Reliability and Microintegration IZM
- Leibniz Institute for Hoechstfrequenztechnik, Ferdinand-Braun-Institut, FBH
- Leibniz Institute for Innovations for High Performance Microelectronics IHP

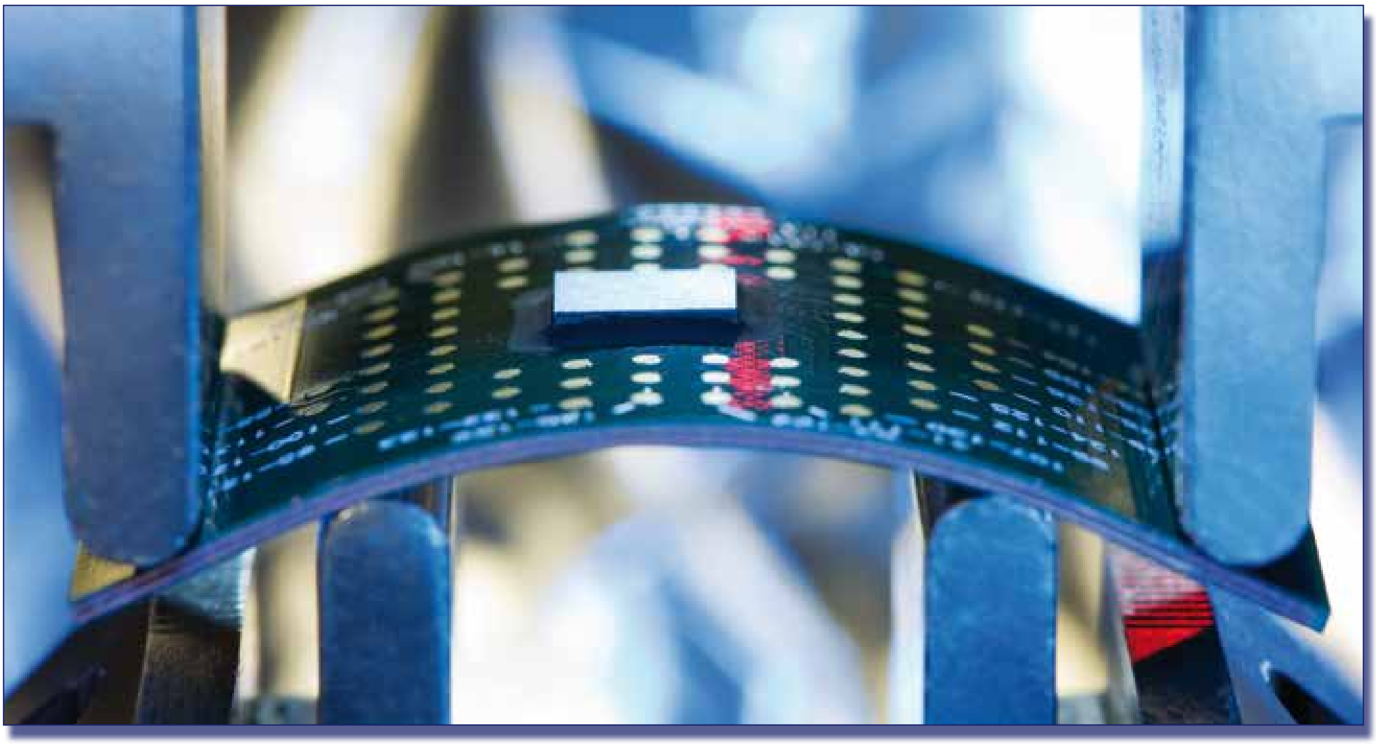


Fig. 2: PCB Module Reliability Test. © Fraunhofer IZM, Jürgen Lösel

Technology park "Design, Test and Reliability"

The ever-increasing complexity of microsystems poses an enormous challenge for the design and the manufacturing of those systems. Novel requirements regarding energy efficiency, performance, size, and – most notably – reliability must be taken into account from the very beginning. In the "Design, Test and Reliability" technology park novel scientific approaches will be developed. This covers firstly the design capability at system and component level and adaptation to the new requirements from the application point of view. Additionally powerful methods for metrological characterization of new materials and devices, performance analysis in conjunction with development, testing and verification of circuits and systems, as well as comprehensive testing of innovative solutions within the context of the system will be covered.

After realization, the evaluation of reliability and service life based on the physical aging and fault mechanisms and the properties of the technology used is part of the activity of the technology park.

Conclusion

The cooperation FMD connects the research and development infrastructure and the technological know-how of the participating institutes in a new manner. The exceptional multi-disciplinary cooperation within this technology park enables the FMD to develop innovative, adaptable and reliable system solutions together with customers.

The FMD is funded by the Federal Ministry of Education and Research under the project reference numbers 16FMDO1K, 16FMDO2 and 16FMD03.

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Contributions to Topical Fields of Innovation

Beiträge zu aktuellen Innovationsfeldern

Smart Systems Integration – Trends and Tendencies, New Examples

Thomas Otto, Fraunhofer Institute for Electronic Nano Systems ENAS, Center for Microtechnologies, Chemnitz University of Technology

Currently, we hear and read a lot about digital transformation, which is influencing many aspects of daily lives. "The digital transformation is in full swing all round the world. The technological progress is rapid and is changing the way we communicate, work, learn and live. It offers tremendous potential for improving people's quality of life, for doing business more efficiently, and for creating revolutionary business models."[1]. Our world is becoming more and more connected. Thousands, millions, billions of connected devices create a bridge between real and virtual world. Fundamental basis for the internet of things is the integration of hardware, software and connectivity. Smart integrated systems play thereby an important role as they are the hardware basis for a connected world.
Therefore, smart systems integration has become a driving force behind almost all product innovation. Smart-enabled solutions can be found in almost every application field: transportation, health, manufacturing, the Internet of Things (IoT), energy, natural resources and security. Smart systems are developed by using key enabling technologies and by integrating the knowledge from a variety of disciplines. They benefit from the progress in nanoelectronics and nanotechnologies, but also from design methods and tool development.
EPoSS – the European Platform on Smart Systems Integration has published its 2017 update of its Strategic Research Agenda (SRA), defining research and industry priorities for the next 15 years to come. Within this research agenda the building blocks of smart systems are described [2]. What separates a smart system from a system that is purely reactive is the knowledge base, which ranges from a set of parameters for a feedback loop to embedded databases and algorithms. It is a necessary condition for the smartness of a system to provide safe and reliable autonomous operation under all relevant circumstances. The building blocks of a smart system are shown in Figure 1. System functionalities determine advancements in "smartness" These can be expressed in terms of the different generations of smart systems. The SRA covers for the first time not only the application field but also the important transversal topics like technologies for smart systems, safety and reliability as well as security. This clearly indicates the importance of these transversal topics. In the following two new examples will be presented.

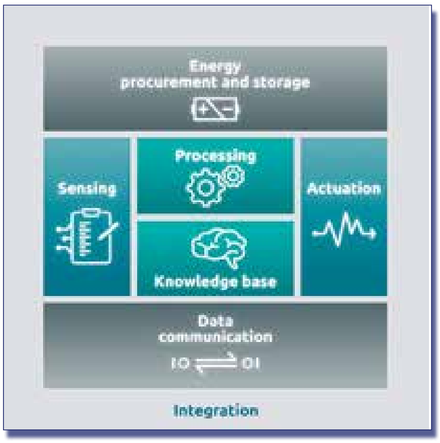

Fig. 1: Building blocks of smart systems [2]

Smart FRP components

Due to an increased use of FRP components for the reduction of energy consumption in mobile applications, the condition monitoring of these lightweight structures is of increasing importance. This topic is addressed within the cluster of excellence MERGE at the Chemnitz University of Technology. One highly innovative approach is that of in-situ functionalization during production by means of in-mould-coating techniques and integration of nanocrystal-based sensor films. The integration of transducers and electronics into load-adapted FRP components requires novel interconnection, attachment and housing

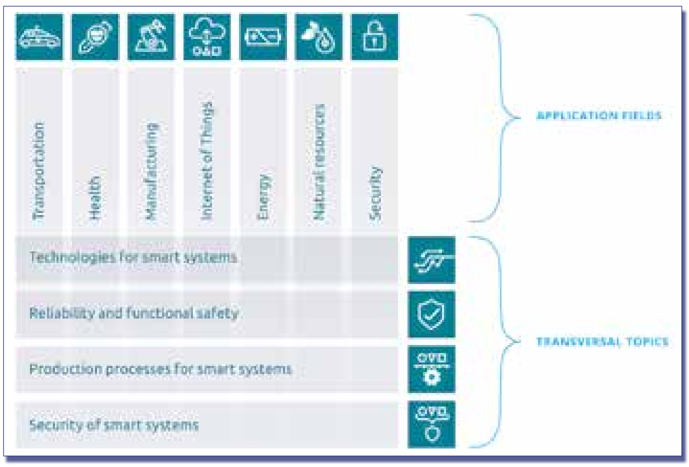

Fig. 2: Structure of SRA [2]

Fig. 3:
Load detection by quantum nano dots

technologies. The major research objectives are the performance and reliability of signal transfer from hybrid structures to sensors and actuators, as well as the energy supply and response data linkage regarding cost-efficient production processes.
Film-based sensors with Quantum Dots allow for the detection, temporary storing and subsequent optical retrieval of electrical information, thus creating a large variety of possible applications in event monitoring and structural health monitoring. Combined with a force-sensitive element the stored information can be used as an indicator of the status of or the stress within mechanical lightweight material, Figure 3. Thanks to the film-based design allowing for immense mechanical flexibility, and its stand-alone functioning the sensors are ideal for integration into lightweight materials. [3]

Sens-o-Spheres: mobile spheres as a measuring device

Bioprocess engineering is essential to the development of pharmaceutical products, obtaining enzymes from renewable resources, and other biotechnological products. To achieve highly efficient, resource friendly and consistent biological target products, the exact knowledge of the data within its process is one of the main issues. A new type of measuring device for bioprocess engineering is a small spherical sensor with a diameter below 8 mm, which can be directly brought into such processes instead of using conventional electrodes. Due to the spheres' extremely small diameter of only 7.9 mm in combination with their special encapsulation, the procedure is minimally invasive. Furthermore, innovative bioreactors for new biotechnological production processes frequently make the installation of conventional probe systems impossible due to their design or dimensions, or else they exhibit inhomogeneities.
The spheres are equipped with advanced electronics for the measurement and the communication. The measured data is continuously transmitted to an external base station until the process is completed. Using this information, the base station can immediately influence the process. With a suitable encapsulation of the electronics, the measurement device is minimally invasive. In order to let the measurement device float freely in the fluid, its density has to be identical to the density of the medium itself. For a fully autarkical operation, a battery powers the electronic components. Using a specially developed wireless charging technology, the spheres are charged up again simultaneously after a process is completed. [4]
Until now, the Sens-o-Spheres are equipped with a temperature sensor. In the future, however, the spheres will be combined with other typical measuring devices – for pH values or dissolved oxygen content, for example. The development of the Sens-o-Spheres involved the Fraunhofer Institute for Electronic Nano Systems ENAS, the Technical University of Dresden and four partners from industry.

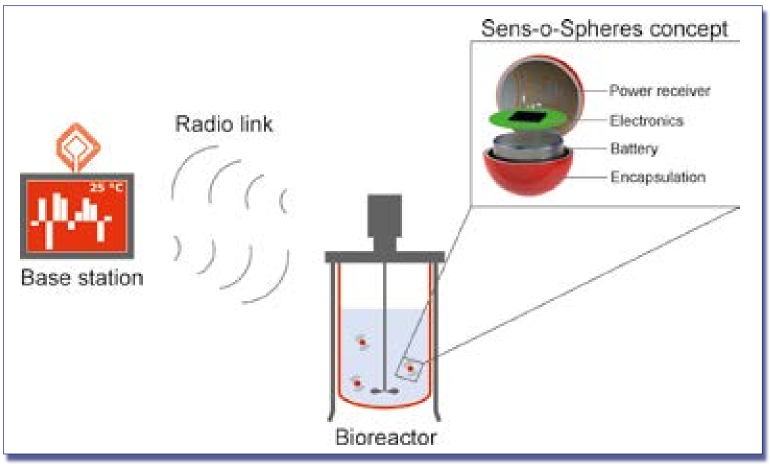

Fig. 4:
Sens-O-Spheres concept

[1] White Paper of Digital Platforms of Federal Ministry for Economic Affairs and Energy)
[2] Strategic Research Agenda of EPoSS (European Platform on Smart Systems Integration)
[3] Lueke, T.: Sens-o-Spheres: mobile spheres as a measuring device. Microelectronic News of Fraunhofer Group for Microelelctronics. 68(2017)
[4] Moebius, M.; Martin, J.; Hartwig, M.; Baumann, R.R.; Otto, T.: Detection of mechanical loads in lightweight structures using quantum dots photoluminescence. Smart Systems Integration Conference 2017 (SSI), Cork (Ireland), 2017 Mar 08-09; Proceedings, pp 423-426, ISBN: 978-3-95735-057-2.Figure 4 Sens-O-Spheres concept and demonstrator

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MEMS Integration on Foundry-fabricated CMOS Backplanes

Due to massive use of sensors and actuators in mobile and industrial applications, smaller systems combined with low power consumption and higher versatility are required. As highly integrated and miniaturized devices System-on-chip (SoC) solutions are offering smallest feature sizes. Especially, MEMS-on-CMOS technology is often the choice to serve these demands. In order to reduce the development costs and time-to-market the combination of standard CMOS processes from foundries with a subsequent MEMS processing is recommended. This technology offers a way to separately drive and adapt CMOS manufacturing and the specific developments of the MEMS part.
MEMS are transducers that sense or control physical, chemical or optical quantities creating devices for applications in the field of 3D-motion tracking, pressure and gas sensing, light shaping or detection of irradiation. The combination of MEMS with an application specific integrated circuit (ASIC) based on CMOS technology enables the entire system to interact with the outside world. These ASICs are providing required features such as analog-to-digital conversion, amplification, filtering, information processing and storage as well as external communication.
Fraunhofer IPMS offers a wide range of surface and bulk micromachining technologies which are particularly suitable for the fabrication of sensors and actuators on CMOS backplane wafers using monolithic integration. Bulk and surface micromachining are applied for a large variety of MEMS devices e.g. spatial light modulators (SLM) and capacitive micro-machined ultrasonic transducers (CMUT).

Micro-Mirror Arrays as an example for MEMS-on-CMOS applications

Micro-mirror arrays or so-called spatial light modulators (SLM, figure 1) may contain several millions of individually addressable and deflectable mirrors. To supply every single mirror with one or more individual voltages the mirror array is driven by a circuit that is similar to a DRAM. The micro-mirrors translate the analog voltages that are stored in simple DRAM cells underneath the mirrors into an analog deflection state due to applied electrostatic forces. This complexity and high level of integration density can only be achieved by monolithic integration of surfaced micro-machined optical MEMS onto CMOS backplanes suppling high voltages up to 35 V.
If no specific high performance materials are needed and the substrate temperature during MEMS processing can be limited to 450 °C the monolithic integration of MEMS on CMOS substrates is the method of choice. All advantages are now on hand – high integration densities, low parasitic capacitances and an effective usage of CMOS area. Figure 2 shows schematics of a setup for monolithic integration and a cross-section through a complete micro-mirror array with MEMS on top of a CMOS.

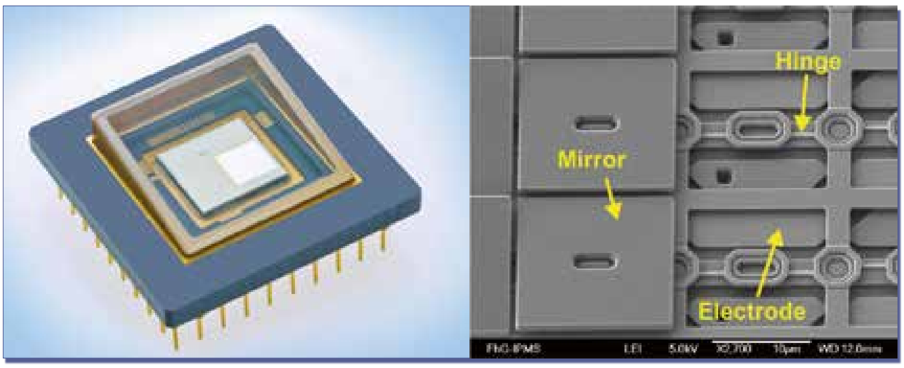

Fig. 1: Spatial Light Modulator (SLM) assembly (left) and SEM image enlargement (right)

Capacitive micro-machined ultrasonic transducers CMUTs

Capacitive micro-machined ultrasonic transducers (CMUT; figure 3) is an emerging application which is using the same surface micro-machining processes as micro-mirror arrays to realize air gaps between two electrodes. Figure 3 shows in left drawings of the working principle – how to detect or generate ultrasonic sound by deflecting top plate and measuring a change in capacitance. The right picture is showing a SEM cross-section through a CMUT cavity. For actuation and readout of the CMUT, a custom specific ASIC concept based on X-FABs 0.35 μm process was developed. It consists of a push-pull stage to generate a high voltage pulse

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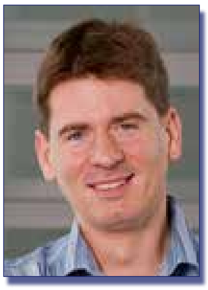

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for transmission mode of the CMUT and a low noise trans-impedance amplifier (TIA) stage for readout in receiver mode. Transmitter and receiver functionality can be switched to the same CMUT cell sequentially. Each monolithic CMUT-CMOS combination builds a single channel "standard cell". An array of those standard cells, connected to a common supply voltage and a digital bus, in combination with a programmable delay for each cell and a common synchronization, offers the system designer the ability to build highly specialized systems and arrays for medical and industrial applications.

Solutions for MEMS-on-CMOS integration on foundry-fabricated CMOS backplanes

In a typical project flow CMOS and MEMS parts will be manufactured and tested independently and in parallel to shorten development time. After decision for a foundry partner and finalization of ASIC design using its process design kit (PDK) a Multi- Project- Wafer run (MPW) in the selected CMOS foundry shall follow. Using these MPW runs a complete characterization of CMOS functionality can be realized in an early project state at low costs. Parallel to CMOS testing the entire MEMS process development can be realized on passive devices (w/o CMOS) in our MEMS fab. If CMOS and MEMS characterization is completed the MEMS part will be monolithically integrated on these customized CMOS backplanes. Fraunhofer IPMS is offering profound knowledge and technology solutions to face specific challenges for the integration of MEMS on foundry-fabricated CMOS backplanes such as:

- Modifications of last CMOS and interconnect layers (metal / ILD) to realize an appropriate and adopted interface to the following MEMS processes
- Clarification of PCM test environment, depth of test structures and possible arising contamination issues
- In-chip surface topology after interconnect processing to define necessary actions to achieve required planarity for further processing, especially for optical applications
- Tuning mix & match lithography to achieve high overlay accuracies
- Required chip design features when using sacrificial layer technology, e.g. using SiO_2

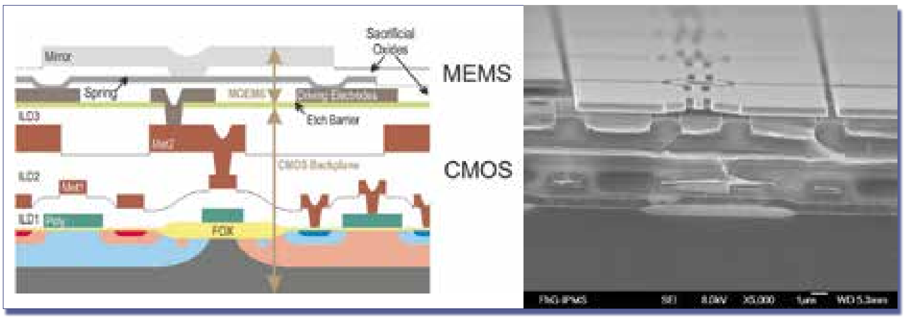

Fig. 2: Monolithic integration of a complex Micro Mirror Array (SLM)

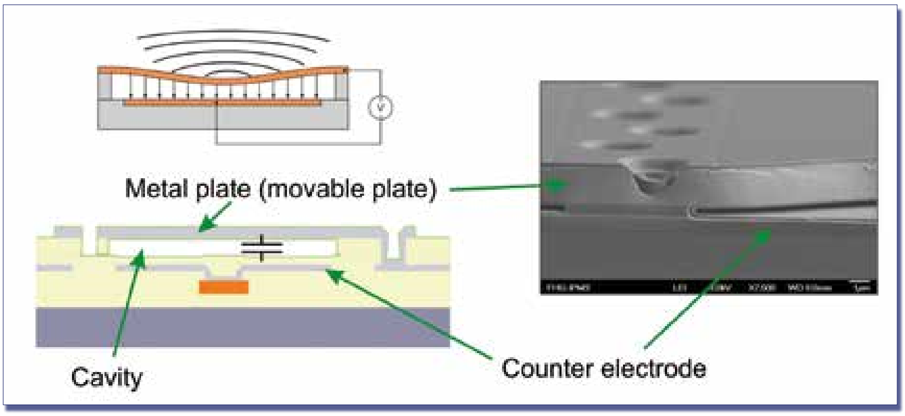

Fig. 3: CMUT Principle (left) and a SEM cross-section through a CMUT cavity (right)

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New Current Sensors for High Power Density Power Electronics

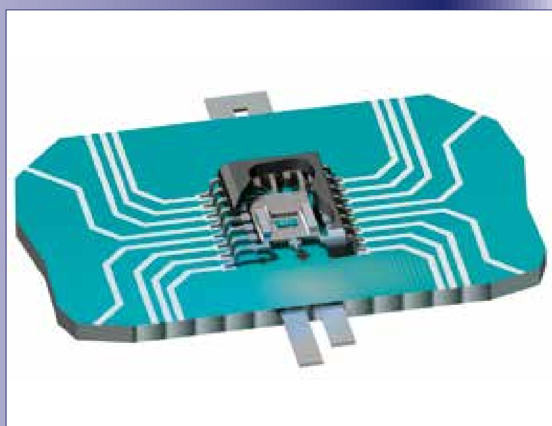
Electrical currents need to be measured in a wide variety of different applications in the field of power electronics. However, the requirements for these measurement devices are becoming steadily more demanding regarding accuracy, size and especially bandwidth. In order to increase the power density of power electronics, as particularly important in the field of electromobility, there is a clear causal chain. Soft switching leads to higher efficiency and higher frequencies, which enable smaller dimensions for a given power output. Higher switching frequencies allow the size of magnetic components to be reduced significantly, resulting in more compact and lighter designs. This trend is now being reinforced by use of new wide bandgap semiconductor materials like silicon carbide (SiC) and gallium nitride (GaN), as their low on-resistances and low parasitic capacitances reduce switching losses. In order to meet the above mentioned requirements, magnetoresistive (MR) current sensors are ideally suited due to the fact that the bandwidth of the MR-effect extends up into the GHz-range.

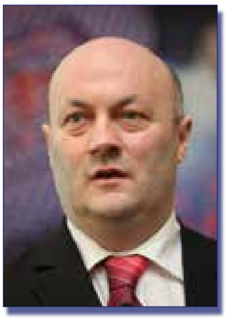
The MR-effect is particularly attractive in the field of electrical current measurement. The very high sensitivity means that there is no need to use an iron core to concentrate the magnetic field generated by the conductor carrying the current. This means that MR-based current sensors do not suffer from hysteresis and that they have a significantly higher bandwidth, enabling current sensors with bandwidths in the MHz area. Compared to shunt resistors MR-based sensors have the benefit of galvanic isolation and dramatically lower power losses. This is particularly important in high voltage applications and where overall power efficiency is a major design driver.

The new programmable current sensor CFS1000 has been developed for the highly dynamic electronic measurement of DC, AC or pulsed current with integrated galvanic isolation. The sensor device consists of an AMR sensitive sensor chip, a signal conditioning circuit and two biasing permanent magnets. The latter are for maintaining the initial magnetization direction of the AMR structures in the cases of high overcurrent spikes. Due to the high sensitivity of AMR sensors, a flux concentrator is not necessary. It is designed for high resolution and very fast electronic measurement and enables a differential magnetic field measurement by an advanced geometry of the MR elements. Due to this arrangement the sensor is immune to homogeneous interference fields. By variation of the geometry of the external primary current conductor the system can be adapted to different current ranges and applications. The permanent magnets material and the AMR-sensitive sensor material are applied on wafer substrates by a special process, thus can be processed further on with standard semiconductor methods, concern-

Fig. 1:
CFS1000 current sensor: programmable SMD housed AMR current sensor from Sensitec.

Fig. 2:
CFS1000 current sensor consisting of AMR sensor chip, signal processing circuit and two bias magnets.





Dr. Rolf Slatter
Sensitec GmbH

ing singulation or assembly. A special leadframe as well as an advanced assembly technique enable a "system in package" (SIP) solution. All system components are overmolded within a JEDEC compliant SOIC16 housing. The product can be mounted with standard pick-and-place equipment onto a PCB and subsequently reflow soldered.

The sensor is measuring the field gradient of a magnetic field H. The field gradient can be created in general by two arbitrarily shaped current lines with opposed flow directions. This primary current conductor is typically U-shaped with its straight parallel parts underneath the sensor. The primary current to be measured is fed below the sensor on a PCB or through a busbar. Using a U-shaped conductor allows the generation of a differential magnetic field that reduces the influence of external magnetic stray fields. Due to the high sensitivity of the AMR sensor an excellent signal resolution can be achieved.

The external primary current conductor concept provides on the one hand a very good dielectric isolation towards the sensor, and secondly enables a flexible design concerning different current ranges. The sensor system works in closed loop operation, providing high linearity and a low temperature dependency. An adjustable fast overcurrent alarm output ensures immediate reaction to overload events to protect connected devices. In order to optimize the overall system accuracy, the CFS1000 current sensor allows end-of-line calibration directly in the end device.

One particularly interesting application field for high-speed current sensing arises for DC/DC converters (Fig. 3). The requirements for the bandwidth is rising into the MHz range in order to increase the power density. But also in safety critical applications, e.g. in traction inverters, where overcurrent situations need to be detected in the ns-range, extremely fast current sensors are necessary. Further applications are in the automotive sector, electrical speed drives (industry, e-mobility), in frequency converters, for battery management and renewable energy. The high bandwidth combined with high precision enable users to achieve a higher power density in their power electronics, particularly when the sensor is used in combination with new wide band gap power transistors. Sensitec offers an evaluation board for those new to the technology who wish to learn the features and benefits of the current sensors in a quick and simple manner (Fig. 4).

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Fig. 3: CFS1000 attached to controller board of a DC/DC converter (source: Fraunhofer IISB)

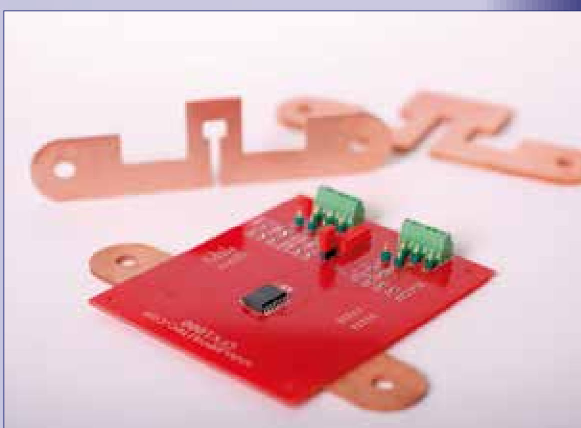


Fig. 4: CFK1000 Demoboard: offers the opportunity to learn the features and benefits of the CFS1000 current sensors in a quick and simple manner.

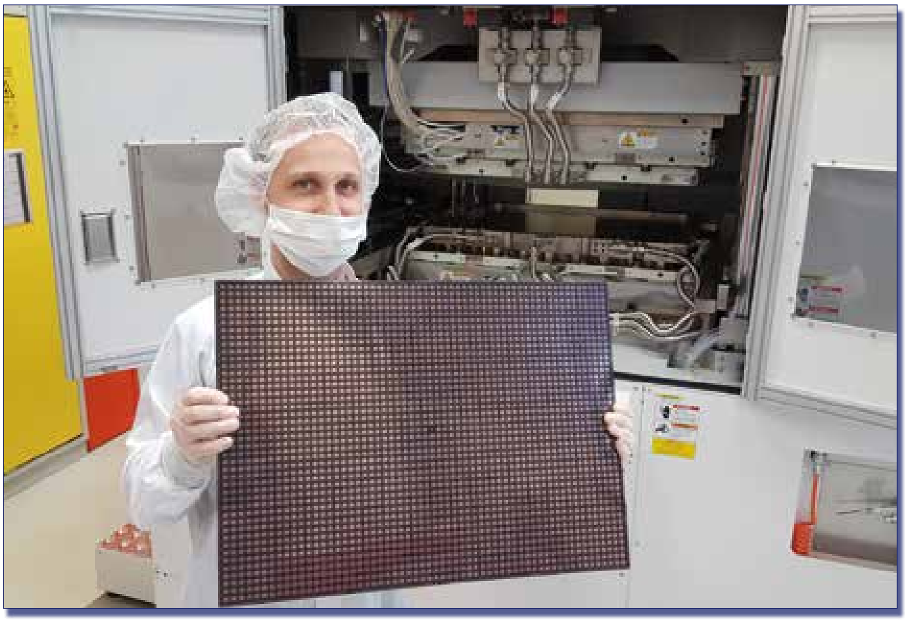
Panel Level Packaging as a Future Platform for ICs and Sensors

Wafer level packaging (WLP) using redistribution layer technology (RDL) was the winner for being the optimal chip-scale package (CSP) combining low cost, smallest size and high electrical performance. This package was the only possibility to solve the dilemma for moving flip-chip assembly to printed wiring boards (PWBs) using a ball grid array (BGA). Unfortunately Moore's Law is still shrinking the die size from year to year. Fan-out WLP has therefore been developed to stay on a relaxed BGA pitch through the creation of additional space by embedding the chips or other components like sensors for heterogeneous integration into the planar molding compound. The components are separated from each other by a space filled with the epoxy resin that is used to enlarge the footprint for the RDL to a relaxed BGA pitch for the PWB assembly. Only pre-tested known good dies (KGDs) are used for this embedding process. A kind of reconfigured wafer is therefore created. The components are glued on a carrier foil or glass plate and are overmolded. The carrier is then removed and the active side of the components can be used for the RDL.

Fan-out wafer level packaging (FOWLP) has already been proven as one of the most versatile packaging technologies in recent years for hand-held, automotive and other advanced applications. The technology combines high-performance and increased functionality with a high potential for heterogeneous integration and a reduction in the total form factor. Main advantages of the FO-Packages are:

- Exceptionally thin package requiring no substrate
- Low thermal resistance
- Excellent RF performance achieved by short and planar connections with bump-less chip connections instead of e.g. wirebonds or soldered contacts
- Substantial reduction of inductance compared to FC-BGA packages
- Optional integration of functional components like capacitors, resistors, inductors, or antennas in the redistribution layer
- Design of multi-chip packages and systems-in-package (SiP)

Especially the inductance of FOWLP is much lower compared to FC-BGA packages. In cooperation with TU Berlin Fraunhofer IZM intensively works on this topics, in publicly funded projects as well as in direct industry cooperation. Within the H2020 project "smart-MEMPHIS" the goal is to design, manufacture and test a miniaturized autonomous energy supply consisting of a piezo-MEMS energy harvester, power management circuitry and energy storage. Target applications are a lead-less pacemaker and structural health monitoring, the packaging technology of choice for maximum miniaturization is a fan-out panel level approach. Furthermore low cost technologies are developed in the BMBF-funded project "InteGreat", also based on large area mold embedding. An advanced and cost effective LED package is here the project goal. Industry projects are focusing among others on the evaluation of new materials for FOWLP for RF applications and process development for optical sensor systems.



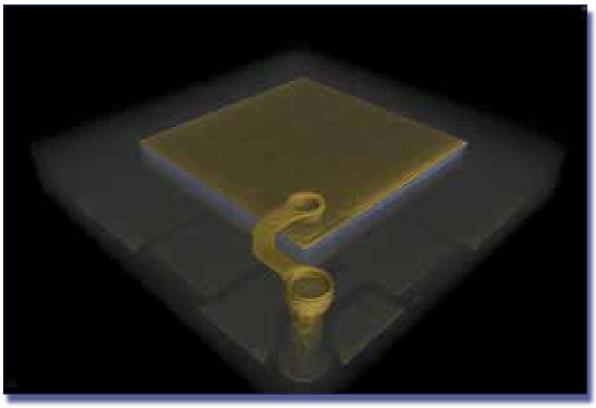
Embedded chips in molding compound Panel Level Packaging on 18" x 24" (457x305 mm² panel size)

Dr. Michael Töpper

Dr. Tanja Braun

Multiproject wafer technology which is well established for Si wafers offering a fast and cost effective access to a low volume number of chips as multiple clients share the cost for one manufacturing run can be also expanded to the FOWLP-concept. Here even dies from different sources or different technologies with varying thickness and size can be combined into WLPs. Basis for this approach are common design rules including package size and thickness, number of layers, layer thicknesses, lines and spaces, via diameters and others. The move of FOWLP from 200mm to 300mm, or to 330mm technology is a dead-end pathway on account of the limits of existing wafer size formats that will not change in the near future. Additionally, the 450mm wafer size is still postponed. The move to panel level processing will push the technology further to a real low-cost processing. This can be viewed as a merge between the embedded die technology based on PWB infrastructure, and FOWLP technology based on the wafer level. Higher productivity can be achieved and packaging costs can be brought down by the current trend to move from wafer to panel formats, scaling FOWLP up to fan-out panel level packaging (FOPLP). Common panel sizes can reach 610 x 457 mm² (24 x 18 inch standard in PCB production) or larger.

Fan-out packaging of LEDs with double-sided routing including


X-Ray image, 3D routing with embedded LED

Fraunhofer IZM in Berlin has initiated a panel level packaging consortium with the goal of acquiring advanced process technology steps for the move to a large format. A fully-equipped wafer processing line for Si wafer and glass wafer sizes between 100 and 300mm is running for prototyping together with a full panel level line for substrates up to 18" x 24" in size. In total, Fraunhofer IZM has invested several millions of euros to install a completely new and state-of-the art panel level processing line. This investment enables pre-competitive activities which are further driven by an international consortium from the United States, Japan, Taiwan, and Europe headed by Fraunhofer IZM. Members of the consortium are Ajinomoto, ASM Pacific Technology, AT&S, Atotech, Brewer Science, Evatec, Fujifilm Electronic Materials, Hitachi-Chemicals, Intel, Meltex, Merck, Mitsui Chemicals, Nanium (now part of Amkor), Semsysco, ShinEtsu, SüssMicroTec and Unimicron. The main objectives of the consortium are the evaluation of materials and equipment for world-class PLP technology, the development of all necessary processes, the consolidation of the process flows, the evaluation of yield and cost issues, and the establishment of standardized equipment and material solutions for fan-out packages. With Fraunhofer IZM as the development hub in Berlin, the consortium is committed to powering the transition to a new global production standard.

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Quality and Process Flexibility with Glass – The Advantages of New Glass Wafer and Substrate Materials for MEMS Packaging

Yutaka Onezawa examines the demanding requirements for MEMS devices and how TGV (Through-Glass Via) substrates are helping to meet them by rising to the reliability challenge.

In recent times, there has been a staggering increase in global demand for Micro Electro Mechanical Systems (MEMS) – an industry trend forecast to continue[1]. These tiny powerhouses are changing the world through their use in smartphones, medical devices, datacom, and industrial automation. As powerful as they are, these micro-machines are also inherently fragile. This presents a challenge: how can we protect MEMS devices to support their long-term functionality in harsh working environments? Hermetic packaging provides an answer: its outstanding protective properties and reliability support the precise operation of MEMS devices. At SCHOTT, we have taken our outstanding competence in glass wafer technology and combined it with more than 75 years of experience in hermetic glass-to-metal sealing to develop some of the most advanced and reliable MEMS protective packaging available today.

Limitations of Through Silicon Vias (TSV)

The use of through-via technology for 3D WLCSP (Wafer Level Chip Size Packaging) is not new. However, using silicon wafers in high-volume production has been limited for numerous reasons. Customer designs generally require multiple vias for each chip. Because silicon is half-conductive, a thin oxide layer (usually copper) must be applied to the vias using a plating process. This can produce bubbles in the copper vias, resulting in poor conductivity and a low-quality chip. Furthermore, CTE mismatch of the materials can lead to reliability issues caused by 'via peeling.' Defect rates of TSV vias are typically between 2 to 3%. However, if there are 20 or more vias per chip, the defect rate would increase to a prohibitive and unacceptable 50%.

Through Glass Vias – Superior Reliability. Smallest Via-Pitch.

From the idea to develop miniaturized, fully hermetic 3D WLCSP, SCHOTT created HermeS®, a glass substrate with hermetically sealed "Through Glass Vias" (TGV) to allow reliable conduction of electrical signals and power in MEMS devices. HermeS® glass wafers combine solid metal vias with glass, which offers superior characteristics such as high mechanical, thermal and chemical resistance. The low dielectric constant of glass offers excellent RF properties, while highly conductive solid metal vias

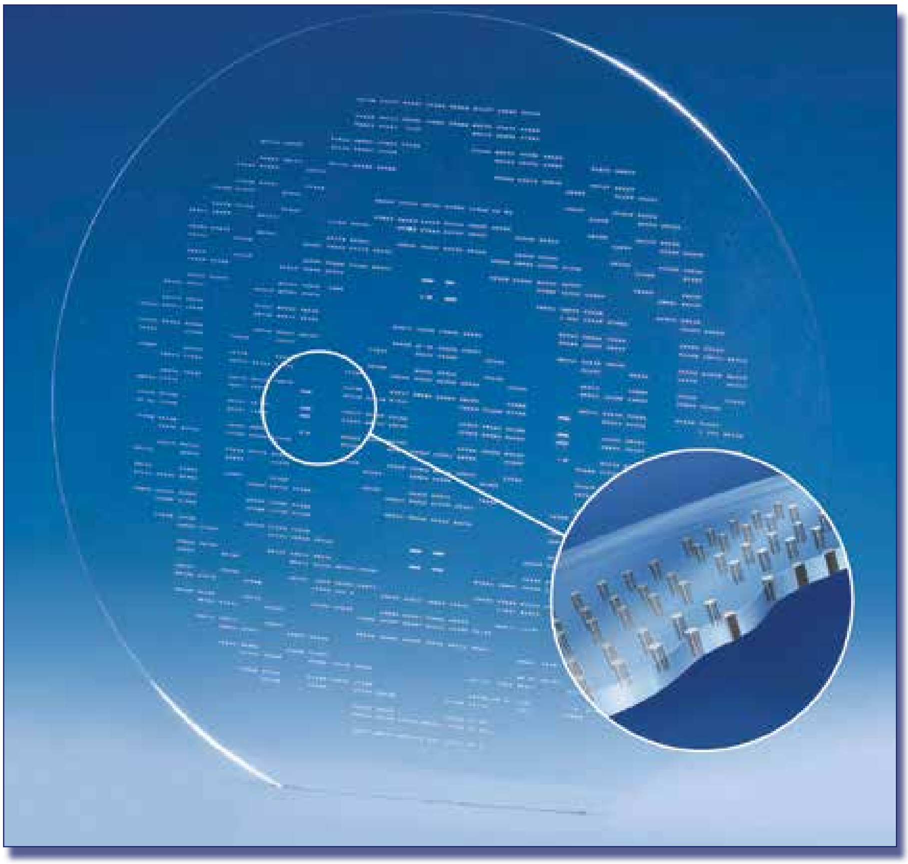

Fig. 1: One of the advantages of SCHOTT HermeS® compared to TSV (Through Silicon Vias) is optical transparency of glass. It enables better processing and quality control during the production process of a MEMS device. Image: SCHOTT

enables high-performance electrical and thermal pathways to the PCB.
Solid metal vias are directly embedded in the glass substrate, enabling extremely fine via pitches with up to 90,000 vias per wafer. Matching CTE allows glass wafers and metal vias to bond without any interface materials. TGV provides long-term gas-tightness, even after reflow (260°C) and anodic bonding (350-400°C). This superior technology allows for usage in a wide temperature range and supports reliable MEMS devices with a smart design.
In contrast, other TGV suppliers use a multi-stage mechanical drilling process for the vias that are then filled with copper. Due to low adhesion between glass and copper, this can result in via peeling, leading to hermeticity loss and electrical conduction issues. This mechanical drilling process also limits the number of vias, as the quality suffers significantly beyond 10,000 vias per wafer.

Fig. 2: SCHOTT HermeS® glass substrate wafers with hermetically sealed Through Glass Vias (TGV) are available in several glass/metal configurations, depending on the application. Via pitch and overall layout can also be configured by the customer (with the specifications of the chosen glass/metal combination). Image: SCHOTT

Benefits for Industrial, RF and Medical MEMS Applications

HermeS® TGV substrates are compatible with established glass-bonding processes. This provides benefits for MEMS devices, especially MEMS sensors and switches used in harsh environments, as they require hermetic packaging in order to work precisely and reliably.
The excellent RF properties of HermeS® also enable improved power efficiency, greater bandwidth and better environmental isolation in a simplified hermetic package for RF-enabled MEMS devices. TGV glass wafers offer opportunities for medical MEMS: in addition to sensors and blood analysis systems, the superior reliability and miniature design of HermeS® enables utilization in miniaturized devices, whose successful commercialization is dependent on the reliability of the hermetic package.

Conclusion

Huge demands are placed on MEMS-powered devices and sensors for both reliability and performance, and these will only continue to grow as utilization of these devices continuously increases. TGV glass wafers present an answer to the application demands for these devices. Drawing from over 130 years of experience in specialty glass and materials, SCHOTT has developed HermeS® TGV glass wafers to solve the challenges of wafer-level packaging for MEMS devices, both today and in the future.

[1] http://www.sensorsmag.com/components/mems-market-expected-to-reach-26-8-billion-globally-by-2022

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Novel Printed Circuit Boards – Innovative Solution based on Polyurethane for Flexible and Stretchable Systems

Abstract

Up to now, many technologies have been developed for the manufacture of stretchable electronic systems based on conventional circuit board manufacturing processes. In these novel electronic systems made of new material polyurethane, properties such as flexibility, stretchability as well as robustness are combined. As a result, these circuit boards conform to free-form surfaces and are ideally suited for integration into textiles or wearables. The soft and skin-friendly properties of polyurethane are predestined for the use in medical applications as well. In some projects with customers in the field of medical, sensor and automotive technology, different stretchable printed circuit boards based on polyurethane have been manufactured. Stretchable FPC, textile-integrated bandages and light systems, electrode arrays for EMG are some examples.

Stretchable Printed Circuits

Electronic systems that retain their functionality during mechanical deformation enable new features such as the ability to adapt to any desired shape or could be strain reversibly, and are therefore used in many areas such as medical technology, prosthetics, aircraft and automotive, softrobotics and textiles. New designs based on polyurethane printed circuit boards allow the creation of innovative ultra flexible and stretchable systems. These circuit boards are realized through conventional etching techniques whereby the extensibility of the metallic conductors can be achieved by a special meander design. Since copper has low intrinsic extensibility, the interconnect patterns should be shaped into a suitable two-dimensional geometry. Depending on the conductor geometry, an expansion between 5 and 20% for dynamic applications and up to 60% for a single expansion is also possible reliably. The so-called "horseshoe" structures have been particularly successful (Figure 1). Extensible structures can also be designed with half circles or rectangular meander shapes as well. Single-sided and double-sided circuit boards as well as flexible systems with partial stiffener are offered under the name TWINflex®-Stretch (Figure 2 and 5).

With suitable surface finish, skin-friendly or even biocompatible circuits based on Polyurethane can be realized. These printed circuits are capable of conforming to a wide range of shapes and contours, enabling applications on and for humans.

Polyurethane Foils

Thermoplastic polyurethane is made of diols and isocyanates without any plasticizers and is available in different physical modifications from hard to soft to elastic. In daily life, we often encounter polyurethane in foamed modification. The products such as mattresses, soles or imitation leather are made of this material. In addition, polyurethane is known to have characteristic properties such as high surface energy, scratch-resistance, self-healing effect, high tear propagation and quite good thermal insulating. For this reason, this material is often used as a surface coating of furniture or fittings, as a thermal medium or as a filler to increase the stability of building structures. In the electronics industry, polyurethane is used as an adhesive or encapsulation material at most. Thermoplastic polyurethane foils as carrier material in the circuit board industry are an ultimate innovation.

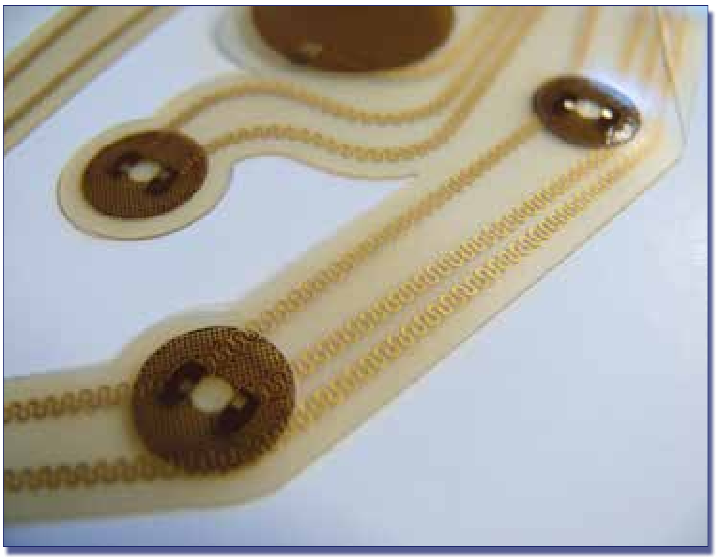

Fig. 1: Example of Polyurethane Printed Circuit Board with Meandering Shape of Conductors

Dr. Alina Schreivogel

These elastic films adhere excellently to copper; they have good physical and chemical stability, so that they can also be used as a base material for circuit board technology. Multiblock co-polymer chains consist of hard and soft segments. In this way, contrasting properties are combined such as flexibility or extensibility as well as robustness and resistance. Polyurethane circuit boards are available in 50-200 µm thickness and are assembled at <180 ° C.
As a new base material for printed circuit boards polyurethane provides an innovation boost in electronics. Whilst the focus is not only on electrical performance, but also on properties such as elasticity or softness. Furthermore, the processing technologies are also a significant factor since the novel printed circuit boards can be glued, welded, formed, overmolded etc.

Application Examples

Due to its wide profile, stretchable circuit boards are used in a wide range of applications in the fields of medicine, sensor technology, automotive, portable, textile electronics or softrobotics.
Also encapsulated, overmolded or combined with 3D printing technology, polyurethane circuit boards are transformable in any shape. A remarkable supplement to them is the deep-drawing process or thermoforming. SMD-assembled polyurethane circuit boards could be laminated to a suitable polymer carrier and then made into the desired shape by thermoforming process.
Textile electronics and wearables are an integral part of everyday life. The electronics or sensors are often connected via the cables. Polyurethane conductor similar to flexible printed circuit can also remedy this. Lightweight, stretchy and semitransparent printed circuit boards can be laminated directly onto the textiles and thus ensure a high wearing comfort. As an example, a jacket for cyclists with interactive safety lighting onto polyurethane circuit is shown in Figure 3. Another example shows an electrode array for electrical stimulation of the muscles (Figure 4). This polyurethane circuit board has several electrode elements with silver finishing and can be used in rehabilitation of paralyzed muscles, for example in the case of stroke patients. The stimulation takes place via individual or over all electrode elements. Thus, several muscle groups can be addressed. The flexibility of the polyimide is not sufficient for this application. The particularly soft, pliable and skin-friendly polyurethane, however, fits very well and comfortably to the irregular shape of the forearm and leaves fewer marks on the skin. Similar applications directly on the skin or embedded in a textile can be implemented with this technology.

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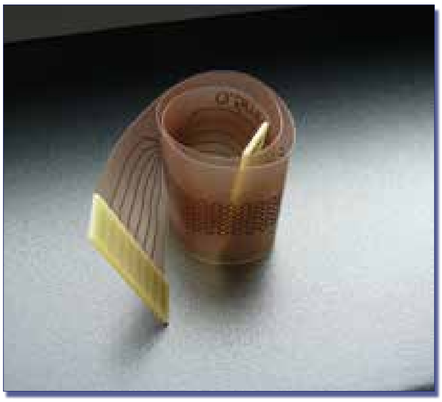

Fig. 2: TWINflex® PCB Made of Polyurethane with Partial Stiffener

Fig. 3: Example of Use: Cyclist Jacket with Embedded Polyurethane Circuit Board (Utope, Wolfgang Langeder and Fraunhofer IZM)

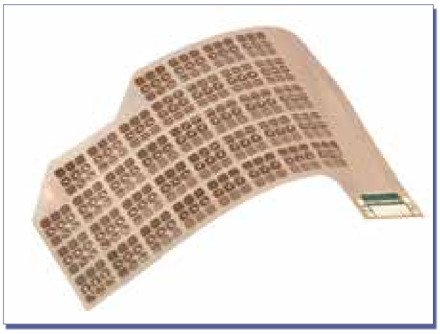

Fig. 4: Example of Use: Electrode Array for Electrical Stimulation of the Muscles Based on Polyurethane Circuit Board

Fig. 5: Stretchable Polyurethane Based Board

Smart Microsystem Technology: Self-optimizing Ultra-high Precision Assembly Processes

Tobias Müller, Group Leader for Precision Assembly and Automation
Sebastian Sauer, Research Associate for Precision Assembly and Automation
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Short product life cycles combined with dynamic markets are driving steep increases in the complexity facing manufacturing companies. Companies need to be able to scale up or down production whenever the market demands a higher or lower quantity. Additionally, the diversity in customer requirements calls for the capacity to apply the very same production solution to manufacture a range of products or product variations. The need to meet both of these demands in equal measure, presents a challenge which is virtually insurmountable via organizational measures alone. For although a certain degree of flexibility in terms of increased output can be achieved through organizational changes, the limitations quickly become clear when new staff have to be trained in order to increase the production volume. Generally speaking, complex micro-assembly processes for technologically demanding products can be performed only by highly experienced employees. Whilst adaptive, self-optimizing automation solutions certainly have the potential to improve the flexibility of the company, they still have a number of obstacles to overcome as far as product and product variations are concerned.

In order to remain competitive, manufacturing companies must learn not simply to reduce complexity but to make complexity manageable. To this end, the German Research Foundation is funding the "Integrative Production Technology for High Wage Countries" project involving more than 25 interdisciplinary partners from the RWTH Aachen University and the Fraunhofer Gesellschaft. The overarching aim of the project is to bridge the gap between scalability and diversity of variations in order to exploit economies of both scale and scope. Approaches from planning and value orientation are pooled in order to achieve this within the project. The Fraunhofer Institute for Production Technology IPT addresses the adaptability of production solutions, of individual machines and even of entire production networks in this project and specializes in planning complex production process chains. The institute in Aachen is pursuing the self-optimization approach; The self-optimizing production solution is thus characterized by a reduction in the planning required. This is achieved by providing the production system with cognitive capabilities, for example. These enable the system to react autonomously to uncertainties in the process.

Three basic principles for self-optimizing production

To be capable of taking action, a self-optimizing production system requires the following three characteristics: Firstly, perception to be able to understand the environment or selected parts of it. Secondly, cognition, in order to process information and draw conclusions and thirdly, the actuator technology, which describes the capacity to influence the environment physically. The perception and actuator technology categories are easily accessible to the production engineer. These include sensors and data collection systems as well as the kinematics of robot and gripper mechanisms. However, the cognition category is likely to raise questions and perhaps even skepticism in the minds of technologists. One of the aims of the Fraunhofer IPT in its engagement with Industry 4.0 is, therefore, to develop and refine new, adaptive micro-assembly systems with self-optimizing capability

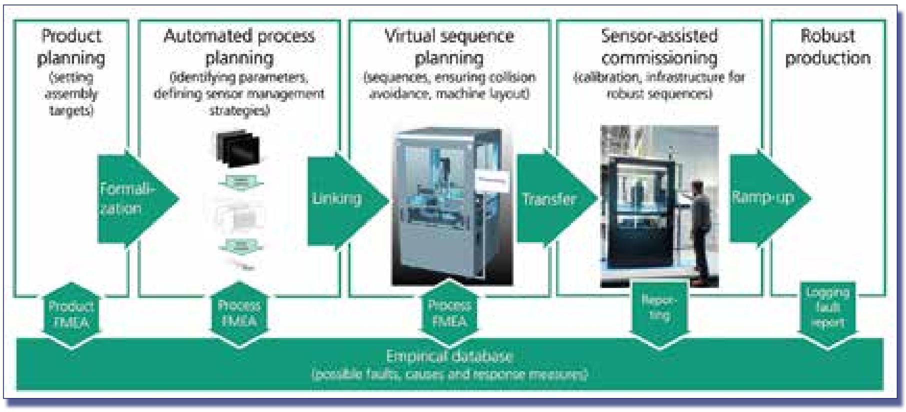

Fig. 1: Model-based machine tool chain for complex, sensor controlled assembly processes

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and to refine them to the point of compliance with industrial standards.

The keys to success lie in the digitalization and so-called activation of models produced via computer-aided design (CAD) and other modelling and simulation environments. The combination of previously developed models and well-matched smart algorithms ensures that the production system can cope even with situations which arise unexpectedly and make the right decisions autonomously. As a result of the application of digital models, micro-assembly processes can be planned without the need for costly machine capacity as this type of process planning can be conducted completely offline. The steps involved in progressing from a product model to a robust production process are shown in Figure 1.

From virtual reality to a micro-assembly cell

The greatest challenge facing the model-based approach lies in how to transfer processes planned offline to actual production systems. This is due to component and manufacturing equipment tolerances which cause uncertainties for the process control. Sensor and image processing systems provide sensing or perception. These permit calibration routines to be implemented, ensuring that processes planned offline can be performed on actual production systems despite existing tolerances.

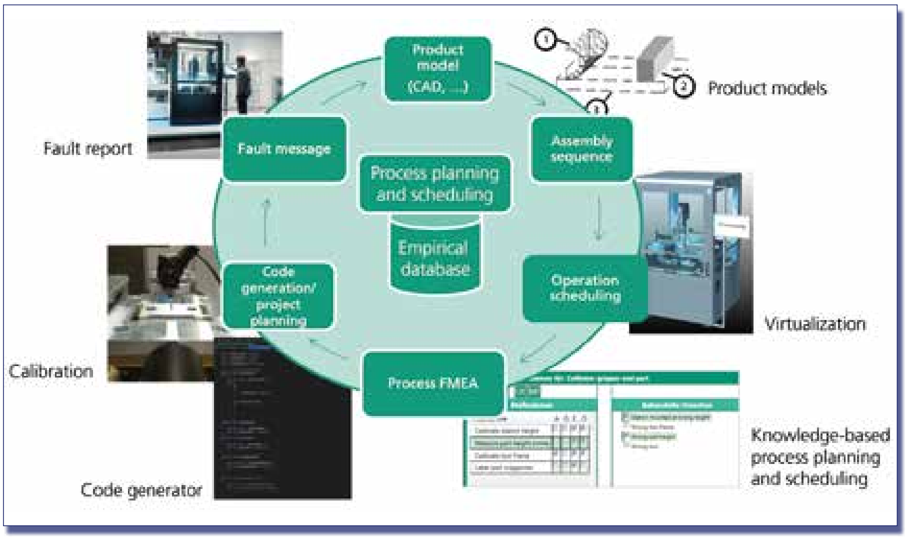

Fig. 2: Model and experience based cycle for planning complex processes

Tool box for the process planner

The planning software creates links to product models from which parts lists, for example, can be imported. A specially developed software module permits the components which have to be joined to be identified and the micro-assembly targets to be set and adhered to. This results in an assembly sequence which can be defined independently of the assembly hardware. At this point there is a leap into a virtual planning environment containing the assembly line´s digital twin: Final touches can be put to the assembly sequence in the virtual environment and the planning process is supported by automated path planning algorithms.

Digitalization and modelling have already come to be regarded as important basic technologies for companies committed to adaptive production. Equipped with efficient and smart algorithms whose cognitive skills look set to expand substantially, they form the interface to the world of information technology and data processing. Industry 4.0 has the potential to maintain and even to further increase the value-added component in high wage economies in the long term.

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How do my Microsystems become Intelligent and IoT-ready?

Dr. Tolgay Ungan,
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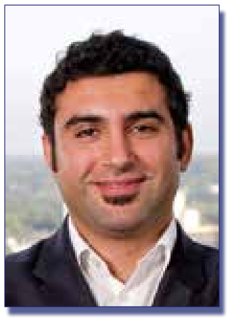


Application scenarios of endiio wireless technology

How do intelligent microsystems and "being a father" fit together? That's what I had to think about when, one Monday morning, I was faced with the urgent situation that my little son had fallen ill. My wife had to leave for an important appointment. And as a modern father, I was required not to drive to my workplace, but to support my sick child as a caring father. And with the attention that this health crisis required. But what did this mean for my professional duties on this day?

As a managing director, I always have to keep an eye on the fate, systems and employees of my company, I want to be reachable and know that if problems occur in the company, solutions will be immediately examined and initiated even if I am not present. I realised that there are other parents in similar positions who try to meet all professional and personal needs, and who need support.

Intelligent microsystems through new wireless technology

To return to the initial question: how can intelligent microsystems help in such situations? What information do CEOs need to keep track of everything via smartphone or tablet? endiio has solutions for these and many other challenges. We invented and patented a completely new wireless technology for this purpose. Through the interaction of sensors, this intelligent network provides continuous data analysis, which presents to me in real time what is happening in my company, in production, delivery, monitoring, security, etc. etc. etc.

Intelligent microsystems provide real-time solutions

Let me go into detail with some examples. I would like to describe application scenarios and show you where endiio wireless technology can be used: Suppose my company uses photovoltaic energy to generate energy. Here, the biggest security risk is the risk of fire. Switching off individual solar modules must be possible immediately and at any time in case of danger. I need to be able to do this, even if I stay at home with my sick child. Intelligent microsystems can now provide real-time shutdown of affected solar modules, real-time problem reporting, and manual repair or replacement by using hardware-attached sensors and endiio wireless technology. For example, I hear about it at home through a brief notification while I support my son. While he is asleep, I briefly use the tablet and see real-time data in my endiio cloud. There, all data of the activated wireless modules are transmitted via the endiio gateway and a data line. At a glance, I see the complete analysis of all data sent and which solutions have already been initiated. That gives me peace. Everything is proceeding in the usual way. I go back to concentrating on my duties as a father.

Intelligent microsystems monitor power-saving cooling systems 24/7

A second scenario could be more relevant for the outlined health situation in the example shown. Let's say we need medicines to provide medical care for my sick son. For example, there would be an "encounter" with another endiio operation site in the field of temperature

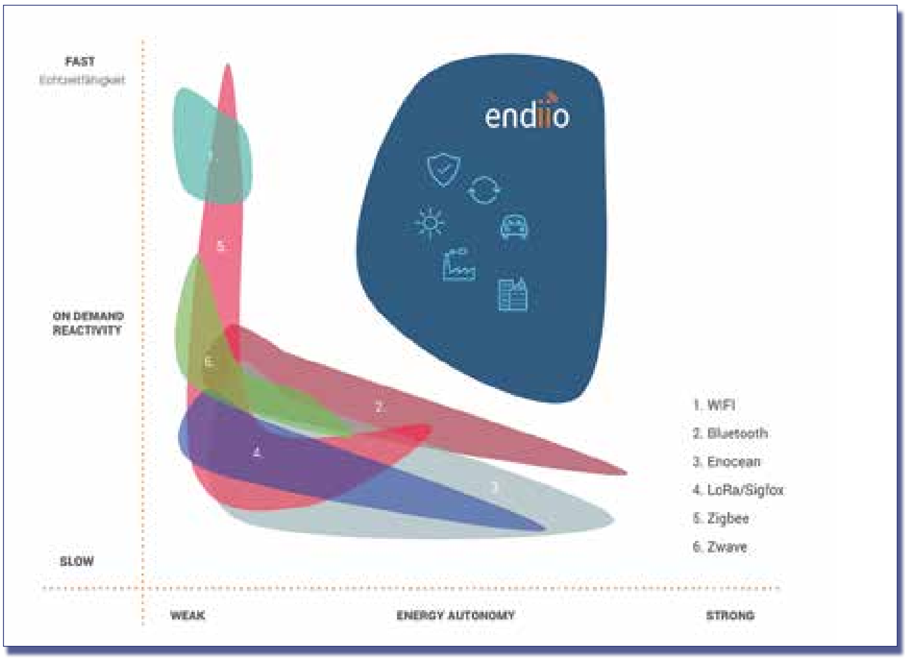
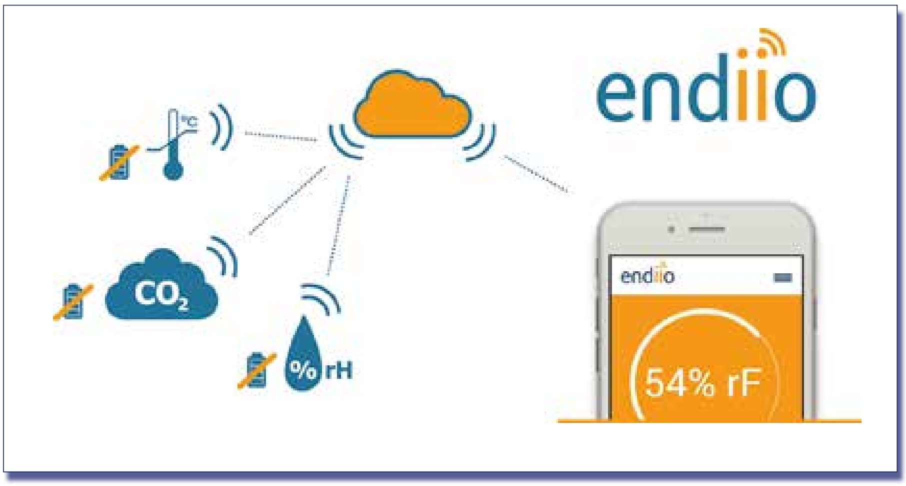


Fig. 1: endiio wireless technology is real-time and low power as the only one.

Fig. 2:
endiio IoT solution from the wireless module to the cloud from a single source.

Fig. 3
Self-powered sensor platform without batteries enables retrofit IoT applications.



control in cooling systems. Sensors with an integrated endiio wireless module are used there to detect and regulate temperatures of refrigerators in the pharmacy sector. And in the event of a system failure, it will be important that an error message triggers an immediate repair in real time. This allows endiio to ensure that the cold chain is not interrupted, so as not to limit the effectiveness of the medication. This application scenario requires stable and temperature-resistant sensors and, of course, seamless data transmission (24/7) thanks to sensors with an integrated endiio wireless module. With properly supervised, stored and transported medicines - and of course the assistance of his father - my son will soon get better.

Economical intelligent microsystems

The new endiio wireless technology overcomes traditional technology boundaries, works in real-time mode and now the best thing is done - up to 10,000 times more efficient than with all conventional communication solutions. Thanks to energy harvesting and wake-up technology, power consumption is reduced to a minimum in an accessible state and maintenance-free and batteryless operation for decades is guaranteed.

endiio offers IoT platform to test new business models

For sensor manufacturers and system integrators, our maintenance-free and easy-to-install endiio IoT platform offers overwhelming opportunities to test new business models and then adapt the software to the new application, without altering or even touching the hardware. New wireless products and wireless services can quickly be created with our Rapid Development Kit's end-to-end IoT solutions. This makes it possible to ensure availability, power consumption, communication range, network size or security level, without compromises. The endiio wireless module complies with the latest ETSI code EN 300 220-2 V3.1.1.1 (2016-11) for Europe.

One-stop solution for intelligent microsystems

The endiio wireless module is available as a certified Internet of Things (IoT) solution for both OEM systems and as part of the endiio Evaluation Board. It is also part of a modular building block system for implementing multiform IoT applications and enables fast and cost-efficient integration of endiio technology into a wide variety of products and solutions. endiio offers an IoT solution from the wireless module to the cloud from a single source. When implementing new IoT solutions, endiio partners with developers and OEMs to bring innovative products to the market in a cost-efficient and rapid way, and to improve existing solutions. I am very curious to see which common paths will arise here.

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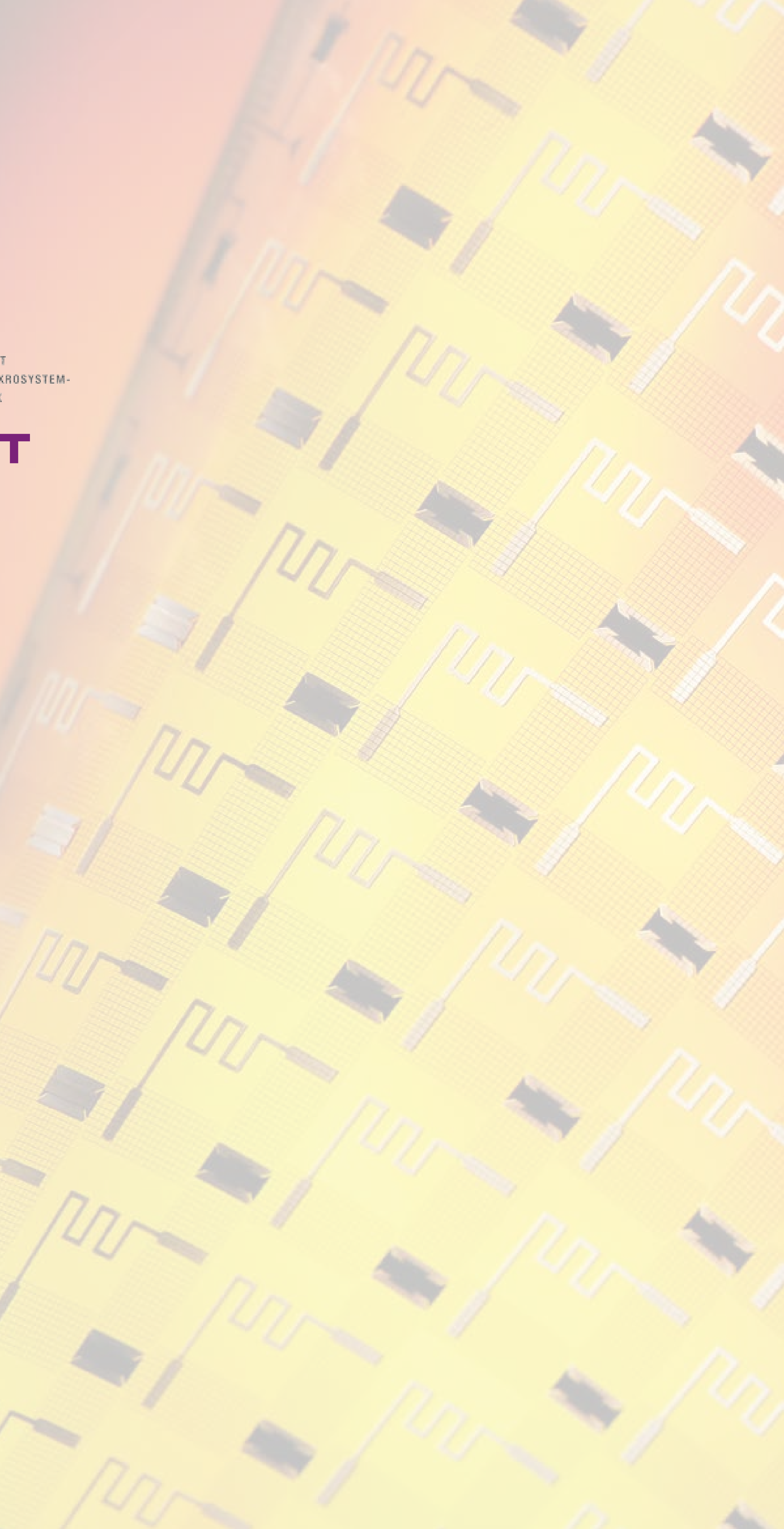

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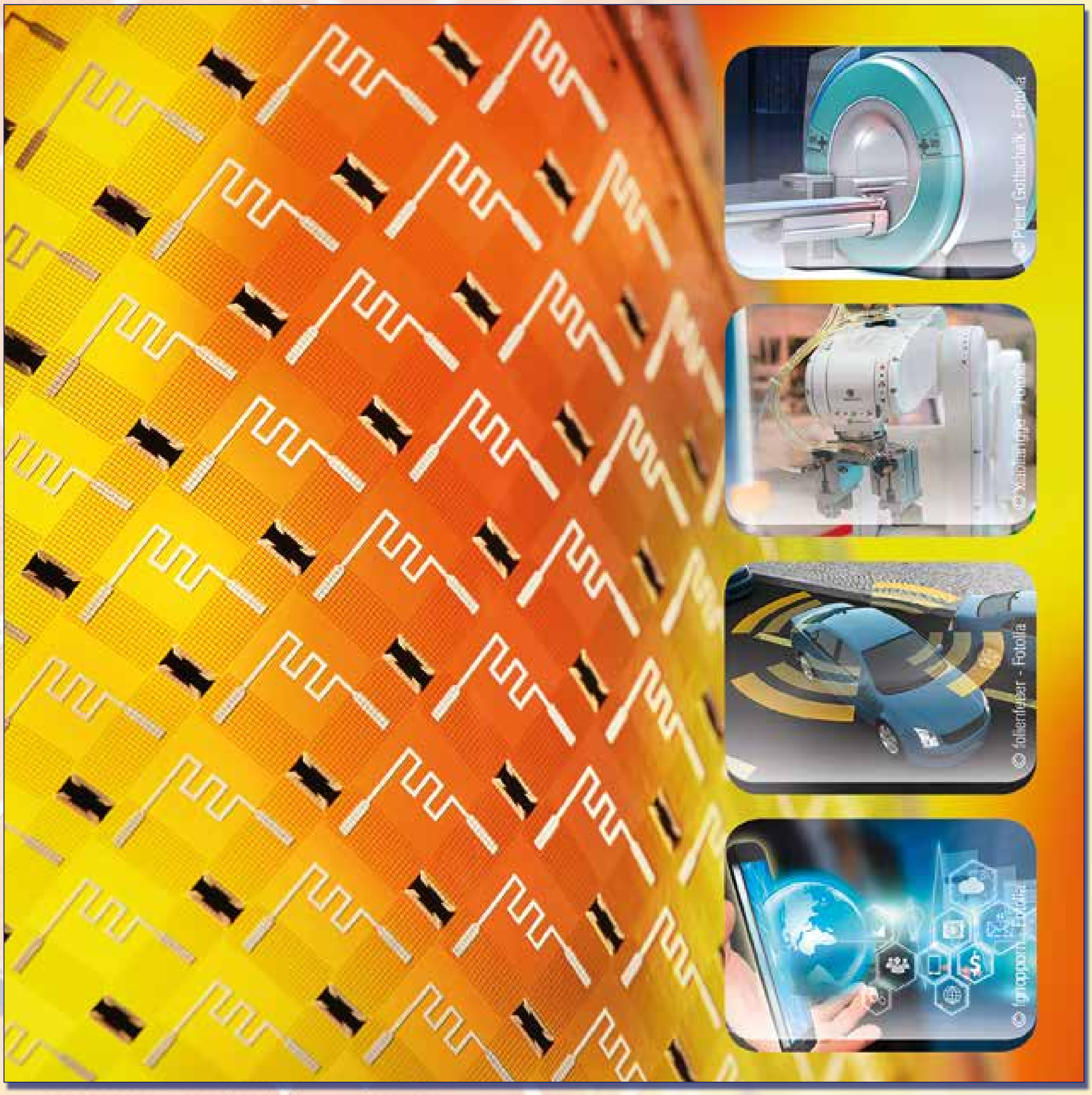

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BiCMOS Embedded RF-MEMS Technologies

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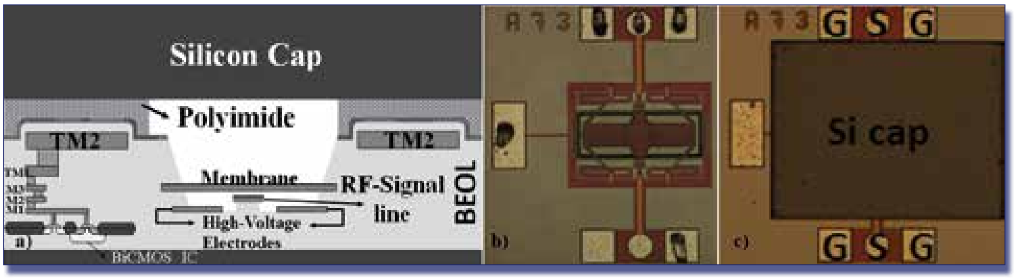

Fig. 1: The generic cross section of the packaged 0.25 µm BiCMOS technology RF-MEMS switches (a) and the micrograph of K-band RF-MEMS switches before (b) and after Si cap (c) [3].

Introduction

Novel communication system technologies demand not only miniaturization but also multifunctionality. From this perspective, RF-MEMS devices are promising candidates to add functionality into future RF systems. With their good RF performances, there is a growing need and interest in RF-MEMS switches for both RF and mm-wave applications in the recent years. This need is expected to increase tremendously in the near future with more applications operating at mm-wave frequencies.

IHP has developed two BiCMOS embedded RF-MEMS switch technologies for two different technology lines, namely the 0.25 µm and the 0.13 µm SiGe BiCMOS. In both technologies, RF-MEMS Single-Pole Single-Throw (SPST) and Single-Pole Double-Throw (SPDT) switches are realized for mm-wave applications. The technologies offer two different packaging technologies for the RF-MEMS switches, namely Silicon cap packaging and thin film wafer-level encapsulation.

Technologies

0.25 µm SiGe BiCMOS

The RF-MEMS switch module is initially embedded into IHP`s 0.25 µm SiGe BiCMOS technology using the Back-End-Of-Line (BEOL) metallization layers [1]. The 0.25 µm SiGe BiCMOS technology has 5 aluminum metallization layers in BEOL. The high-voltage electrodes of the switch are formed using M1 while M2 is used as the RF-signal line. A thin Si_3N_4/TiN stack, which is part of the BiCMOS metal-insulator-metal (MIM) capacitor, forms the contact region and provides DC isolation between movable membrane (M3) and the RF-signal line. After the MEMS releasing process, the RF-MEMS cavities are sealed with the silicon (Si) caps at wafer-level [2] - [3]. Fig. 1(a) shows the generic cross section of the packaged RF-MEMS switch in 0.25 µm BiCMOS technology [3].

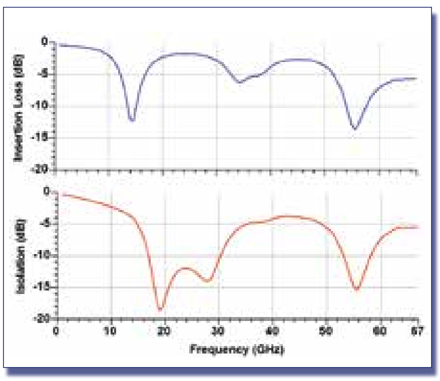

Fig. 2: The measured S-parameters of the K-band RF-MEMS SPDT switch in 0.25 µm SiGe BiCMOS technology.

Based on the 0.25 µm SiGe BiCMOS technology RF-MEMS module, RF-MEMS switches for K-band (18–27 GHz) are designed, fabricated and packaged. The micrograph of K-band RF-MEMS switches are shown in Fig. 1 (b,c) before and after the Si cap packaging [3]. Furthermore, the developed K-band RF-MEMS switch is used as a standard building block for an RF-MEMS SPDT switch [4]. The S-parameter measurement results of the fabricated SPDT switch are shown in Fig. 2 and show an insertion loss of 1.8 dB and an isolation of 12.4 dB at 25.5 GHz.

0.13 µm SiGe BiCMOS

The second integration of RF-MEMS module is done in the IHP`s 0.13 µm SiGe BiCMOS process. IHP`s 0.13 µm SiGe BiCMOS process represents one of the fastest currently available SiGe heterojunction bipolar transistor (HBT) technology with peak f_T/ f_{max} values of 505 GHz/720 GHz [5]; thus opening potential markets for SiGe BiCMOS technologies (i.e. imaging systems at 94 and 140 GHz, THz spectroscopic systems at 240 GHz and beyond).

SelinTolunay Wipf

Alexander Göritz

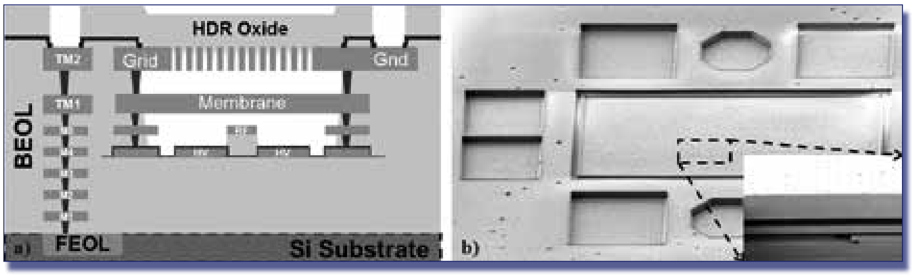

Fig. 3: The schematic cross section (a) and SEM image (b) of the WLE RF-MEMS switch [6].

Compared to the 0.25 µm SiGe BiCMOS technology, the BEOL metallization stack of the 0.13 µm SiGe BiCMOS technology includes 7 metal layers instead of 5; hence a different integration scheme is used (Fig. 3(a)). The RF-MEMS switch in 0.13 µm SiGe BiCMOS technology consists of high-voltage electrodes (M4), RF-signal line (M5) and a movable membrane (TM1). For the packaging, a thin film wafer-level encapsulation approach is developed using the standard BiCMOS fabrication steps. Fig. 3(b) shows the fabricated wafer-level encapsulated (WLE) RF-MEMS switch in the 0.13 µm SiGe BiCMOS process, developed for the D-Band (110 – 170 GHz) applications [6]. By using the developed 0.13 µm SiGe BiCMOS embedded RF-MEMS switch technology, a 140 GHz center frequency SPDT is designed with a tee junction that is connected to two RF–MEMS switches with each side λ/4 microstrip lines. The D-band RF-MEMS based SPDT switch has been successfully demonstrated, with its measured 1.42 dB insertion loss (IL) and 54.5 dB isolation at 140 GHz (Fig. 4) [7].

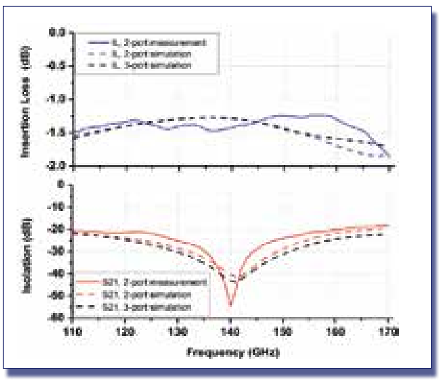

Fig. 4: Comparison of the measured and simulated S-parameters of the D-band RF-MEMS based SPDT switch in 0.13 µm SiGe BiCMOS technology [7].

Conclusion

IHP has developed BiCMOS embedded RF-MEMS switch technologies for both 0.25 µm and the 0.13 µm SiGe BiCMOS lines. Each technology has applied different packaging techniques; namely, Si cap packaging and wafer-level encapsulation. In both technologies, RF-MEMS SPST and SPDT switches for mm-wave applications are successfully realized.

Acknowledgment

The authors would like to thank to Fraunhofer IZM, Berlin, for the Si cap packaging.

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Active Q-Factor Control of Piezoelectric MEMS Cantilevers for High Speed AFM Applications in Vacuum

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Abstract

When integrating an AFM (atomic force microscope) into vacuum chambers, such as needed for the operation of scanning electron microscopes, it is most beneficial to provide a tuneable Q-factor of the resonantly operating AFM cantilever. In order to investigate the potential of active damping for high speed measurements while maintaining a high lateral resolution, test cantilevers are fabricated with an integrated piezoelectric aluminium nitride (AlN) layer. The status of the oscillation represented by the conductance response of the AlN thin film is feed back into the cantilever excitation amplitude what results in active damping. With this approach, the Q-factor is reduced by a factor up to 7 in vacuum, thus reaching almost the damping at atmospheric pressure.

Introduction

Nowadays, modern sensor solutions based on MEMS (micro electro-mechanical systems) cover a large area of different applications. With the use of cantilever based devices, chemical and physical quantities are detectable and by resonant operation with electromechanical, capacitive or piezoelectric actuation an enhanced sensitivity is achieved [1]. In our approach the top-electrode (gold) and the active piezoelectric layer (aluminium nitride (AlN)) are deposited on a highly p-doped silicon device layer which serves in parallel as the bottom electrode of the mechanical resonator. Compared to other piezoelectric materials (i.e. lead zirconate titanate (PZT)) AlN is compatible with complementary metal oxide semiconductor (CMOS) processes and shows a high temperature stability. AlN is integrated as functional material in MEMS devices such as sensor elements for the determination of the density and viscosity of liquids [2], in surface acoustic waves (SAW) [3] or in MEMS mirrors [4].
The atomic force microscopy (AFM) is a well-established technique for surface-related analyses i.e. to measure surface roughness [5]. If a tip attached to a cantilever approaches a surface, surface forces act on the cantilever tip and the oscillation parameters of the cantilever (i.e. frequency, amplitude and phase) are affected. The piezoelectric layer is used for the electrical readout so that a compact system design compared to common used optical readouts results.
When operating an AFM in the high vacuum environment of a scanning electrode microscope (SEM), the cantilever damping is significantly reduced and as a consequence, the time constant is increased [6]. The feedback dependent stimulation of the piezoelectric element modifies the oscillation amplitude by reducing the stimulus and this reduces the time constant to ensure an equivalent scanning speed compared to an operation in air.

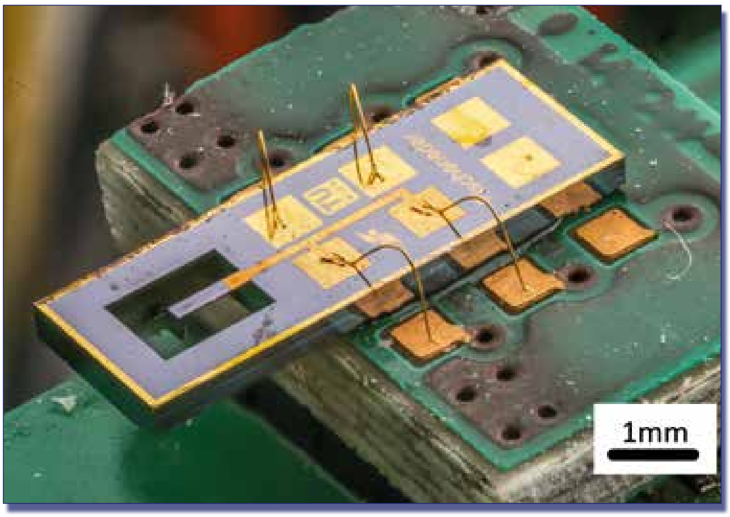

Fig. 1: MEMS cantilever with dimensions of 1000 µm (length) and 80 µm (width) being covered by 200 µm AlN in length

Experimental details

To evaluate the potential in Q-factor adjustment piezoelectric cantilevers as shown in Fig. 1 are fabricated and a specific HF-NF amplifier with I/U transformer is developed. The frequency spectrum and the time domain of the mechanical oscillation are measured optically by laser Doppler vibrometery (LDV) or by the electrical response of the piezoelectric layer, thus providing a feedback on the Q-factor of the cantilever due to the electrical actuation of the piezoelectric layer.

Electrical measurement

The electrical excitation signals to stimulate the cantilever oscillation are generated outside of the vacuum chamber with a Lock-In amplifier (Zürich Instruments) and a frequency generator, respectively.

The sinus signal (U_{AC}), the real part of the cantilever signal (U_{fdG}) and the DC voltage signal (U_{in}) are used to power the cantilever and the cantilever compensation circuit needed to eliminate any parasitic resistance and capacity. Only the resonance part of the current is amplified by the U/I converter and the Lock-In amplifier generates a feedback to reduce the stimulation amplitude (Fig. 2).

Results

The cantilever velocity and the electrical output spectra at different ambient pressure levels (i.e. air or vacuum at $1.2 \cdot 10^{-1}$ Pa) and feedback values k_{fbG} (0 to 2000) are shown in Fig. 3. The resonance frequency increases by 50 Hz and the Q-factor increases about 9 times from 1100 to 9400 when changing from air to vacuum. With a k_{fbG} of 2000, however, the Q-factor is reduced down to 3600. While scanning a sample surface the impact of the k_{fbG} on response time is shown in Fig. 4. By increasing k_{fbG} the time constant τ_G is reduced to about 10 ms, which represents a Q-factor of about 850 and is comparable to the time constant in air of 9.2 ms with a corresponding Q-factor of 780.

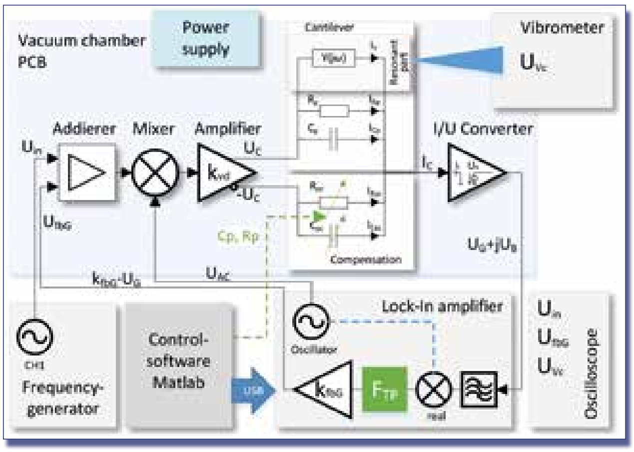

Fig. 2: Overview of the electrical circuit arranged outside and inside the vacuum chamber

Conclusion and future work

This work demonstrates the potential of closed loop feedback operation for piezoelectric AFM cantilevers in vacuum. A time constant in vacuum similar to the operation in air is achieved, thus promising similar scanning speeds with comparable lateral resolution. In the next step, a physical surface will be approached to the cantilever with a tip to determine the response characteristics to a pre-defined surface step. In addition, compensation structures integrated on chip will improve the signal quality and lower the noise level at the Lock-In amplifier.

Acknowledgements

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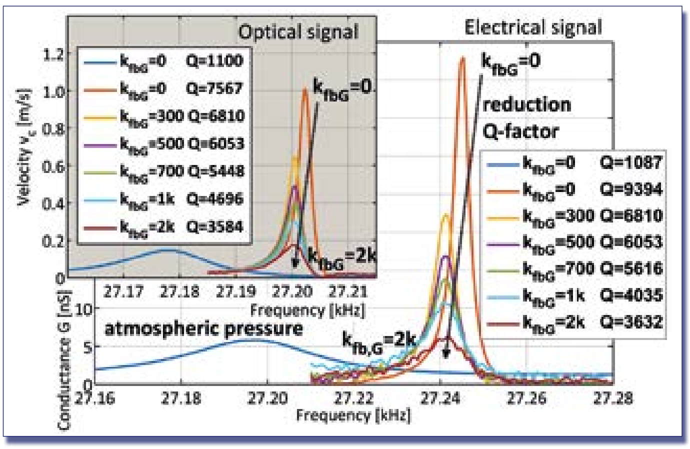

Fig. 3: Frequency spectrum of the MEMS cantilever as a function of the feedback k_{fbG} resulting from the optical and electrical measurements

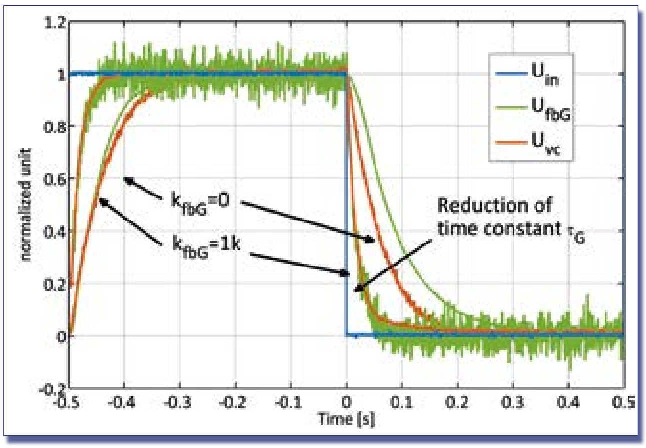

Fig. 4: Normalized step response of the optical and the electrical signals dependent of the feedback k_{fbG}

Millimeter Wave Sensor System for Oxygen Concentration Measurement

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Abstract

A millimeter wave spectroscopic approach for oxygen detection is presented. The designed compact sensor system envisages a Fabry-Pérot resonator as a sample cell for the target gas and addresses a frequency range between 55 GHz and 65 GHz. The resonator virtually increases the absorption path of the spectrometer. To achieve a compact sensor system, the resonator is coupled to an integrated transmitter and receiver fabricated by SiGe technology for transmission and reflection measurements.

Introduction

The presented oxygen sensor is based on the principle of rotational absorption in the millimeter wave frequency range. Oxygen shows a significant absorption spectrum as it is shown in Figure 1 [1]. The presented sensor uses the absorption maximum around 60 GHz for oxygen measurement.
To reduce the length of the absorption cell the absorption path can be virtually increased using a Fabry-Pérot resonator (FPR) with high quality factor Q [2]. State of the art FPRs are of very big size and operate with low pressure to measure concentrations in the ppm region [3]. The sensor approach presented here uses a small FPR the size of a handheld device for oxygen measurement at ambient pressure.

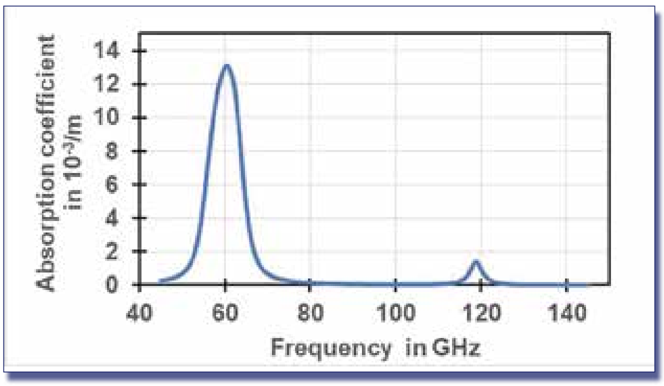

Fig. 1: Absorption spectrum of oxygen at atmospheric pressure and room temperature [1]

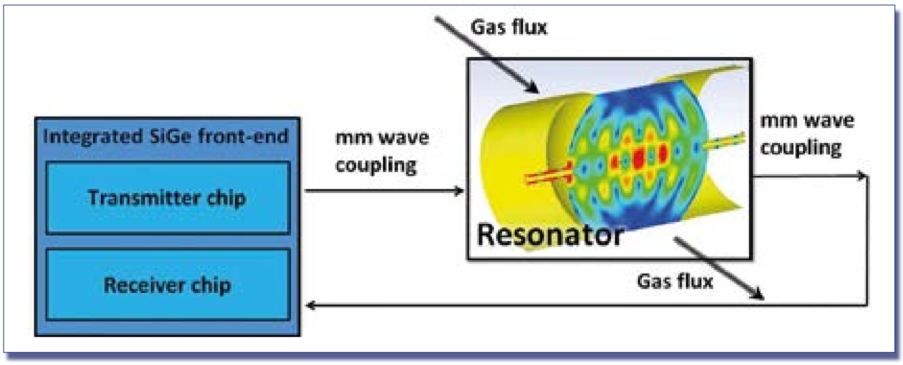

Fig. 2: Block diagram of the sensor system

Sensor concept

Figure 2 shows the block diagram of the sensor system. For the transmission and reflection measurement, the resonator is connected to the integrated transmitter and receiver chips via two millimeter wave coupling structures. The chips are manufactured in SiGe technology and can be used for the frequency range 50 GHz to 75 GHz. These front-ends are realized as heterodyne structures with integrated directional couplers. The transmitter chip provides a differential reference IF output channel to control and monitor the output power. The receiver chip provides a differential IF output channel for the detected transmission. Both channels are recorded on the PC with the Matlab software. This allows a simple analysis and calibration of the measured data.

Fabry-Pérot resonator

The FPR consists of two concave reflectors with highly reflective surfaces. It provides a very high Q, because the main field propagation is in free space without conductivity losses. Applying a target gas inside the resonator, dielectric losses occur due to the absorption of the gas. The Q is reduced depending on the gas concentration.
The resonator was dimensioned for a small size sensor system with sufficient high Q for oxygen measurement at ambient pressure: radius of curvature r = 120 mm, reflector distance d = 110 mm and reflector radius a = 25 mm.

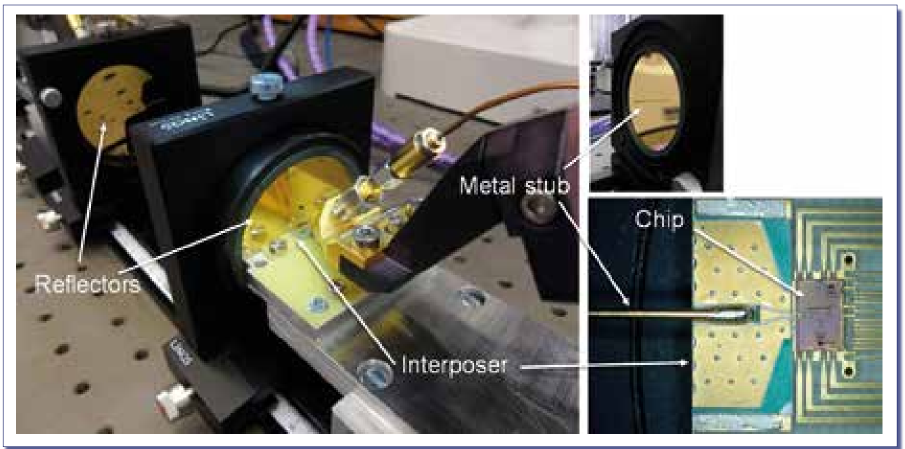

Fig. 3: Coupling between resonator and chip

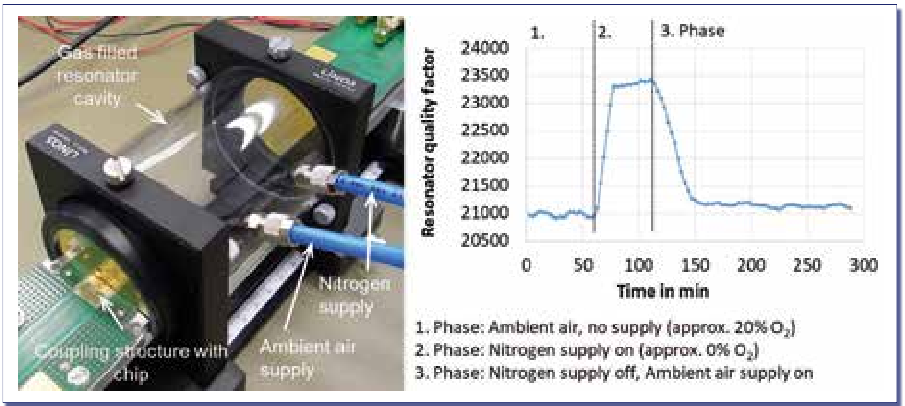

Fig. 4: Oxygen measurement with sensor system

The large distance between the reflectors leads to high order resonant modes in the axial direction. The resonator transmission spectrum in the wavelength range between 50 GHz and 70 GHz is thus covered by multiple resonances with a peak density of 1.33 GHz.

Coupling between resonator and chip

For a close connection between chip and resonator an axial coupling was chosen. It was realized using a metal stub penetrating through the center of the reflector and ending in a short L-shaped antenna. Thus, a weak coupling of the resonator is achieved with the result of a high Q of the coupled resonator. The metal stub is attached to an interposer made of high frequency PCB substrate. The matching structure on the interposer provides a transition from a narrow coplanar line with ground plane to a wide coplanar line for soldering the metal pin. Chip and interposer are glued on a circuit board and connected by wire bonds.

Experimental results

The integrated SiGe front-end is able to measure the resonant peaks in the frequency range 50 GHz to 75 GHz. The transmitter chip generates a signal with +5 dBm output power and the receiver chip is able to detect a signal as low as 30 µV/Hz.
For the functional test of the sensor system, the resonator cavity was purged with nitrogen and compressed air in order to achieve oxygen concentrations of 0% and 20%. Every three minutes, an 8 MHz frequency sweep was used to sample the resonant peak at 60.3 GHz in high resolution. Q was determined from the 3 dB bandwidth of the resonant peak. At the beginning of the measurement the resonator cavity was filled with ambient air and a Q of 20900 was measured. The Q was thereby reduced by the absorption of oxygen. Figure 4 shows the change of Q in the course of the measurement with reference to the first Q value. The supply of nitrogen displaces the oxygen, which results in an increase of Q. The change of the oxygen concentration by 20% could be detected clearly and with high resolution.

Conclusion

The measuring system shows a resolution of less than 2% vol. for oxygen concentration measurement in the range 0%-20%.
Compared to common small size oxygen measurement sensors like electrochemical sensors or metal-oxide sensors the sensor is working at low temperatures. This provides the opportunity to use it in explosive environments.

Acknowledgement

The research leading to these results has received funding from the European Union's ENIAC-JU ESEE project (http://www.eniac-erg.org) under grant agreement nº324284. The authors acknowledge the support by the Federal Ministry for Education and Research under grant agreement nº16ES0042.

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Customized Micro Mirror Arrays for High Speed Laser Processing

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Introduction:
Micro mirror arrays (MMA) [1] modulate phase, polarization or intensity of light. Typically, they feature roughly 10^3 –10^6 mirrors of 10 µm to 100 µm in size and can be reconfigured at rates in the kHz to MHz range by electrostatic addressing of mirrors. Specific MMA advantages are a high channel count, high speed, low polarization dependency and potential to access a spectral range from DUV to NIR. Mirrors are switched between endpoints ("binary MMA")[2] or deflected gradually (i.e. in more than 2 levels) by balancing electrostatic forces and spring forces ("analog MMA")[3-6]. MMAs are used in industrial applications such as microlithography, where they may serve as reflective "reconfigurable photomask" to project variable intensity patterns onto a photoresist. While binary MMAs generate binary dose patterns (or greyscale patterns by multiple exposures), analog MMAs may project a new greyscale pattern for each laser pulse. At a given MMA resolution, greylevel exposure allows a more precise tuning of feature size and placement than binary exposure. Applications with very demanding performance requirements may require customized MMAs.

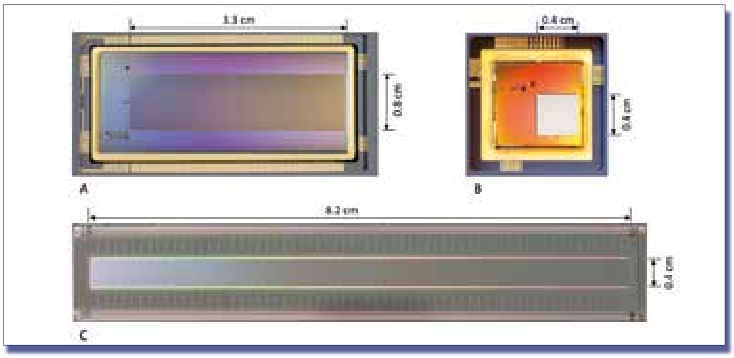

Fig. 1: Exemplary MMAs developed at Fraunhofer IPMS: ASLM1M (A), ASLM64k (B), and ASLM8k (C).

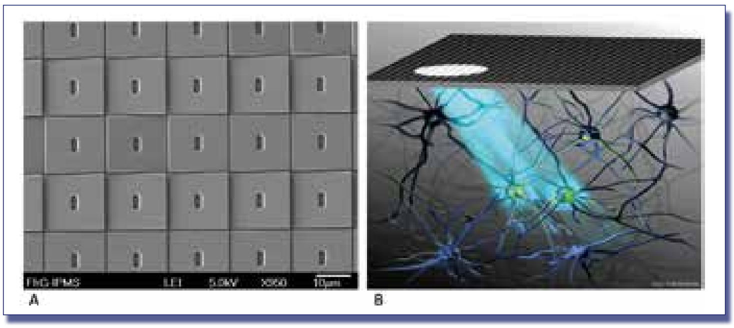

Fig. 2: ASLM64k A: SEM image of individually addressed mirrors. B: Illustration of spatio-angular control.

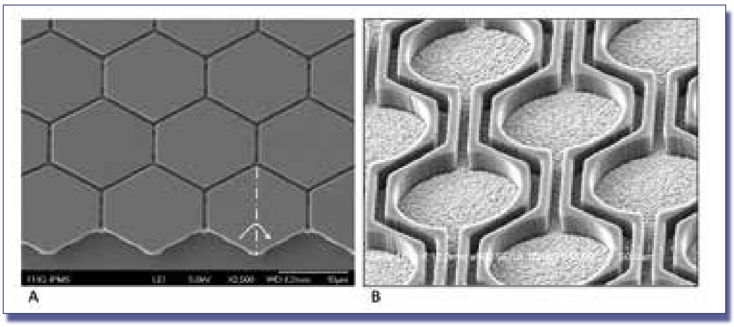

Fig. 3: ASLM8k A: SEM image of mirrors. B: SEM of 15µm dry film resist patterned at feature size 6µm L/S.

MMA development at Fraunhofer IPMS:
Fraunhofer IPMS offers project-based development and pilot processing of custom MMAs for partners in science and industry. In result of a government-financed modernization of the institute's pilot fabrication line, the processing of larger wafers with 200mm diameter will become possible in 2018. MEMS devices may then be integrated at IPMS also on top of advanced CMOS substrates provided by external foundries. IPMS has developed MMA modules for various applications, such as semiconductor microlithography in the DUV and UV spectral range, microscopy or adaptive optics. Three exemplary MMAs based on the "reconfigurable greyscale mask" concept (details in [3,6]) are shown in Figure 1. All MMAs feature mirrors allowing continuous tilt about a single axis of rotation. MMA parameters are summarized in Table 1.
The ***ASLM1M*** (Fig. 1A) is a DUV modulator with monolithically integrated CMOS. Reading data from the on-board memory of the driver electronics, a frame rate of up to 2 kHz and a high pattern rate of 2 GPixel/s (greyscale) are achieved. The MMA is a perfect match

MMA type	Resolution	Pitch	Frame rate	Single pixel area	Active area	Fill factor	Analog mirror tilt range	Spectral range
	Pixel	µm	kHz	µm²	cm²	%	deg	nm
ASLM1M	2048 x 512	16	2	256	2.68	>90	0 … – 0.64*	193 … – 248*
ASLM64k	256 x 256	16	1	256	0.16	>90	0 … – 3.5*	193 … – 1600*
ASLM8k	8192 x 1	10	1000	38592	3.16	>90	0 … – 0.87*	193 … – 405*

Table 1 Parameters of three MMA developed at Fraunhofer IPMS (* extended deflection/spectral range on request)

for excimer lasers pulsed at kHz rates. The ASLM1M is being successfully used in a laser direct writer for semiconductor masks developed by the Swedish company Mycronic [4-5]. The tool allows a high throughput in the production of less critical masks that do not require the ultimative resolution of electron beam writers.

The ***ASLM64k*** (Fig. 1B) has been designed as a universal modulator for life science applications. With an extended mirror deflection range, it operates at wavelengths in the DUV to NIR spectral range [6]. Available as kit with a driver electronics, the MMA with integrated CMOS operates at frame rates of 1 kHz using image data stored in the on-board memory of the electronics board, whereas 100 Hz are achieved when data are provided through USB interface in closed loop. Figure 2A shows a SEM image of the ASLM64k. Figure 2B illustrates the aim of a current project with Institute Pasteur, France: Based on two ASLM64k chips, modules for structured illumination in optical microscopy are implemented, that allow the selective object illumination with spatial and angular light control to observe or activate single cells within a 3D-ensemble [7*].

The ***ASLM8k*** (Fig. 1C) is a high-speed MMA supporting frame rates of about 1MHz, corresponding to the enormous pattern rate of about 8GPixel/s (greyscale). It was designed to modulate a 355nm ps-laser with 80MHz repetition rate and several 10Watt average optical power. Figure 3A is a SEM image of mirrors. The axis of rotation is oriented vertically. Several hundred mirrors of same row are binned to deflect in sync. They form large "superpixels" capable of a high switching speed. The ASLM8k has been applied in a laser direct writer developed by the company Mycronic for the manufacturing of interposers for chip packaging [8]. As key feature, the tool measured the minute lateral deformations of each substrate panel and exposed it (by means of the ASLM8k) with a corrected pattern to ensure perfect matching of vias in successive metal layers. Figure 3B shows a SEM image of a resulting via-test structure on an interposer panel. High features correspond to a 15µm thick dry film resist structured at minimal feature size of 6µm. The low area is filled with electroplated copper.

Conclusion:

Micro mirror arrays (MMAs) are versatile components for the modulation of light. Fraunhofer IPMS has developed MMAs for use with different laser sources in applications like maskless lithography, structured illumination, and wavefront shaping. To support the exploration of new MMA applications, the institute offers a development of custom MMAs with application-specific chip formats, actuator designs, structural materials and driver electronics based on collaboration in publicly or industry-funded projects. But new applications seem conceivable even for existing MMAs: For example, large MMAs developed for use in microlithography like the ASLM1M or the ASLM8k (with very large pixels) allow to modulate lasers with an average optical power in excess of several 10Watts. At this power level also a use for parallel high-speed / high resolution direct laser processing (ablative thin film patterning, laser induced crystallization/annealing, rapid prototyping, or multi-photon polymerization) was possible.

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Thinned Capacitive Pressure Sensors in Flexible and Stretchable Extra Soft Substrates for Tactile Sensing

Studies on the dependence of the output signal on bending

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Abstract
When people lose an extremity they usually got a prosthesis to replace it. Most of these prostheses do not allow any haptic feedback to the wearer. To solve this challenge, results of a study on flexible and stretchable sensor arrays present an add-on for tactile sensing for robots or prostheses as a skin replacement. The aim of such sensor arrays is the detection of tactile sensation with high resolution. This array consists of thinned and thereby flexible silicon pressure sensors embedded into an extra soft silicone substrate. They are connected with conducting lines whose shape allows stretching by more than 80 % without faults. The output signal of these thinned capacitive pressure sensors shows a dependence on bending. To minimize this dependency, two pressure sensors were mounted back to back and their individual dependencies were used for compensation by numerical methods.

Introduction
Human skin is a very complex system that allows healthy people to accurately detect touch or pressure with high local resolution [1]. In addition, it can record temperatures, is very flexible and stretchable and adapts to almost all surfaces. The adoption of these properties to a technical system implies significant challenges. One of them is the realization of flexible and stretchable electrical conductors on extra soft substrates. These substrates have already been developed in an earlier work using a similar manufacturing process as in this study [2]. Another challenge is the thinning of capacitive pressure sensors to achieve a bending capability (see Figure 1) [3]. The bending of these sensors in turn affects their output signal. This has already been demonstrated in previous investigations [4].

System description
Concept of the System
The system studied in this work is based on an extra soft silicone substrate (Young's modulus of about 50 kPa) with integrated thinned and flexible sensor spots. In order to connect different sensor spots with a readout unit (as shown schematically in Figure 2) the sensors are connected with flexible and stretchable conducting lines. Each sensor spot consists of two thinned capacitive pressure sensors which are mounted back to back to form a sensor stack. One side of this stack is faced down to the substrate. The other side is faced up to allow contact with the environment.

Sensor Stacking
Considering this sensor stack with thinned capacitive pressure sensors separately, two bending states can be observed under load. Depending on the direction of bending, capacitive pressure sensors will expose tension or compressive stress that affect the sensor output signal differently [5]. By comparing the sensor output signals of the bent sensors stacks under load, the dependence of the bending on the sensor output signal can be compensated by a numerical solution.

Results and Discussion
Sensor characterization
The mechanical compressive or tensile stresses lead to a convex bending of the membranes of one of the sensors and to a concave bending of the other. This influences the output signal of a single sensor depending on the load case. Figure 3 shows a separate characteriza-

Fig. 1: Photo of thinned and bent capacitive CMOS pressure sensors

Fig. 2: 3D model of an extra soft silicone substrate with four integrated pressure sensor spots connected to a size-optimized readout unit

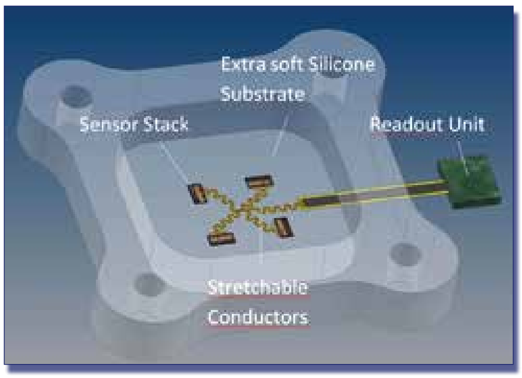
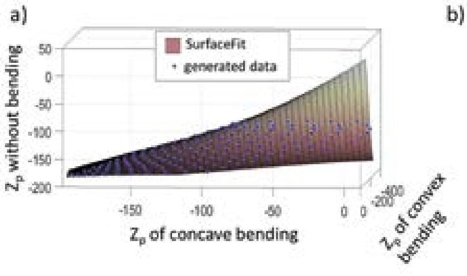


Fig. 4:
a) Surface fit of a capacitive pressure sensor stack consisting of two pressure sensors to compensate the bending dependence of the sensor output signal; b) Comparison of an unbent capacitive pressure sensor with a bend-compensated sensor stack

a)



b)

Bending [mm]	0,01	0,01	0,045	0,057	0,045
Pressure [mbar]	1000	1150	1150	1200	1200
$Z_{p,reference}$	-198	-152	-152	-134	-134
$Z_{p,convex}$	-199	-148	-141	-118	-123
$Z_{p,concave}$	-199	-147	-156	-143	-139
$Z_{p,compensated}$	-199	-151	-151	-133	-134
rel. Deviation	-0,3%	0,09%	0,09%	0,33%	0,0%

tion of these states before stacking. It can be seen that different measuring curves occur. Thus, an individual sensor signal adjustment for the concave and the convex bending was performed at ambient pressure (see fit in Figure 3). Each pressure value of the fit can be described by:
w is the deflection of the substrate in the middle of the sensor and p the applied external pressure. However, the fit of the concave-curved sensor is valid only for small deflections, because the sensor output signal reaches its electronic stop for larger deflections and therefore no further signal changes can be measured (see Figure 3 a)).

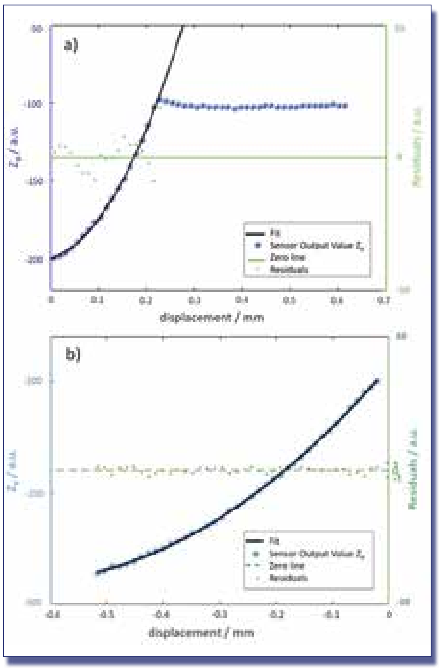


Fig. 3:
Sensor-Output-Signal Z_p to deflection curve fit for concave a) and convex b) bent pressure sensors with a thickness of 44 µm at an ambient pressure of 1.0 bar; The differences between measured values and fit as residuals

Sensor stack characterization

In addition, the pressure dependence Z_p was measured for each deflection. These measurements show that the pressure sensor output signal of a convex bent sensor is always lower than the one of a concave bent:
As a result of this knowledge, the bending direction of the sensor stack can be clearly determined.
Performing a surface fit in Matlab with these data yields a fourth order polynomial function of the fourth class describes this fit (Figure 4). In order to be able to make a statement about the quality of the fit, the sensor output signals of the bent stack are related to the sensor output signal of an unbent sensor:
Fig 4 b) shows the relative deviation for random bending points using the values of the fit (Zp, compensated) compared to the pressure dependence of an unbent pressure sensor (Zp, reference). The relative deviation of maximal 0.33 % between fit and measured value results in an absolute deviation of around 4 mbar for the capacitive pressure sensors used in this work.

Conclusion

A compensation of the bending dependence of the sensor output signal of thinned capacitive pressure sensors is possible. For this purpose two sensors were stacks by gluing them back to back. Because the sensor signal provides different values under compressive and tensile stress, the bending direction of the sensor stack can be determined unambiguously. The pressure value of each sensor is then determined by a surface fit and has a maximum deviation to the unbent sensor pressure value of 0.33%.

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Miniaturization of Micro Diaphragm Pumps for the Integration in Mobile Phones

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Fraunhofer EMFT

Introduction

High manufacturing cost limits a use of micropumps for consumer applications. Using a MEMS component mobile phone, cost has to be less than 1 US$. Most available micropumps work with a piezo actuation and are realized with different materials (silicon, metal, or plastic).Not only the material cost have to be considered (metal, plastic are cost efficient), but also cost for joining and mounting technology and fluidic test. Manufacturing silicon micropumps on full wafer level means a high number of chips can be realized in parallel, as well as back end steps like glueing piezo ceramics and fluidic testing of the pumps. FhG EMFT follows this „wafer level strategy" since a long time [1]and develops methods for mounting piezos and testing pumps on wafer level. Up to now, the pump chip has a size of 7x7x0,8 mm³ and is still one of the smallest in the world. However, this chip is too expensive for a use in mobile phones.

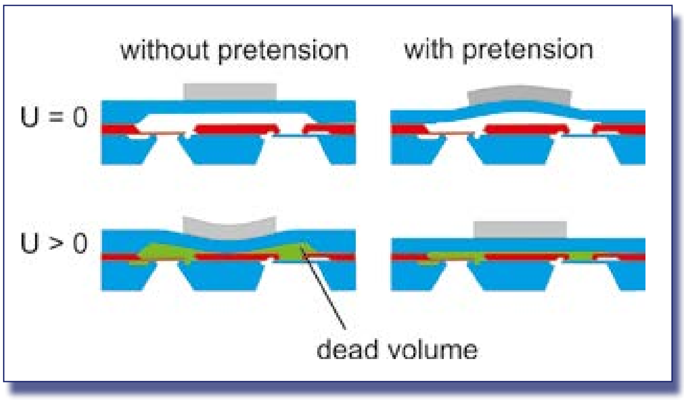

Fig. 1: Reduction of dead volume by pretension

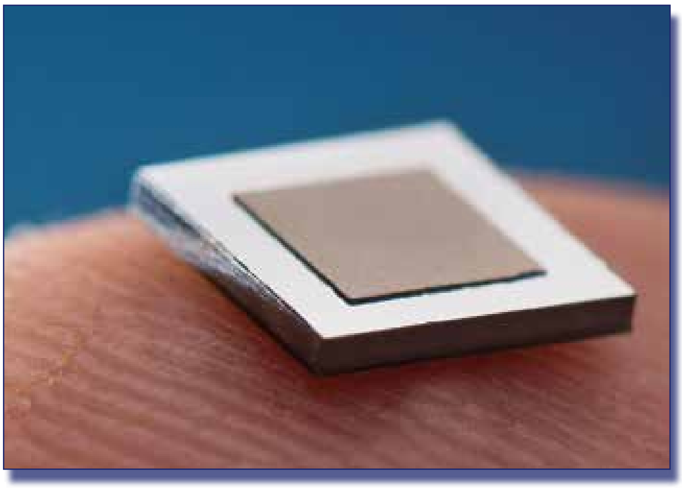

Fig. 2: 5x5 mm² silicon micropump on finger tip

Problem of miniaturisation

Considering the theory of plates, the stroke volume V_M of a homogeneous plate (thickness h, Young modulus Y, poisson number ν), which, under pressure p, depends on the 6th power of the side length a of the plate:

$$V_M = \frac{a^6}{2\,\pi^4 D}\,p;\ \text{with plate stiffness } D = \frac{Yh^3}{12(1-\nu^2)}$$

Reducing the side length by a factor of two, the stroke volume ΔV (which is proportional to V_M) is reduced by a factor of 64. The dead volume V_0 (volume of the pump chamber when the diaphragm hits the bottom position) cannot be reduced by the same factor. Therefore the compression ratio $\varepsilon = \Delta V/V_0$ is getting very small with decreasing diaphragm size, leading to poor bubble tolerance and weak air backpressure, which means they are not good for practical use. The problem will be even worse due to the nature of piezo actuation: according to the "butterfly" characteristic, the piezo will depolarize, if the negative field exceeds a value of about -0,4 kV/mm. There is more than 80 % of the stroke with positive voltage in "downward" direction. The state of the art piezo driven micropump needs a pump chamber "space" for the stroke, which generates a significant "unavoidable" dead volume at the edges of the diaphragm (Fig. 1 left, bottom).

Reduction of the dead volume

A new method solved this problem: the piezo ceramics are glued while applying an E-Field for pretension. After dispens-

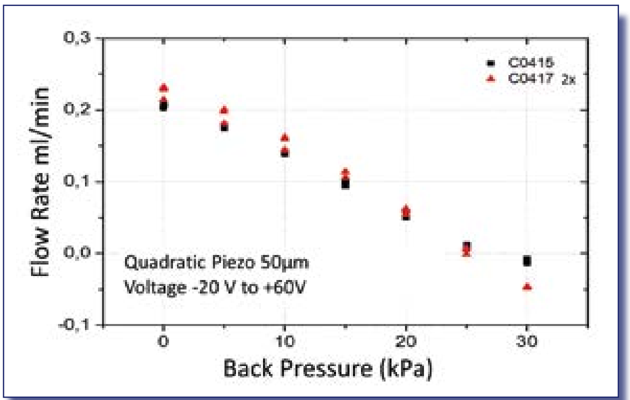

Fig. 3: Air pump rate at 100 Hz vs. backpressure.

Fig. 4: Demonstrator micropump and humidity sensors, integrated in a mobile phone.

ing the glue, pick & place the piezo on to the silicon chip, an electrical voltage U_{mont} is applied to the piezo. The piezo shrinks laterally according to the d_{31} coefficient, which is always negative. After application of U_{mont}, the glue will be hardened, the shrinkage is “frozen”. After glue-hardening U_{mont} is switched off, the fixed piezo-silicon-diaphragm “buckles up” (Fig. 1, right top). During actuation, the piezo can actuate to be “flat”, so that the pump chamber height is very small (Fig. 1, right bottom). That new pretension technology enables a chip size well below 7x7 mm² without losing of bubble tolerance and self-priming ability.

Design of the 5x5 mm² micropump

A design of the 5x5 mm² has been carried out, assembled, mounted and tested (Fig. 2).

With a diaphragm thickness of 30 µm and a piezo thickness of 55 µm a stroke volume of 53 nl is simulated with an actuation voltage of +60 V to -20 V. The actuator was pretensed with mounting voltages between +90 V and +120 V. The pump chamber height is 1,5 µm, the flap thickness of the valves 15 µm, the flap dimensions are 800x460 µm², the width of valve seat is 6 µm.

Results

More than hundred 5x5 mm² micropumps were assembled, mounted and tested. A yield of about 50 % was already achieved in the first development lot.
The micropump has a pump rate of 600 µl/min, according to 10 mm³/s at a pump frequency of 500 Hz. That pump rate can purge a dead volume of several mm³ between a smartphone inlet and an gas sensor in less than 1 second.
Fig 3 show air back pressure measurement at 100 Hz. A max. air backpressure of $p_{max,gas}$ = 25 kPa was found.
The comparison between simulated (sim) and measured (exp) pump performance was good:

- stroke volume [nl] (sim 54; exp 33);
- max. air back pressure [kPa]: (sim 19; exp 25);
- max. air pump rate [µl/min]: (sim 670; exp 600)

Smartphone Demonstrator

A mobile phone demonstrator with integrated micropump together with two humidity sensors (Bosch BME280) was realized (Fig. 4). While the micropump supports air sampling to the first humidity sensor, the second humidity sensor has just diffusion as transport mechanism. The sensor/micropump module communicates by Bluetooth with an “app” within the smartphone, which controls the micropump and reads out the sensors at the same time. The reaction time of the humidity sensor is reduced according to the slow diffusion from several minutes to a few seconds with pump support, see table 1.

air channel, cross section A, length L	Micropump status	T63% rise time [s]	T63% fall time [s]
A = 0,2x0,5 mm2, L ca. 10 mm	Off	480	600
A = 0,2x0,5 mm2, L ca. 10 mm	On	10	7
A = 0,4x1,0 mm2, L ca. 10 mm	No Pump	204	198

Tab.1: Measured reaction time of the humidity sensors.

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Pulse Current Electrochemical Deposition of Copper for Through Silicon Vias in MEMS: Experiment and Simulation

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Introduction

3D-integration with Through Silicon Vias (TSVs) is a promising for miniaturizes electronic systems. For MEMS that cannot be thinned below a critical value, a large TSVs depth (>300 µm) and high aspect ratio (HAR) (>5:1) are used [1]. One challenge is the conformal metallisation. The high conductivity, compatibility to solder contacts, as well as the possibility of a patterned electrochemical deposition (ECD), makes copper an advantageous material. Pulse reverse plating (PRP) is an alternative method compared to the common DC deposition. In the latter, additives provide for a conformal deposition in TSVs (Fig. 1.1a). Drawbacks are their high consumption and the complex process control. In PRP, copper is dissolved at regions with high current density. For TSVs, this is the TSV opening at which a higher undesired growth takes place. Figure Fig. 1.1b shows the principle and parameter definition of PRP.
This paper presents results of experiment and simulation of the BMBF project VEProSi [2]. The objective is to investigate Cu-PRP in TSVs with a reduced additive amount in order to prevent the mentioned drawbacks.

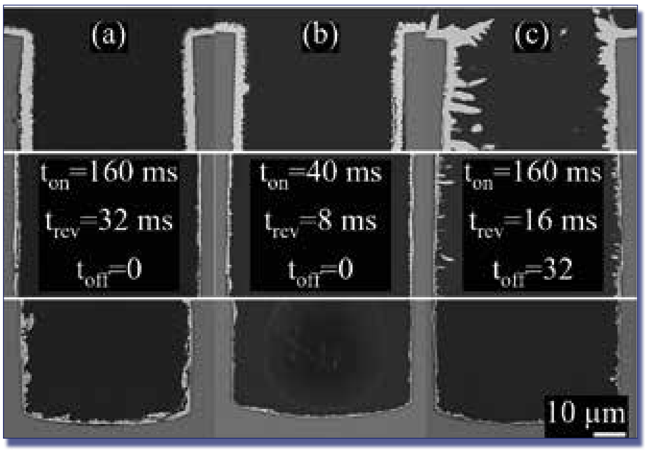

Figure 2: SEM-images of TSV cross sections after PRP without (a+b) and with suppressor (c)

Experimental

Design of experiment

The experiment was divided into the investigation of: a) basic film properties (e.g. roughness) and b) TSV step cover-age. One approach uses no additives and a second approach uses a suppressor according to an expected improved wet-ting behaviour [3]. Different pulse times and current densities were used: t_{on} = [20;40;80;160] ms, t_{rev} = [0.1;0.2]×t_{on}, t_{off} = [0;1] ×t_{on}, j_{on} = 1 A/dm², and j_{rev} = [1;2] A/dm². The deposition time was 113 … 300 s (a) and 17 … 45 min (b) for a target thickness of 300 nm and 3 µm, respectively. All experiments were carried out in a beaker on Si-coupons (3 × 3 cm²). For the TSV samples, blind holes were fabricated with 50 µm diameter and 400 µm depth. A MOCVD based TiN/Cu film system was used as barrier-/seed layer.

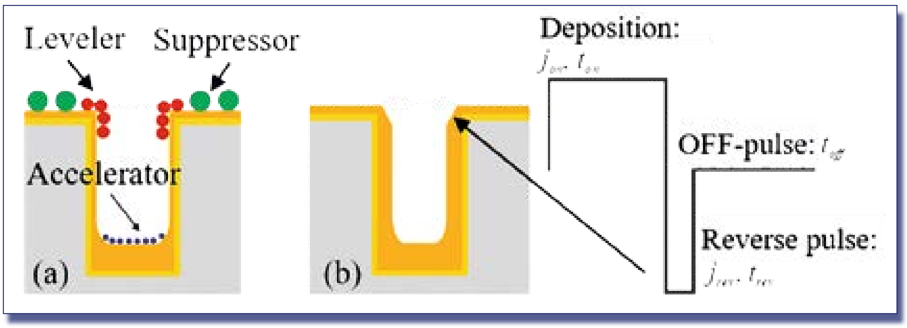

Fig. 1: DC-ECD with additives in TSVs (a) compared to the principle of PRP (b)

Results

For a deposition without additives, the roughness is mainly dependent on the deposition pulse with an increasing rough-ness (R_a = 13 … 33 nm) for a decreasing t_{on}. With suppressor, the roughness is very high (R_z = 600 nm) for t_{rev} = 0.2 × t_{on}, while no clear dependence on other parameters can be observed. SEM images in Fig. 2.1 show examples of TSV cross sections after deposition without and with suppressor. With respect to a conformal deposition, a better behaviour can be observed for an increase in t_{on}. The usage of a suppressor apparently cannot improve the conformal deposition but leads to a strong dendrite growth. For a quantitative analysis, the step coverage values (ratio of the thickness on the TSV sidewall vs. thickness on the top surface) is determined (Fig. 2.2). The experiments

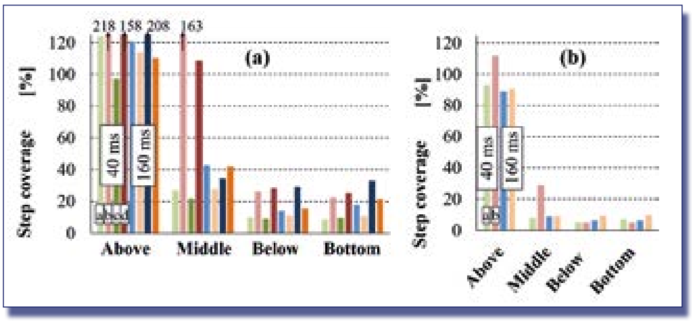

Fig. 3:
Step coverage of PRP Cu films in TSVs:
a) without additives and
b) with suppressor

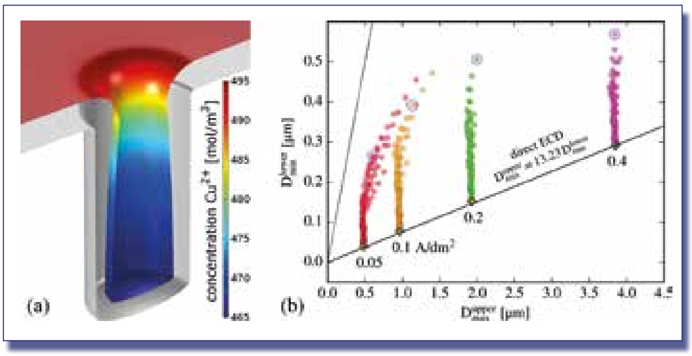

Fig. 4:
TSV model with simulated copper layer (colored surface) after of DC ECD (a) and (b) D^{lower}_{min} vs. D^{upper}_{max} for different average current densities with the best processes marked (circle)

with suppressor yield a low step coverage (≤10%), while almost no impact of the pulse parameters could be detected. For the deposition without additives the best result is found for t_{on} = 160 ms, t_{rev} = 32 ms, and t_{off} = 0 ms with a step coverage of 30%.

Simulation

Model system and theory

Simulations are carried out within a radially symmetric TSV of 100 µm diameter and 400 µm depth and some adjacent volume of electrolyte. The electrolyte is copper sulfate with a copper ion concentration of 500 mol/m³. The motion of ions, driven by diffusion and migration, is described by a Nernst-Planck equation. The kinetics of the copper deposition follows a concentration-dependent Butler-Volmer relation [4,5]. The resulting system of partial differential equations is solved (in the 2D axisymmetric geometry) with the finite element method using COMSOL Multiphysics [5].

Results

A visualization of the TSV geometry and the simulated copper layer is depicted in Fig. 3.1a. The non-conformity of the copper layer is measured by the ratio $D^{upper}_{max}/D^{lower}_{min}$ between maximum and minimum copper layer thickness at the upper and lower part of the TSV sidewall. For an optimized PRP process, a large variety of different pulse parameter combinations are used. Each simulation starts with 30 min of direct, followed by 30 min of pulsed ECD. The resulting values of D^{lower}_{min} and D^{upper}_{max} are shown in Fig. 3.1b. Direct ECD is characterized by a line of slope ~13. PRP is always better than direct ECD because all point are above that line. The best processes are closest to the line of perfect conformity with slope 1.
A careful inspection of raw data reveals guidelines for optimal PRP processes: (i) small average current density j_{avg}; (ii) large ON current density; (iii) no OFF pulse time; (iv) REV pulse time equals ON pulse time for small j_{avg}.

Conclusion

Experimental results show the impact of the PRP parameters on the roughness and step coverage in HAR TSVs.
The roughness was found to decrease with increasing deposition pulse time for PRP with no additives, while the use of a suppressor leads to extreme roughness values. An improvement of the wetting in TSVs, as expected from [3], could not be achieved by the use of a suppressor. For the deposition without additives, a step coverage of 30% was obtained for: t_{on} = 160 ms, t_{rev} = 32 ms, t_{off} = 0 ms, and a deposition time of 25 min. Comparable results are realized by DC-ECD for yet smaller current densities and a deposition time up to 1-2 h. By simulation of the PRP ECD it was found that, compared to the DC-ECD, the pulsed ECD yield an improvement in the deposition conformality by at least a factor of 2. From the simulation clear guidelines for an optimization of the PRP process could be derived.

Acknowledgement

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Additive Manufacturing of Membrane Electrode Assemblies for Fuel Cells and Electrolyzers

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Fuel cells and electrolyzers

One challenge coming along with establishing renewable energy sources, like wind and solar power, is the flexible storage of the generated "green" electricity. Water electrolyzers in combination with fuel cells offer an appealing solution to this problem, building a so-called "hydrogen economy". While electrolyzers can store electricity by splitting water into oxygen and hydrogen by consuming electricity, fuel cells reverse this process by converting the chemical energy again into electricity. Besides energy storage, this combination can also realize emission-free mobility, as in fuel cell powered vehicles. Compared to Li-Ion batteries, fuel cells have the advantages of a larger driving range and shorter refueling time, making them particularly suitable for heavy duty vehicles.
The heart of fuel cells and electrolyzers is the membrane electrode assembly (MEA) which determines the overall performance and lifetime. The MEA consists of a membrane that is coated with two porous electrodes. Fig. 1 shows the working principle of a fuel cell MEA. At the anode side of the membrane, hydrogen is split into protons (H^+) and electrons (e^-). The protons are conducted through the polymer electrolyte membrane, usually sulfonated PTFE, towards the cathode, where they recombine with oxygen and electrons to generate water. The electrons are conducted via an external circuit to power a load. These processes are reversed in an electrolyzer, which consumes electricity to split water into hydrogen and oxygen.
State-of-the-art MEAs are fabricated by depositing the electrodes on a transfer foil, which are then hot-pressed onto both sides of a membrane foil. While so far the membrane and electrodes are optimized separately, recent studies show, that the interfaces between these functional layers have a major impact on performance [1]. We therefore present a novel additive manufacturing technique for high power fuel cells, where the membrane is directly deposited onto the electrodes.

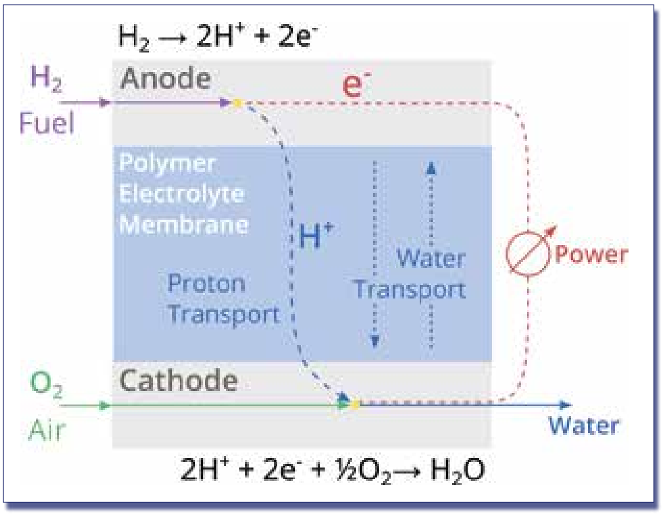

Fig. 1:
Working principle of a hydrogen fuel cell.

Additive manufacturing

Direct membrane deposition

With additive manufacturing we open up new ways for the fabrication of fuel cells. Instead of processing the membrane in the form of a foil and the electrodes in a spray and transfer step, we can fabricate the entire MEA in one subsequent spray process (Fig 2). First, the electrode is fabricated by depositing the carbon supported catalyst onto a gas diffusion substrate. In the second step, the direct membrane deposition (DMD), a membrane dispersion is sprayed onto the electrodes. Finally, two of these substrates are pressed together at the membrane interface to form a fuel cell. Figure 2 also shows the fabrication of a reinforced membrane: nanoparticle decorated nanofibers of a stable, inert polymer, e.g. PVDF, are deposited via electrospinning prior to the DMD step. All shown processes, spray coating and electrospinning, are capable of upscaling, e.g. in a roll-to-roll-process.

Compared to a commercial MEA, the DMD fuel cell showed a 40 % higher peak power density (Fig 3a) [2] in spite of identical electrodes and membrane thickness. This improvement is attributed to water management at the cathode due to the increased interfacial area between membrane and electrode [3]. Therefore, also at high current densities enough oxygen can still be supplied at the cathode without being blocked by generated water.

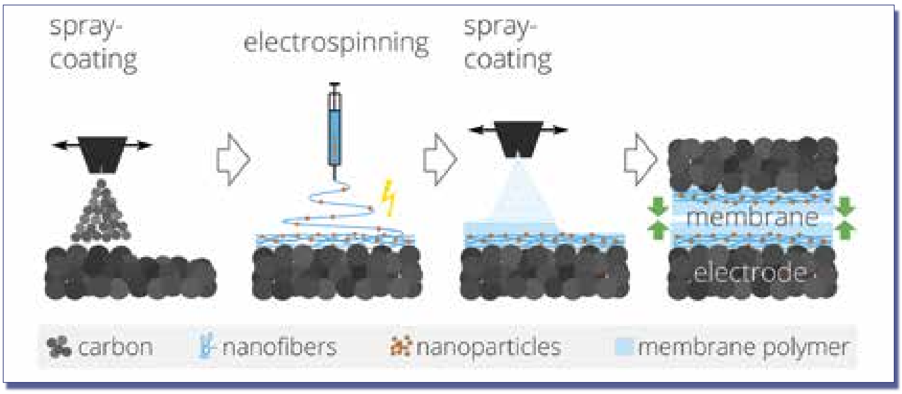

Fig. 2:
The conventional membrane foil in fuel cells is substituted by two directly deposited layers consisting of nanoparticles, nanofibers and electrolyte polymer.

Besides better performance, DMD can also improve the durability of fuel cells via the integration of nanofibers and nanoparticles to enhance the mechanical and chemical stability [4]. As shown in the accelerated stress test in Fig. 3b, integrated CeO_2 nanoparticles mitigate the voltage loss by acting as radical scavengers.

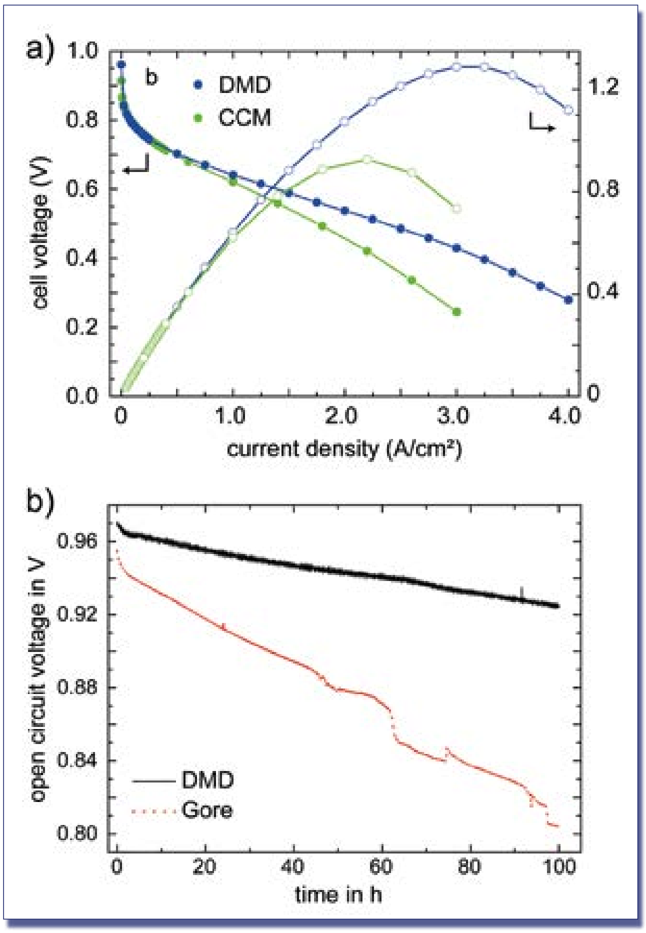

Fig. 3 :
a) DMD fuel cells show a significantly higher peak power density than a commercial catalyst coated membrane (CCM) [2].
b) Improved stability of the cell potential during an aging test (reference: Gore Select) can be achieved due to the integration of CeO2-nanoparticles in a DMD fuel cell [4].

Innovative MEA design

With the design freedom of additive manufacturing, improvements in-plane and through-plane are thinkable, e.g. gradient-like interfaces of the proton conductive domain in the electrode or membranes with an internal transport selective layer to prevent gas crossover. These additional layers can be deposited very thin as to not affect the functionality of the cells [5]. In-plane variation of the polymers could create hydrophobic and hydrophilic regions that facilitate water transport in channels. For water electrolyzers additive manufacturing could help reduce the ionomer content in the electrodes drastically. Fabricating standard MEAs requires a certain amount of ionomer to transfer the electrode onto the membrane. Additive manufacturing solves this problem since the membrane is directly deposited onto the electrode [6].

In summary, additive manufacturing for fuel cells and electrolyzers enables many novel concepts and already has proven to enhance the performance and stability of fuel cells.

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Multilayer Ceramic and Ceramic Injection-Molding – a Technological Combination to Fabricate Three-dimensional Ceramic Systems with Integrated Functions

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Introduction

The Multilayer Ceramic Technology (MLC) is a promising platform for electronics, sensors and microsystem devices. Due to its outstanding ability to integrate functional structures, the manufacturing of highly complex circuits, robust sensor functionalities or even microfluidic systems is possible. However, this technology offers poor geometrical freedom in the third dimension caused by its layer-based manufacturing process. Contrary the ceramic injection molding (CIM) provides almost unrestricted abilities in the geometrical shaping. This technology is normally used to implement complex three-dimensional ceramic components for textile processes, mechanical engineering and medicine applications but offers poor functionalities in turn. Thus, the combination of these two technological approaches establishes new promising opportunities for innovative ceramic systems, figure 1. The technical approach is planned to injection-mold around functionalized unfired multilayer-laminate inserts and to sinter this component, afterwards (co-sintering). Thereby the specific restrictions of each single technology can be overcome.

Material development

Decreased sintering temperatures are required to use excellent conductive materials, like Au, Ag or Cu as integrated terminations. For that purpose, low temperature co-fired ceramic (LTCC) is chosen as base material. The requirements for the selection of the LTCC-system are following:

- Powders of the LTCC-system have to be available to generate the feedstock for the injection-molding,
- A suitable paste-system is available,
- The lateral shrinkage fits to the shrinkage of injection-molding feedstocks or is adaptable and
- A sufficient state of knowledge is required for the processing of the LTCC-system.

Best results during the feedstock development were observed when mixing the powder with the same organic like the LTCC-tapes. This provides a homogeneous debindering of the component during the sinter process. Furthermore the shrinkage of the feedstock was adjusted by an increased solid content.
To generate even more geometrical flexibility, for instance to integrate chambers in the component, we investigate several sacrificial materials for the injection-molding. This type of material is used to create undercuts by injection of a lost-core. Due to that the sacrificial mold requires a sufficient stability during subsequent injection-steps as well as a good extraction during the debindering of the component. Best results were achieved with polyoxymethylen (POM) and a pure thermal extraction.

Technology development

The fabrication of a ceramic piezo resistive pressure sensor with monolithic media port was established to demonstrate the technical approach. Therefore several steps regarding the in-mold labeling were under investigation. First the LTCC-multilayer laminate was

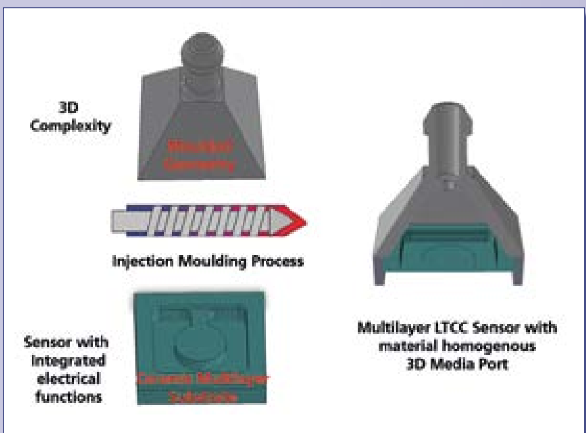

Fig. 1: Principle of the new technology approach

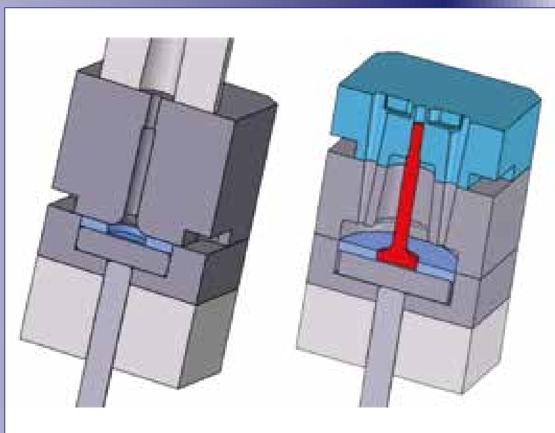

Fig. 2: Illustration of the different injection tools

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inserted in the injection-molding tool. Then the lost core was processed which creates the pressure chamber after the firing process. In the third step, the LTCC media port was injected around the lost core and upon the LTCC laminate, figure 2. Different tool cavities were used for this procedure. Figure 3 illustrates the approach. Due to the fact, that a defect-free debindering and sintering of the component was succeeded, the sequence was expanded by the usage of a functionalized LTCC-laminate to fabricate real functional components. Based on the investigations, a small batch series of ~100 ceramic pressure sensors with monolithic media ports and sufficient sensor characteristics was fabricated. Hence the approach to in-mold labelling of functional LTCC-laminates was successfully demonstrated, figure 4.

Conclusion

Based on our results, a new technology platform was demonstrated which combines the typical multilayer ceramic technology and the ceramic injection-molding to overcome the weaknesses of each single approach. Due to that a new type of ceramic component with a high geometrical complexity and an outstanding degree of functionality is feasible. Therefore the realized pressure sensor is representative for the miscellaneous opportunities to upgrade planar MLC substrates with three-dimensional structures (e. g. cavities, reinforced areas or antennas) as well as CIM-components with electrical and sensory functions (e. g. abrasive wear detection, load sensing, tempering, electrical conductors). Suitable materials for this approach are LTCC-systems (glass ceramic or glass-ceramic-composites) and HTCC-systems (Al_2O_3, ZrO_2). In addition the effort analysis verifies an excellent adaptability of this solution for medium to high batch-series due to attractive fabrication costs and consequently enables new applications as complex electronic packages as well as devices for the process automation and Internet of things with a demand of an outstanding robustness and reliability.

Acknowledgements

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Fig. 3: Illustration of the production sequence

Fig. 4: Batch production of pressure sensors

Nanofiber-deposited Porous Platinum Enables Glucose Fuel Cell Anodes with High Current Density in Body Fluids

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Active medical implants have become an integral part of modern medical care, being widely applied in neuro-stimulation, pain treatment, epilepsy therapy, or the monitoring of vital parameters such as blood pressure or blood glucose levels. Nevertheless, the reliable and continuous supply of medical implants remains a challenge and has not yet been solved satisfactorily [1,2]. To date, batteries are the only practically available power source, however, these are limited in their charge capacity and life-time. For instance in case of cardiac pace makers, this necessitates a surgical procedure after typically 10-12 years to replace spent batteries [3]. This not only has a negative effect on the patients' life quality, but also causes financial burden for the health care system.

In this context, glucose fuel cells are a promising technology to realize a battery-independent power supply for medical implants. Theoretically, they can continuously generate electricity by the conversions of glucose and oxygen readily available in body fluids such as blood and tissue fluid. At the anode, glucose is oxidized to gluconic acid (Fig.1). The released electrons flow via an external load circuit, e.g. a pace maker, to the cathode, where they take part in the reduction of oxygen to water [4].

Compared to enzymatic catalysts, which are heat sensitive and typically undergo degradation within a few days or weeks, abiotic catalysts such as platinum are of particular advantage for longer-term applications. In particular, they are amenable to proven sterilization procedures such as heat treatment, which are prerequisite for implantation. On the other hand, glucose fuel cells using abiotic catalysts typically show a lower power density than their enzymatic counterparts. The field of application for abiotic glucose fuel cells are thus typically low-power implants, ranging from pace makers (power demand ~10 µW) to implantable sensors (~1 µW).

Abiotic glucose fuel cells: state of the art and challenges

In physiological glucose solution, our platinum-based abiotic glucose fuel cells have been continuously operated over periods of several months [5]. Under these simple operating conditions, up to 6 µW cm^{-2} have been achieved [6], which would be more than sufficient to power a cardiac pacemaker by a fuel cell placed on its casing [3,5]. However, in more realistic media such as artificial tissue fluid (containing all amino acids and further small organic molecules), the cell potential collapses after only a few hours (Fig.2a) [6]. This is predominantly caused by a poisoning of the anode, where some amino acids and organic molecules adsorb to the surface of the platinum catalyst and inhibit further glucose oxidation (Fig.2b) [6].

Solution strategy: massive increase in specific surface area

Previous experiments showed that even in the presence of poisoning amino acids a residual glucose oxidation current remains [7]. This suggests, that increasing the electrode's specific surface area would lead to an increase in the glucose oxidation current even in the presence of endogenous amino acids. This way, the current density achievable under physiological conditions could be increased to levels that are useful for technical application. We therefore developed a fabrication method for anodes with large specific surface areas by depositing highly porous platinum onto 3-dimensional carbon nanofiber mats (Fig.3) [8]. Compared to state-of-the-art anodes fabricated on flat substrates, this results in an almost three-fold increased active surface area with a roughness factor (ratio of actual to geometrical area) of 16500 ± 2300 [8].

Performance under realistic conditions

The performance of the newly developed 3D-anodes was tested under realistic conditions using horse serum as substitute for tissue fluid. The anodes were polarized at a typical operation potential of -200 mV vs. SCE, and

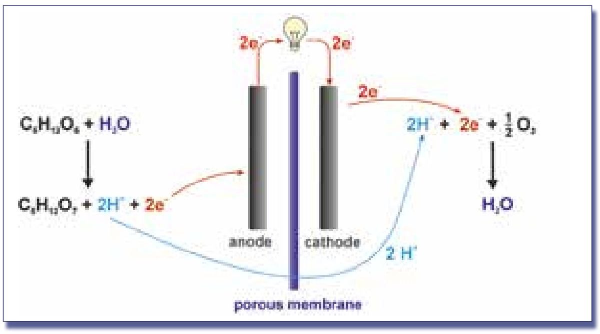

Fig. 1:
Working principle of an abiotic glucose fuel cell. At the anode, glucose is oxidized to gluconic acid, releasing two protons and two electrons per glucose molecule. The electrons flow through an external load, the protons diffuse through the porous membrane. At the cathode, oxygen is reduced to water with the help of protons and electrons [4].

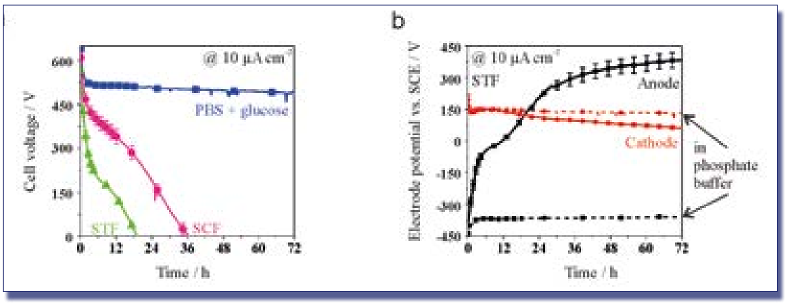

Fig. 2:
a) Cell voltage development at a continuous load of 10 µA cm^{-2} in neutral phosphate buffer containing glucose in physiological concentration (PBS + glucose), simulated tissue fluid (STF, PBS + glucose + amino acids and small organic molecules), and simulated cerebrospinal fluid (SCF, PBS + glucose + amino acids and small organic molecules) [6]. **(b)** Anode (black) and cathode (red) potentials in simulated tissue fluid (STF, solid line) and neutral phosphate buffer containing the physiological concentration of glucose (dashed line) [6]. © Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, reproduced from [6] with permission.

the generated current density was continuously monitored over a period of 30 days. As shown in Fig.4, the 3D-anodes yield current densities of (7.2 ± 1.9) µA cm^{-2} after 30 days of continuous operation, whereas state-of-the-art anodes show considerably smaller values of (1.3 ± 0.1) µA cm^{-2} [8]. Remarkably, the higher current density of the 3D-anodes cannot be fully explained by the larger surface area: the surface is only increased by a factor of 2.4 but the achieved current density is more than 5 times larger compared to state-of-the-art-anodes [8]. Presumably, this results from an enhanced catalytic activity for the oxidation of glucose and other molecules present in horse serum and/or an improved poisoning resistance of the nanofiber deposited platinum catalyst [8]. Possibly, this results from a favourable change in the micro structure of the porous platinum surface.

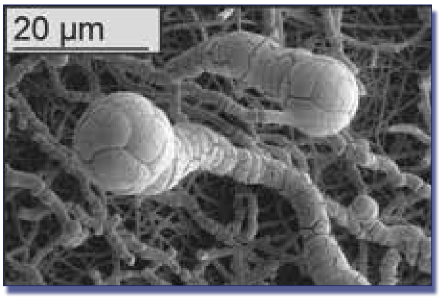

Fig. 3:
Scanning electron micrograph of carbon nanofibers coated with highly porous platinum. Platinum and copper were deposited simultaneously from a sulfuric acid based electrolyte, followed by selective dissolution of copper resulting in the formation of a porous platinum coating [8]. Reprinted from Journal of Power Sources, 362, Frei, M., Erben, J., Martin, J., Zengerle, R., Kerzenmacher, S., Nanofiber-deposited porous platinum enables glucose fuel cell anodes with high current density in body fluids, 168–173, Copyright (2017), with permission from Elsevier.

A look ahead

The next step will be the application of the newly developed anodes together with an oxygen-reducing cathode in complete fuel cell studies. In combination with a typical platinum cathode operated at +100 mV vs. SCE [6], power densities in the range of 2 µW cm^{-2} at a cell potential of 300 mV in a realistic body fluid environment can be expected. This would already be sufficient for pacemaker or sensor application.
In any case, extended in-vitro and in-vivo studies will be required to prove the fuel cell's performance and biocompatibility over extended periods of time. Further research is also required with respect to the functional integration of the glucose fuel cell together with a medical implant. In this context, the conversion of the fuel cell voltage (~300 mV) to the voltage levels typically required by implant electronics (>2 V) will be of particular importance. Besides the development of efficient DC-DC-conversion circuits also the development of low-power electronics and their interfacing with the glucose fuel cell may be a promising approach that warrants future research.

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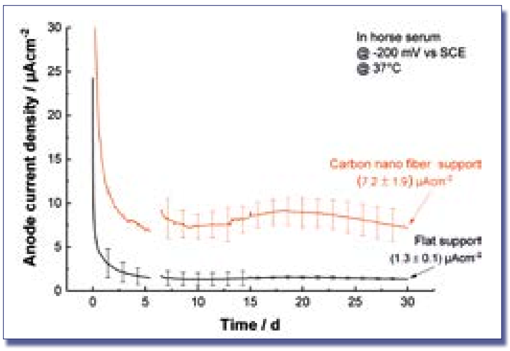
Fig. 4:
Current density over time of platinum anodes on carbon fibers (red) and a standard flat support (black) at -200 mV vs. SCE in horse serum. For a better readability a finite number of error bars representing the sample standard deviation are given [8]. Reprinted from Journal of Power Sources, 362, number, Frei, M., Erben, J., Martin, J., Zengerle, R., Kerzenmacher,S., Nanofiber-deposited porous platinum enables glucose fuel cell anodes with high current densityin body fluids, 168–173, Copyright(2017), with permission from Elsevier.



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Investigations on a Novel Silicon MEMS Microphone Concept for a High Signal-to-Noise Ratio

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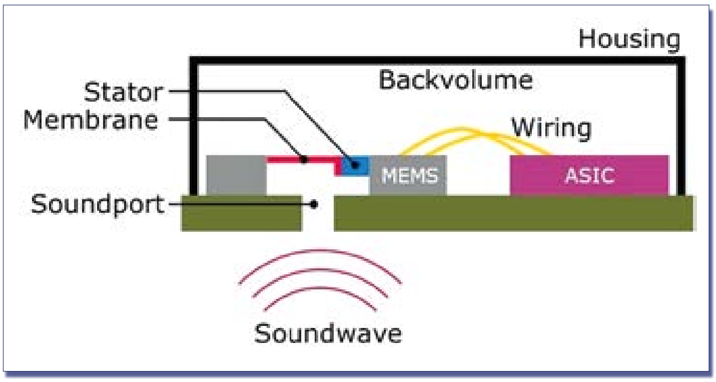
Abstract
Silicon MEMS microphones are widely used in mobile devices and lately in speech recognition for smart home applications. For these applications excellent sound quality and therefore a high signal-to-noise ratio (SNR) is essential. The majority of commercially available microphones feature a capacitive readout realized as membrane-backplate system, whose performance is limited by the noise caused by viscous damping losses. To overcome this drawback, a novel backplate-less design based on a capacitive comb finger read-out is conceived. To evaluate the potential of this design, a fully energy-coupled, modular system-level model is developed, predicting very low noise with a high SNR of 73 dB (A).

Introduction
Being on the market for more than a decade, silicon MEMS microphones reached a quite mature state, providing remarkably high signal-to-noise ratios (SNR) of 65-70 dB (A). In general, the setup of a silicon MEMS microphone with capacitive readout consists of a transducer chip with a membrane-backplate system and an application specific integrated circuit (ASIC) for signal processing, both placed inside a housing. The membrane-backplate system consists of the compliant membrane opposed to the stiff, perforated backplate. An incoming soundwave deflects the membrane leading to a capacitance change between membrane and backplate, which is then detected by the ASIC. As shown in [1] a major part of the noise in such a microphone arises from losses originating from thousands of perforation holes in the backplate. This is why we conceived a new design by completely removing the backplate and introducing a comb finger structure at the rims of the membrane in order to detect its motion.

Fig. 2: Schematic view of a MEMS microphone.



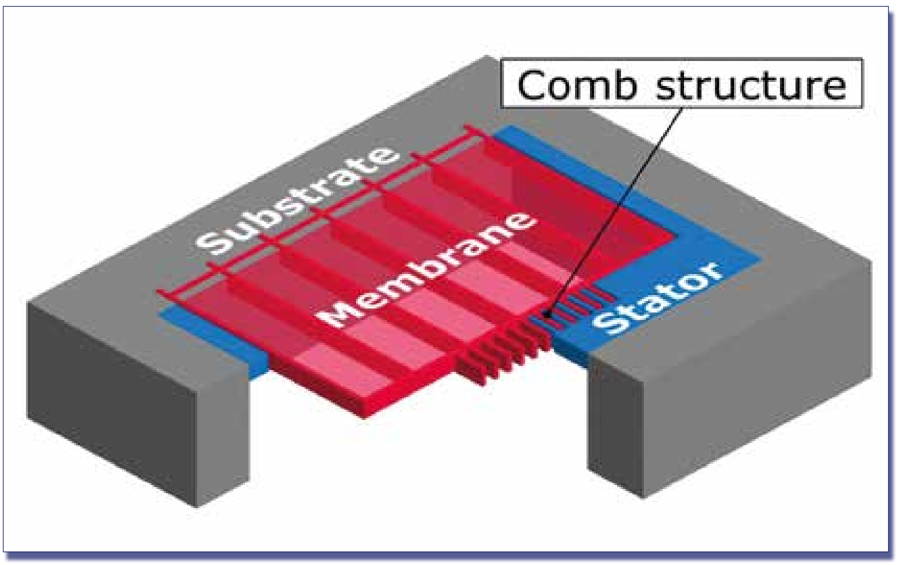


Fig. 1: Schematic view of the novel design with a comb structure.

Design and working principle
The design of the transducer chip is depicted in Fig. 1. A rectangular membrane (red) is fixed to the substrate (grey) with an anchoring structure at one side. The comb structure consisting of two sets of comb fingers is located at the opposite side. One set of fingers is attached to the membrane, and the other set of fingers is attached to the stator structure (blue). The thin silicon layer of the membrane is stiffened by bars. This allows for easily adjusting the compliance of the membrane by varying the number of bars. A deflection of the membrane results in a change of the overlapping area inside the comb

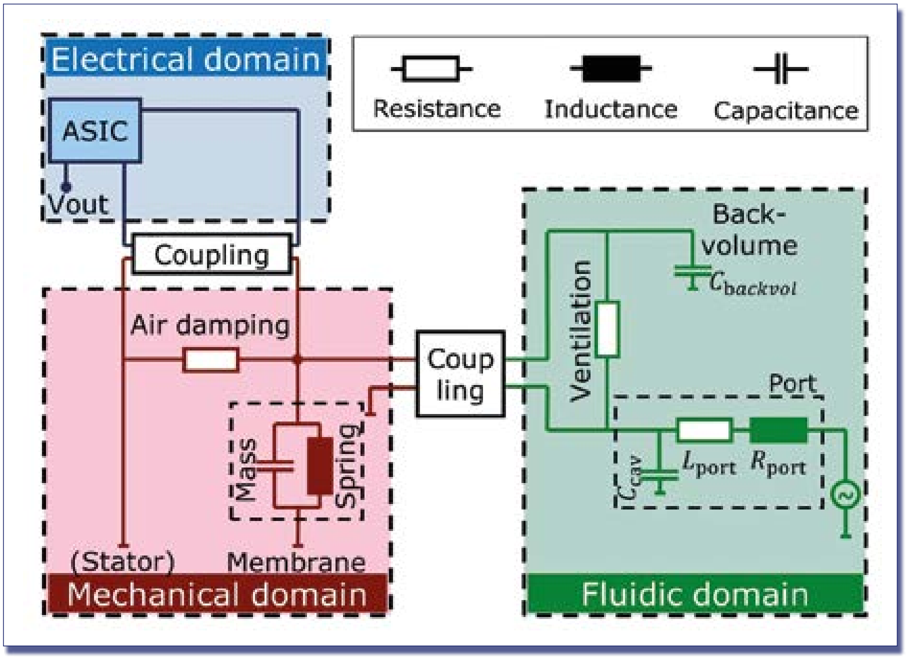


Fig. 3: Network representation of the microphone.

structure, leading to a capacitance change which is measured by the ASIC. To maximize the electrical capacity for a higher output signal, the air slit between the fingers in the comb structure is designed as small as possible. Since the membrane is only hinged on one side, the non-uniform stress distribution induced by the fabrication processes deforms the membrane. The compliance and geometrical parameters of the membrane are designed in such a way that the membrane bends up, resulting in an offset in the comb structure of half the height of the comb fingers in order to obtain the maximum dynamic range. Finally, the transducer chip is mounted together with an ASIC in an encapsulated housing, see Fig. 2.

Modelling and simulation results

The modelling approach is based on an energy and flux conserving multi-energy domain-coupled network description of the system [2]. Lumped elements representing the single subdomains of the microphone are connected to reproduce the operation of the entire microphone. In order to obtain reliable simulation results black box models are omitted and the lumped elements are based on physical equations including design parameters and material constants. We decided to use an intuitive separation of the respective energy domains in the microphone: electrical for the read out circuit, fluidic for the sound propagation and mechanical for the movement of the membrane. Coupling elements are introduced to link the models of each energy domain, leading to the full network model as shown in Fig. 3.

A detailed description of the model and its individual parts can be found in [3]. It is noteworthy, that such a model can easily be extended or adjusted to other MEMS transducers by adding the respective lumped elements in the network. The model was implemented in a standard network simulator. Since all dependencies of the design parameters are included in the model, we were able to perform sensitivity and noise analyses of design variants of the microphone. In a first step we adjusted the geometrical parameters of the microphone to obtain a sensitivity of -38 dBV/Pa at 1 kHz to meet the requirements of the ASIC. Second, a noise analysis was carried out to simulate the noise contributions of single parts of the microphone. The noise of the ASIC has been neglected so far, thus presuming an idealized ASIC. By A-weighting the total noise and integrating it over the audio band a SNR of 73 dB (A) is achieved. This proves the potential of such a comb microphone for the application as a high SNR silicon MEMS microphone.

Conclusion

We present a fully coupled modular network model of a novel silicon MEMS microphone. The new design with a comb structure allows for a backplate-less electrostatic read out mechanism. The simulations are carried out by implementing the network in a standard circuit simulator showing a high SNR of 73 dB (A), confirming the potential of the here presented microphone concept with a comb read-out.

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Ergebnisse und Leistungen aus Forschungseinrichtungen

Results and Portfolios of Research Institutions

InP HBT Technology for Terahertz Applications at FBH – Offering the Complete Value Chain

FBH develops microelectronic components for terahertz (THz) applications such as high-resolution radar, wideband wireless communications, and sensing. These components are based on the in-house indium phosphide (InP) heterobipolar transistor (HBT) device technology, while dedicated THz detection devices rely on FBH's GaN HEMT technology. FBH is a microsystems competence center covering the entire chain from device processing and circuit design to system-on-chip microsystems. Beyond fundamental research on THz components, FBH supports industry by satisfying the application-driven demand for mature and stable THz technologies along with a reliable supply chain.

Transferred Substrate InP HBT Fabrication Process

FBH has developed a transferred substrate InP HBT process with transistor cut-off frequencies f_t = 350 GHz and f_{max} = 550 GHz at 20 mA collector current and > 4 V_{CEO} breakdown voltage. The proven monolithic heterointegration of InP HBT-on-Si BiCMOS is a key enabler for compact high-performance THz RF front ends, leading to a reduction in size, weight, and dissipated power as compared to existing assembly techniques. The combined InP-on-BiCMOS process is offered together with the Leibniz institute IHP.

Circuits are assembled by flip-chip mounting providing excellent manufacturing control of placement and interconnect path. Small-signal RF measurements of back-to-back flip-chip transitions fabricated at FBH show an insertion loss < 0.5 dB per interconnect and a return loss > 10 dB from DC up to 500 GHz. This mounting technique is a viable route for manufacturing low-cost mm-wave and THz assemblies.

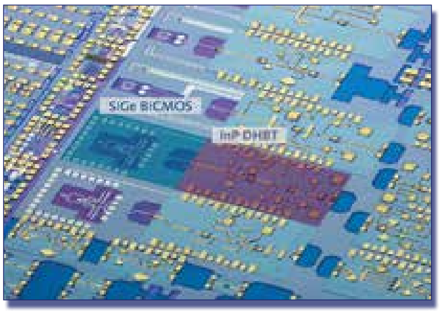

Fig. 1: Heterointegrated circuits combining the high RF output power of InP DHBT and the complexity of SiGe BiCMOS technology
Source: ©FBH/schurian.com

Fig. 2: A building block for THz detector modules in terahertz systems: GaN THz HEMT detector Source: ©FBH/schurian.com

Fig. 3: On-wafer terahertz measurement setup: preparing an InP DHBT wafer for comprehensive circuit characterization up to > 500 GHz
Source: ©FBH/schurian.com

Circuits & Detectors for THz Frequencies

FBH develops InP HBT MMICs and GaN THz HEMT detectors as building blocks for transmitter and receiver modules in THz systems. Circuits include oscillators up to 300 GHz with > 0 dBm output power and good phase-noise properties, multipliers up to 500 GHz, full-band frequency multipliers at D- and G-band, power amplifiers at D-band, chipsets including up/down converters as well as power amplifiers with > 150 mW output power operating in W-band, and low-noise amplifiers. FBH has also developed integrated GaN HEMT plasmonic detectors and detector arrays with state-of-the-art performance with record noise equivalent power values for 0.5 – 4 THz for focal plane THz cameras and THz spectroscopy systems applications.

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Photonics made in Jena – 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. 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 in or realized by the Fraunhofer IOF.

Micro-optical telescopic arrays for LED light sources

Micro-optics offer great potential for light shaping of LED light sources. Well-known examples are fly´s eye condensers realized as tandem microlens arrays or holographic diffusers. The low divergence, large area LED light source developed at Fraunhofer IOF consists of an array of collimated LEDs and a micro-optical telescope array. Efficient collimators with homogeneously illuminated pupil, low aberration and minimum stray light were designed and realized. Nonetheless, this LED light source has to be accomplished by a telescope producing a sharply defined circular top-hat spot in the farfield.

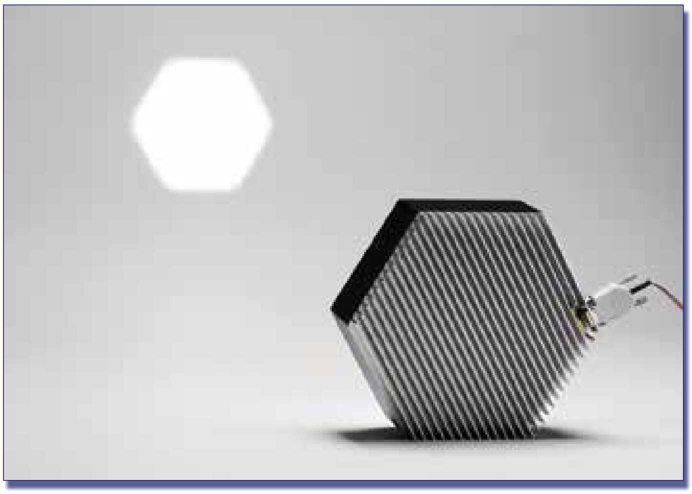

Fig. 1: Micro-optical telescopic arrays for LED light sources: LED light source and generated spot on a screen. ©Fraunhofer IOF

A multi-aperture micro-optical array approach was chosen to realize a telescope array with minimum thickness. The basic design consists of Kepler telescopes with a pinhole to properly tailor the light beam. Aperture sizes, element thicknesses, and radii of lens curvature scale linearly with the permissible decentration errors, thus, a trade-off between required precision and system length has to be established.

At Fraunhofer IOF, comparatively large 1 mm diameter lenslets require lateral alignment precision in the 10 micrometer range.

AR coating and peculiar design of apertures help to minimize adjacent channel cross talk inside the filter. The system was realized with two borofloat glass wafers equipped with aperture layers buried under the lens arrays, which are polymer-on-glass elements. To achieve correct placement of the wafer with respect to each other, alignment marks for lateral adjustment and a replicated spacer structure for correct focusing are added.

Antireflection Coatings for Strongly Curved Glass Lenses by Atomic Layer Deposition

Antireflection (AR) coatings are indispensable in numerous optical applications and are increasingly demanded on highly curved optical components. Commonly, such thin films applied in precision optics are produced by physical vapor deposition (PVD). Due to the line-of-sight nature of PVD, the

Fig. 3:
Antireflection Coatings for Strongly Curved Glass Lenses by Atomic Layer Deposition.
©Fraunhofer IOF

surface of a convex lens that is normal to the deposition flux receives a higher amount of material than the edges of the lens and significant thickness gradients might occur on highly curved lenses.

At Fraunhofer IOF, optical thin films of SiO2, Al2O3, TiO2 and Ta2O5 were prepared by atomic layer deposition (ALD), a modified form of chemical vapor deposition, where the precursors are sequentially exposed to the surface until saturation is reached. Film growth is based on self-limiting surface reactions leading to a uniform film thickness on arbitrarily shaped surfaces.

Through this method, the average reflectance could be minimized to 0.3 % for a fused silica half-ball lens with 4 mm diameter and a steeply curved B270 aspherical lens in the visible spectral range from 400 to 700 nm. Similar reflectance spectra across the entire lens surface at normal light incidence are a result of the very good conformality of ALD coatings. The good agreement between design and coatings confirms the precise thickness control of ALD thin films.

GRISM Manufacturing for Spectroscopy in Space

Nano-optical structures - such as gratings - are fragile structures and therefore very sensitive. To use these gratings in satellite instruments, the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena has developed a technical solution which resists the inhospitable conditions in space and does not affect the gratings. The grating is firmly connected to a prism at atomic scale - in detail via oxygen bridges - without further aids. The resulting component is called GRISM (grating in prism). The connection technology is known from the field of silicon wafers; also known as hydrophilic bonding. Pressing the surfaces together under elevated temperatures in a vacuum, the oxygen atoms form a solid (covalent) connection between the two parts. The oxygen bridges connect grating and prism firmly together, the radiation in space cannot harm them. In addition, there is no intermediate layer as with adhesives, which would falsify the measurements with the grating. The challenge is the positioning of the grating and prism exactly to each other with an accuracy of one arc minute.

The GRISM achieves a new level of quality through this assembly and connection technology. It is predestined for space applications due to its high stability. Installed in space spectrometers, light emitted by the earth can be precisely dissected into its individual colors; and the extent of greenhouse gases in the earth's atmosphere can be analyzed.

Fig. 2:
Directly bonded fused silica GRISM (Prism + Grating) with ALD coated grating at the inner surface.
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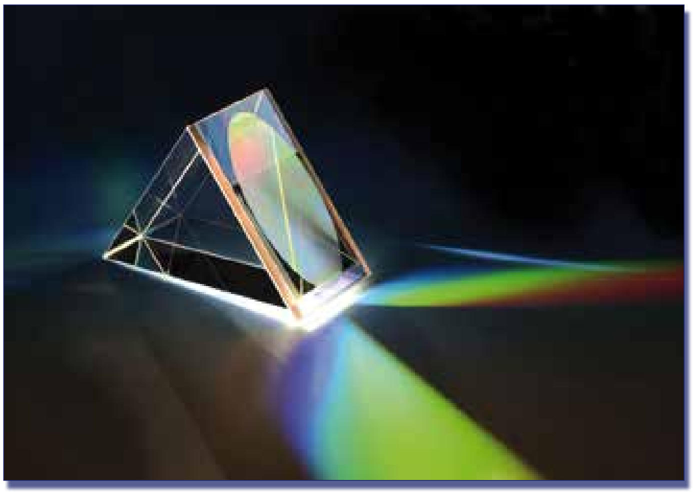

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Getting Started: Fraunhofer IMM is now an Independent Fraunhofer Institute

In 2013 we have been integrated into the Fraunhofer-Gesellschaft as the Fraunhofer ICT-IMM and now, nearly five years later, we have become an independent Fraunhofer institute. Since January 1st, 2018, we may call ourselves Fraunhofer Institute for Microengineering and Microsystems IMM. 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 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 innovation fields: Energy, Chemistry and Raw Material, Safety, Health and Nutrition, Mobility and Transport and Industry 4.0.

Find out what is behind these innovation fields:

Our competencies in the field ***Energy, Chemistry and Raw Material*** include Catalysis, Hydrogen Technology, Biofuels, Heating and Cooling Management, Energy Storage, Flow Chemistry, Nanoparticles, Photochemistry, Electrochemical Synthesis and Reactive Intermediates. Let's have a closer look at the in-situ production of Grignard reagents with continuous process control. Since its discovery more than 100 years ago, the synthesis of Grignard reagents and their conversion with a variety of organic molecules such as ketones and aldehydes has been one of the most effective methods of C-C bond formation. In the synthesis of the top 50 active pharmaceutical ingredients, in about 10 percent of the synthetic pathways one Grignard reaction or more can be found. The production of Grignard reagents in a continuous process in-situ offers many advantages, like for example improved heat transfer, no runaway of the reaction, a continuous supply of magnesium, integrated magnesium activation, integrated process control and in-line analytics via IR measurements.

Our scientists also perform research in CBRN Detection and Water Analysis in the innovation field ***Safety***. The rapid identification of threatening substances in the air allows for rapid action. In times where the release of biochemical substances in the context of a terrorist attack is quite possible this is of great importance. The use of microfluidic, contamination-safe disposable cartridges in combination with robust analytical methods, such as sensitive and ultrafast qPCR, enables the realization of automated systems with high multiplexing functionality. By eliminating manual steps, the reliability of the analysis increases and risks for the users are significantly reduced by avoiding potentially dangerous handling errors.

In the field ***Health and Nutrition*** our subjects are Lab on a Chip for Point-of-Care Testing, Encapsulation of Active

Fig. 1:
Grignard pilot reactor

Fig. 2:
Simplex – point-of-care platform for molecular diagnostics

Fraunhofer IMM

Fig. 3: Sensor platform for gas detection

Fig. 4: Biodiesel test plant

Ingredients, Sustainable Drug Synthesis and Microelectrode Probes for Neurotechnology. The trend towards miniaturization has become well established in medical diagnostics and will be further continued, in particular by use of the lab-on-a-chip technology which enables rapid tests in disposable plastic chips. Therefore, innovative physicochemical methods are miniaturized and automated. They are used in systems which allow regular point-of-care tests or continuous patient monitoring. Personalized medicine (e.g. oncology) is another trend in which the use of miniaturized tests allows for an individual therapeutic approach using genetic characterization. Due to the unique, broad coverage of all necessary core technologies (integration of bioassays, chip design and manufacturing, systems engineering, prototype and apparatus engineering, optics and sensor technology, electronics and software) we are able to rapidly develop an application idea to a fully functional demonstrator.

Mobility and Transport deals with matters of Fuel Processors, Exhaust Gas Purification, Synthesis of Biofuels and Oil Sensor Technology. As an alternative for the conventional fuel production from crude oil, fuels from renewable resources (biofuels) gain considerable importance. Biodiesel is a first generation biofuel and is gained in a conventional process by transesterification of vegetable oil with methanol at standard pressure and temperatures between 55 und 80 °C. This process is comparatively slow and the reaction times usually take up to four hours. We have developed a process which shortens this to a time demand between half a minute and five minutes. The key technology is the catalyst which is applied in solid form as a layer on a metallic carrier and thus, does not have to be separated later in the process.

Industry 4.0 includes the topics Detection Systems for Biological Contaminations and Process Monitoring. Our systems are particularly suited for applications based on process parameters with short or medium half-lives. Thereby, one or more parameters can be determined simultaneously and various methods of analysis (chemical, optical and optical-spectroscopic) can be combined.

This is just an excerpt of what we do. With more than 25 years of experience we cover a broad range of competencies and love to face up every new challenge.

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Metamorphic and Stretchable Electronic Systems – A Materials, Assembly, and Interconnection Challenge

S. Biswas, M. Mozafari, J. Reiprich, L. Schlag, N. A. Isaac, T. Stauden, J. Pezoldt, and H. O. Jacobs

The Institute of Micro- and Nanotechnologies of the TU Ilmenau – the IMN MacroNano® - combines the know-how and resources of the key research areas of Microsystems Technology and Nanotechnology for the fields of application in Life Sciences, Energy Efficiency and Photonics. One outstanding feature of the IMN MacroNano® is the interdisciplinary and cross-faculty orientation, which encompasses the competence of natural sciences, technology-focused disciplines of microsystems technology and nanotechnology and application-oriented engineering sciences.

Recent research in the field of electronics has taken a new focus to realize an electronics world where the electronic systems are not only bendable, but stretchable, conformable, shape changing, and metamorphic. The field is challenging from a technology point of view since it requires the integration of active devices on a rubber substrate. Specifically, the devices need to be assembled with high precision on an elastomeric substrate that does not sustain high temperature processing. Moreover, stretchable interconnects have to be realized to connect the device components. To address this challenge we are focusing on two fronts.

(i) Assembly Challenge – We are presently developing a fluidic self-assembly process to assemble microscopic chips on the required substrates. The current progress on an automated roll-to-roll fluidic self-assembly process will be presented.

(ii) Interconnection Challenge – Currently we are evolving a process to fabricate and study stretchable printed circuit boards which enables a reliable interconnection of the devices. First prototypes have been fabricated. The boards are stretchable (up to 320%) and maintain electrical connectivity to/ and in between the assembled components under various forms of deformation. First metamorphic demonstrators are shape changing illuminators, and metamorphic microphone arrays with shape changing receive characteristics.

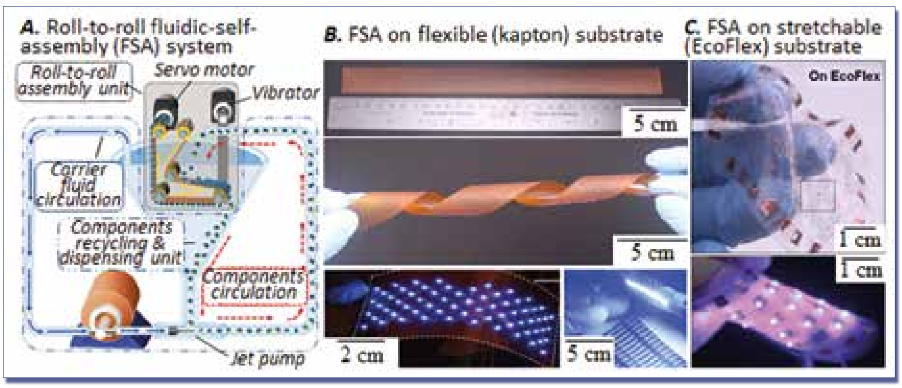

Figure 1: *Roll-to-roll (RTR) fluidic-self-assembly (FSA) system and demonstrators.* (***A***) Automated RTR FSA scheme in combination with a component recycling and dispensing unit, carrier fluid circulation and a pumping system. The RTR unit consists of a servo motor, a vibrator, and assembly ribbon. (***B***) Photographs depicting assemblies of 500 µm wide Si chips onto a 2 cm wide and 29 cm long assembly region (top), flexibility of the assembled ribbon with Si chips (middle), and demonstrator of flexible solid-state lighting module using FSA (bottom). (***C***) Demonstrators of FSA of Si chips onto a rubber substrate (EcoFlex) (top), and FSA of light emitting diodes (LED) for mm-thin rubber-like solid-state lighting module.

(i) Assembly Challenge: A Roll-to-Roll Fluidic Self-Assembly Comes to Aid.

To overcome the assembly challenge we are currently developing an automated roll-to-roll fluidic self-assembly process. The current design involves a conveyer belt and an automated chip agitation concept and achieves an assembly rate of 15 k chips per hour. **Figure 1A** illustrates the layout. The system has two main parts: (i) RTR assembly unit (shaded in grey) consisting of a servo motor, vibrator, rollers and polyimide web to precisely control relevant parameters such as chip agitation, web moving speed, and tension of web as well as a (ii) component recycling and dispensing unit (shaded in blue). The components are transported to the inlet using a narrow channel. The substrate holds copper squares, which are coated with a low melting point solder. The self-assembly takes place in a liquid, which is heated to the melting point of solder. The metal contact on the chips adheres to the molten solder based receptors on the substrate. This adhesion is driven by the minimization of the surface free energy of the liquid solder yielding a stable, aligned, and electrically connected position. ***Figure 1 B, C*** depicts some assembly results. In (***B***) 1523 silicon chips were assembled on a polyimide substrate (top). In (***C***) LEDs were assembled on a stretchable rubber-like (EcoFlex) substrate. The bottom image shows a mm-thin flexible and stretchable solid-

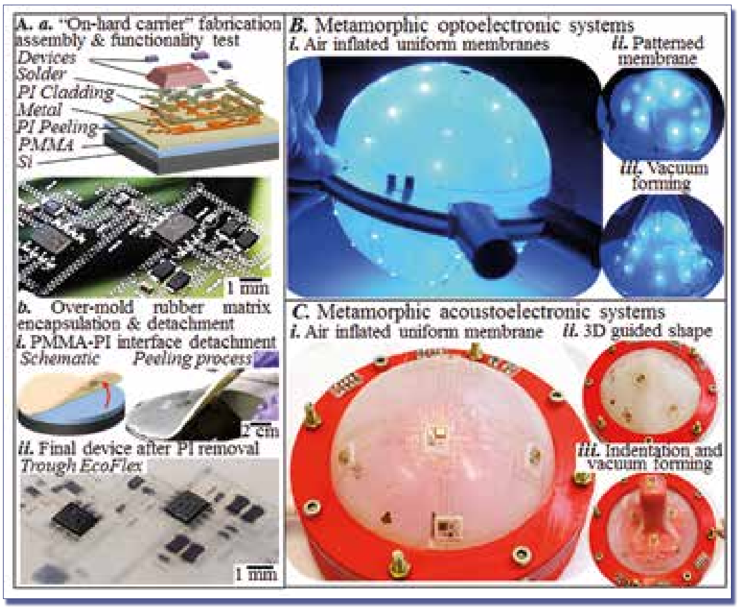

Figure 2: *Integrated stretchable printed circuit board process (A), and demonstrators of metamorphic electronics, optoelectronics (B), and acoustoelectronics (C) systems.* (***A***) "On-hard carrier" fabrication, assembly, and functionality test (a), the fabrication involves the application, patterning, and alignment of several layers, specifically: a PMMA release layer (blue), a PI peeling layer (greenish grey), and a metallization layer (orange). (***b***) Over-mold rubber matrix encapsulation showing PMMA-PI interfacial detachment (***i***), separating the PI peeling layer (greenish grey) from the PMMA (blue) coated carrier (black), and final device after PI layer removal (***ii***). (***B***) and (***C***) shows the demonstrators of metamorphic optoelectronics and acoustoelectronics systems respectively. The morphology of the electronics can be controlled in different manners.

state lighting module that is fabricated with the method.

(ii) Interconnection Challenge: Stretchable Printed Circuit Boards will be required.

Unlike most of the reported methods in this field, the group is developing a method to produce an integrated multilayer stretchable printed circuit board, which delays the use of the stretchable rubber support to the end of the processing sequence (***Fig. 2A***). In summary, the method involves fabrication on a hard carrier substrate with multilayer stacks of sacrificial materials, which help to release the structure later. Several layers of metal tracks are in principle possible which are electrically connected through vertical interconnect accesses (VIAs). To isolate the metallization layers a photopattern able polymer material can be used. Specifically, the entire circuit containing interconnects, unpackaged chips or chip-scale packaged surface mount devices (SMDs) is fabricated and assembled on a hard carrier. This facilitates high temperature processing, automated mounting, precision alignment, and functionality test on hard carrier (***Fig. 2A a***). Finally, the circuit is encapsulated using rubber mold and detached from the carrier substrate (***Fig. 2A b***).

So far this processing sequence has been limited to a single metallization layer and an effective routing of the metal tracks is not possible. However, in future research we will aim to demonstrate multilayer interconnects.

Metamorphic Electronics – A World of Electronic Products which Morph to Take on New 3D Shapes.

Metamorphic electronics is a concept that we have recently introduced. It describes electronic devices which morph to take on new geometrical shapes. At present two examples have been realized. ***Figure 2B*** presents ***metamorphic optoelectronic systems*** and ***Figure 2C*** presents ***metamorphic acoustoelectronic systems*** to illustrate the idea. Both use morphological changes to adjust the emit or receive characteristics of the system. Different concepts of deformation have been tested. For example, (i) the hemispheres are produced by air inflation of a sealed rubber membrane. (ii) Further morphological control can be achieved by using additional 3D guided shapes. For example, a pyramid formed through indentation using a pyramidal guide, and a tower shape formed through a combination of indentation and vacuum forming.

Future research will have to focus on integration of microscopic chips, an increase in the number of possible interconnects, and increase in the number of possible metal layers. Moreover, registration and reliability challenges will have to be addressed as well. However, once fully developed most electronic system known to mankind could morph to take on new interesting form factors in the future. Many interesting shape adaptive functions could be demonstrated. Imagination is limitless.

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Advanced Packaging and System Integration Technologies

Fraunhofer IZM helps companies assemble robust and reliable electronic systems and integrate these into the application environment. With its application-oriented research Fraunhofer IZM bridges the gap between microelectronic component providers and technical system manufacturers in a broad range of industries, such as automotive, medical and consumer technologies.

A part of Fraunhofer IZM focuses on the development and application of thin-film processes for microelectronic packaging. Clean room facilities in Berlin and Dresden with production-compatible equipment for thin-film processing determine the technological possibilities.

Backside via last integration for 3D sensor packaging

Fraunhofer IZM offers several process options for customized backside via last integration of TSVs into ASIC or sensor wafers. In case of a backside via last implementation flow, straight TSVs are etched from the wafer backside down to dedicated IO landing pads which are part of the BEOL metallization.

One example of a specialized backside via last process is the fabrication of micro camera devices based on CMOS image sensor wafers and lens wafers. The image sensor wafers are processed with the TSVs and redistribution to reroute the IOs to the backside of image sensor dice. In the last process step the lens wafer is bonded to the image sensor wafer front side forming final camera devices with a volume far below 1 mm^3 after singulation.

Sensor development

Fraunhofer IZM offers the complete development – from requirements, concept, design, manufacturing of sensor elements to packaging and test – of sensors for the measurement of physical parameters e.g. pressure, acceleration, force, gas concentration. For the realization of micro-mechanical sensors, different physical semiconductor effects can be used to achieve a sufficiently high sensitivity and satisfying linearity.

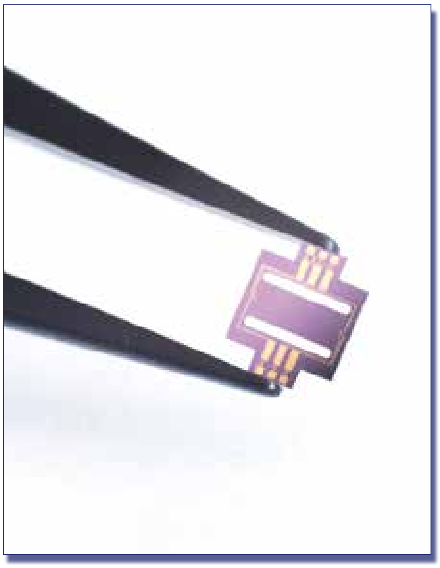

Fig.2: Piezo resistive low pressure sensor for high temperature application

Pressure Sensors

- Miniaturized pressure sensors (1 – 400 bar, up to 125 °C)
- High pressure sensors (up to 1000 bar, up to 125 °C)
- Low pressure sensors (< 100 mbar, sensitivity area µV / VkPa, up to 125 °C)

Acceleration Sensors

- High-G acceleration sensors up to 60.000 g
- Precision accelerations detection for motion recognition with high sensitivity & good linearity performance

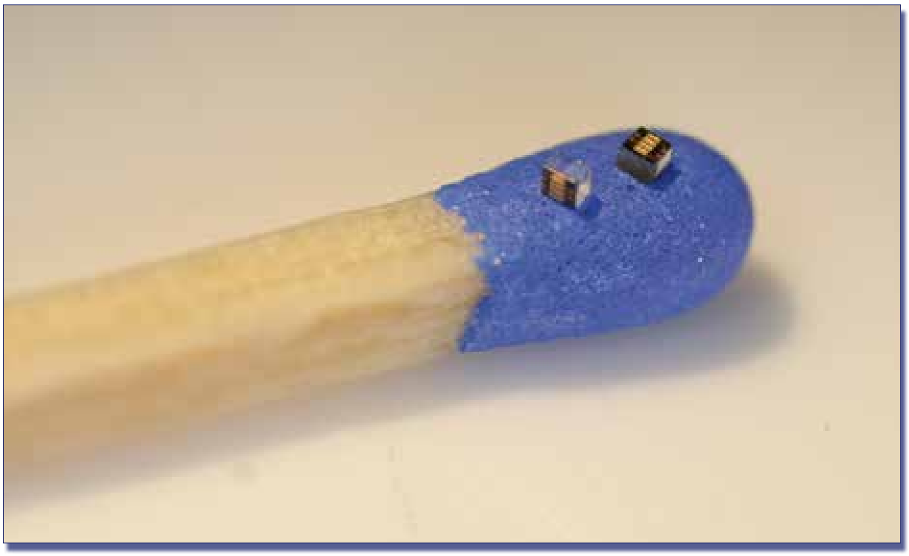

Fig.1: CMOS image sensors with through silicon vias

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Gas Sensors

- VOC gases detection with SiC-based heating platforms
- Detection of CH4, H2, NO2, CO and C02 with metal oxide sensor layers

Sensors for Harsh Environments

- SOI-based force sensors for temperature up to 250 °C
- SOI-based sensors for plastic industry up to 350 °C
- SiC-based sensors

Wafer to wafer bonding, capping and hermetic sealing

Several permanent and temporary wafer to wafer bonding technologies are available, using fully automated alignment and bonding equipment. The processes are based on anodic bonding, direct bonding, thermo-compression bonding, transient liquid phase bonding, soldering as well as low or room temperature adhesive bonding. Metallic bonding materials are deposited by semi-additive, subtractive or lift-off structuring. Adhesive bonding materials are deposited by spin / spray coating or lamination techniques and structured by photo patterning, transfer printing, dry etching or laser ablation.

Typical bonding materials include AuSn, CuSn, Au-Au, Cu-Cu as well as thermally curable or UV curable polymeric adhesives. Temporary bonding for the handling of wafers with thicknesses < 50 µm is enabled by adhesive bonding of carrier wafers and different kinds of de-bonding approaches like thermal slide, laser exposure or mechanical de-bonding.

Typical application fields of the available bonding techniques are thin wafer handling, hermetic or quasi-hermetic bonding of recess wafers for device protection and sealing as well as functional stacking of active or passive devices like ICs, MEMS, spacers or lens structures.

The large variety of permanent bonding approaches in combination with high performance temporary bonding also enables advanced technologies like wafer level device capping. Such approaches allow the placement or pre-processing of components or custom specific cap / lid structures at temporary carrier wafers and their subsequent transfer bonding to a target wafer. This approach allows the transferred devices to be laterally smaller than the landing devices on the target wafer so that peripheral IOs on the landing devices are still accessible.

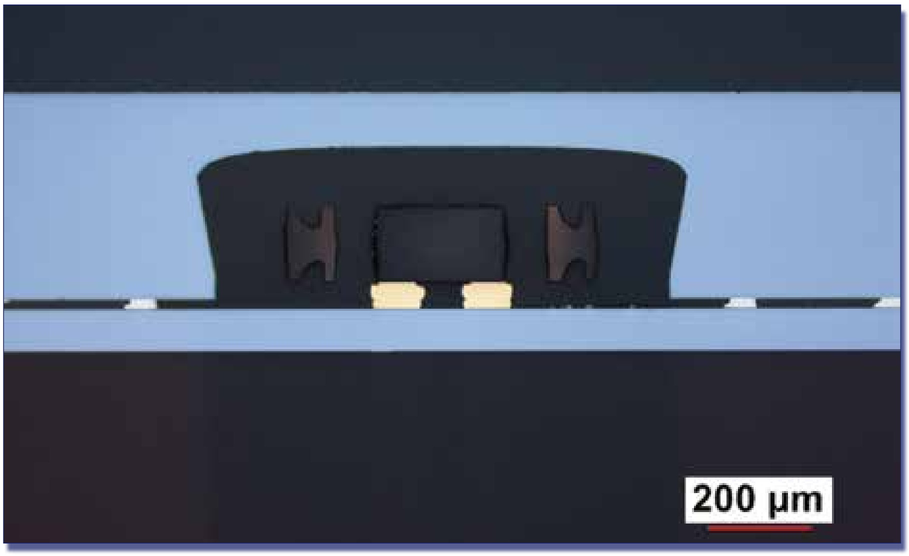

Fig.3: Hermetic bonding of TSV and cap wafers

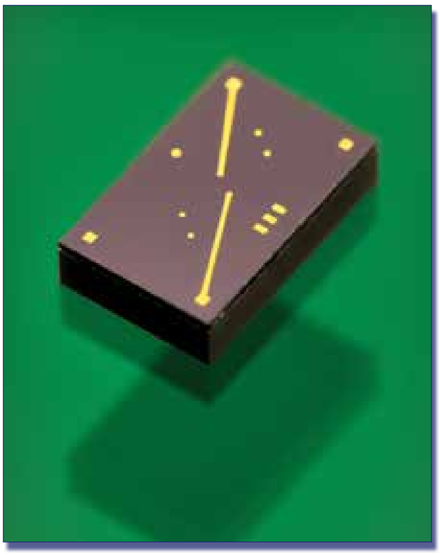

Fig.2: Wafer level packaged MEMS component

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MEMS Packaging Technologies

Mario Baum, Tim Schroeder, Frank Roscher, Maik Wiemer

The manufacturing costs of microelectronic components like Micro Electro Mechanical Systems (MEMS) are strongly correlated to involved packaging technologies like the wafer bonding process. Typically wafer-level packaging of MEMS is done by direct bonding with activated surfaces, field assisted bonding or bonding with intermediate bonding layer (IBL) on adhesion promoters if necessary. The following article shows actual developments in MEMS packaging technologies for wafer-level bonding by using metal based IBL.

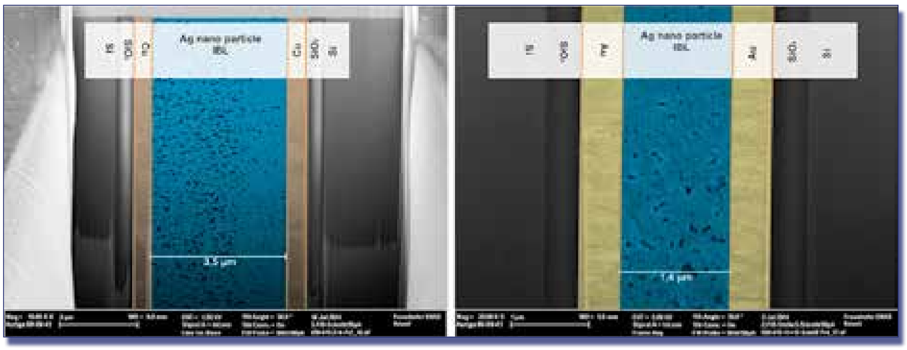

Fig. 1: SEM picture after FIB preparation of a silver nanoparticle intermediate layer between adhesion promoter Cu (left) and Au (right) after wafer-level bonding

Today's requirements for metallic bonding technologies to reach process temperature below 300 °C are challenging, especially for strong mechanical bond as well as hermetically sealed MEMS. Thermo compression bonding represents such a bonding process preferable with a certain metallic material at the bond interface plays an important role. Typical metals are Au, Cu and others. They can be deposited by sputtering and electroplating respectively. The bond formation is achieved through the atomic contact, diffusion and grain growth supported by temperature impact and pressure. At least the surface quality in respect of flatness, homogeneity, and cleanliness is of high importance for this process [1].

For process integration aspects the bonding process should be improved regarding bonding temperature decrease and shorter process time. Because these issues are related to diffusion and self diffusion respectively the actual research is done for optimizing the surface quality of the metal layers and dry pre-treatment technologies e.g. oxide reduction for copper layers.
New investigations show that such IBL can be also deposited by using printing processes like screen printing, stencil printing or aerosol-jet printing (AJP). Whereas the deposition of glass solder pastes is a well-established process for hermetically sealed wafer-level encapsulation there is still the need for high bonding temperatures in the range > 350 °C, that gives limitations especially while using heterogeneous substrate materials. By using novel nano particle IBLs not only process-related costs could be saved (low bonding temperature, digital manufacturing), but also new possibilities could be realized, like metallization of MEMS at stages of manufacturing, where no wet chemical processes, no electroplating or no lithography steps are suitable anymore [2]. Furthermore, the metallization patterns can be easily generated by CAD data.

Wafer-level bonding using additive AJP and screen as well as stencil printing for deposition of Ag and Au nano particle IBLs was investigated on 100 mm and 150 mm Si wafers coated with Au and Cu adhesion promoters. For Ag nanoparticles, deposited with AJP, the results show that there is a high potential to enable a mechanical stable bond of the IBL towards Au and Cu adhesion promoters at temperatures low as 200 °C for 30 min (see Figure 1).

Compared to glass frit bonding the Au nano particle IBL printed with screen printing enables three times higher bond strength at a bond temperature of 200 °C. Increasing tool pressure while bonding leads to increasing tensile strength, shear strength, grain growth and densification. The achievable results are strongly related to the printed pattern morphology. The process is capable to be adapted to chip level or can be expanded to 3D integration applications.

The market for power packaging grows with about 8 % each year. Higher power densities, needs for lower costs, reliability and a higher grade of integration demand for new packaging concepts

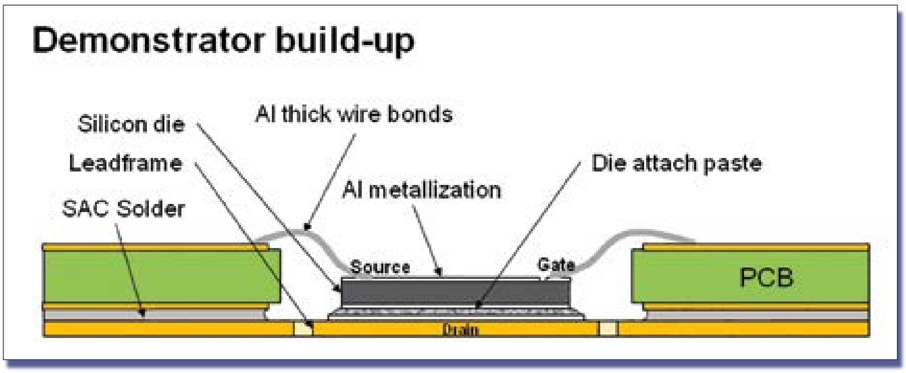

Fig. 2: Schematic built-up of a die attach sample, ready for power cycling tests

and materials. One critical point is the die attachment, which can lead to premature failing of a power module [3]. The usage of a lead frame instead of a DBC (direct bonded copper) substrate reduces costs, but poses the risk of a high warpage due to the CTE mismatch of copper to silicon. Thus, the die attach process must be carefully optimized in terms of material selection and bonding parameters. Fraunhofer ENAS investigated not only silver sintering materials, but also transient liquid phase (TLP)-based pastes for die attach within a research and development project together with SHINKO (J).

Paste-based die attach processes used at Fraunhofer ENAS employ 4 steps in general:
(1) Paste printing, (2) Removal of excess solvent by drying under normal or inert atmosphere, (3) die placement and (4) bonding. For power cycling tests, the bonded sample on the leadframe is attached to a PCB and connected with wire bonds. Figure 2 shows the overall built-up.

To get optimum process parameters, a parameter screening is done for the die attach material. Printing parameters, drying conditions and the bond process have to be considered. In general, the bonding parameters have the highest influence. It is necessary to keep the bonding temperature low to not crack the samples due to CTE mismatch. Examples of the resulting interface are shown in Figure 3.

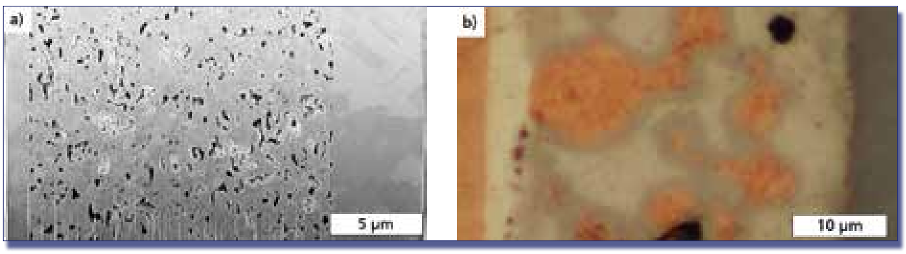

Fig. 3: Die attach interfaces. a) Sintered silver bonded at 250 °C, b) CuSn bonded at 225 °C

The samples are tested in a power cycling test afterwards. Failures are classified in die attach or wire bond failure. Up to now, wire bond failures dominate die attach failures for both die attach materials, accounting for high reliability of the module.

By using new materials and new technologies for packaging at wafer and chip level it could be shown, that important process parameters could be improved as well as the performance of the bonded device. In future the materials and the technologies will be merged more and more to stay with More-than-Moore philosophy.

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[2] Maik Wiemer, Frank Roscher, Tobias Seifert, Klaus Vogel, Toshinori Ogashiwa, and Thomas Gessner, “Low Temperature Thermo Compression Bonding with Printed Intermediate Bonding Layers” Electrochemical Society Transactions, 2016, 75: 299-310

[3] Siow, K.S.: Are Sintered Silver Joints Ready for Use as Interconnect Material in Microelectronic Packaging, Journal of Electronic Materials 43:947-961, 2014

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Optimized Interconnection Technologies for Novel UV LED Packages

High power LED have conquered the mass market in recent years. Besides the main development focus to achieve higher productivity in the field of visible semiconductor LED processing, the wavelength range is further enhanced by active research and development in the direction of UVA / UVB / UVC. UVB and UVC LED are new and promising due to their numerous advantages compared to conventional mercury discharge lamps and xenon sources. UV LED emit in a near range of one single emission peak with a width (FWHM) below 15 nm. Furthermore, the UV LED size is in the range of a few hundred microns and offers a high potential of significant system miniaturization. Of course, LED efficiency, lifetime and output power have to be increased.

One lifetime limiting characteristic of UVB/UVC LED is the very high thermal stress in the chip resulting from the higher forward voltages (6-10 V & 350 mA), the lower external quantum efficiency below 10 % (most of the power disappears as heat) and the R_{th} of conventional LED packages not being able to dissipate these large amounts of heat for spreading. Beside the circuit boards and submounts which should have maximum thermal conductivity, the dimensions of contacts as well as the interconnection of the UV LED to the submount/package determine the resolvable amount of heat.

Most end users need assemblies in the form of modules and systems.

UV LED modules must be designed according to the requirements of the specific application. Specifications regarding dimensions, operating conditions, radiation power density, sensing and controlling requirements, power supplies, interfaces, heat dissipation and many other parameters have to be met. In most cases modules consist of several UV LED arranged as a line or a matrix array that needs suitable UV optics, a heat dissipation system and a power supply.

Fig. 1:
Fully automatic micro-assembly center. Source: CiS Forschungsinstitut für Mikrosensorik GmbH

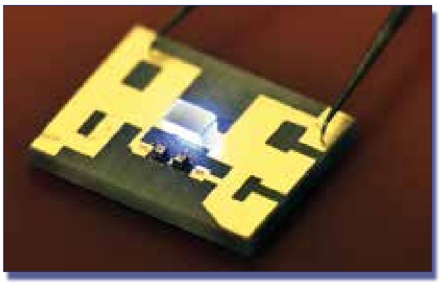

Fig. 2:
UV LED flip-chip mounted on a AlN-substrate Source: CiS Forschungsinstitut für Mikrosensorik GmbH

CiS coordinates the field of work “Modules & Measurement” within the “Advanced UV for Life” consortium, funded by the Federal Ministry of Education and Research. The focus of CiS in this context is the further development of flip-chip mounting technologies for UVB and UVC LED. A particular challenge is the mounting of the UV LED with a precision of approx.5 µm.

Cost-effective solutions are required to transfer these technologies to industrial manufacturing.

With the fully automated micro-assembly center (Fig.1), the “Advances UV for Life” consortium will be given the opportunity to mount with high precision up to 3 pieces UV LED per 10 seconds in flip-chip technology.

With the research of CiS a cost-effective production of UVB / UVC LED submounts (Fig. 2) and modules becomes possible.

CiS Forschungsinstitut für Mikrosensorik GmbH

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Innovations and Competencies of Companies

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MUEGGE-PLASMA SYSTEMS

Plasma decapsulation technology

Dr. Klaus Martin Baumgärtner
CEO of MUEGGE

The MUEGGE – R³T plasma decapsulation tools STP 2005 and DeCap Compact are particularly made for fast etching of mould compound and polyimide to open the packaging of microchips without attacking the sensitive wiring. In order to enable failure analysis of encapsulated product chips, a new plasma enhanced decapsulation process was introduced.

Microwave Remote Plasma Source (RPS) inside

The Rapid Reactive Radicals Technology (R³T), introduced by the Remote Plasma Source (RPS), provides the capability for fast decapsulation of microchips with high selectivity and no attack on metals. The radicals generated by the RPS only produce chemical reactions at the surface of the substrates, leading to pure chemical etching at high rates with extremely low thermal load, thus keeping the effect on the microchip and on the bonding wires as low as possible.

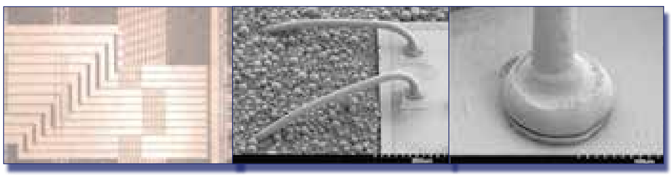
Microwave plasma decapsulation process – special features

- fast, isotropic etching by radicals only
- no ions, no microwave radiation, no electrical fields in the area of the samples
- very low thermal impact only by chemical reaction energy due to the effect of the radicals
- very high removal efficiency (> 200 µm/h including inorganic filler materials)
- no attack on bonding wires made of e.g. Au, Al, Cu or Cu/Pd
- almost no attack on Ag bonding wires
- only slight etching of chip passivation (high selectivity > 500:1)
- short decapsulation times: typically 1-3 hours after laser ablation
- high environmental compliance due to nearly complete dissociation of greenhouse gases like CF_4
- field proven

Key elements of the plasma decapsulation tools STP 2005 and DeCap Compact

	STP 2005	DeCap Compact
		
Dimensions	W = 980 mm, L = 930 mm, H = 2200 mm	W = 835 mm, L = 840 mm, H = 835 mm, fits on a table of 800 mm x 800 mm
Working area	W = 320 mm, L = 320 mm	W = 240 mm, L = 240 mm
HF power	max. 2 kW cw, 2450 MHz	max. 1 kW cw, 2450 MHz
Temperature range of the working plate	20°C-200°C (heating/cooling fluid: oil)	30°C-70°C (heating/cooling fluid: water)
Decapsulation processes	Supported by fluorine compounds, but pure oxygen ashing at elevated temperature possible, too	Supported by fluorine compounds
Application areas	Industrial tool	Compact table top tool for R&D labs, institutes or small fabs

Decapsulation results



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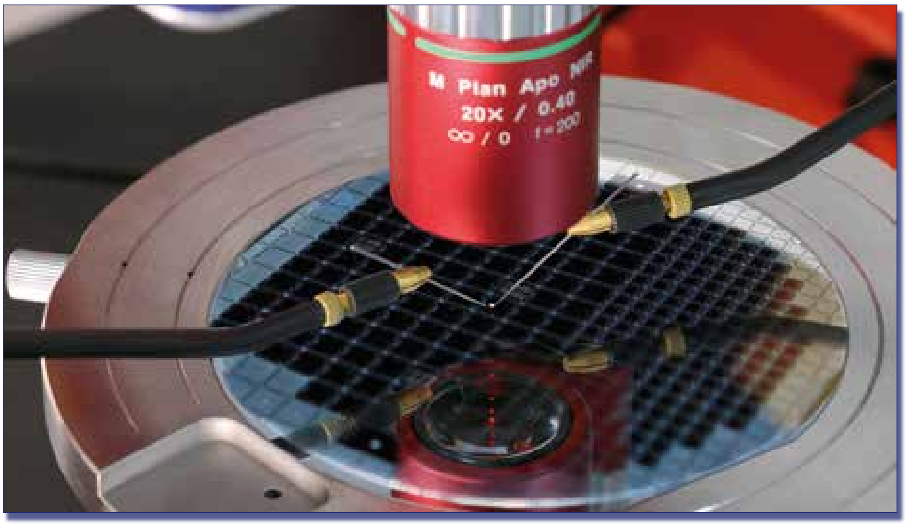
Optical Measurement Tools for State-of-the-Art Microstructure Development and Testing

Polytec



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, non-invasively, 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 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 selection of devices prior to packaging. For this task the Polytec MSA Micro System Analyzer 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

By 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. Here, Polytec's award-winning UHF-120 Vibrometer allows the characterization of out-of-plane vibrations at such ultra-high frequencies, extending the vibration frequency bandwidth up to 2.4 GHz.

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Tailored Plasmonics

Nanostructures with plasmonic activity are a huge trend in nanofabrication due to their significant impact on established fields (e.g. sensor technology, medicine, catalysis, optical components, data storage or energy conversion) combined with straightforward device configurations and significant tuning of their properties via control of the structuring process.

The plasmon resonance behavior depends on shape, size and material of the nanostructured elements. Thus, it presents the knowledgeable nanofabrication expert with a toolbox of tuning parameters to conceive of tailor-made devices for the respective intended applications.

By efficiently converting radiative electromagnetic waves to strongly localized fields (antenna effect) and vice versa, any light-matter interaction process is vastly enhanced in close proximity to the nanostructures.

The severely increased interaction strength was shown to be advantageous for photocatalytic reactions and for Raman scattering sensors – to name two examples that we at AMO are working on.

As a technology venture with 20+ years of experience in nanotechnology, AMO offers activities in development and production based on its state of the art clean room, with special tools for nanolithography processes such as E-Beam, stepper photolithography, deep-UV interference lithography and UV nanoimprint (SCIL).

Our lithography tool set is complemented by a variety of deposition and etching equipment as well as peripheral services, providing us with a complete in-house fabrication route from optical simulation to diced chips.

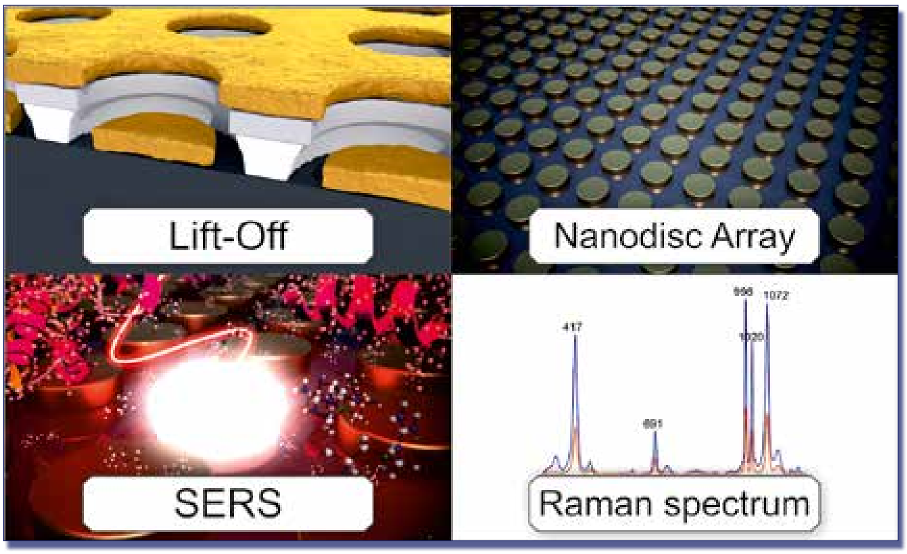

Fig. 1 (from top left to bottom right): schematic cross-section of the nanostructured resist double layer (gray & white) with deposited gold (yellow) before the lift-off step; resulting periodic metal nanodisc array on the substrate after lift-off step; schematic field enhancement in the metal nanodisc for surface-enhanced Raman spectroscopy (SERS) for molecule detection; and measured SERS spectra.

Using these facilities, we succeeded in establishing a fabrication process for highly homogeneous plasmonic sensor chips for surface-enhanced Raman spectroscopy (SERS). By employing periodic nanostructures generated with interference lithography and reproduced with nanoimprint lithography, we ensure homogeneous resonance behavior with controlled field enhancement.

The best part, however, is that we can do this reliably, over large areas (6" wafer scale) and relatively cheap due to the nanoimprint replication process.

As the nanostructure geometry is optimized according to optical simulations of the plasmonic characteristics, the final product is completely tailor-made to the respective requirements. For example, if the application is based on a 785 nm laser, we will shift the resonance frequency to that wavelength while still offering high field enhancement and photon efficiency.

In this way, AMO can contribute significantly to your plasmon-based projects. We would be happy if we have piqued your interest and you intend to take advantage of our experience and technology to explore new concepts and components in the field of plasmonics. We place ourselves at your disposal for requests.

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AEMtec GmbH: Development & Production of Complex Microelectronics

AEMtec

MEMBER OF exceet

AEMtec based in the prestigious science and technology location of Berlin-Adlershof is a leading global specialist for the development, qualification and production of a variety of precision electronic microsystems, optoelectronic products, including components, subsystems, modules and complete systems. Precision microelectronic Products include MEMs, Optical Assemblies, Micro-Optics, Imaging Arrays, VCSEL Assemblies, Sensor Systems, Optical MEMs, Hybrid Electronic Assemblies, active and passive alignment.
The company is part of exceet Group S.E. with excellent technology competence in the area of intelligent electronics and IT security solutions.

Extensive know-how in new product development and process engineering

Our solutions for customer-specific products are highly complex assemblies with precise component placement requirements up to +/-1 µm. 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.

High Standard of Technological Equipment

Extensive know-how in a broad range of packaging and assembly technologies on multilayer and complex substrates allows us to turn innovative product ideas into functional and reliable solutions. AEMtec produces medium to high quantities in a cleanroom environment. In our cleanrooms (ISO/class 5/100 to 8/100,000) AEMtec offers a unique spectrum of high-end chip level technologies: Wafer Back-End Services (UBM, SBA, Au Stud Bumping, Dicing), high speed / high accuracy Bare Die- and Flip Chip Bonding, Au and Al Wire Bonding, SMT, assembly of Optical Components, Box-Build and 3D integration. With analysis equipment like x-ray inspection or SAM, complex packages can be analyzed down to the smallest detail, e.g. when using special soldering technologies.

Complete Service Offering

AEMtec´s provides all services to the customer base as a single source. Customers benefit from shorter time to market cycles: Concept/Product/Process Development, Prototyping, Supply Chain Managment, Test Systems/Life Time Qualification, Volume Production and EOL/After Sales Services. With longstanding experience in the product development and manufacture of sophisticated electronic components, in compliance with relevant quality standards (ISO 9001, ISO 13485, ISO 14001 and ISO/TS 16949), AEMtec has positioned itself as a reliable partner for the manufacturing of products with a high level of integrity and reliability since many years.

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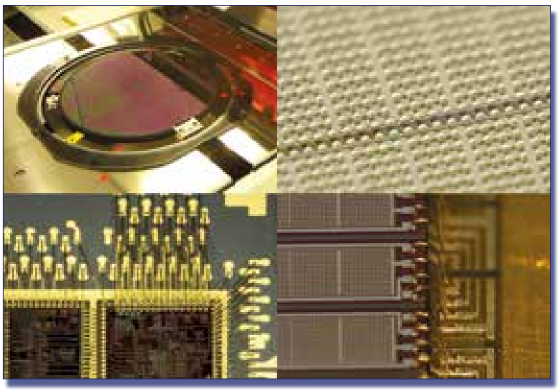


Fig. 1: Manufacturing Technologies

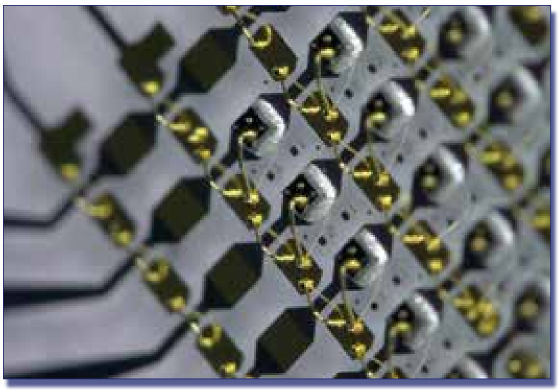
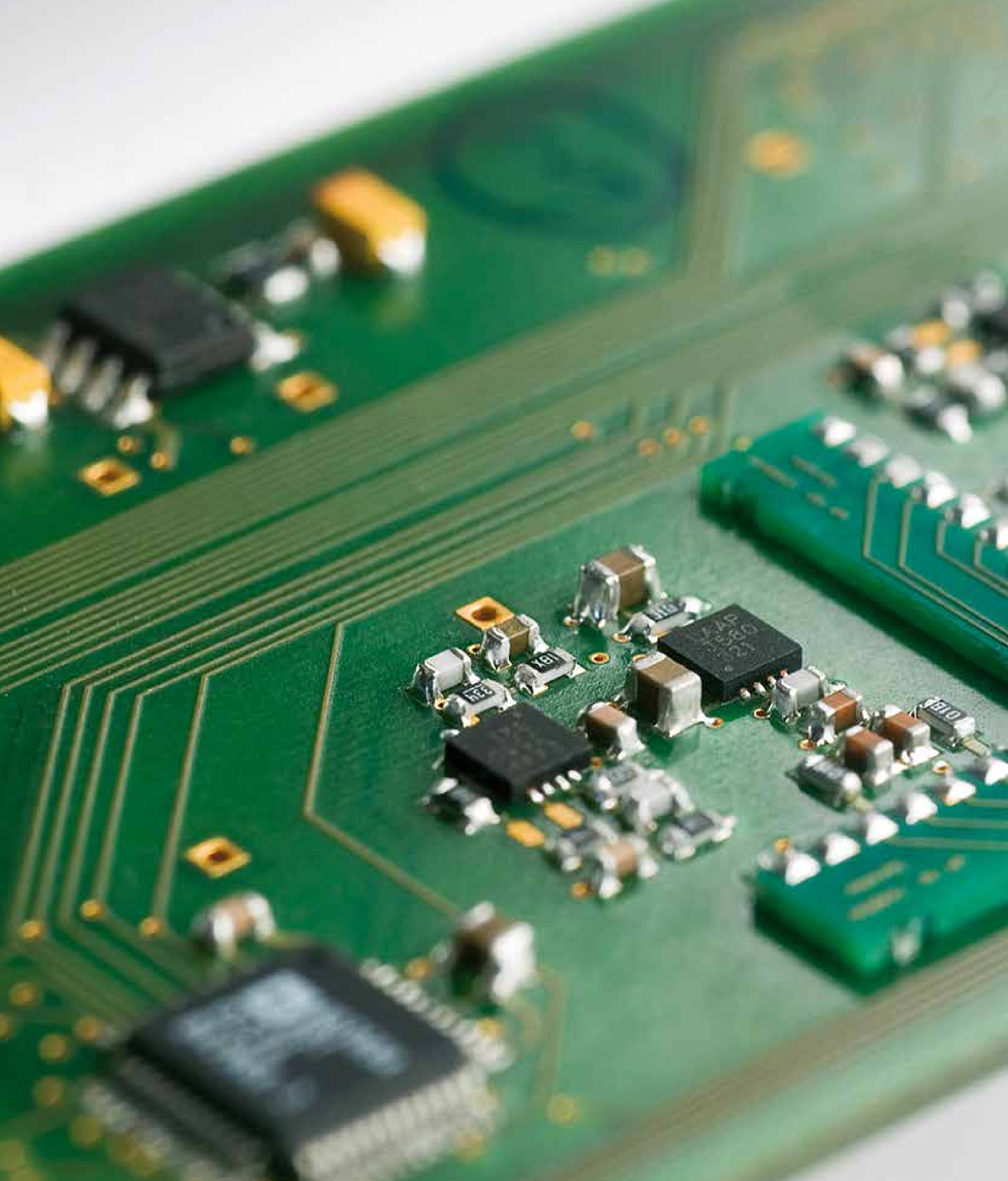
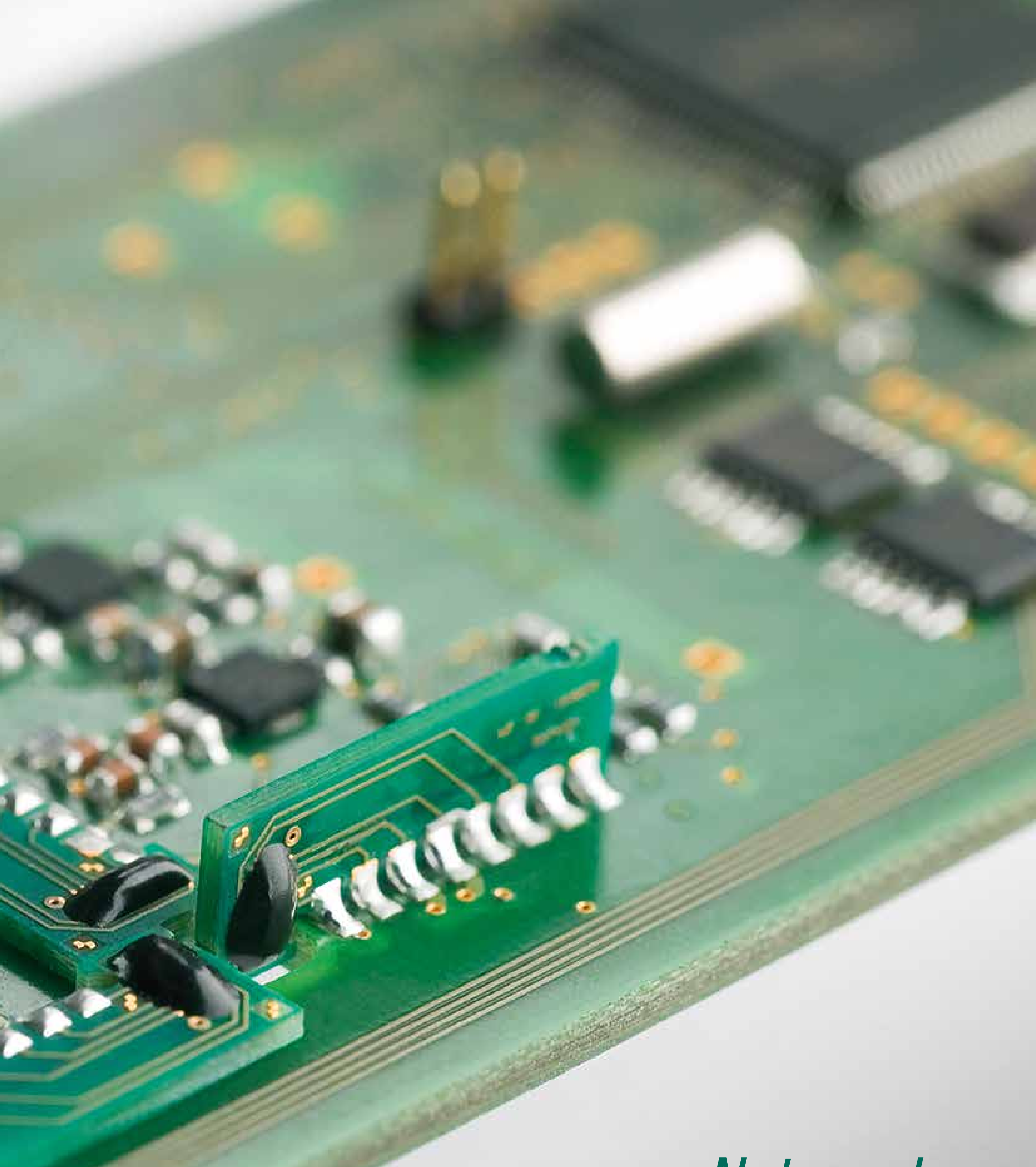


Fig. 2: High-Precision Placement (VCSEL array)

Networks between Research and Industry





Netzwerke zwischen Forschung und Industrie

VDMA
The German Engineering Federation

Electronics, Micro and Nano Technologies

Micro-cameras in cell phones, micro-pumps for insulin, manufacturing tolerances in the µ range, in some cases even in the nanometer range for exact components and surfaces, microprocessors, functional integration in integrated circuits, nanorobots, lab-on-a-chip systems: These are just a few examples that show the trend in miniaturization.

These examples 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 nanoelectronics as well as micro- and nanotechnologies. In the past, those two sectors developed side by side. 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 the meantime, however, they have merged increasingly. System integration is the magic word. This enables more miniaturization and creates higher product diversity.

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: 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 was time to join forces for the benefit of our members and their customers.The German Engineering Federation (VDMA) therefore founded the VDMA sector association Electronics, Micro and Nano Technologies, gaining synergies from the sector groups Productronics (Electronics Production) and Micro Technologies (micro products and micro production technology). The sector groups define and realize customized activities for the respective sector industries. The association develops joint activities. Both, sector groups and the association, are in close contact with the working groups Organic Electronics Association (OE-A) and Photovoltaics Equipment as well as with the industry group VDMA Battery Production.

medium sized member companies of the sector group Productronics concentrate on specific types of machines covering a large range of electronics segments and customer markets, such as semiconductors, circuit boards, electronic modules, SMT, hybrids, MEMS as well as flat-panel displays and data storage. In some areas, even suppliers of turnkey factories have been established.
From highly specialized controllers in automotive applications to tablet PCs as a mass product: Electronics are part of a wide range of applications and customer segments. Keeping track of individual specific requirements and technological innovations as well as the development of individual markets is not always easy. The sector group

Figure 1: Assembly of micro metering pumps, Source: HNP Mikrosysteme GmbH

Productronic –
Electronics Production in Detail:
The complexity of products and production processes in electronics has led to strong specialization among machine manufacturers. The small and

Productronics supports its members by identifying new technologies and markets, as well as by preparing und communicating the information to orient themselves within their own market and identify future trends.

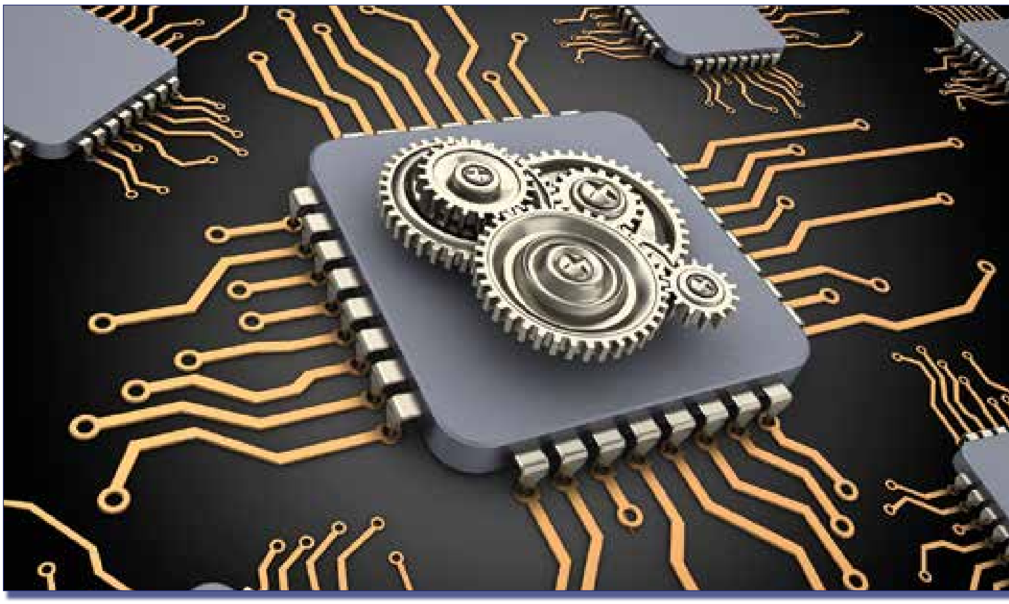


Figure 2: Source: Maxim_kazmin by fotolia.de

Micro Technologies – opportunities and potentials.

The modern world has been expanded by micro technologies, which are paving the way to new – and therefore unknown – realms of feasibility. Altogether new applications of existing products are becoming possible in the mechanical engineering, medical technologies, life science industries, precision engineering, automotive engineering, electrical and electronics industries, to name but 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 technologies are 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.

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Benefits for users everywhere.

Miniaturization 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 an 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, Iran, Brazil, Berlin and Brussels. VDMA Electronics, Micro and Nano Technologies (EMINT) is one of the 36 Sector Associations within VDMA.

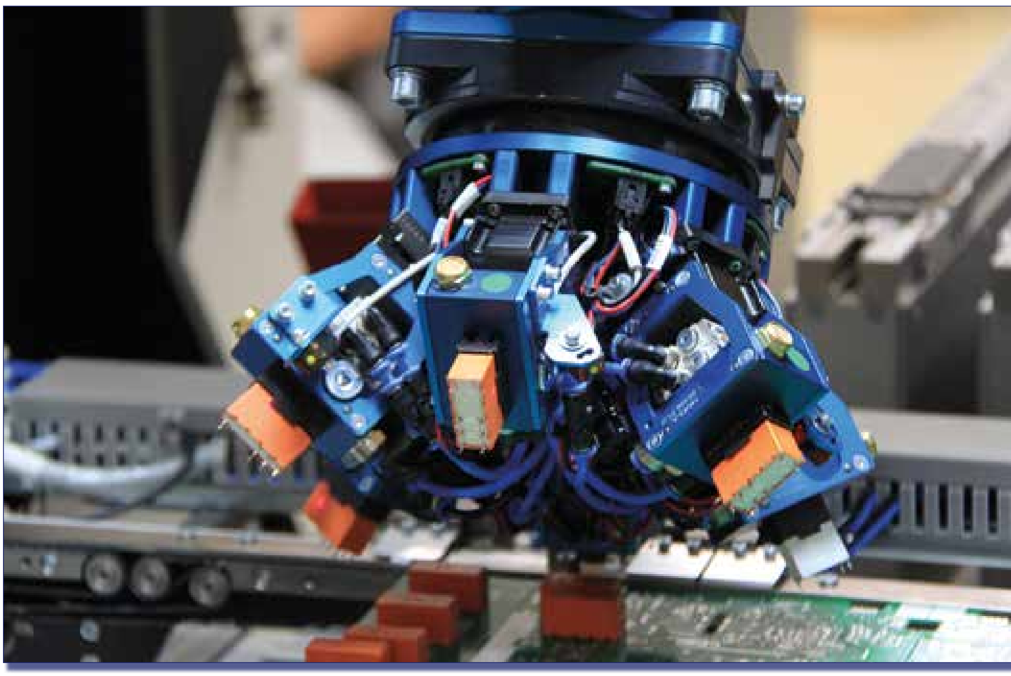


Figure 3: "High Speed Placement Head" , Source: IPTE Deutschland

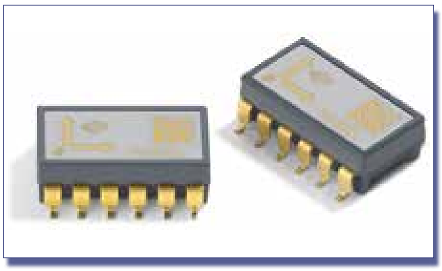
ZVEI - German Electrical and Electronic Manufacturers´ Association

Microsystems technology combines electronics, microelectronic components and software to create intelligent miniaturised complete systems. These are used for information processing and are connected to the natural environment by sensors and actuators.

Germany has a leading position in the world market for microsystems. The increasing need for control and automation - notably in view of the megatrend "Industry 4.0" and the continuing digital transformation of all areas of life - will further promote its importance. It is unthinkable to make further progress in the areas of industrial production, energy supply, building automation, health or mobility without microsystems technology.

Microsystems technology plays an important role in the competitiveness of the German industry and contributes to the creation and securing of future-oriented jobs in Germany.

This is what the microsystems technology companies organised by the ZVEI - German Electrical and Electronic Manufacturers´ Association stand for. In addition to large semiconductor companies, these include industrial microsystems technology providers and highly specialised small and medium-sized enterprises (SMEs). This is where you may find the Hidden Champions.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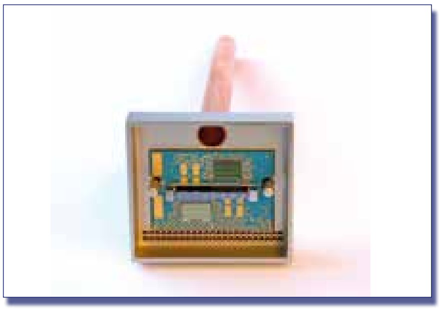
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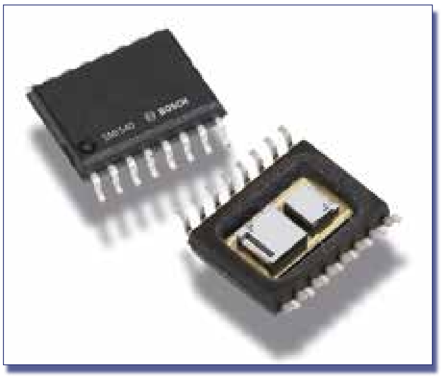

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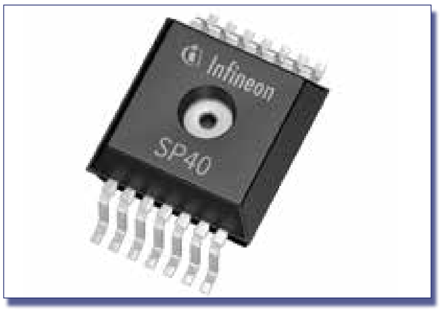

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The association's commitment focuses on the continuous development of technologies and tools in a pre-competitive environment. The shared goal is to bolster microsystems technology in Germany as a key enabling technology and to advance the sustainable growth of this industry segment.
With the "Microsystems Technology - Sensors/Actuators" group of the Electronic Components and Systems Division, ZVEI offers a platform for representatives of the industry to exchange their experiences. Here, experts establish positions that are introduced effectively to political decision-makers. The partnership with "AMA Verband für Sensorik und Messtechnik e. V." and "IVAM e. V. Fachverband für Mikrotechnik" promotes cooperation between companies and research institutions interested in microsystems technology in Germany.
Aside from that, ZVEI member companies also pursue nationally prepared positions at European level and in the wider international context.
The successes achieved by the association representatives and the 1,600 member companies of the electrical industry confirm the benefits of committed association work - be it in the area of industrial policy objectives, legal regulation, standardisation or public relations, for example.

ZVEI - Zentralverband Elektrotechnik- und Elektronikindustrie e.V.

Die Mikrosystemtechnik verknüpft Elektronik, Mikroelektronik-Komponenten und Software zu intelligenten miniaturisierten Gesamtsystemen. Diese dienen der Informationsverarbeitung und sind durch Sensoren und Aktoren mit der natürlichen Umgebung verbunden.

Deutschland hat im Bereich der Mikrosysteme eine führende Position auf dem Weltmarkt. Der zunehmende Regulierungs- und Automatisierungsbedarf – insbesondere angesichts des Megatrends „Industrie 4.0“ und der fortschreitenden Digitalen Transformation aller Lebensbereiche – wird deren Bedeutung weiter fördern. Ohne Mikrosystemtechnik sind weitere Fortschritte in den Bereichen industrieller Produktion, Energieversorgung, Gebäudeautomation, Gesundheit oder Mobilität nicht vorstellbar.

Die Mikrosystemtechnik leistet somit einen wichtigen Beitrag zur Wettbewerbsfähigkeit der deutschen Industrie und ermöglicht die Schaffung und Sicherung zukunftsorientierter Arbeitsplätze in Deutschland.

Dafür stehen die im ZVEI – Zentralverband Elektrotechnik und Elektronikindustrie organisierten Mikrosystemtechnikunternehmen. Hierzu gehören neben großen Halbleiterunternehmen auch industrielle Mikrosystemtechnikanbieter und hoch spezialisierte Klein und Mittelstandsunternehmen (KMU). Hier findet man die Hidden Champions.

Im Vordergrund des Verbandsengagements steht, Basistechnologien und Werkzeuge weiterzuentwickeln. Gemeinsames Ziel ist, im vorwettbewerblichen Umfeld die Mikrosystemtechnik in Deutschland als Key-Enabling-Technology zu stärken und das nachhaltige Wachstum dieses Branchensegments zu fördern.

Der ZVEI bietet hierzu mit der Fachgruppe „Mikrosystemtechnik – Sensoren/Aktoren“ im Fachverband Electronic Components and Systems eine Plattform, die den Vertretern der Branche einen intensiven Erfahrungsaustausch ermöglicht. Hier erarbeiten Experten Positionen, die wirkungsvoll bei politischen Entscheidungsträgern eingebracht werden. Die Partnerschaft mit „AMA Verband für Sensorik und Messtechnik e.V.“ und „IVAM e.V. Fachverband für Mikrotechnik“ fördert die Zusammenarbeit in Deutschland der an der Mikrosystemtechnologie interessierten Unternehmen und der Forschungseinrichtungen.

Darüber hinaus verfolgen die ZVEI-Mitgliedsunternehmen national erarbeitete Positionen auf europäischer Ebene und auch im weiteren internationalen Kontext.

Die Erfolge der gemeinsamen Arbeit der Verbandsvertreter und der insgesamt 1.600 Mitgliedsunternehmen der Elektroindustrie bestätigen den Nutzen engagierter Verbandsarbeit – sei es im Bereich industriepolitischer Zielsetzung, rechtlicher Regulierung, in der Normung oder beispielweise der Öffentlichkeitsarbeit.

ZVEI: Die Elektroindustrie

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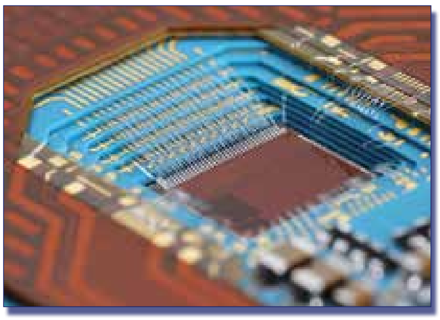

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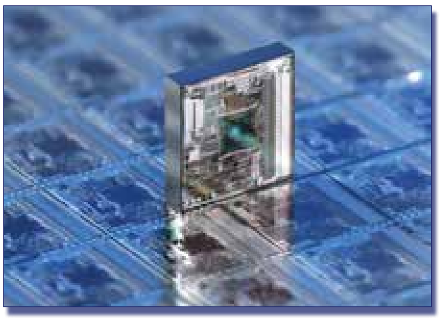

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IVAM – Network with Experience and Vision

Managing Director
Dr. Thomas R. Dietrich

IVAM Microtechnology Network was founded in 1995 and is one of the most experienced and efficient high-tech industry networks in Germany. For more than twenty years, IVAM has been observing the changes in technology, society and market requirements and constantly adapting its strategic orientation and service portfolio to the needs of its member organizations.

Today, IVAM is an international association with members in the fields of microtechnology, nanotechnology, advanced materials, MEMS and photonics. The central mission of the association is to support its members in bringing key enabling technologies to market.

Many technologies that have emerged in the 1990s when IVAM started operating have long since reached maturity. Consequently, technology suppliers today require support in marketing and finding customers. There is a growing need to access international markets, so providing international business opportunities has become an ever more important task for industry networks. IVAM provides members and customers with such opportunities and platforms for exchanging knowledge, initiating collaboration and making business with each other and with their customers.

B2B accelerator: International business platforms

Joint trade fair pavilions: Medical technology and health care have been the most profitable markets for microtechnology suppliers in recent years, and they continue to grow. IVAM has established joint trade fair pavilions at some of the most important medical suppliers' trade shows: At COMPAMED in Dusseldorf IVAM hosts the Product Market "High-tech for Medical Devices" with more than 50 co-exhibitors. At MD&M West, the world's largest trade show for design and manufacturing in medical technology in Anaheim, California IVAM arranges the special exhibition area Micro Nanotech, offering medical suppliers an opportunity to step into the US medical market. At Medical Manufacturing Asia (MMA) in Singapore IVAM organizes a joint exhibition for European companies to get accesses to the ASEAN markets.

Arranged B2B meetings: In order to push business opportunities even further IVAM arranges B2B meetings where innovative companies can exchange experience, discuss business ideas and kick off joint projects. IVAM matches possible business partners and makes appointments, e.g. during trade shows, combined with workshops, conferences or company visits, and in cooperation with international partner organizations. During COMPAMED 2016, 70 arranged business meetings between IVAM's co-exhibitors and enterprises from Fukushima Prefecture took place. In July 2017 the event "Health Business Connect" in Dortmund featured more than 50 arranged business meetings of component manufacturers and medical device manufacturers from Germany, France and other European countries. "Health Business Connect" was established in 2016 in Besancon, France in will be continued in the years to come.

IVAM member microsensys showcased at COMPAMED an RFID sensor data logger. Source: microsensys

IVAM.

New challenges: creating a smarter world through digitalization

Creating a smarter world through continuing digitalization will not be possible without microtechnology and MEMS products such as sensors, actuators or electronic components. Digitalization offers huge opportunities to microtechnology companies for starting new and profitable businesses.

Smart health: The market for medical devices has experienced a rapid upswing in recent years. Almost two-thirds of the microtechnology companies in Europe offer products, technologies or services for medical technology and health care. The trend towards personalized medicine, demographic developments and digitalization are driving technological progress in medical technology and health care. For instance, wearable devices require 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.

Smart home: 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.

Smart production: Microtechnology and MEMS 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 Industrie 4.0., the Internet of Things, automated and integrated industry.

International business-to-business meetings: IVAM matches possible business partners

Smart mobility: The need for more efficient drive systems and the trends for assisted and networked driving recently revived the need of the automotive industry for high-tech innovation. Assisted or autonomous driving and digital transformation are currently the strongest drivers of innovation in automotive engineering. Over the next three years, innovation activity in the supply industry will shift even further towards digital technologies as applications in vehicle networking, navigation and tracking will increase.

Key enabling technologies: motor of ever-accelerating change

Key enabling technologies such as microtechnology, MEMS, nanotechnology, photonics, and advanced materials have significantly accelerated innovation in the late 20th and early 21st century. These technologies have affected, improved or fundamentally changed many areas of society, industry, and economy – either by improving known products and processes or by triggering entirely new, previously unthought-of applications. Looking forward, key enabling technologies will provide answers to urgent questions and solutions for global challenges resulting from ever-accelerating change. And they are essential for addressing and reacting to some of the mega trends of the 21st century.

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microTEC Südwest – the Competence and Cooperation Network for Intelligent Microsystems Technology Solutions for Europe

microTEC Südwest is the competence and cooperation network for intelligent microsystems technology solutions for Europe. 120 members build the active core of this unique technology cluster. Furthermore our organization is the central contact point for all microsystems technology activities in Baden-Württemberg. The central service for members are technological and application oriented special interest groups in which microTEC Südwest's capabilities are bundled for further innovation in the field of microsystems technology. As a link between science, business and government microTEC Südwest supports its members with applications for and management of funded projects. Matchmaking activities are comprised as well.

microTEC Südwest – a remarkable union

The list of our funding members is quite respectable (Festo, Fraunhofer IPA, IMTEK, Hochschule Furtwangen University, Steinbeis, BOSCH, Universität Stuttgart, KIT, IMS CHIPS, digiraster, FAIM, Endress + Hauser, Hahn Schickard, Nothrop Grumman LITEF GmbH, Hochschule Esslingen, SICK) and it has grown over the years. You will find all actual associates on our website. We think it's a remarkable union of industry, universities, universities of applied sciences and research facilities.

The cluster microTEC Südwest with its over 380 cluster partners is one of the largest technology networks in Europe. With global players and many innovative small and medium-sized companies microTEC Südwest provides the basis for future lead innovations and new growth in the region across all industries. With respect to application, the cluster management focuses its work on four fields. Target markets of microTEC Südwest are smart health, smart production, smart mobility and smart energy.

Bundling expertise in our special interest groups

Our special interest groups are handling such fascinating subjects as:

- Cooperative innovation processes
- Intelligent implants
- In-vitro diagnostics
- Functional printing technologies
- Surface engineering
- Smart systems

Innovation and R&D – outstanding projects

With the participation in publicly funded projects, microTEC Südwest is pursuing several objectives:

- We maintain our network and build new contacts.
- We support our members and their partners in the implementation of projects.
- We build and enlarge our own competencies.
- We also use the projects to discuss our topics in Brussels, for example in the project inSSIght.

Current European, federal and regional projects with relevant expertise include:

- Interreg Alpine Space – Care4Tech
  Care4Tech is a huge project to support research and innovation of the following subjects, which all will become smart: mobility, health,

Figure 1: microTEC Südwest cluster conference

Figure 2: Special interest groups

energy, living, production, workplace, administration, trade, agriculture and infrastructure. It's a task force, you can join and participate in innovation.

- European – inSSight
  In the EU project inSSIght, eighteen partners from seven European countries, consisting of clusters, research facilities and industrial enterprises, are working together on the topic of "Smart Systems Integration" (SSI) with respect to the European Technology Platform on Smart Systems Integration (EPoSS). Smart Systems are miniaturised systems, combining data processing with optical, biological, or mechanical sensing, actuation and communication functions. They will be used in self-driving cars, artificial pancreas, the Internet of Things, M2M-enabled advanced manufacturing robots and more applications. Benefit from research or deliver input for the EC work programmes.
- Regional – Allianz Industrie 4.0 Baden-Württemberg
  Intelligent sensors and actuators are the essential components for industrial 4.0 solutions. Microsystems technology is the technology and innovation driver of this evolution and provides new, needs-oriented and sustainable solutions for various applications and requirements from all sectors. Join in, get support and improve your visibility.
- Regional - IDAK
  The system developed by the IDAK project aims to enable hospital staff to recognize patients infected with resistant pathogens much faster, to make more differentiated decisions regarding isolation measures, and to significantly accelerate the initiation of targeted antibiotic therapy. In this way, IDAKs will help to reduce the spread of dangerous hospital infections.
- BMBF – ScaleIT
  Pragmatic industry 4.0 solutions for the production in small and medium-sized industry. The project ScaleIT will develop a scalable technical platform, via which measured values and data of sensors and intelligent tools are provided and linked with the IT systems. With software components (apps), the data will be tied to information. The use of intelligent tools, such as interactive documents, intelligent workpiece carriers and test equipment, intend to make inspection processes more efficient and to support all stakeholders in decision-making.
  Get in contact and get pragmatic solutions for production in SME's.
- BMBF – 3D-Bio-Net
  The manufacturing methods for the production of artificial tissue are very complex since a variety of living cells in combination with different biomaterials must be created by a variety of processing and printing processes. With a generic platform for 3D bio-printing the research project wants to accelerate the innovation potential considerably in the field of artificial tissue, create new solutions and significantly improve the innovation base in Germany. Interested in cooperation? Set up a dedicated community and be successful together!

Hot topics, current trends – meet us at the microTEC Südwest cluster conference

Once a year we organize a cluster conference as performance show of hot topics, current trends and services for approximately 200 users, solution providers researchers and other experts.
We place the service of an online database of companies, specialized in microsystems technology, institutions, research facilities, startups as well as high schools and universities to your disposal.
We create visibility for microTEC Südwest as a network and also for the members.
This cluster meets the excellence criteria of the European Cluster Excellence Initiative (ECEI) and has been awarded with the gold label.

microTEC Südwest

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Figure 3: microTEC Südwest – Joint Pavilion at the MST congress 2017

Figure 4: Smart Production

Berlin: The Place to be for Microelectronics Startups

With around 500 new tech startups per year, Berlin is Germany's capital city also for startups in a fast-growing startup scene and a successful infrastructure for financing and funding. With numerous incubators, accelerators and co-working spaces, the city provides optimal conditions for entrepreneurs from around the world. Berlin is internationally recognized as a startup hub and as a breeding ground for creative people who want to change the world.

Start-A-Factory: From idea to prototype in record time

Start-A-Factory is a new laboratory complex of Fraunhofer IZM in Berlin – it is largely aimed at smaller companies and start-ups from the area of highly miniaturized electronics and sensor technology.
IZM can guide you through all stages, from specifying an idea to development, manufacturing test samples and prototypes, right up to the finished product. Then, statements can be made about feasibility, the technologies used, and the estimated manufacturing costs, which will be an immense help to you in the remaining planning. The laboratory environment is designed in container form in order to be modular and flexible and can be adapted to suit the content of the current development focus.

The Innovation Network for Advanced Materials and its startup accelerator AdMaCom

The Innovation Network for Advanced Materials (INAM) builds and represents an ecosystem for scientists, startups, corporates and experts to develop innovative products and applications with advanced materials. Among its core activities is the Advanced Materials Competition (AdMaCom), a carefully crafted 2-week program for high-tech startups to accelerate their projects, connect with potential partners, find first corporate clients and simply make relevant and meaningful connections.
In 2017 10 startups from 9 countries reaching from Japan over Israel, Egypt, and Europe all the way to Colombia were selected from more than 50 applications to participate in the AdMaCom. All teams went through intensive trainings and one-on-one mentoring sessions with over 50 experts to accelerate their projects.

Partners and supporters include corporates and SMES like Osram, Henkel, JNC and SPECS, research institutions like the Humboldt University or IRIS Adlershof as well as several service providers.

Berlin Partners: One stop agency for business and technology development support in Berlin

Berlin inspires – as a creative metropolis, as a start-up hub, as a place for innovative technology and science. Berlin is one of the most dynamic economic regions in Germany, and we are offering companies, investors and scientific institutions business and technology support with customized services and an excellent science and research network to help companies launch, innovate, expand and secure their economic future in Berlin.

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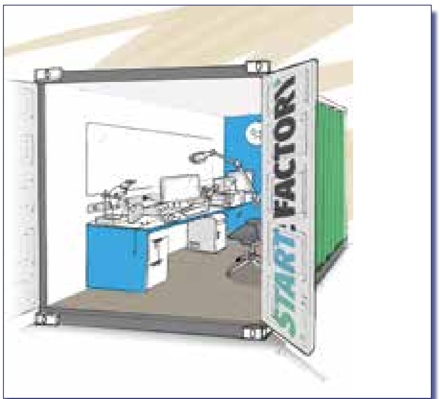

Fig. 1: Container lab of Start-A-Factory © Culture Form

Fig. 2: AdMaCom Class of 2017 © Innovation Network for Advanced Materials e.V.

DORTMUND – Top Location for Micro-and Nanotechnology!

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.

- ✦ 44 companies with approximately 2,900 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 andregional 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 specialissuppliers 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

City of Dortmund
Economic Development Agency

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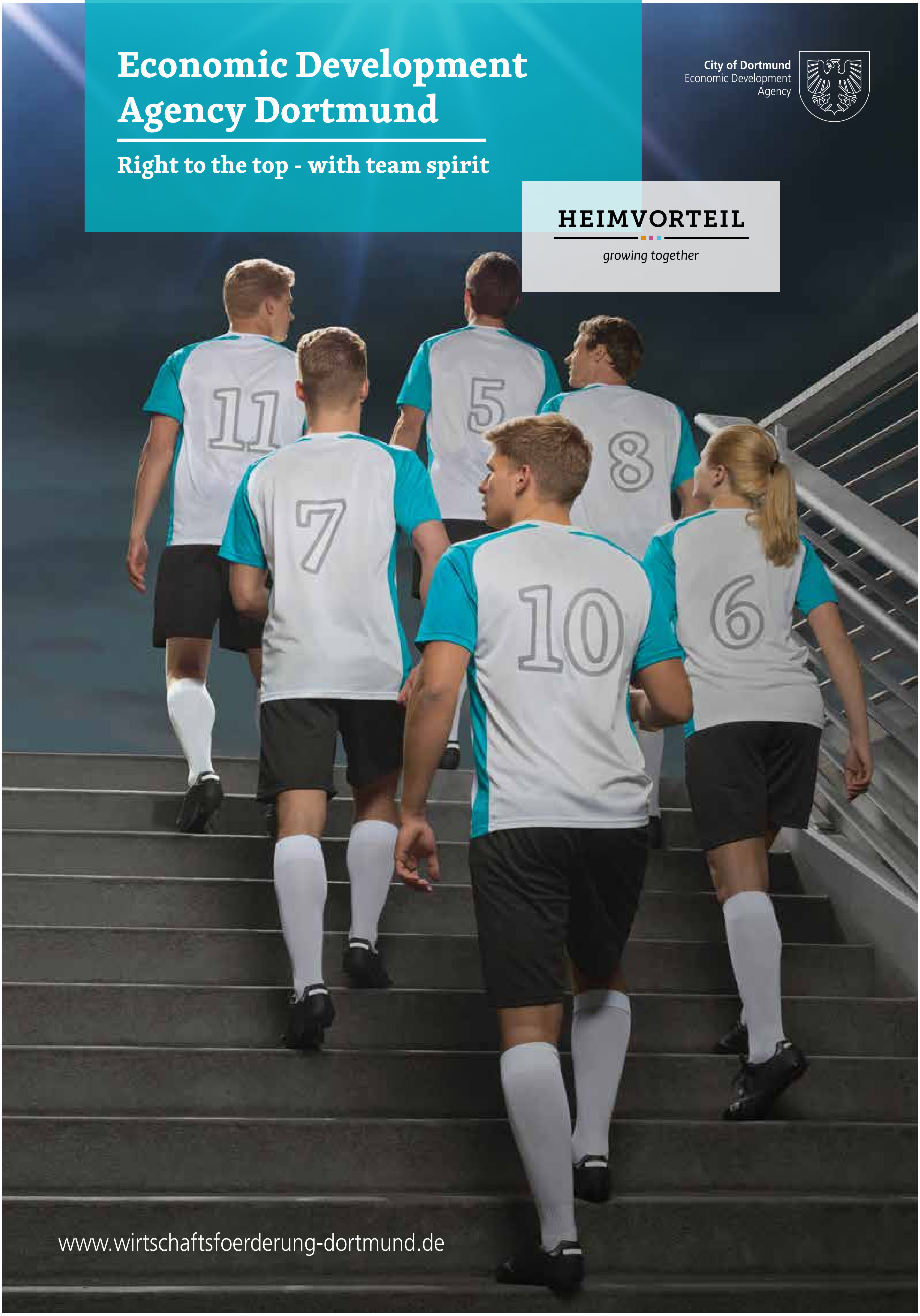
Economic Development Agency Dortmund

Right to the top - with team spirit

City of Dortmund
Economic Development
Agency

HEIMVORTEIL
growing together



www.wirtschaftsfoerderung-dortmund.de

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