Fraunhofer
ISIT

FRAUNHOFER-INSTITUT FÜR SILIZIUMTECHNOLOGIE ISIT

Achievements and Results Annual Report 2011

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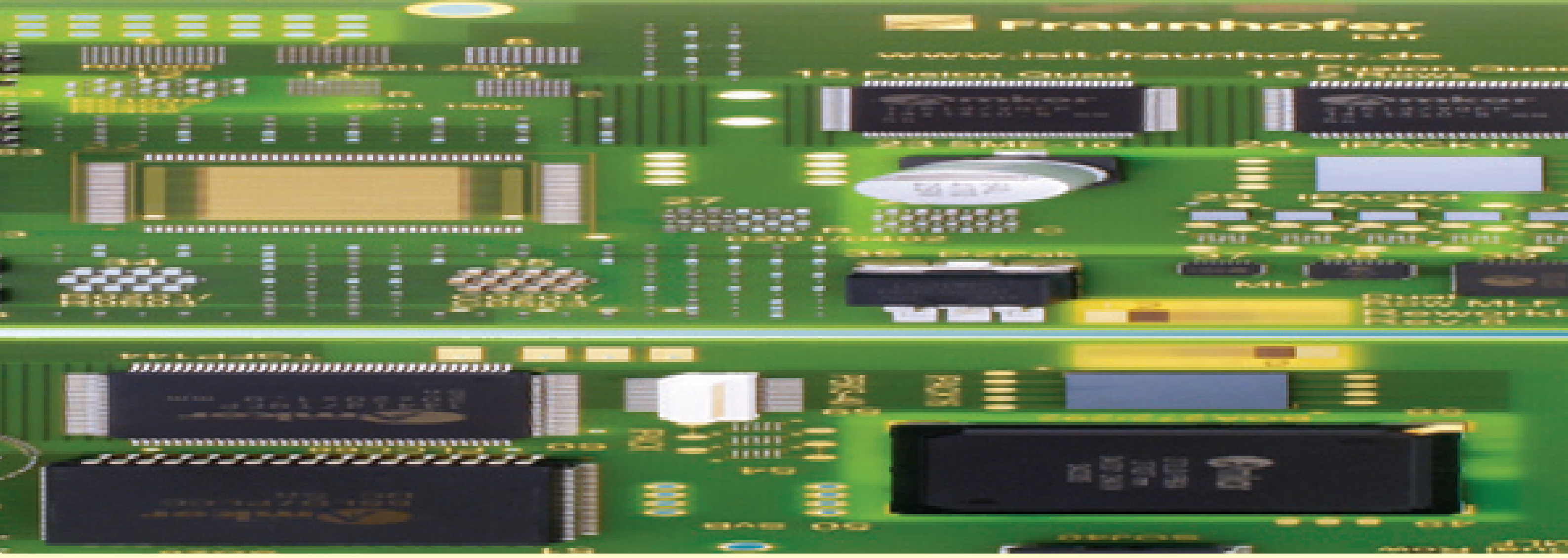


REPRESENTATIVE RESULTS OF WORK

The ground approval for ISIT extension is formally handed over by Minister-President Peter Harry Carstensen to Prof. Wolfgang Benecke.

Pleased with the development of High Tech Itzehoe:
IZET-Director Prof. Ralf Thiericke (right) and his colleagues.

Dear business partners, friends of the ISIT and colleagues,

The institute significantly exceeded the targets it set itself for 2011. I would like to take the opportunity to thank all our business partners, customers, research sponsors, and friends for the good, successful cooperation and the confidence they have placed in us. I would also like to acknowledge in particular the exceptional efforts of all our staff, without whom this successful result would not have been possible.

This annual report will provide you with a brief insight into the work of the institute and progress to date. We hope this will create stimulus for further and future joint R&D projects.

The investment in the 200 mm wafer technology platform has proved to be an important strategic element in guaranteeing our long-term competitiveness in the micro-/nanosystems engineering sector. The associated construction of a new cleanroom for micro-/nanosystems engineering made steady progress as per the timetable. The building department at Fraunhofer Headquarters along with the architects and planning offices involved strictly monitored and checked progress of the construction work. This new facility will allow the ISIT to bolster its leading global position among R&D service providers in micro- and nanotechnology. The close cooperation with our industrial partners at the location proved extremely fruitful for all those involved, thus allowing us to build on our past success. Thanks to the close integration with these partners, it is now also possible to offer product implementation to customers and to users who do not have technology lines of their own.

The results of work conducted at the ISIT have also been presented within the Fraunhofer Microelectronics Alliance

Liebe Geschäftpartner, Freunde des ISIT und Kollegen,

Das Institut konnte die für das Jahr 2011 gesteckten Ziele deutlich übertreffen. Allen unseren Geschäftspartnern, Kunden, Förderern und Freunden möchte ich an dieser Stelle für die gute und erfolgreiche Zusammenarbeit und für das entgegengebrachte Vertrauen danken. Ohne das außergewöhnliche Engagement aller unserer Mitarbeiterinnen und Mitarbeiter wäre jedoch die erfolgreiche Bilanz nicht erreichbar gewesen.

Der vorliegende Jahresbericht gibt Ihnen einen kleinen Einblick in die Arbeiten und zum Stand des Institutes. Wir hoffen, dass er Ihnen Anregungen für weitere und zukünftige gemeinsame FuE-Arbeiten gibt.

Die Investitionen in die 200-mm-Wafer-Technologieplattform hat sich als wichtiger strategischer Baustein für die langfristige Sicherstellung der Wettbewerbsfähigkeit im Bereich der Mikro- und Nanosystemtechnik erwiesen. Der damit verbundene Neubau eines Reinraums für die Mikro- und Nanosystemtechnik konnte im Zeitplan vorangetrieben werden.
Durch die Bauabteilung der Fraunhofer –Zentrale und die beteiligten Architekten und Planungsbüros erfolgt eine enge Kontrolle und Überwachung der Baufortschritte. Das ISIT stärkt damit seine, auch im weltweiten Vergleich, führende Position bei den FuE Dienstleistern in der Mikro- und Nanotechnologie.
Die enge Zusammenarbeit mit unseren Industriepartnern am Standort war, so wie in den zurückliegenden Jahren, ausgesprochen und wechselseitig befruchtend.
Durch die enge Vernetzung mit diesen Partnern ist es nun möglich auch Kunden und Anwendern ohne eigene Technologielinien die Produktumsetzung anzubieten.

Construction site of the new cleanroom and laboratory building

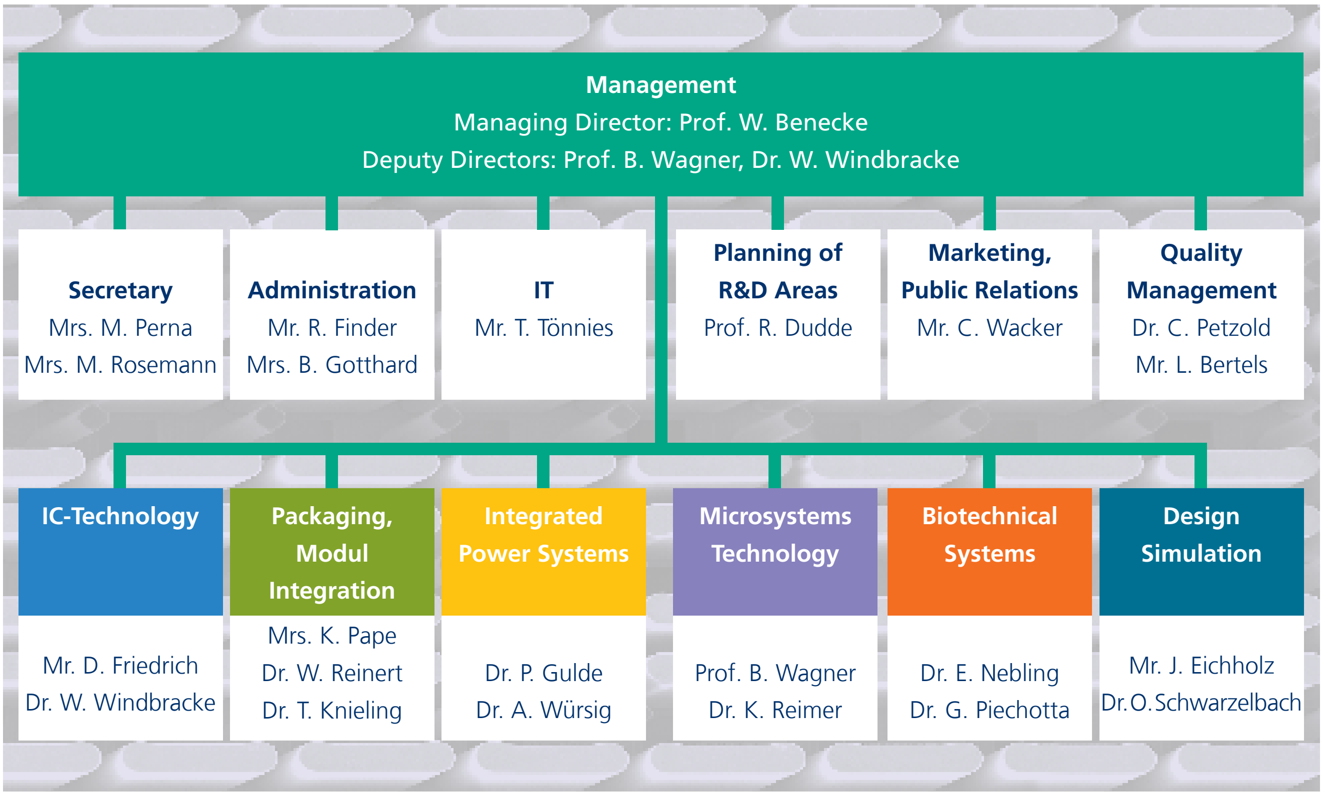
and preparations made for cooperating with other institutes based on a shared workload.

We were also successful in strengthening the backbone of our cooperation with the University of Kiel (Christian-Albrechts-Universität, CAU), particularly with the electrical/electronics engineering and materials science institutes in the Faculty of Engineering. Our involvement in the "SFB 855 Magnetoelectric Composites research center" is generating interesting impetus for new systems solutions.

Auch innerhalb des Fraunhoferverbundes Mikroelektronik werden Arbeitsergebnisse des ISIT vorgestellt und arbeitsteilige Zusammenarbeiten mit anderen Instituten vorbereitet.

Sehr erfreulich gefestigt wurde die Zusammenarbeit mit der Christian-Albrechts-Universität zu Kiel, besonders mit den elektrotechnischen und materialwissenschaftlichen Instituten an der Technischen Fakultät. Die Teilnahme am „SFB 855-Magnetoelektrische

ISIT-Organigramm



ISIT presentation at Nacht des Wissens, Hamburg

Open day at High Tech Itzehoe

We responded with great interest and supported the possibility of participating in the application for a cluster of excellence (Materials for Life) at the CAU.

The work and the results obtained provide a solid base for taking the institute forward. In all our areas of research we will continue to build upon our systems expertise. Know-how that extends beyond system components will become a decisive competitive advantage for the institute. In this respect we intend to continue to utilize our expertise and opportunities for the benefit of society.

Allow me to conclude by once again thanking our customers, partners in the Fraunhofer-Gesellschaft, the universities, the ministries and funding institutions at state and federal level, project sponsors, and the EU for their trust and cooperation. Such thanks go in particular to the Executive Board and central administration of the Fraunhofer-Gesellschaft, the institute coordination officer, and the members of the Advisory Board.

We hope that this annual report will provide you with fresh ideas for future cooperation with the Fraunhofer ISIT.

We look forward to working with you again.

Verbundwerkstoffe" generiert interessante Impulse für neue Systemlösungen. Die Möglichkeit zur Mitwirkung an der Beantragung eines Exzellenz-Clusters an der CAU (Materials for Life) haben wir mit großem Interesse aufgenommen und unterstützt.

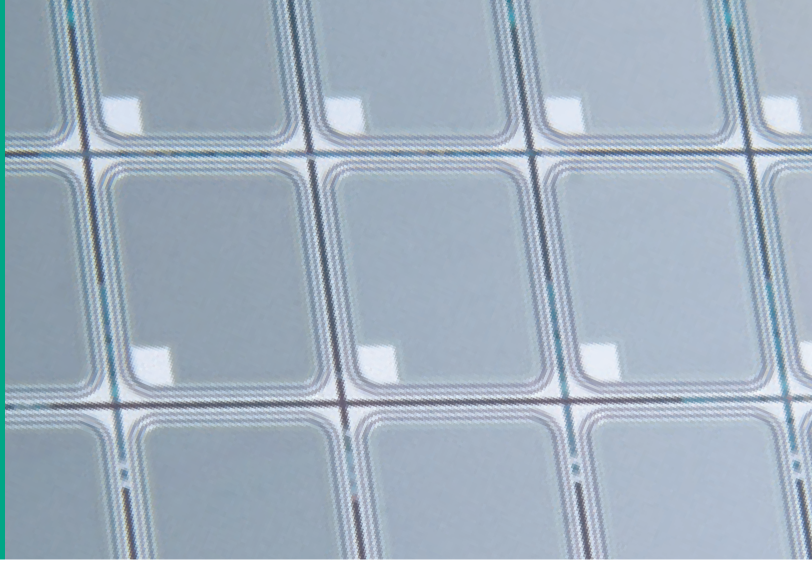
Mit den Arbeiten und den erzielten Ergebnissen ist eine gute Basis für die Weiterentwicklung des Institutes gelegt. In allen Tätigkeitsfeldern werden wir den begonnenen Ausbau der Systemkompetenzen vorantreiben. Das Wissen, über die Systemkomponenten hinaus, wird entscheidender Wettbewerbsvorteil für das Institut sein. In diesem Sinne werden wir unsere Kompetenzen und Möglichkeiten weiter zum Wohle der Gesellschaft einbringen.

Abschließend möchte ich noch einmal unseren Auftraggebern, den Partnern in der Fraunhofer-Gesellschaft, den Universitäten und Hochschulen, den Ministerien und Förderinstitutionen in Land und Bund, den Projektträgern und der EU für die vertrauensvolle Zusammenarbeit danken. Ganz besonders gilt dies auch für den Vorstand der Fraunhofer-Gesellschaft mit der Zentralverwaltung, dem Institutsbetreuer und den Kuratoren.

Wir hoffen, dass der vorliegende Jahresbericht Ihnen Impulse für eine zukünftige Zusammenarbeit mit dem Fraunhofer ISIT liefert.

Wir freuen uns auf die Zusammenarbeit mit Ihnen.

W. Benecke



Application specific MOSFET devices

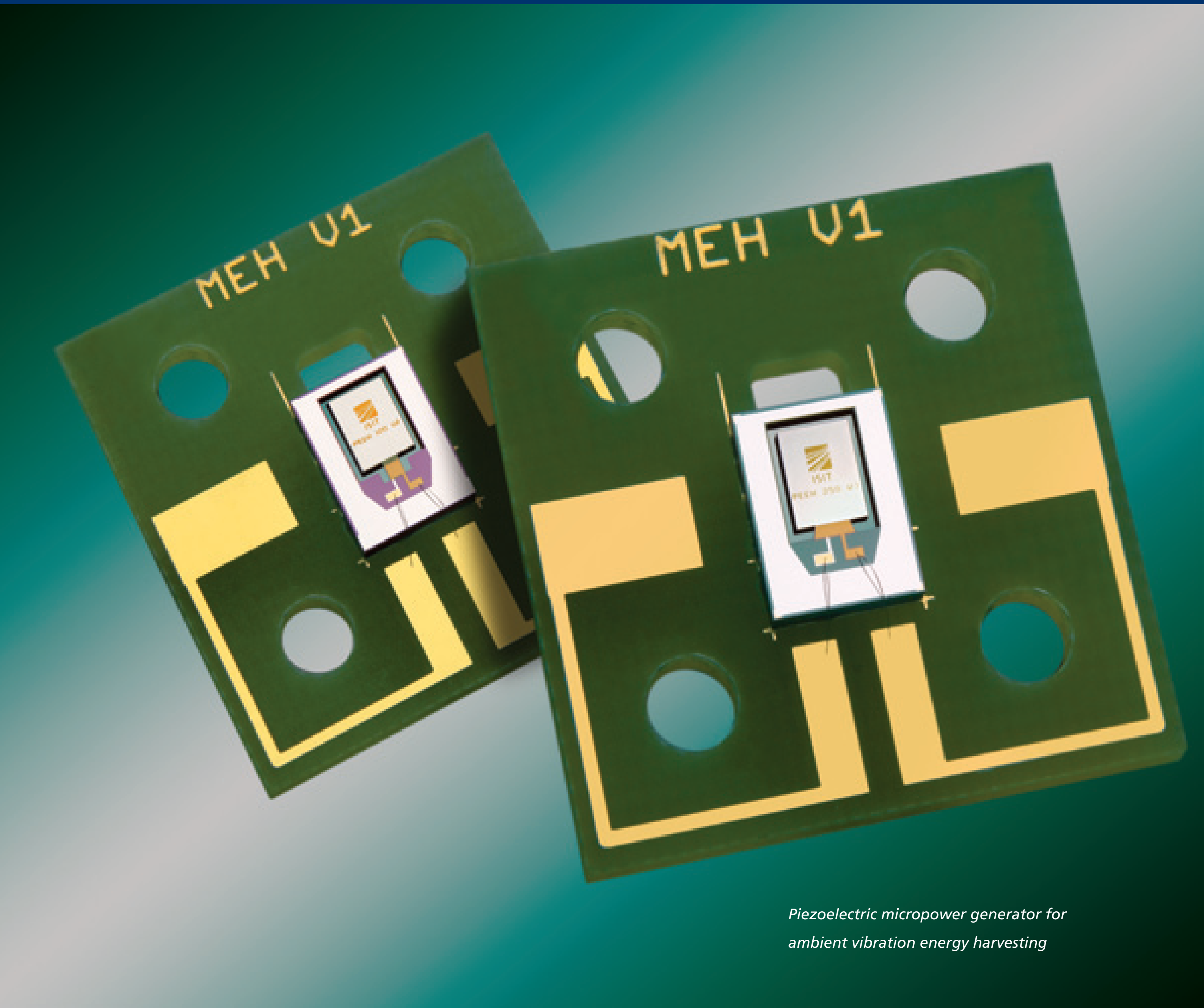
FRAUNHOFER-INSTITUT FÜR SILIZIUMTECHNOLOGIE (ISIT)

Research and Production at one Location

The Fraunhofer-Institut für Siliziumtechnologie (ISIT) develops and produces microelectronic and microsystem components. The advanced process line based on a 200 mm silicon wafer technology and the expertise built up over decades ensure a world-leading position for ISIT and its customers. Micro-components for a wide range of applications are developed by the institute. The main areas of application are automotive and transport engineering, consumer goods industry, medical technology, communication systems and automation. ISIT carries out the design and system simulation of micro-components for its customers and provides prototypes and pilot production, provision of samples and preparation of series production.

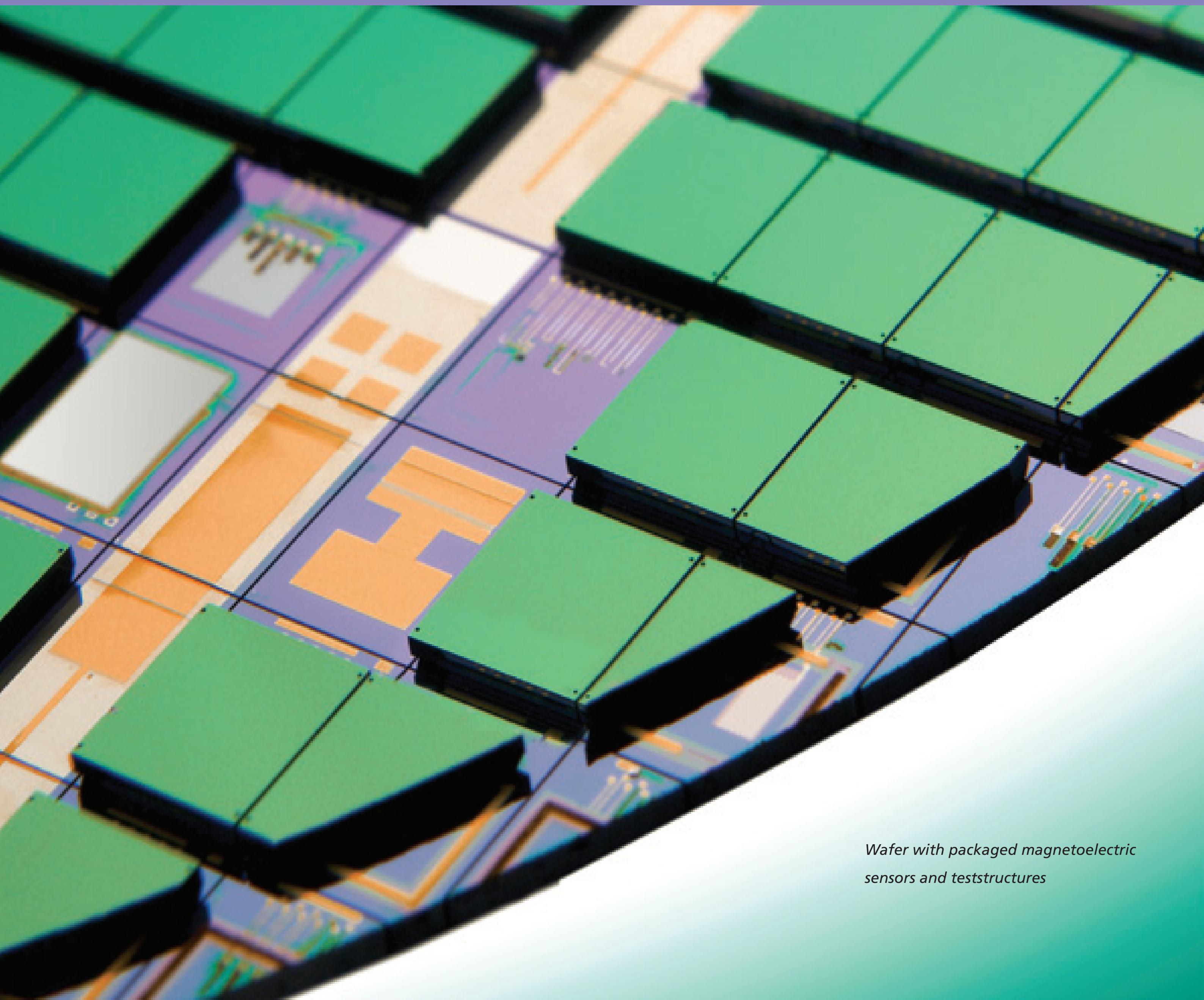
The institute also offers application-specific integrated circuits (ASICs) for the operation of sensors and actuators and deals with all the important tasks involved in system integration, assembly and interconnection technology (packaging) and the reliability and quality of components, modules and systems. Activities are completed by intensive development work on electrical energy storage devices based on Lithium polymer batteries.

MAIN FIELDS OF ACTIVITY

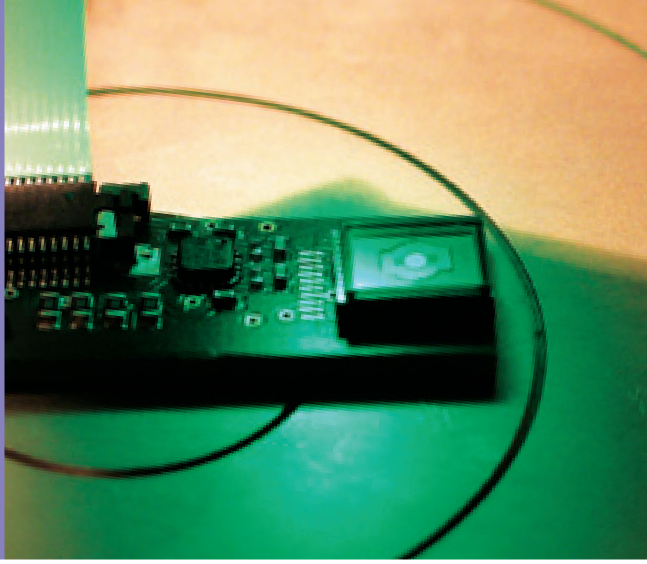


Piezoelectric micropower generator for ambient vibration energy harvesting

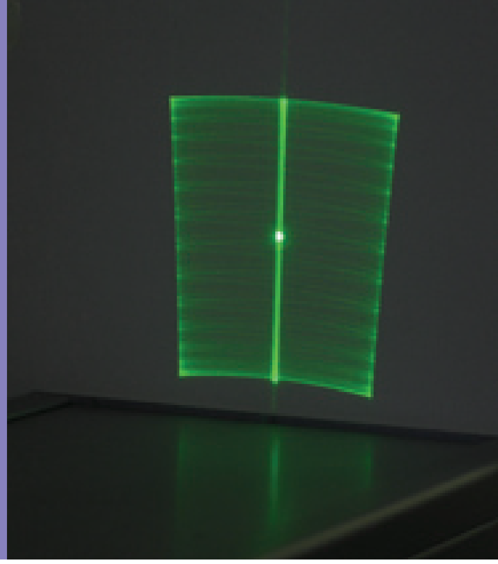
MICROSYSTEMS TECHNOLOGY (MEMS) AND IC DESIGN



Wafer with packaged magnetoelectric sensors and teststructures



2D MEMS scanner on PCP under test



Lissajous scan of 2D MEMS scanner

Research in microsystems technology is a core activity of Fraunhofer ISIT in different departments. For more than 25 years ISIT scientists are working on the development of micro electro mechanical systems (MEMS). This covers the complete spectrum starting from simulation and design, technology and component development up to development of endtest strategies and reliability tests. One of the core competences of the ISIT service offer is the development of integration technologies, like cost effective assembly of several chips in a common package, MEMS packaging on waferlevel (WLP) with defined cavity pressure or a system-on- chip approach. MEMS devices can be combined with a suitable ASIC to miniaturized systems with high functionality.

The ISIT cooperation model allows further to offer also a fabrication of prototypes and starting a pilot production. If high volume MEMS production is requested the on-site operating industrial partner MEMS Foundry Itzehoe (MFI) is able to meet this demand.

ISIT is focussed on MEMS applications in the core areas: physical sensors and actuators, devices and technologies for high frequency application (RF-MEMS), passive and active optical Microsystems as well as piezoelectric MEMS.

In the field of sensor systems strong activities are put on inertial sensors (accelerometer, gyrometer, IMU, magnetometer) and on flow sensors with integrated electronics (ASICs) respectively. Special technological process modules for sensor development are available, e.g. thick poly silicon as a functional layer or hermetic encapsulation on waferlevel.

High frequency microsystems at ISIT are primarily for application in wireless reconfigurable communication networks, in particular developments for RF-MEMS switches, ohmic switches and waferlevel packaging are running.

In the field of optical MEMS devices ISIT is active in the development of micromirrors for laser projection displays, optical scanning systems and light modulators. Passive optical microsystems are also in the portfolio of ISIT, as there are glass lens arrays or aperture systems for laser beam intensity forming.

At ISIT a large number of single process technologies are available. These have been combined to specific qualified MEMS process modules. They work like a tool kit to realize several applications. Special attention is paid to the PSM-X2 process module, which is based on thick polysilicon layer for the fabrication of accelerometers or gyrometers with automotive qualification AEC Q100.

One of the prerequisites for the development of microsystems and microelectronic components is a highly capable integrated circuit design group. The staff at ISIT is specialist in the design of analog/digital circuits, which enable the electronic analysis of signals from silicon sensors. The designers also model micromechanical and micro optic elements and test their functionality in advance using FEM and behavorial modeling simulation tools. A final characterisation on wafer level or module level allows the verification of the design as well as the used technology.

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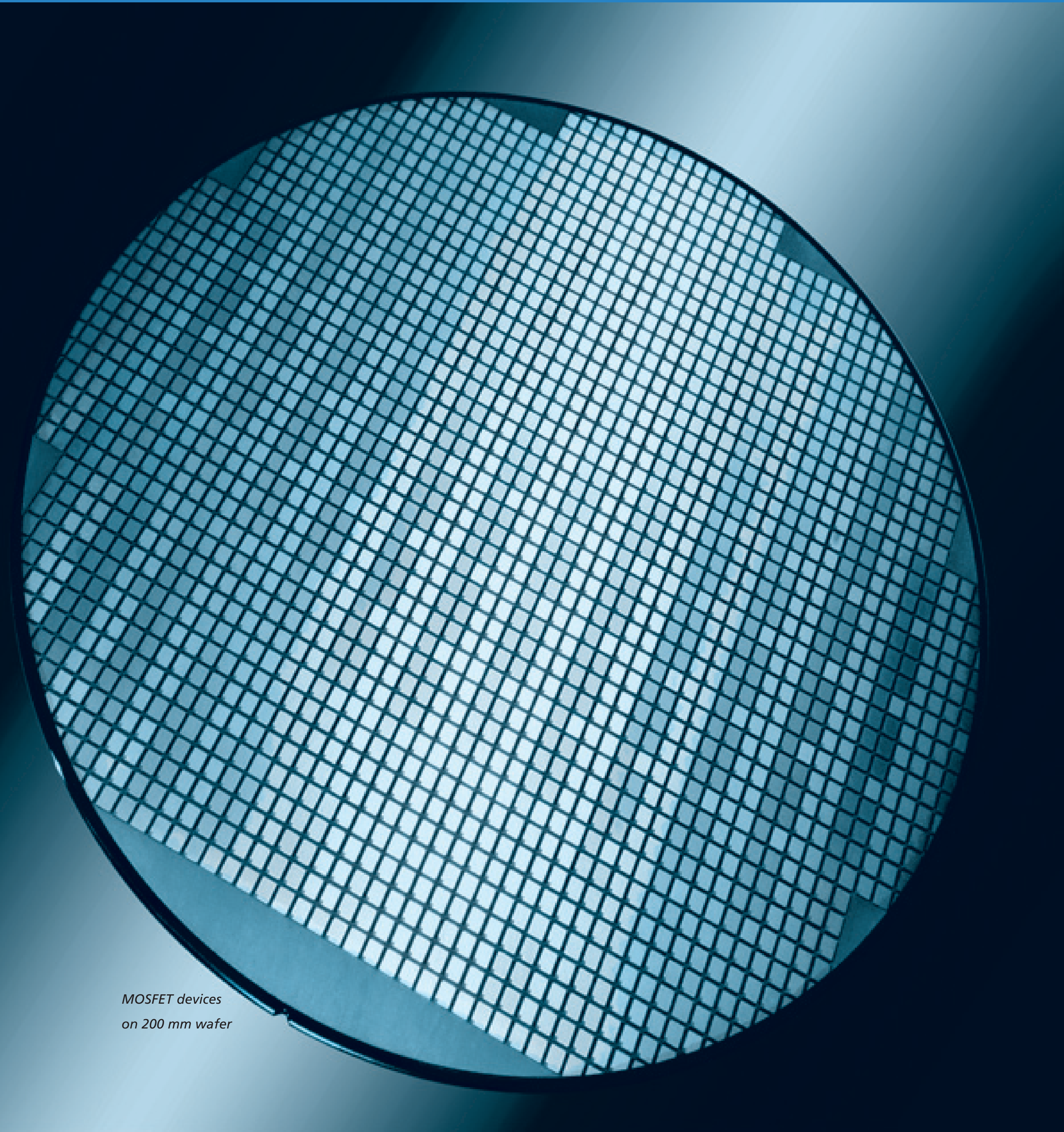
MAIN FIELDS OF ACTIVITY



MOSFET devices on 200 mm wafer

Detail of advanced 5 kVA frequency converter

IC TECHNOLOGY AND POWER ELECTRONICS

The power electronics and IC technology group develops and manufactures active integrated circuits as well as discrete passive components. Among the active components the emphasis lies on power devices such as smart power chips, IGBTs, PowerMOS circuits and diodes. In this context application specific power devices and new device architectures are special R&D areas. The development of new processes for advanced power device assembly on waferlevel is a further important research topic. It comprises e. g. adapted chip metallization and novel techniques for backside processing of ultra thin Silicon substrates. Additional support is provided by a number of tools for simulation, design and testing. ISIT also benefits from years of experience in the design and manufacturing of CMOS circuits.

Passive components developed and fabricated at ISIT are primarily chip capacitors, precision resistors and inductors. Development of materials and the integration of new materials and alloys into existing manufacturing processes play an important role in the development process. ISIT develops individual processes, process modules and complete process flows for diverse applications. The institute also offers processing of customer-specific silicon components in small to medium-sized quantities on the basis of a qualified semiconductor process technology. In the field of power electronics ISIT coordinates a competence centre which was founded in close cooperation with universities and companies of the federal country Schleswig-Holstein. A special R&D group with focus on power electronic systems works on application specific topics covering the interface to system end users.

To support the development of new semiconductor production techniques, production equipment of particular interest is selected for testing and optimization by the ISIT staff. This practice provides the institute with specialized expertise related to e. g. etching, deposition, lithography, and planarization methods. Planarization using chemical-mechanical polishing (CMP) in particular is a key technology for manufacturing advanced integrated circuits and microsystems. The intensive work done by ISIT in this area is supported by a corresponding infrastructure. A special emphasis lies in the application of CMP for the manufacturing of MEMS devices and microsystems.

The institute's CMP application lab is equipped with CMP polishing machines and post-CMP cleaning equipment as well as the corresponding measurement tools for wafer diameters between 100 and 300 mm. The CMP group at ISIT works in close relationship to Peter Wolters AG since many years, as well as with other semiconductor equipment manufacturers, producers of polishing slurries and pads, CMP users and chip and wafer manufacturers.

The group's work encompasses the following areas:

- Testing of CMP systems and CMP cleaning equipment
- Development of CMP processes for
  - Dielectrics (SiO_2, TEOS, BPSG, low-k, etc.)
  - Metals (W, Cu, Ni, etc.)
  - Silicon (wafers, poly-Si)
- Testing of slurries and pads for CMP
- Post-CMP cleaning
- CMP-related metrology
- Implementation of customer-specific polishing processes for ICs and micro systems

IC Technology and Power Electronics
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Point-of-Care diagnostic system

Disposable cartridge with automated sample collection

BIOTECHNICAL MICROSYSTEMS

ISIT is one of the worldwide leaders at the field of electrical biochips. These chips allow the realization of very efficient biosensors and are the basis for fast and cost effective analytical systems.

The electrical biochip technology offers intrinsic advantages over optical biochips because of particle tolerance and mechanical robustness by the direct transduction of biochemical reactions into electrical current. The use of gold electrode arrays combined with integrated reference and auxiliary electrodes along with sensitive, selective measurement techniques like "Redox-Cycling" enables powerful sensor systems. These arrays are useful for the detection of a variety of analytes within one probe simultaneously. User-friendly operability is realized by integrating the biochips into cartridges. In combination with micro-fluidic components and integrated electronics, these electrical microarrays represent the basis of rapid and cost-effective analysis systems. They can be used to identify and quantify DNA, RNA and proteins. Further biosensors enable continuous monitoring, e.g. of metabolites as glucose or lactate. The measurement of these substances is realized by enzymatic conversion and electrochemical detection.

The development of additional micro systems for specialized applications involves the production of different kinds of modified electrodes. Supplementary to gold and platinum, diamond electrodes show intrinsic advantages in direct electrochemical detection of substances, e.g in pulsed amperometry. They are suitable for the detection in chromatography applications (e.g. HPLC) and can be integrated in miniaturized systems like a MEMS chromatography chip.

Miniaturized iridium oxide electrode chips are used for potentiometric measurements in small volume flow through cells and bio reactors.

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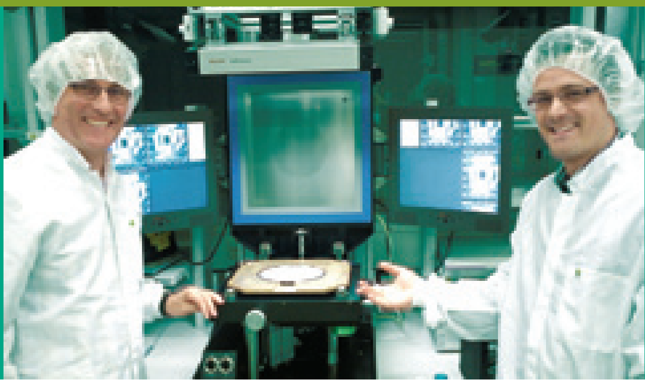
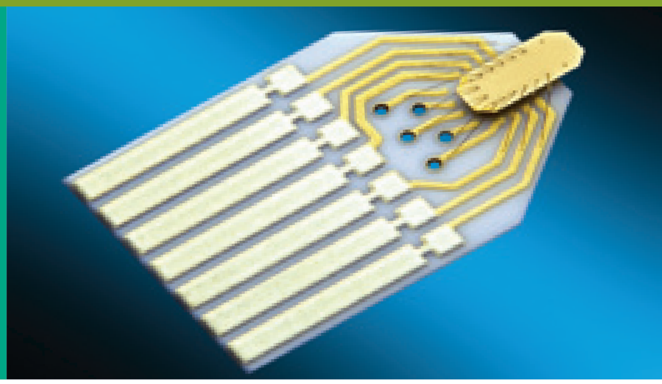


Ball attach on ultra-thin customer CMOS wafer



12 point probe for accurate electrical tests

PACKAGING TECHNOLOGY FOR MICROELECTRONICS AND MICROSYSTEMS

The "Advanced Packaging" group is specialized in detecting and promoting new trends and technologies in electronics packaging. The industrial challenges of tomorrow are addressed in direct collaboration with suppliers of materials, components, modules and equipment. As an example, the automatic pick-and-place assembly of thin dies on flexible substrates was already developed several years ago. For the encapsulation of MEMS components, the glass frit bonding was developed and later on replaced by the more efficient metallic bonding. ISIT equally participates in development activities on organic electronics and RFID technology.

The Fraunhofer ISIT disposes of all basic technologies for the automatic or manual handling of microchips and microsensors, as well as electrical interconnect methods like wire bonding and flip chip technologies.

Through the close relationship between MEMS technology and packaging in ISIT's premises, the institute has become a leading R&D service provider in the domain of waferlevelpackaging. A cross-disciplinary technology portfolio is now available that allows to reduce cost and volume of a system. Even more, the packaging itself can become a functional part of the microsystem in many cases, e.g. by integrating optical elements or directly interconnecting MEMS and ASIC dies. Outstanding success was achieved in the vacuum encapsulation of micromechanical sensors by eutectic wafer bonding, which paved the way towards the industrialisation of a gyro sensor product family for automotive applications.

ISIT continuously expands their assortment of test chips and -substrates that facilitate the ramp up and calibration of production lines for securing quality on a high level.

Packaging Technology for Microelectronics and Microsystems
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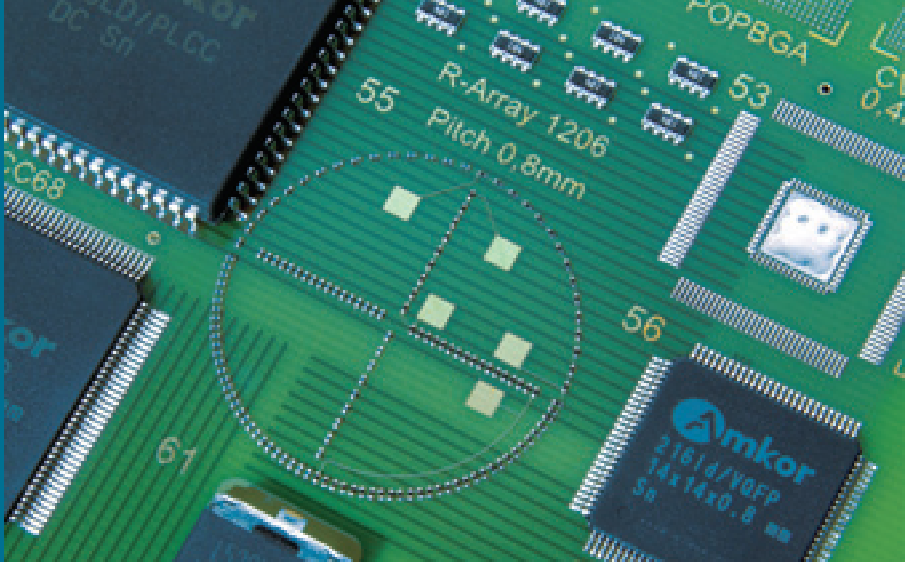

Detail of rework testboard

QUALITY AND RELIABILITY OF ELECTRONIC ASSEMBLIES

Quality evaluation – in particular for the soldering work done in pre-production, pilot and main series lots – represents a continuous challenge for ISIT, as for example whenever new technologies such as lead-free soldering are introduced, or when increased error rates are discovered, or if a customer desires to achieve competitive advantages through continual product improvement. To reveal potential weak points, ISIT employs both destructive and non-destructive analysis methods, such as X-ray transmission radiography and scanning acoustic microscopy. Working from a requirements matrix, ISIT scientists also evaluate long-term behavior of lead-free and lead-containing assemblies alike. They then formulate prognoses on the basis of model calculations, environmental and time-lapse load tests, and failure analysis.

In anticipation of a conversion to lead-free electronics manufacturing, Fraunhofer ISIT is undertaking design, material selection and process modification projects for industrial partners. To effect a further optimization of manufacturing processes, the institute applies process models and produces samples on industry-compatible equipment. The group also addresses issues related to thermal management and reliability for customer-specific power modules.

In addition to these technological activities, the group regularly holds training sessions, including multi-day classes, at the institute or at company site.

Quality and Reliability of Electronic Assemblies
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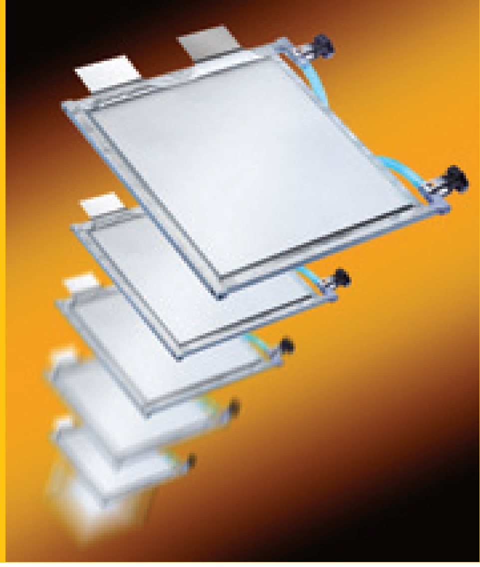

Lithium polymer secondary batteries for stationary power applications

Operation of advanced electrode coater

INTEGRATED POWER SYSTEMS

Secondary Lithium batteries as a powerful storage medium for electrical energy are rapidly capturing new fields of application outside of the market of portable electronic equipment.

These new fields include automobiles, medical devices, stationary electric storage units, aerospace, etc. Therefore, this type of rechargeable batteries has to meet a variety of new requirements. This covers not only electrical performance but also design and safety features. The Lithium polymer technology developed at ISIT is characterized by an extensive adaptability to specific application profiles like extended temperature range, high power rating, long shelf and/or cycle life, extended safety requirements, etc. Also included is the development of application-specific housings.

In the Lithium polymer technology all components of the cell from electrodes to housing are made from tapes. At ISIT the complete process chain starting with the slurry preparation over the tape casting process and the assembly and packaging of complete cells in customized designs is available including also the electrical and thermo-mechanical characterization. This allows access to all relevant parameters necessary for an optimization process. The electrode and the electrolyte composition up to the cell design can be modified.

In addition to the development of prototypes, limited-lot manufacturing of optimized cells on a pilot production line at ISIT with storage capacities of up to several ampere-hours is possible. Specific consideration in process development is addressed to the transferability of development results in a subsequent industrial production.

ISIT offers a wide portfolio of services in the field of secondary Lithium batteries:

- Manufacturing and characterization of battery raw materials by half cell as well as full cell testing
- Selection of appropriate combinations of materials and design of cells to fulfil customer requirements
- Application driven housing development
- Test panel
- Prototyping and limited-lot manufacturing of cells

Additional services are:

- Preparation of studies
- Failure analysis
- Testing (electrical, mechanical, reliability etc.)
- Technical consultation

Integrated Power Systems

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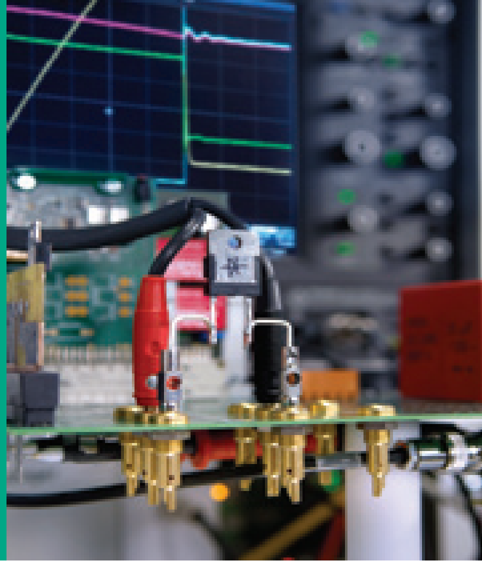
OFFERS FOR RESEARCH AND SERVICE

Lock-in infrared thermography measurement setup

RFID transponder packaged in inmould technology



High voltage dynamic measurement system

FACILITIES AND EQUIPMENT

ISIT operates in collaboration with Vishay Siliconix Itzehoe GmbH a semiconductor production line for 200 mm (8“) Si wafers (cleanroom area 2.500 m²). The process line is used for the development of new components and processes as well as for the production of components (PowerMOS, MEMS). Further cleanrooms (650 m²) are available for specific processes, as needed for example in microsystem engineering, and for chemical-mechanical polishing (CMP). In addition to the basic processes of microsystem engineering, highly developed processes are maintained, e.g. for high-precision deep etching (DRIE), deposition of non-IC-compatible materials such as piezoelectrics, thick-layer lithography and electroplating, glass molding and grey-scale lithography. The institute has particular expertise in wafer bonding and waferlevel packaging (WLP), achieving unique levels of quality for various MEMS components (gyroscopes, scanner mirrors, RF-MEMS, etc.). Further laboratory areas (1.500 m²) are equipped for characterization, qualification and assembly and interconnection technology. The scope of activities is widened by laboratories for the development of Lithium polymer batteries, in which a pilot production plant is operated for sample production and evaluation tasks.

To expand the institute’s capacity, a further cleanroom and laboratory building is presently under construction. The completion is scheduled for mid 2013. The ISIT’s facilities are certified to ISO 9001-2008.

RANGE OF SERVICES

Fraunhofer ISIT has many years of experience in industrial collaboration. Primarily the concept of technology platforms is pursued, i.e. the definition of process procedures in which the customer-specific solutions take place through the design and packaging. This allows to offer services which, beyond the technical specifications, are attractive in terms of risk, development time, development expense and production cost. Series production can ultimately be carried out in close cooperation with the locally based MEMS Foundry Itzehoe GmbH (MFI).

CUSTOMERS

ISIT cooperates with companies of different sectors and sizes.
In the following, some companies are presented as a reference:

ABB AG, *Ladenburg*

Advaplan, *Espoo, Finland*

Airbus-Systeme, *Buxtehude*

aixACCT Systems GmbH, *Aachen*

Analytik Jena AG, *Jena*

AJ eBiochip GmbH, *Itzehoe-Jena*

Andus electronic GmbH, *Berlin*

Atotech Deutschland GmbH, *Berlin*

BASF SE, *Ludwigshafen*

Basler Vision Technologies, *Ahrensburg*

Biont, *Bratislava, Slovakia*

Boschmann Technolgies B.V., *EX Duiven, Netherlands*

Carl Zeiss SMT GmbH, *Oberkochem*

B. Braun, *Melsungen*

Cassidian Electronics, *Ulm*

Condias GmbH, *Itzehoe*

Conti Temic, *Karben*

Conti Temic microelectronic GmbH, *Nürnberg*

Continental, *Nürnberg*

CS Energy Materials GmbH, *Goslar*

Danfoss Drives, *Graasten, Denmark*

Danfoss Silicon Power GmbH, *Schleswig*

Datacon Technology AG, *Radfeld/Tirol, Austria*

Delong Instruments a.s., *Brno, Czech Republic*

Design und Siebdruck Freudenberg GmbH, *Dresden*

Diehl Avionik Systeme GmbH, *Überlingen*

Dispatch Energy Innovations GmbH, *Itzehoe*

Dow Chemical Company, *Lausanne, Switzerland*

Dräger Systemtechnik, *Lübeck*

E.G.O. Elektro-Gerätebau GmbH, *Oberderdingen*

EADS Deutschland GmbH, Corporate Research Germany, *München and Ulm*

EN Electronic Network, *Bad Hersfeld*

Engineering Center for Power Electronics GmbH, *Nürnberg*

EPCOS, *Nijmegen, Netherlands*

EPCOS AG, *München*

ESCD, *Brunsbüttel*

ESW-Extel Systems GmbH, *Wedel*

EVGroup, *Schärding, Austria*

Evonik Degussa GmbH, *Hanau*

FeCon GmbH, *Flensburg*

Freudenberg & Co. KG, *Weinheim*

Fujitsu Siemens Computers GmbH, *Augsburg*

Hako-Werke, *Bad Oldesloe*

Hannusch Industrieelektronik, *Laichingen*

Harman & Becker, *Karlsbad*

Hella KG, *Lippstadt*

Heraus Materials Technology GmbH Co. KG, *Hanau*

Ifm electronic GmbH, *Essen*

IMS Nanofabrication AG, *Wien, Austria*

Jenoptik Innovavent GmbH, *Göttingen*

Jungheinrich AG, *Norderstedt*

Kristronics GmbH, *Harrislee-Flensburg*

Kuhnke GmbH, *Malente*

Lam Research, *Fremont, USA*

Landshut Silicon Foundry GmbH, *Landshut*

Lenze Drive Systems GmbH, *Hameln*

Limedion GmbH, *Mannheim*

Liebherr Elektronik, *Lindau*

Litef, *Freiburg*

Mair Elektronik GmbH, *Neufahrn*

Manz AG, *Reutlingen*

Marquardt, *Rietheim-Weilheim*

MASER Engineering B.V., *Enschede, Netherlands*

Maxim Integrated Products Inc., *Oberkochen*

Meder eletronic AG, *Engen-Welschingen*

MEMS Foundry, *Itzehoe*

Microelectronics Packaging, *Dresden*

Micropelt GmbH, *Freiburg*

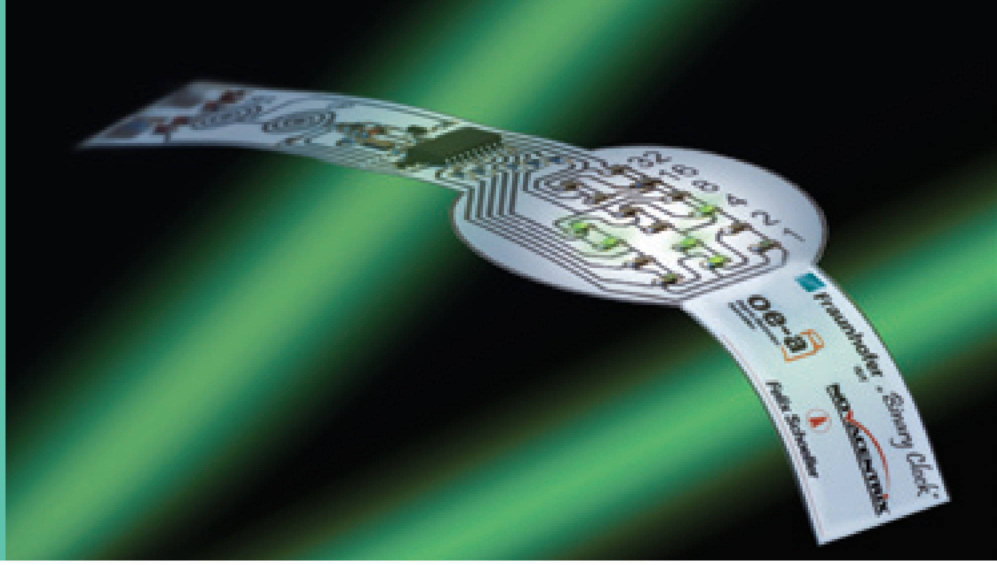
MKS, *München*

mut AG, *Wedel*

NXP Semiconductors, *Hamburg*

Océ-Technologies B.V., *Venlo, Netherlands*

Oerlikon AG, *Liechtenstein*



Binary clock with printed lines on paper

Okmetic Oyj, *Vantaa, Finland*

OMT/ECC GmbH, *Lübeck*

Osram Opto Semiconductors GmbH, *Regensburg*

Oy Advaplan Inc., *Espoo, Finland*

PAC Tech, Packaging Technologies, *Santa Clara, USA*

Panasonic, *Neumünster*

Panasonic Electric Works Co. Ltd., *Osaka, Japan*

PAV Card GmbH, *Lütjensee*

Peter Wolters GmBH, *Rendsburg*

Picosun Oy, *Espoo, Finland*

PlanOptik AG, *Elsoff*

Plath Eft GmbH, *Norderstedt*

POCDIA GmbH, *Itzehoe*

Preh GmbH, *Neustadt a.d.S.*

Prettl Elektronik Lübeck GmbH, *Lübeck*

Protec Process Systems GmbH, *Siegen*

Raytheon Anschütz GmbH, *Kiel*

Reese und Thies, *Itzehoe*

RefuSol GmbH, *Metzingen*

Rehm Anlagenbau GmbH, *Blaubeuren-Seissen*

Rena Sondermaschinen GmbH, *Gütenbach*

Robert Bosch GmbH, *Reutlingen*

Robert Bosch GmbH, *Salzgitter*

Robert Bosch GmbH, *Stuttgart*

SAES Getters S.p.A., *Lainate/Milan, Italy*

SartoriusHamburg GmbH Research & Development, *Hamburg*

Sauer, Danfoss, *Nordborg, Denmark*

SEF GmbH, *Scharnebek*

Sensonor Technologies AS, *Horten, Norway*

SensorDynamics (SD), *Lebring, Austria*

Siemens AG, *Erlangen*

Silex Microsystems AG, *Järfälla, Sweden*

SMA Regelsysteme GmbH, *Niestetal*

Smart Material GmbH, *Dresden*

Smyczek, *Verl*

Solar Direct GmbH, *Itzehoe*

SolMateS B.V., *Enschede, Netherlands*

Sony Deutschland GmbH, *Stuttgart*

Spheros GmbH, *Gilching*

ST Microelectronics, *Crolles, France*

Sterling Industry Consult GmbH, *Itzehoe*

Still GmbH, *Hamburg*

SÜSS Microtec AG, *Garching*

Technolas, *München*

Thales, *Paris, France*

Theon, *Athens, Greece*

TNO, *Delft, Netherlands*

Trainalytics GmbH, *Lippstadt*

Treichel Elektronik GmbH, *Springe*

Trinamic, *Hamburg*

Umicore AG & Co., *Hanau*

Vectron International GmbH & Co. KG, *Neckarbischofsheim*

Vishay BCcomponents Beyschlag GmbH, *Heide*

Vishay, *Dimona and Holon, Israel*

Vishay Siliconix Itzehoe GmbH, *Itzehoe*

Vishay Siliconix, *Santa Clara, USA*

Vistec, *Jena*

Volkswagen AG, *Wolfsburg*

Wabco Fahrzeugbremsen, *Hannover*

Würth Elektronik GmbH, *Schopfheim*

X-FAB Semiconductor Foundries AG, *Erfurt*

INNOVATION CATALOGUE

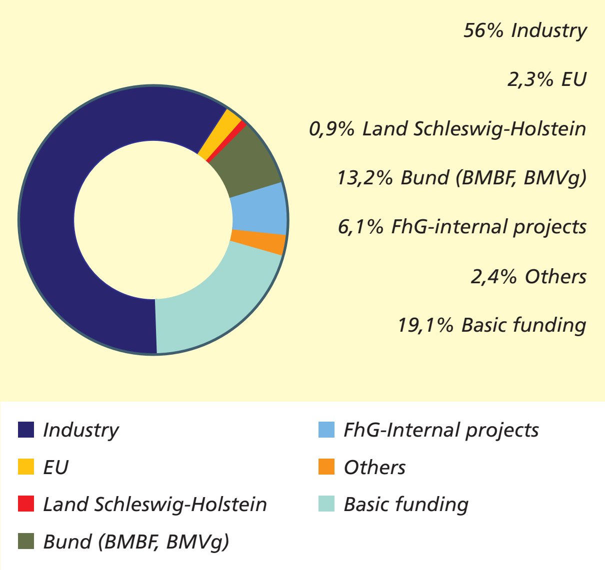
ISIT offers its customers various products and services already developed for market introduction. The following table presents a summary of the essential products and services. Beyond that the utilisation of patents and licences is included in the service.

Product / Service	Market	Contact Person
Testing of semiconductor manufacturing equipment	*Semiconductor equipment manufacturers*	**Dr. Gerfried Zwicker** *+ 49 (0) 4821/17-4309* *gerfried.zwicker@isit.fraunhofer.de*
Chemical-mechanical polishing (CMP), planarization	*Semiconductor device manufacturers*	**Dr. Gerfried Zwicker** *+ 49 (0) 4821/17-4309* *gerfried.zwicker@isit.fraunhofer.de*
Wafer polishing, single and double side	*Si substrates for device manufacturers*	**Dr. Gerfried Zwicker** *+ 49 (0) 4821/17-4309* *gerfried.zwicker@isit.fraunhofer.de*
IC processes and power devices CMOS, PowerMOS, IGBTs	*Semiconductor industry IC-users*	**Detlef Friedrich** *+ 49 (0) 4821/17-4301* *detlef.friedrich@isit.fraunhofer.de*
Single processes and process module development	*Semiconductor industry semiconductor equipment manufacturers*	**Detlef Friedrich** *+ 49 (0) 4821/17-4301* *detlef.friedrich@isit.fraunhofer.de*
Customer specific processing	*Semiconductor industry semiconductor equipment manufacturers*	**Detlef Friedrich** *+ 49 (0) 4821/17-4301* *detlef.friedrich@isit.fraunhofer.de*
Microsystem products	*Electronic industry*	**Prof. Ralf Dudde** *+ 49 (0) 4821/17-4212* *ralf.dudde@isit.fraunhofer.de*
MEMS process development and integration	*Sensors and actuators*	**Christian Schröder** *+ 49 (0) 4821/17-4515* *christian.schroeder@isit.fraunhofer.de*
Inertial sensors	*Motorvehicle technology, navigation systems, measurements*	**Dr. Klaus Reimer** *+ 49 (0) 4821/17-4213* *klaus.reimer@isit.fraunhofer.de*
Piezoelectric microsystems	*Sensors and actuators*	**Hans-Joachim Quenzer** *+ 49 (0) 4821/17-4643* *hans-joachim.quenzer@isit.fraunhofer.de*
Microoptical scanners and projectors	*Biomedical technology, optical measurement industry, telecommunication*	**Ulrich Hofmann** *+ 49 (0) 4821/17-4553* *ulrich.hofmann@isit.fraunhofer.de*
Flow sensors	*Automotive, fuel cells*	**Dr. Peter Lange** *+49 (0) 4821/17-4506* *peter.lange@isit.fraunhofer.de*
Microoptical components	*Optical measurement*	**Hans-Joachim Quenzer** *+ 49 (0) 4821/17-4643* *hans-joachim.quenzer@isit.fraunhofer.de*
RF-MEMS	*Telecommunication*	**Dr. Thomas Lisec** *+ 49 (0) 4821/17-4512* *thomas.lisec@isit.fraunhofer.de*
Beam deflection components for maskless nanolithography	*Semiconductor equipment manufactorers*	**Dr. Klaus Reimer** *+ 49 (0) 4821/17-4233* *klaus.reimer@isit.fraunhofer.de*

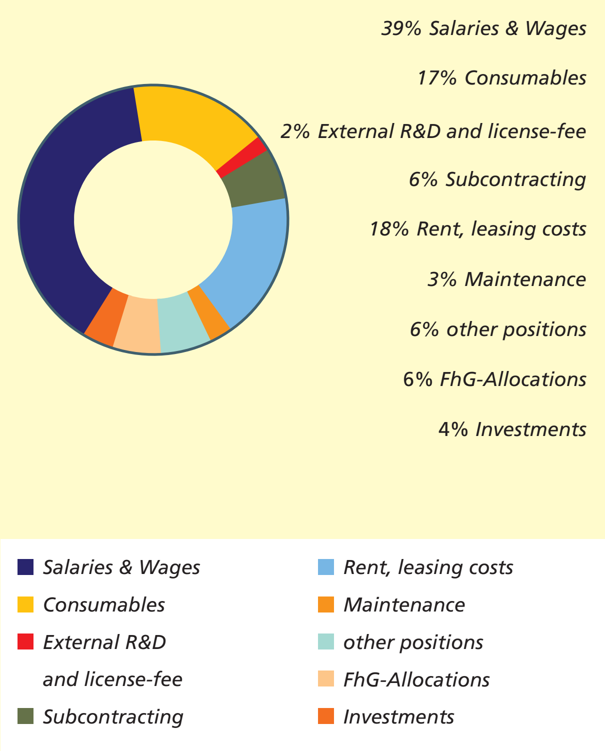
Product / Service	Market	Contact Person
Design and test of analogue and mixed-signal ASICs	*Measurement, automatic control industry*	**Jörg Eichholz** *+ 49 (0) 4821/17-4253* *joerg.eichholz@isit.fraunhofer.de*
Design Kits	*MST foundries*	**Jörg Eichholz** *+ 49 (0) 4821/17-4253* *joerg.eichholz@isit.fraunhofer.de*
MST design, behavioural modelling and wafer tests	*Measurement, automatic control industry*	**Jörg Eichholz** *+ 49 (0) 4821/17-4253* *joerg.eichholz@isit.fraunhofer.de*
Electrodeposition of microstructures	*Surface micromachining*	**Martin Witt** *+ 49 (0) 4821/17-4613* *martin.witt@isit.fraunhofer.de*
Electrical biochip technology (proteins, nucleic acids, haptens)	*Biotechnology, related electronics micro-fluidics, environmental analysis, Si-Chip-processing, packaging, chip loading*	**Dr. Eric Nebling** *+ 49 (0) 4821/17-4312* *eric.nebling@isit.fraunhofer.de*
Microsystem production service	*MEMS fabless manufactorers*	**Dr. Peter Merz** *+ 49 (0) 4821/17-4221* *peter.merz@memsfoundry.de*
Secondary lithium batteries	*Mobile electronic equipment, medical applications, automotive, smart cards, labels, tags*	**Dr. Peter Gulde** *+49 (0) 4821/17-4307* *peter.gulde@isit.fraunhofer.de*
Battery test service, electrical parameters, climate impact, reliability, quality	*Mobile electronic equipment medical applications automotive, smart cards, labels, tags*	**Dr. Peter Gulde** *+49 (0) 4821/17-4307* *peter.gulde@isit.fraunhofer.de*
Quality and reliability of electronic assemblies (www.isit.fraunhofer.de)	*Microelectronic and power electronic industry*	**Karin Pape** *+ 49 (0) 4821/17-4229* *karin.pape@isit.fraunhofer.de*
Material and damage analysis	*Microelectronic and power electronic industry*	**Dr. Thomas Knieling** *+ 49 (0) 4821/17-4605* *thomas.knieling@isit.fraunhofer.de*
Thermal measurement and simulation	*Microelectronic and power electronic industry*	**Dr. M. H. Poech** *+ 49 (0) 4821/17-4607* *max.poech@isit.fraunhofer.de*
Leadfree / RoHS transformation in electronic assembly	*Electronic industry*	**Helge Schimanski** *+49 (0) 4821/17-4639* *helge.schimanski@isit.fraunhofer.de*
Packaging for microsystems, sensors, multichip modules (www.isit.fraunhofer.de)	*Microelectronic, sensoric and medical industry*	**Karin Pape** *+ 49 (0) 4821/17-4229* *karin.pape@isit.fraunhofer.de*
Wafer level packaging, ultra thin Si packaging and direct chip attach techniques	*Microelectronic, sensoric and medical industry, automotive industry*	**Dr. Wolfgang Reinert** *+ 49 (0) 4821/17-4617* *wolfgang.reinert@isit.fraunhofer.de*
Vacuum wafer bonding technology	*Microelectronic, sensoric and medical industry, automotive industry*	**Dr. Wolfgang Reinert** *+ 49 (0) 4821/17-4617* *wolfgang.reinert@isit.fraunhofer.de*

REPRESENTATIVE FIGURES

Income



Expenditure



EXPENDITURE

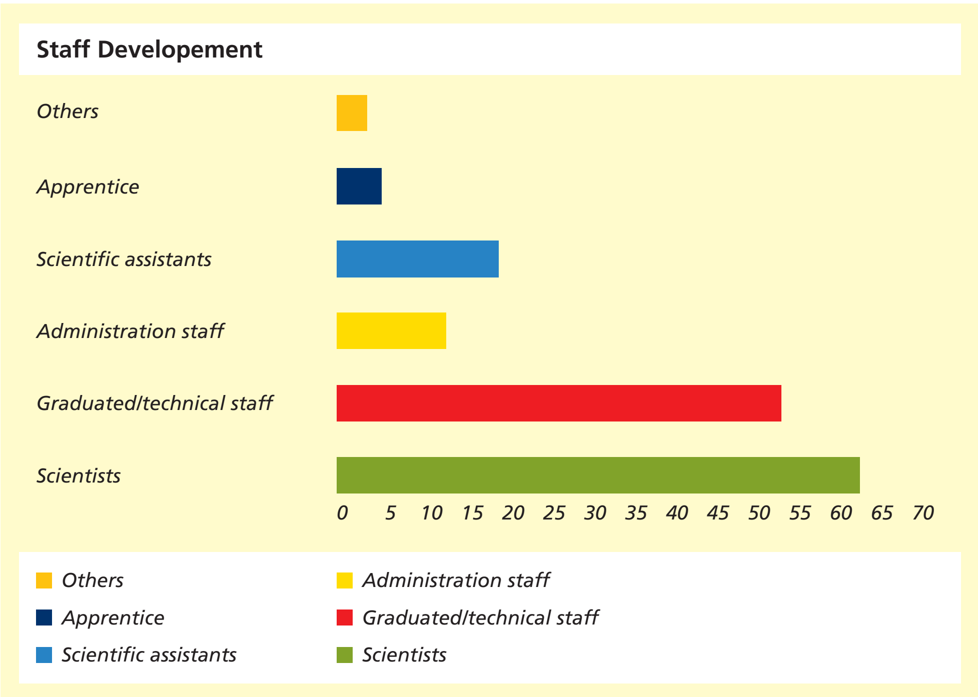
In 2011 the operating expenditure of Fraunhofer ISIT amounted to 21.342,6 T€. Salaries and wages were 8.293,1 T€, material costs and different other running costs were 12.263,2 T€. The institutional budget of capital investment was 786,3 T€.

INCOME

The budget was financed by proceeds of projects of industry/industrial federations/small and medium sized companies amounting to 13.096,1 T€, of government/project sponsors/federal states amounting to 3.284,0 T€ and of European Union/others amounting to 1.099,4 T€. Furthermore there were FhG-projects about 1.431,0 T€ und basic funding with 4.475,1 T€.

STAFF DEVELOPMENT

In 2011, on annual average, the staff consisted of 128 employees. 62 were employed as scientific personnel, 53 as graduated/technical personnel and 13 worked within organisation and administration. The employees were assisted through 19 scientific assistants, 5 apprentices and 3 others.



THE FRAUNHOFER-GESELLSCHAFT

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains more than 80 research units in Germany, including 60 Fraunhofer Institutes. The majority of the more than 20,000 staff are qualified scientists and engineers, who work with an annual research budget of €1.8 billion. Of this sum, more than €1.5 billion is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

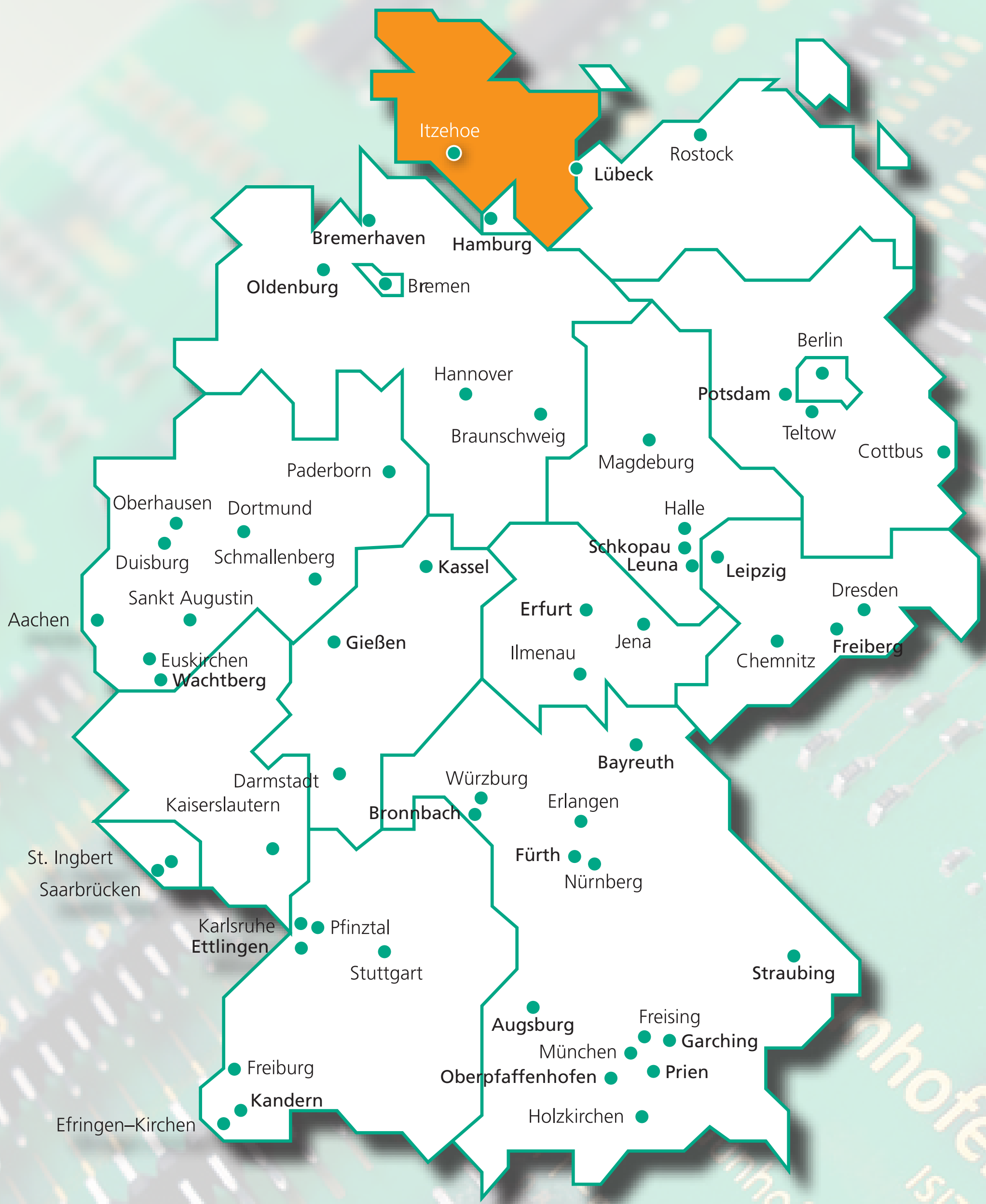
Affiliated international research centers and representative offices provide contact with the regions of greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

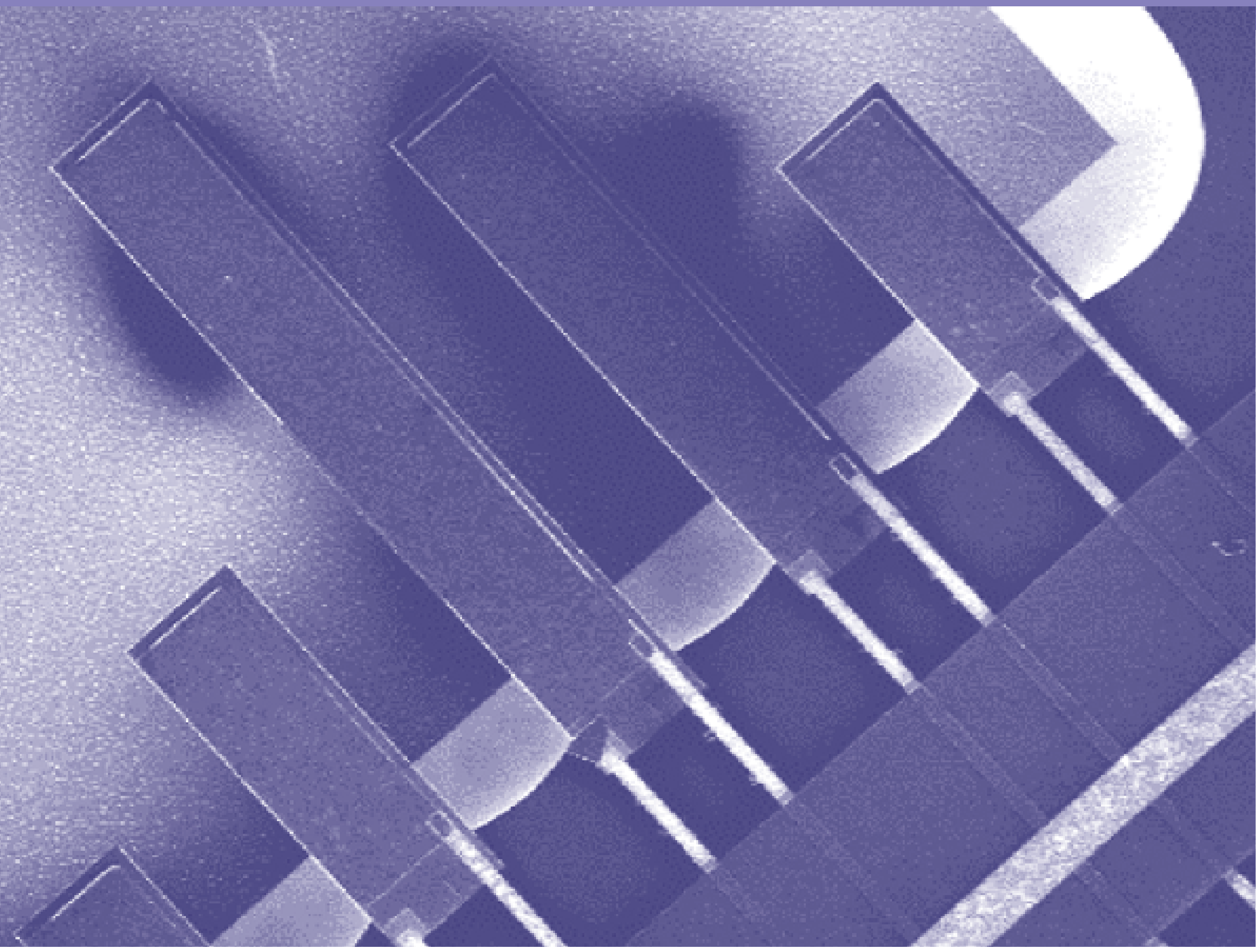
As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

LOCATIONS OF THE RESEARCH ESTABLISHMENT



MICROSYSTEMS TECHNOLOGY (MEMS) AND IC DESIGN



SEM micrograph of a magnetoelectric sensor device

MEMS MAGNETIC FIELD SENSOR BASED ON MAGNETOELECTRIC COMPOSITES

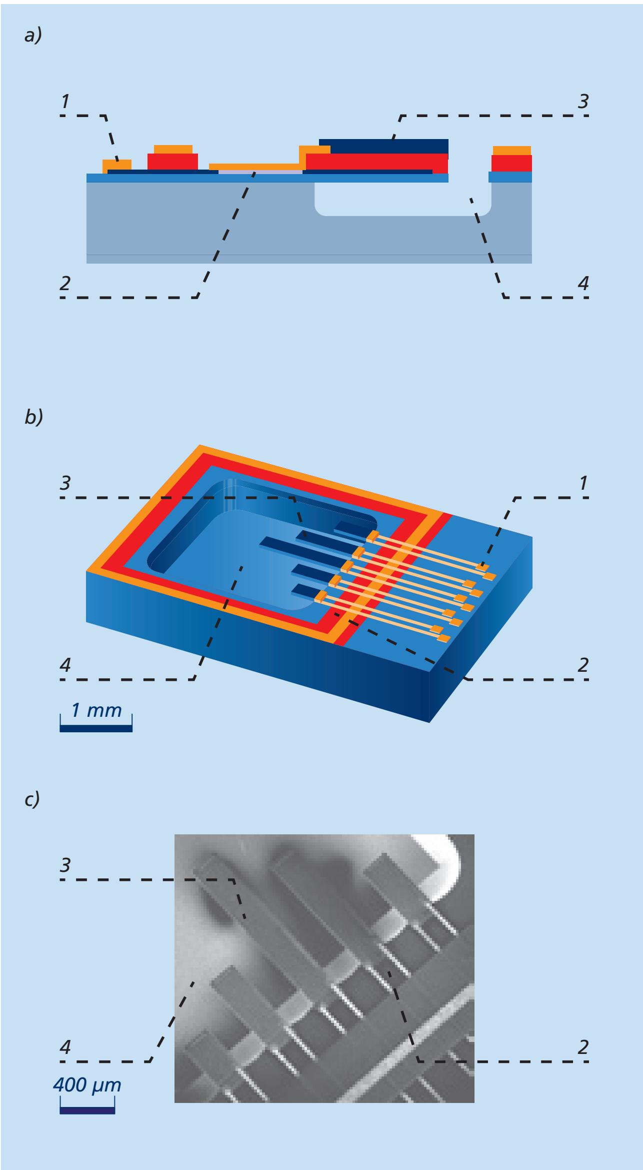


Figure 1: Schematic cross section (a), drawing (b), SEM micrograph (c) of a micro ME sensor device with 1. bond pad, 2. strip line, 3. ME cantilever and 4. etch groove

The Fraunhofer ISIT is part of the Collaborative Research Center SFB 855 "Magnetoelectric Composite Materials" which has the goal to develop new, uncooled and unshielded biomagnetic interfaces. In close collaboration with the "High-frequency Laboratory" and the department for "Inorganic Functional Materials" of the University of Kiel we developed a high sensitive MEMS magnetic field sensor based on magnetoelectric (ME) composite. Newly developed magnetoelectric composites have coefficients which are several magnitudes higher than natural multiferroics; therefore they are of recent research focus for magnetic field sensors. Due to the enhancement of detecting magnetic fields at mechanical resonance and the passive nature makes them highly potential as ultra-sensitive magnetic field sensors in the picotesla regime.

Of high interest is their application for non-invasive medical imaging like magnetoencephalography or – cardiography (MEG, MCG) as a replacement for state-of-the-art sensors based on superconducting interference devices (SQUIDs). Despite the high sensitivity of about 10^{-15} Tesla/$\sqrt{Hz}$ for detecting magnetic field SQUIDs have to operate at low temperature of 4.2 K. Therefore the use of these bulky and expensive sensors especially for sensor arrays is strongly limited. The integration of ME composites in microelectromechanical systems offers miniaturized low-cost sensors with high sensitivity.

In ME sensors magnetostrictive and piezoelectric layers are mechanically coupled. By applying a magnetic field H the magnetostrictive material changes in length and mediate stress σ to the piezoelectric material, which causes an electrical polarization P in the piezoelectric material. The polarization results in an electrical voltage U, which is proportional to the magnetic field.

The voltage response of the sensor is described by the ME voltage coefficient α_{ME}:

$$\alpha_{ME} = \frac{\delta E}{\delta H}\left[\frac{V}{cmOe}\right]. \qquad [1]$$

Using surface micromachining processes a cantilever beam with a stack of SiO_2/Pt/AlN/FeCoSiB, was fabricated on a 6" Si (100) wafer. The corresponding thicknesses were 0.65 µm, 0.1 µm, 1.0 µm and 2.0 µm. The platinum with a titanium adhesion layer was evaporated while the aluminium nitride and the metallic glass alloy $[(Fe_{90}Co_{10})_{78}Si_{12}B_{10}]$ were prepared by sputtering and forming the magnetoelectric 2-2 composite. A bulk silicon release etch process with XeF_2 was used to create free standing rectangular cantilever beams with a width of 0.2 mm and a length between 0.3 to 1.12 mm (Figure 1). For electrical contacting the FeCoSiB and the Pt bottom electrode were connected to bond pads via gold strip lines.

The characterization of the ME coefficients was done in a setup consisting of two electromagnets. One coil generates a DC magnetic bias field whereas the other coil generate an AC driving field. The device was placed inside the coils and thus both fields were aligned along the long axis of the cantilevers. The bias field shifts the operating point of the magnetostrictive layer to its optimum and maximizes the ME coefficient. A simplified schematic of the measurement setup is shown in figure 2.

The frequency dependency of the ME voltage U_{ME} and ME coefficient α_{ME} of the MEMS ME sensor is shown in figure 3. The ME coefficient at the mechanical resonance is 800 V/cmOe. A static ME coefficient of 11 V/cmOe is calculated using the quality factor of Q=73. Figure 4 shows the ME voltage U_{ME} and ME coefficient α_{ME} in dependency of the applied bias field. The optimum bias field H_{bias} is 10 Oe.

Figure 2: Schematic of the measurement setup

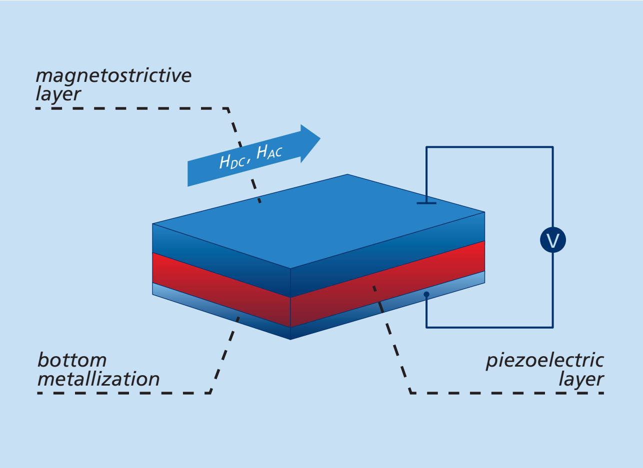
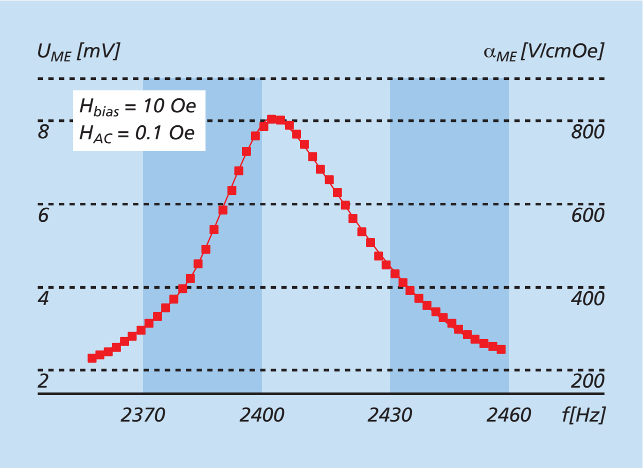


Figure 3: ME voltage and ME coefficient in dependence of the drive frequency



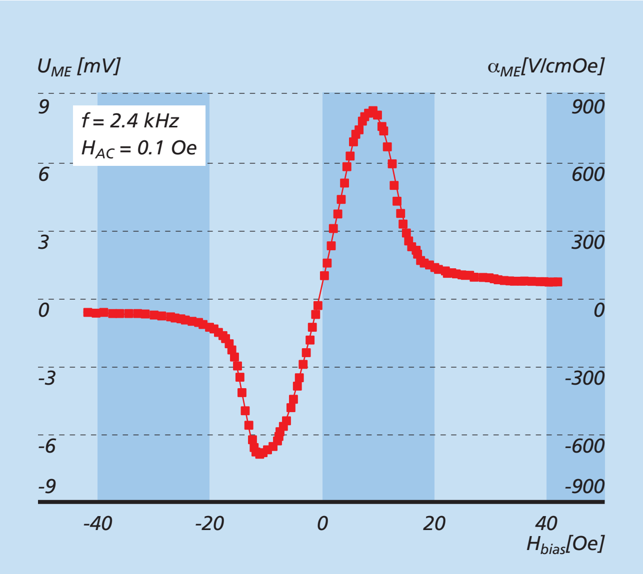


Figure 4: The dependency of the ME voltage and ME coefficient from the applied bias field

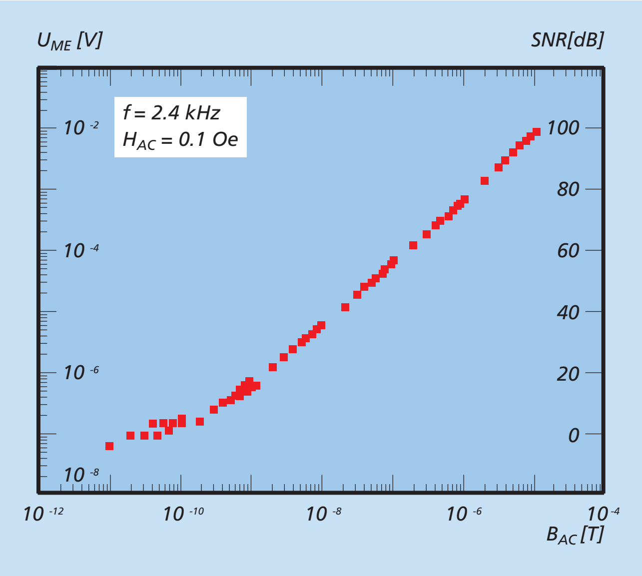


Figure 5: Sensitivity and linearity of the MEMS ME sensor

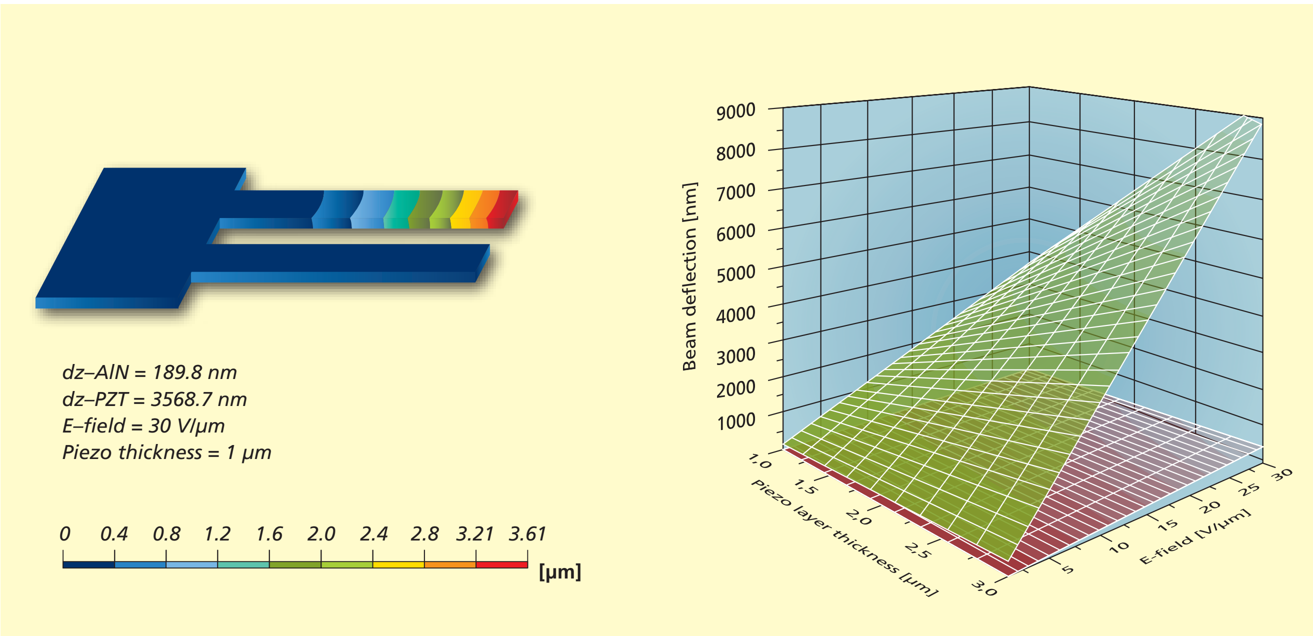
The measured sensitivity curve of the sensor is given in figure 5. The sensor behaves linear down to 100 pT from there on the measured values begin to scatter because of a low signal-to-noise ratio (SNR). The output values no longer depend on the applied magnetic field strength.
The sensitivity of the sensor in resonance is 780 V/T and the static sensitivity is 11 V/T, respectively. The sensitivity will be further increased by vacuum encapsulation of the device. The measured magnetic field noise of the sensor yields to a value of $B_{noise} = 10^{-10}$ Tesla/$\sqrt{Hz}$.

Despite the fact that the investigated micro ME cantilevers beam is significantly smaller than state-of-the-art centimeter sized ME sensors the ME coefficient of 800 V/cmOe, sensitivity of 780 V/T and noise level above 100 pT/$\sqrt{Hz}$ are quite competitive. This shows that MEMS sensors based on ME composites have potential as high sensitivity and high spatial resolution magnetic field sensors.

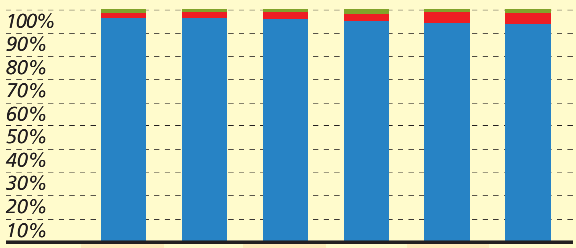
PIEZO- AND FERROELECTRIC THIN FILMS FOR MEMS APPLICATIONS

Optimization and application of piezoelectric thin films for realization of MEMS devices are part of research since several years. Using the inverse piezoelectric effect in MEMS fabricated actuators is the most efficient way to transform electrical in mechanical energy. Compared to aluminium nitride and zinc oxide the large electromechanical coupling coefficient of lead zirconate titanate (PZT) makes it highly attractive for the realization of fast microactuators to generate large forces, momenta and motions (see figure 1) at low power consumption. High quality PZT thin films have been fabricated and integrated successfully into silicon microsystems – but to the present day - in low volume and mostly limited to the area of research. The obstacles to prevalence of MEMS fabricated PZT thin film actuators include integration difficulties into a fabrication process and the material complexity of PZT itself that results in demanding deposition technologies. Nevertheless PZT is, and will remain (see figure 2), the most favourable ferroelectric material. The possibility of depositing PZT thin films directly by a common used MEMS process technology, such as magnetron sputtering, is therefore of great interest. As a future-oriented institution Fraunhofer ISIT already started in 2009 a bi-lateral

Figure 1: Simulated deflections for two similar MEMS fabricated cantilevers with AlN (brown plane) and PZT (green plane) as piezo-actuated active layer



Proportion of materials



	2010	2011	2012	2013	2014	2015
BST	5	7	10	16	16	17
SBT	24	26	29	33	41	58
PZT	851	873	902	946	1060	1188

Ferro electric thin films market forecast by materials

Figure 2: Predicted application of ferroelectric materials [E. Mounier, Yole Developpement, piezoMEMS workshop 2011]

EU project "piezoVolume"

For most small and medium sized enterprises a PZT deposition process is restricted by throughput and cost due to time-consuming manual deposition. Other global operating companies are using proprietary processes for the deposition of piezoelectric PZT thin films and there exist no open piezoelectric MEMS (piezoMEMS) foundries to date. Therefore tools for higher volumes of PZT thin films at lower costs are now requested by industry.

The EU project "piezoVolume" (grant agreement n° 229196) will develop these tools as well as processes allowing to fabricate piezoMEMS cost-effectively and with high throughput. Moreover the concept of "piezoVolume" is to cover the complete microfabrication process including design guidelines, modelling and simulation for piezoMEMS, procedures, production tools and fabrication as well as testing.

project with OC Oerlikon Balzers Ltd., a globally leading company in the field of advanced thin film vacuum deposition systems, and laid the foundation for a new application field Fraunhofer ISIT is now able to operate in.
In close collaboration with Oerlikon, Fraunhofer ISIT developed an in-situ magnetron sputtering process for piezoelectric PZT thin films on 6" wafers on a prototype PVD module for an already at Fraunhofer ISIT existing Clusterline CLN200 sputtering tool.

Figure 3: Participants of EU project "piezoVolume"

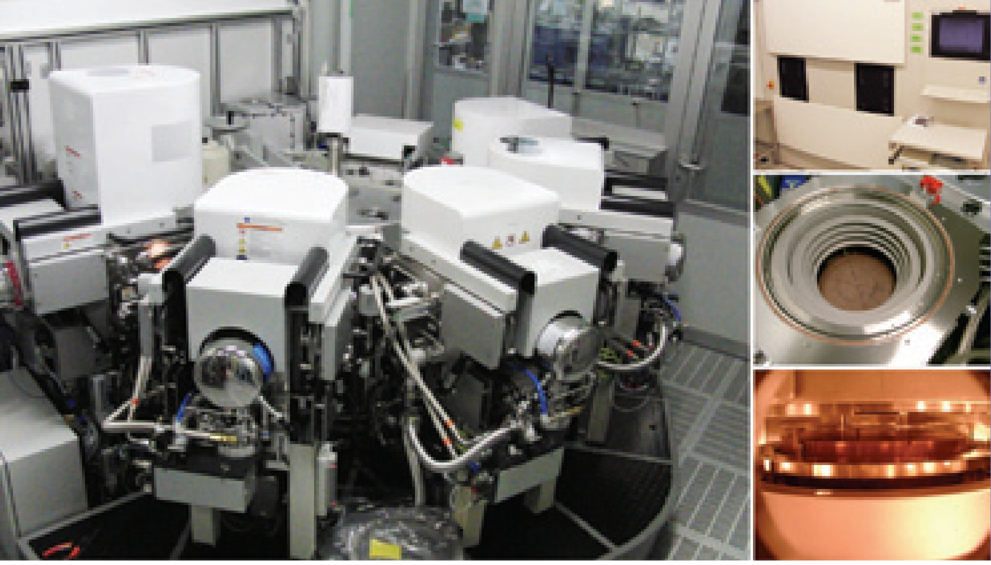


Figure 4: Clusterline CLN200 sputtering tool with auxiliary stations for substrate alignment, degassing and cooling and five process modules for soft etching and deposition of molybdenum (Mo), aluminum-copper (AlCu), aluminum nitride (AlN) and lead zirconate titanate (PZT)

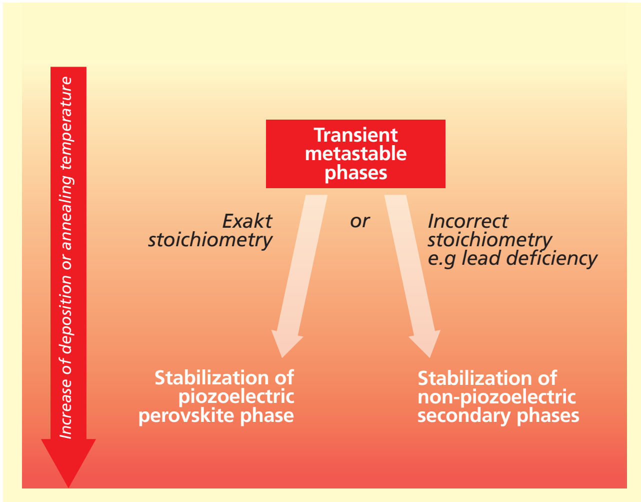


Figure 5: Growth mechanism of lead zirconate titanate films

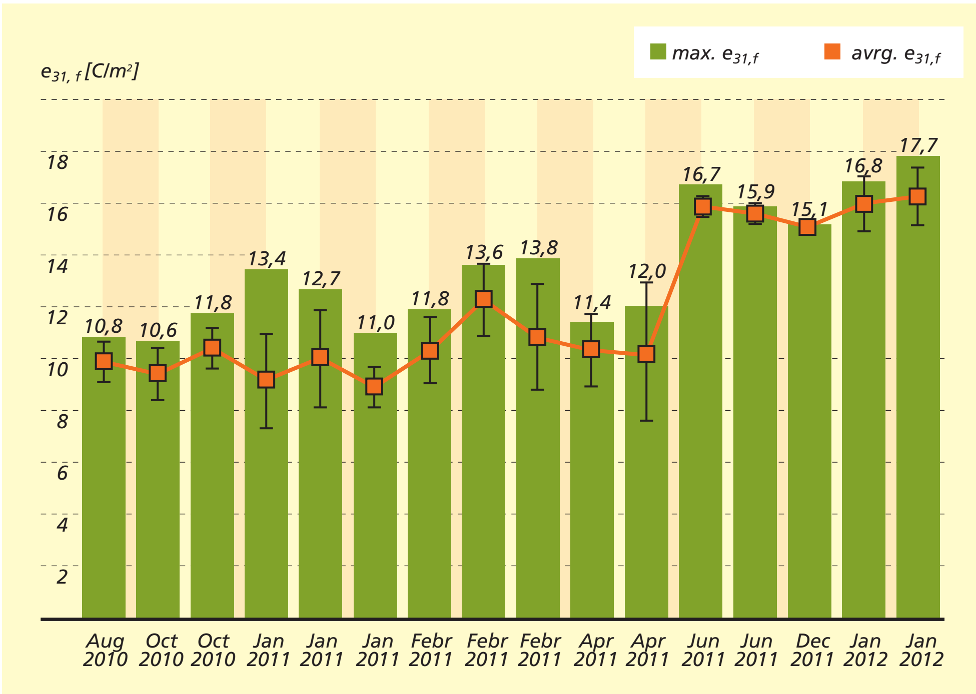


Figure 6: Evolution of the transversal piezoelectric module $e_{31,f}$ for PZT thin films sputtered on Fraunhofer ISIT's Clusterline CLN200

The participation in the project "piezoVolume" is the consistent continuation of Fraunhofer ISIT's development work in the field of piezoelectric thin film application in MEMS devices. As one of ten project partners (see figure 3), Fraunhofer ISIT is responsible for the up-scaling of its 6" wafer sputter deposition process to a process convenient for 200 mm wafers. A commercially available cluster sputtering tool (see figure 4) for 8" wafer processing is equipped with a prototype module for PZT sputtering.

This module possesses some particular features necessary for an in-situ growth (i.e. without need of an additional post-annealing treatment) of high quality piezoelectric PZT thin films:

- Maximum RF sputter power up to 5 kW + additional RF bias power supply
- Optimized gas distribution system for high plasma uniformity
- 200mm substrate holder capable of reaching chuck temperatures up to 800 °C with integrated backside gas flow for superior thermal coupling
- Robust 300 mm ceramic target for sputtering at high plasma power

By means of this tool, Fraunhofer ISIT's final objective in "piezoVolume" is to successfully adapt its developed sputter deposition process of optimized and characterized PZT thin films on 200 mm wafers within the duration of the project. This includes uniformity of thickness and piezoelectric properties, optimal target composition, sputtering rate and compositional drift with target lifetime. Furthermore an application note will be established to support marketing for the hardware equipment. These tasks will be performed by Fraunhofer ISIT in close collaboration with Oerlikon.

PZT deposition process

The challenge in the deposition of PZT thin films is their sensitivity to the correct chemical composition. PZT is a solid solution consisting of the elements lead, zirconium and titanium in an oxidized form. Unfortunately, the combination of these elements can result in different phases whereas only one of these phases, the so-called perovskite phase, is piezoelectric [see figure 5]. Particularly lead is highly volatile compared to zirconium and titanium at high temperatures which however are necessary to nucleate and grow the piezoelectric perovskite phase. As a result an in-situ deposition process of piezo-active films is governed by a strong competition between an incoming flux of Pb and/or PbO species and their rate of re-evaporation, and the simultaneous incorporation of Ti and Zr.

Due to the combination of appropriate process parameters such as sputter pressure, sputter power and substrate temperature, the PZT sputtering process developed by Fraunhofer ISIT allows the nucleation and growth of thin films with remarkable piezoelectric, ferroelectric and dielectric properties.

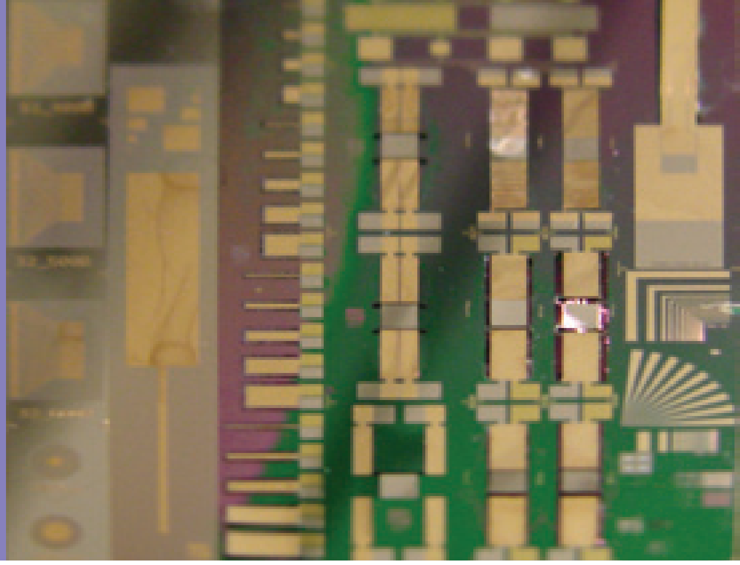


Figure 8: Demonstrator chip with several fabricated piezoMEMS structures

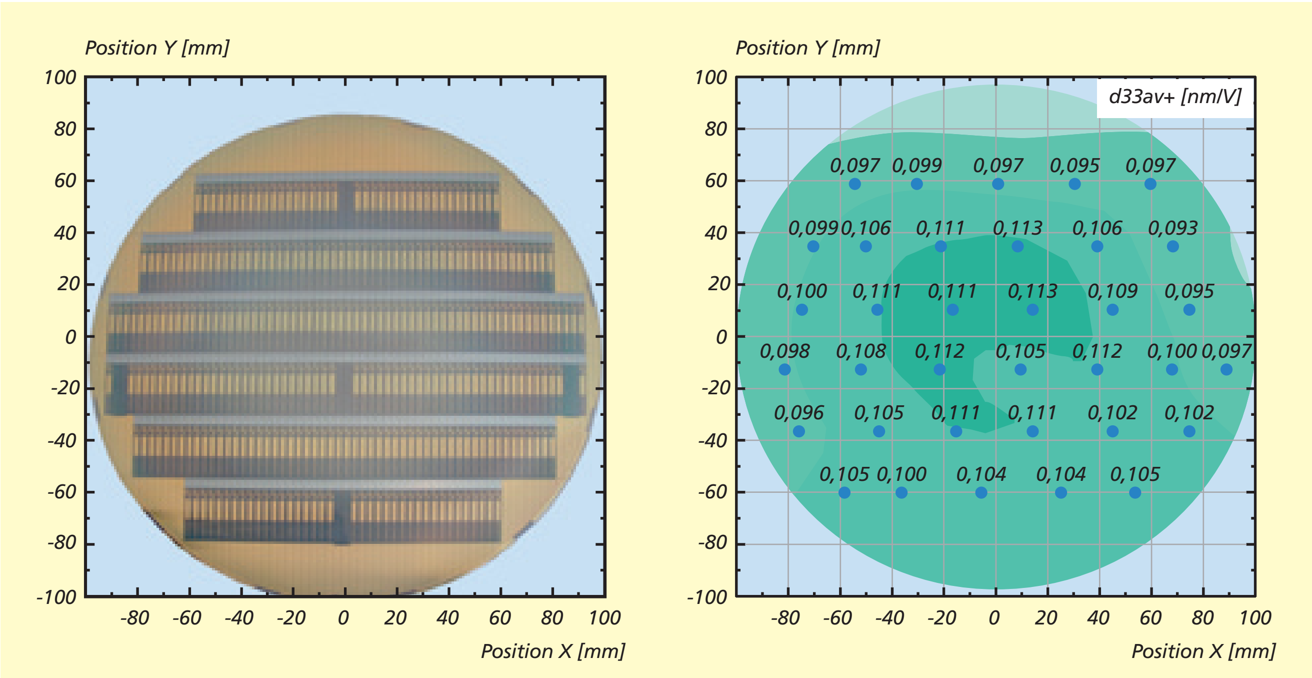


Figure 7: 200 mm wafer for test and characterization of sputter-deposited PZT thin films and a mapping of the longitudinal piezoelectric coefficient $d_{33,f}$

A measure for the piezoelectric activity of thin films are the piezoelectric module $e_{31,f}$ and the piezoelectric coefficient $d_{33,f}$ which describe the transversal and longitudinal piezoelectric response of a film, respectively. In cooperation with CAU Kiel Fraunhofer ISIT has set-up measuring systems from aixACCT Systems to determine both the transversal $e_{31,f}$ and the longitudinal $d_{33,f}$ coefficient of sputtered PZT thin films. Figure 6 and Figure 7 show the evolution of the transversal piezoelectric module $e_{31,f}$ over a certain project period and a wafer mapping of the longitudinal piezoelectric coefficient $d_{33,f}$ of PZT films deposited on a 200mm substrate. The films show piezoelectric coefficients which exceed the values for common used aluminium nitride (AlN) by a factor of more than 15 and 20, respectively.

In addition to the deposition process development work Fraunhofer ISIT continually increased its spectrum which can be offered. Beside the possibility of depositing PZT thin films, Fraunhofer ISIT also works on processes to pattern ferroelectric PZT thin films by wet and dry etching technology and the integration of these films for fabrication of piezoMEMS.

First test structures [see figure 8] and devices for acoustic, RF-MEMS and optical MEMS applications prove the functionality of PZT films deposited by the developed RF magnetron sputtering process.

SI-MICROMACHINED THERMAL FLOW SENSORS: DEVICES, SIMULATIONS AND APPLICATIONS

Thermal flow meters are facing growing opportunities due to the increasing demand for measuring gaseous and fluidic media in process and emission control. Emission monitoring drives the application of thermal flow meters, due to their ability of easy installation by insertion technology and the capability for measuring different gases and fluids. In the following a number of media which are subject of interest is given:

gases	liquids
Methan, Propane, other flammable	Water networks
Argon, Nitrogen, CO_2, other inert	Water drain lines
Oxygene, Ozone	Coolant fluid
Natural gas, flare gas, flue gas	Fuels and fuel oils
Landfill gas, bio gas	Oil and hydraulic fluid

Overview of gaseous and liquid media for flow sensing application

The market for these application will grow substantially in the next 5–10 years. Overall the flow meter technology is dominated by ultrasonic, turbine, differential pressure and magnetic measurement principles. Only a few percent of this market accounts for the thermal principle. Accordingly this system consists of two sensors: a heated sensor and another sensor that measures the temperature of the media. Mass flow is calculated from the effects of cooling of the heater in the downstream. This is currently the main stream technology and fabricated by many vendors all over the world. A typical example is shown in figure 1. Now, in this fast growing market a new technology, Micro-Electro-Mechanical-Systems (MEMS) is emerging. This is made possible by using semiconductor technologies, which fabricate high numbers of ultra small devices on a wafer. Initial costs are high, but high numbers of devices result in low costs for single devices. There are industrial applications (medical, process automation), in which miniaturization by micromachining results in better process performance and higher accuracy at substantial decreased costs at the same time. On the other hand, the cost decrease for a MEMS flow sensor enables an application in a high number in sensor networks. Together with wireless data transmission a wide field of flow monitoring can be entered, for example a completely new overall concept for a municipal water supply network, where it should be possible to detect damage, intrusion or failure and to apply reactions. In general

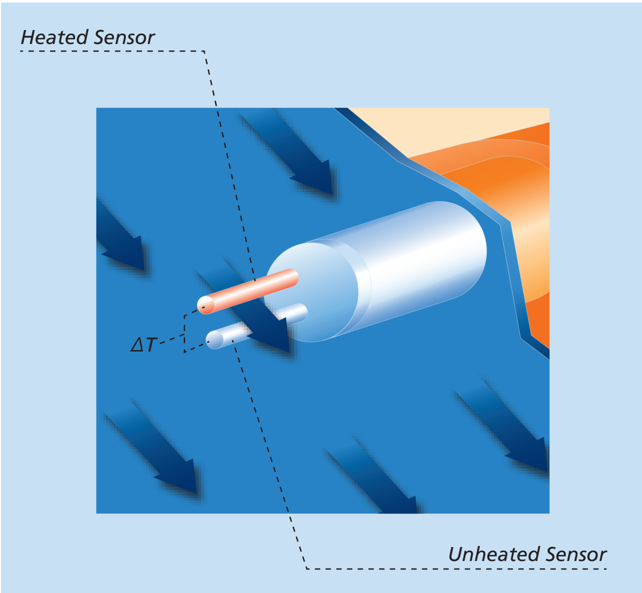


Figure 1: Thermal flow meter. Image courtesy of Fluid Components Intl. LLC

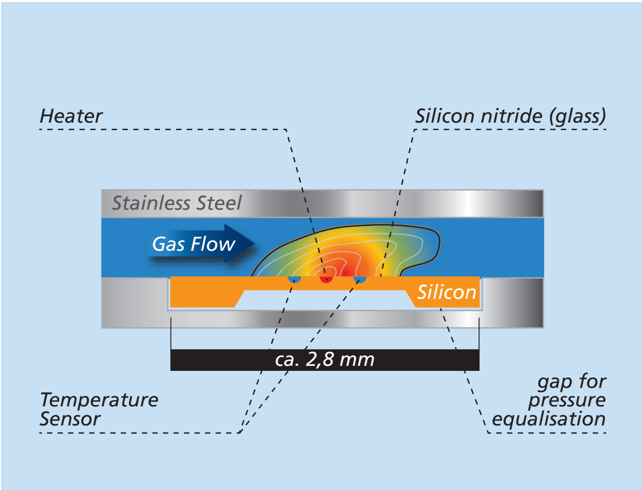


Figure 2: Calorimetric principle, change in temperature profile enables calculation of mass flow

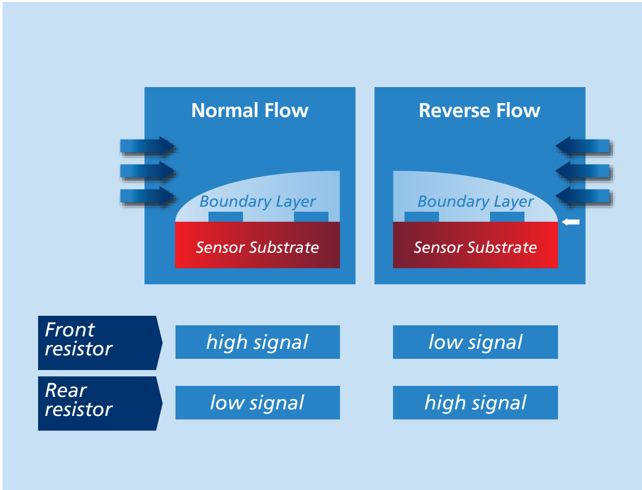


Figure 3: Anemometric principle, from the heat loss of the heater the mass flow is calculated

thermal mass flow sensors are measuring masses instead of volumes and make the signal independent of ambient effects like temperature or pressure. This already results in first applications for smart gas metering. Due to the micromachining technology, thermal mass flow sensors are constituting a membrane technology which result in small thermal masses and short response times which makes pulsed measurement techniques possible.

Technology

Principles of operating:

Anemometric vs calorimetric measuring principle

For the above mentioned reasons all micromechanical thermal mass flow sensors are containing the measuring elements on membranes. The principles of thermal mass flow measurements are based on the heat transfer from a heated wire to the adjacent media. Many different solutions exist, but in general two different measurement technologies can be described. In the calorimetric principle, a heated sensor is located between two temperature sensors (resistors or thermopiles). In the noflow case the temperature profile is symmetrical, in the flow case this profile becomes asymmetric (see figure 2). From this change the mass flow can be calculated and the direction can be read out.
The anemometric measurement configuration reported here and shown in figure 3 is based on the heat loss of a heated wire. For the recognition of the directionality these wires are located twice one behind another. Due to the warming of

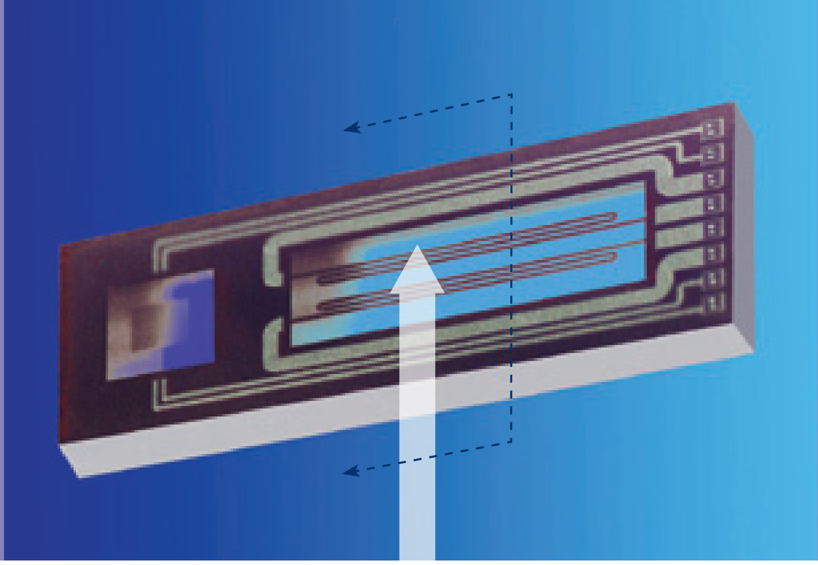


Figure 4: Micromachined thermal mass flow sensor

the medium at the first heater, the second one is cooled less. The cooling conditions for both heaters are different. From this difference in temperature or resistance the mass flow and direction can be calculated. If sensors for the measurement of ambient temperature are included and a constant temperature is applied using a Wheatstone bridge configuration, the resulting difference signal is nearly independent of the environmental temperature. An example of this sensor is shown in figure 4. The left membrane contains high ohmic reference sensors for the measurement of the ambient temperature. The right membrane contains the two heater resistors for the measurement of media flow, indicated by the arrow. The cross section shown in figure 5 and 7 is indicated by the dashed lines. In the case of static heat transfer from the heater to the ambient, the electrical power I^2Rw is equal to the heat loss

$$I^2Rw = h\,A\,(T_w - T_a) \qquad [1]$$

with

h = film coefficient of heat transfer, A = heat transfer area

h considers essentially the heat transfer through the boundary layer to the bulk of the stream of gas or fluid. The indices w and a are standing for wire and ambient. No analytical comprehensive solution exists: These media-specific transitions result in distinguishable curves in the Kings Law.

$$I^2R_W{}^2 = U^2 = (T_W - T_a)\,(A + B \cdot v^n) \qquad \text{“King's law” [2]}$$

The voltage drop (U) is used as a measure of velocity (v). A, B and n are empirical gas- and system-specific constants. For gaseous media the measurement of different gases is easy using a calibration routine. In figure 5 a simulation using COMSOL software is shown, demonstrating the different behaviour of gaseous (left) and liquid (right) media. The measurement of liquid media is much more difficult and has been demonstrated at ISIT only for clean water.

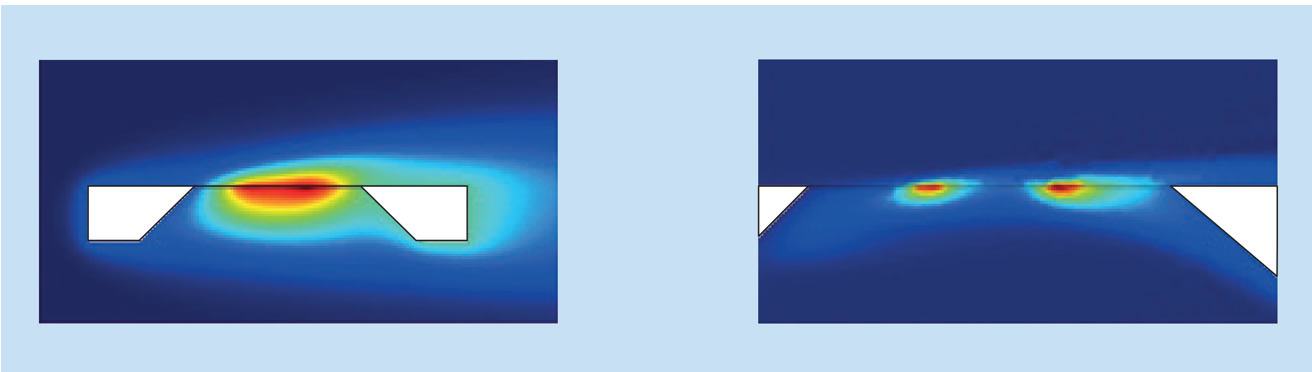


Figure 5: Cross-section through mass flow sensors in an air stream (left) and water flow (right)

Features of processing

The material for the heater can be chosen out of a variety of materials, for example tungsten, nickel, platinum or as shown here, titanium. The choice depends on the temperature coefficient of the resistance of the material and the compatibility with an available process flow. We have chosen titanium which was embedded in TiN for passivation reasons. Titanium is very reactive with adjacend media especially under elevated temperatures, TiN with thicknesses in the nanometer range is effectively hindering Ti diffusion reactions.

The Ti/TiN-formation is a sputter process which parent processes are used in a MOS semiconductor fabrication line for the production of modern PowerMOS devices on 8 inch wafers. The temperature dependence of this material for the heating-resistance is 3700 ppm/K. A characteristic dependence of the resistance R[Ohm] on the temperature T[°C] is given in figure 6. For the choice of the membrane several opportunities are available, being almost dependent on the technological capabilities of the silicon-processing line. A silicon-oxynitride deposited in a PECVD reactor, an off-stoichiometric silicon-nitride in an LPCVD reactor or a multilayer of CVD films are mostly used. We have chosen a combination of silicon-nitride, -oxide and -nitride. After anisotropic etch all these membrane layers show a slightly tensile stress. A cross section of the sensor is given in figure 7. The multilayer system of 1 µm thickness carries the heater/reference resistors and is subsequently covered with a passivation layer of siliconnitride. This layer is deposited in a PECVD system and is widely inert against most environmental detrimental effects and is also biocompatible. The anisotropic wet etch process was done in KOH solution under elevated temperature. Wet etch processes in TMAH or deep reactive dry etching can also be considered.

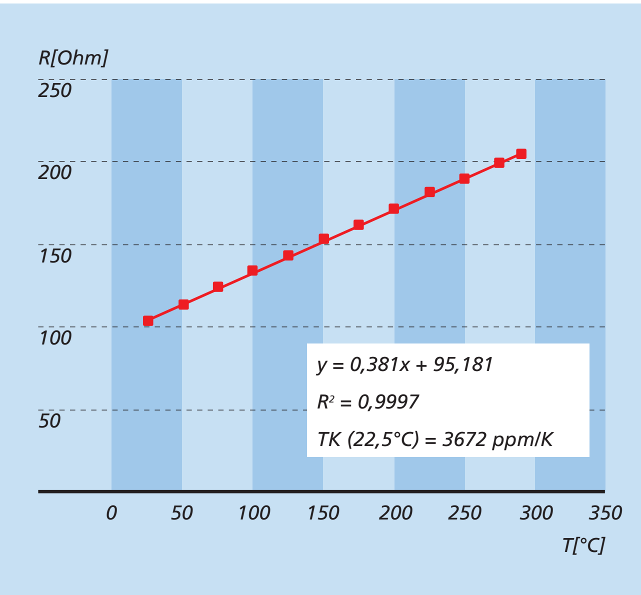


Figure 6: Dependence of the resistor R[Ohm] as a function of T [°C]

Simulation

A thermal resistance network (see figure 8) enables modelling of the mass flow sensor. The sensor is idealised by nodes and resistors. Nodes are "volume elements", typically with high heat conductivity, i.e. with small temperature gradients. Resistors are the heat conducting paths of solid material, with appropriate length, cross section, and heat conductivity assigned, or the given surfaces with an estimated heat transfer coefficient. With small adjustments, the model results agree well with measurements. A formula from boundary layer theory has been used which takes into account the fluid flow boundary layer of a plate with heater at a given distance from the plate's starting edge. This has been combined with a formula to calculate the heat transfer due to buoyancy in still fluids.

A model calculation was performed for the application in air and in water, the results are shown in figure 9. For the

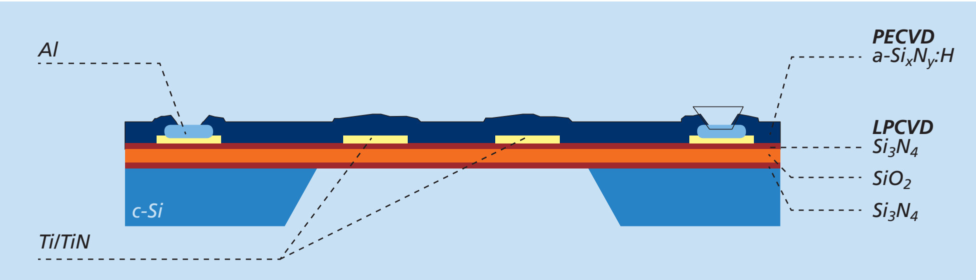


Figure 7: Cross-section of the flow sensor

application in water, the backside cavity was filled with polydimethylsiloxan (PDMS) to assure a distinct signal from the front side of the sensor. For air, we found a steadily increasing difference signal, indicating that the difference of the two signals can be used for calculation of mass flow. In water, first an increasing, then a decreasing difference signal is observed. From this simulation the difference of the signals can be used for mass flow calculation for gases. For water this is only possible for low flow rates. For higher flow rates the signal change from one heater has to be used, for the recognition of the directionality the second heater can be switched on and by comparison the direction can be concluded.

Additionally the response for different gaseous media was calculated from this model. We found that the response for air, nitrogen and argon is very similar, but is different for hydrogen and helium The gas velocity appears to be 4 times higher to generate a similar signal response than the "heavy" gases, this is showing the effect of different heat capacities and heat transfer through the boundary layer. This is a clear demonstration of the ability of such a system to measure different gases and even gas mixtures. However, appropriate signal evaluation systems and calibration routines have to be applied.

Signal detection

A sketch of the principle measurement set up is shown in figure 10. It shows two Wheatstone bridges, whereby the gray indicated resistors are contained on the sensor device. The other elements are part of an external circuit and are located on a small board within the applied system. This evaluation

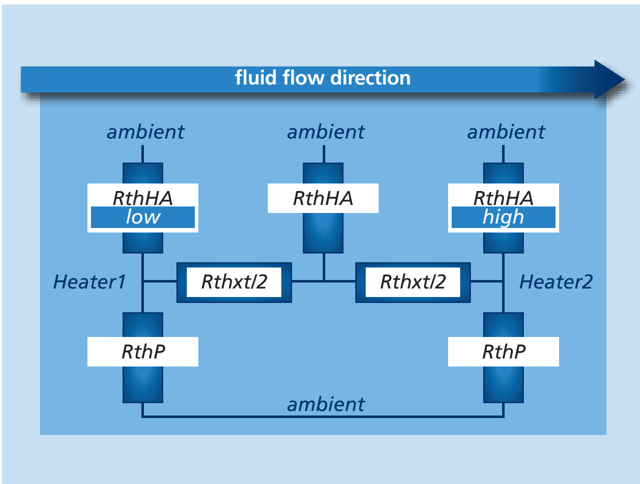


Figure 8: Thermal resistance network. Rth: thermal resistances, RthHA: heat transfer to fluid, RthP: heat conduction through package (membrane, die, PCB) to ambient, Rthxt: thermal "cross talk" heat conduction, Heater 1 and 2: heating resistors

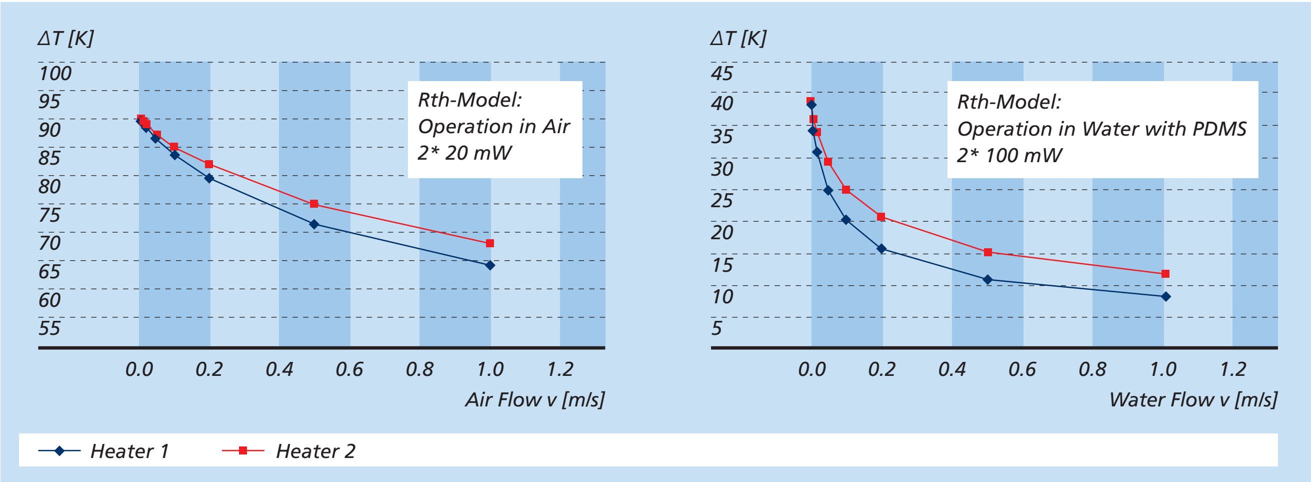


Figure 9: Temperature-change as a function of flow speed in air (left) and water (right)

circuit is driven at constant temperature mode and the current respectively the voltage difference can be used for mass flow calculation. In the case of water measurements only one circuit may be used, the other one is for comparison for the detection of the flow direction.

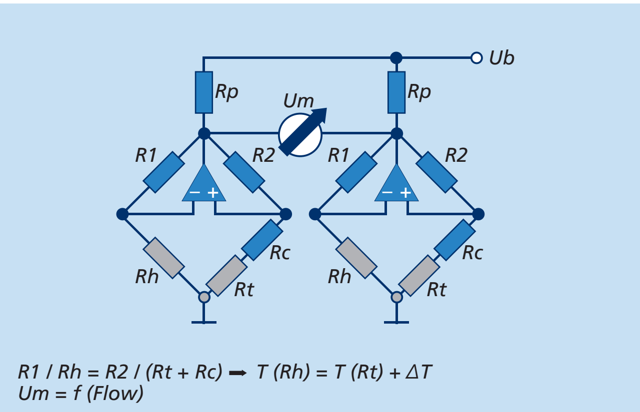


Figure 10: Principle measurement set up. R1, R2: trimming resistors, Rt: temperature resistors, Rh: heating resistors, Rc: compensation resistors, Rp: pull up resistors, Ub: supply voltage, Um: measurement voltage

Application in air

We have performed measurements in air in a demonstration set up in our laboratory. We measured the change in resistor under flow, the difference of the change in both resistors is displayed on the y-coordinate as a function of negative and positive flow in velocity units in figure 11, left. Also a curve from a commercial system is shown in figure 11, right. Here the signal evaluation was performed using the constant temperature mode under employment of two Wheatstone bridges. The difference of the voltages of the two bridges is displayed as a function of air flow in slpm (standard litre per minute). In both cases a symmetrical flow for both directions can be demonstrated. The performance of the microsensor system has been demonstrated for various gases.

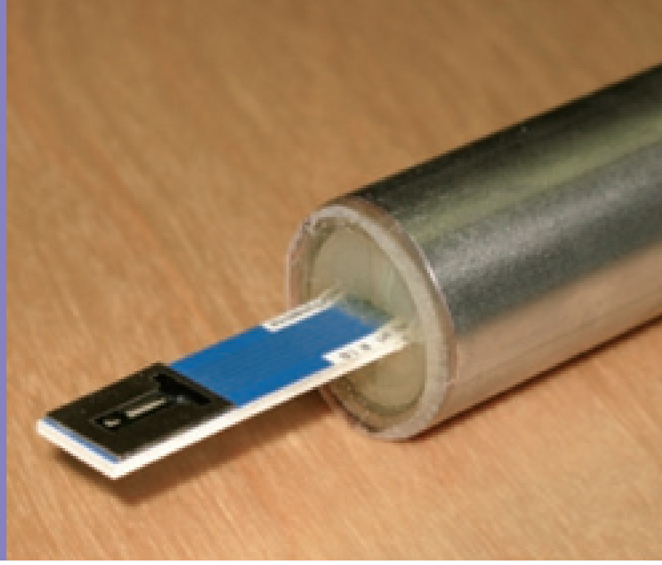
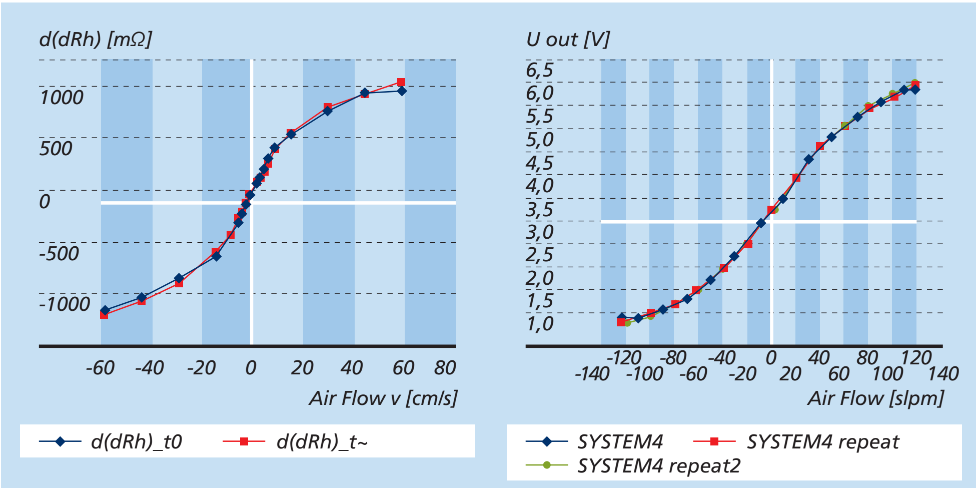


Figure 13: Sensor set up on ceramic in a steel pipe

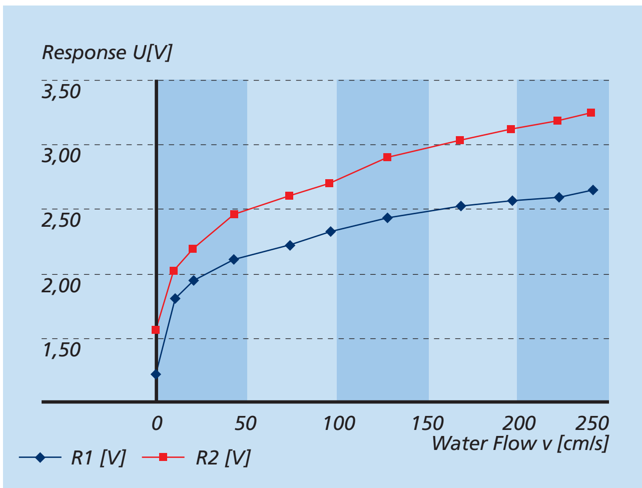
Figure 11: Signal response as a function of flow for a demonstration set-up (left) and for a commercial system (right)



Application in water

Flow measurements in water have been performed to cover a typical range of flow speed for a water station ranging from 0 to 250 cm/s with pressure variance from 0 to 3 bar with peaks of 7 bar. A typical result for both heaters is given in figure 12. Here the response of each Wheatstone bridge U[V] is given as a function of the waterflow v [m/s]. The appearance of bubbles and deposits, which disturb the signal, can be prevented by applying pulsed measurement techniques. The setup mounted in a stainless steel pipe, shown in figure 13, contains batteries, evaluation electronics and a mini USB connector. In future it should be equipped with a data logger and wireless communication (GSM) module. These water flow sensors can be autonomous, smart and optimized to environmental conditions. A network of such sensors can communicate with each other and constitute a “swarm intelligence”. The data from this network enable a fast recognition of intrusions, if presented in an appropriate way: Visual Analytics is such a new discipline, which connects an automatic data analysis with new techniques of visualization.

Figure12: Signal response U[V] as a function of flow speed v[cm/s] in water for both heaters



DEVELOPMENT OF AN AUTONOMOUS NINE DEGREES OF FREEDOM SENSOR MODULE FOR POSITION AND ORIENTATION IDENTIFICATION (9D SENSE)

Nowadays sensors find their way in many different applications in our daily lives and make the use of many electronic products much more versatile, easier and smarter. Many new applications in the field of medical technology, safety technology and consumer electronics markets looking for intelligent sensor systems, especially in terms of size, quality and power consumption. In order to fulfill in the future these requirements of specific applications, the joint project „9D-sense" has the goal of developing a cost-effective and energy-independent multi-sensor system of small size, which consists of a sensor module for three parameters (angular rate, acceleration, magenic field), a power supply unit with thin film batteries and energy harvester and a secure wireless data transmission.

To achieve these objectives 11 partners from 4 countries work together within a joint project. In this framework, the Robert Bosch GmbH, the Fraunhofer Institute for Silicon Technology (Fraunhofer ISIT), the Institute for Micro Technology and Information Technology of the Hahn-Schickard Society (HSG-IMIT) and Austria Microsystems (Austria) develop technologies for the sensor system. The development of the energy supply unit is done by Robert Bosch GmbH together with the Technical University of Darmstadt. The University of Helsinki (Finland) and Air Liquide (France) are working on a thin film battery. The partners Micropelt and HSG-IMIT are developing harvester systems. As end-users Gemalto (France), Otto Bock HealthCare and Bosch Sensortec manage demonstrators in focusing on security technology, medical

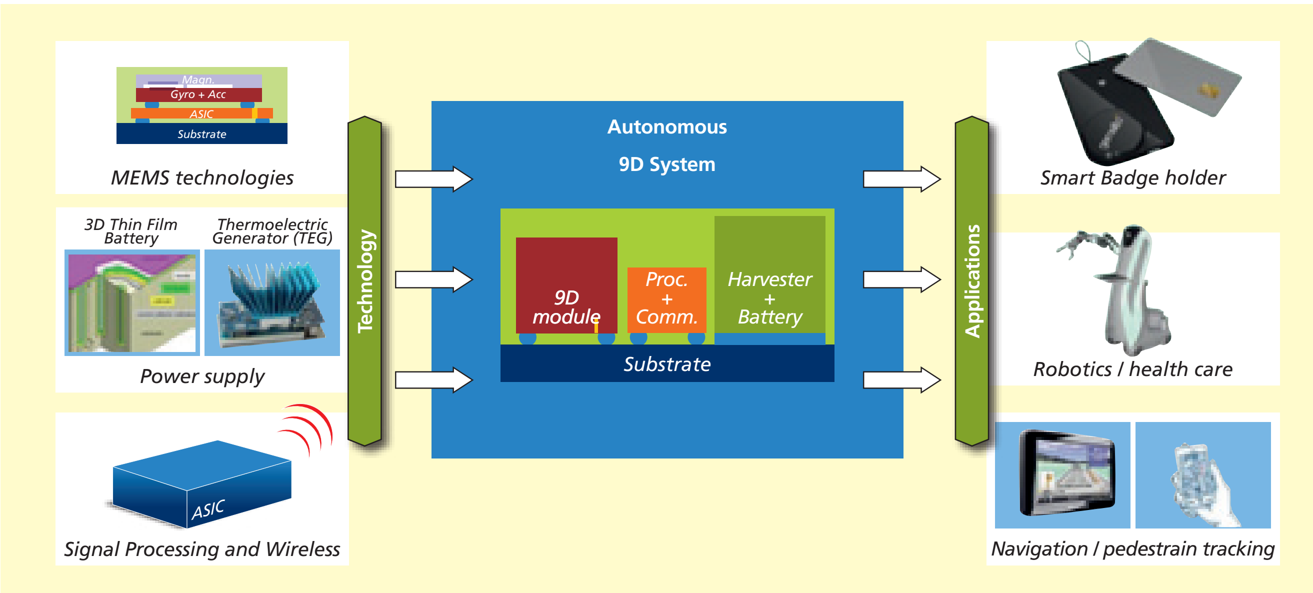


Figure 1: Project overview: Technology (left) and application topics (right) addressed in 9D Sense

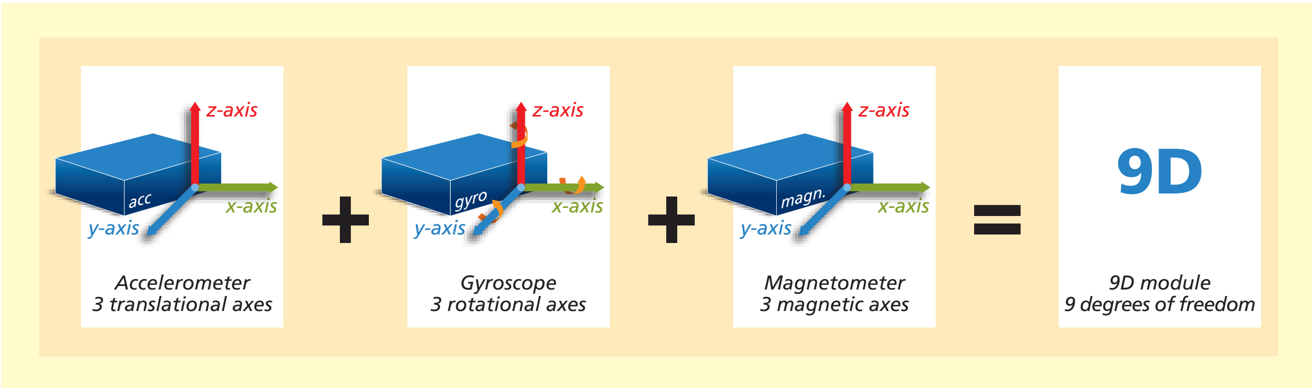


Figure 2: Distribution of 9D system, consisting of 3-axis accelerometer, gyroscope and magnetometer

technology and navigation. Together, the European consortium was able to apply successfully in CATRENE (Cluster for Application and Technology Research in Europe on NanoElectronics) 3rd call. The project started in November 2011 with a maturity of 3 years and is funded with about € 6 million Euros from the BMBF for the German partners.

The project 9D-Sense aims at an autonomous integrated 9 degrees of freedom sensing module and will therefore develop technologies for sensing, energy harvesting, energy storage and wireless communication. This small-sized and heterogeneous integrated system is addressed to enable cost competitive solutions in the fields of consumer and health care applications (figure 1). The 9D sensing system consists of a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis magnetometer all of them are based on Silicon wafer technology (figure 2). Extreme energy efficient technologies will be developed and applied. Central goal is building prototypes of the sensing system as well as their testing and proof of functionality in dedicated application environments. Besides functional requirements of specific applications, market relevance and acceptance is mainly cost driven. Therefore, future markets aim for high integration of diverse sensors and systems on minimum chip and package size. These demands result in the following technological challenges and targets 9D Sense is going to deal with:

- integration of the micro sensors on a single chip or in a single package to achieve a footprint area smaller than 5x5 mm². To reach this goal new wafer and packaging technologies, like 3D integration need to be developed.
- development of high capacity thin film battery, capable of being integrated e.g. on a MEMS or ASIC chip.
- development of energy efficient thermo electrical generator, capable of converting small amounts of thermal energy, e.g. body heat in semi-clinical applications.
- wireless data transmission technology.
- efficient power management/ low power technology.
- integration of the heterogeneous system in one small package.

The Fraunhofer ISIT works on multiple objectives in the joint project „9D Sense“, which will be processed in parallel in the three-year project period. The focus is on the following scientific and technical tasks:

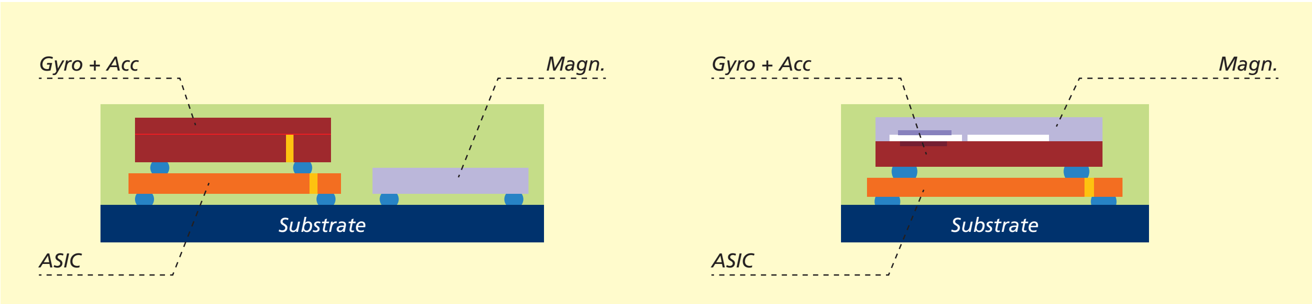


Figure 3: Concepts for on-chip integrated accelerometer + gyroscope in a module package together with an ASIC and magnetometer (left: magnetometer side by side, right: magnetometer as cap)

Magnetometer

A compass for the earth magnetic field requires 3D measurements of the rather weak earth's magnetic field which is in the range of 30 to 60 µT. The field direction should be measured with an accuracy of better than 1°. Fraunhofer ISIT will develop a 3D MEMS magnetometer based on Lorentz-force. This concept is based on a micromechanical structure which is deflected if an external magnetic field is applied. Goal is the development of an efficient MEMS-based magnetic field sensor, which uses at Fraunhofer ISIT and Bosch existing technologies for the manufacturing of accelerometers and gyroscopes as a basis to ensure a possible on-chip integration. The magnetic sensor is manufactured in the first phase of the project as an autonomous component for integration at the package level. In the second phase of the magnetic field sensor will be designed as an active cap for single-chip integration with acceleration and angular rate sensor (see figure 3).

Through-Silicon-Vias for MEMS to MEMS Wafer Stacking

Through-Silicon-Vias (TSV) are the basic elements of 3D integration of heterogeneous MEMS device clusters. Figure 4 shows the basic elements which a TSV tool box has to fulfill. Based on the concept of MEMS wafer preparation MEMS wafer stacking by using the standardized interface will be very easy and reliable. Fraunhofer ISIT will investigate such a TSV concept with respect to the sensor module concept and specification, especially the development of technology modules for vertical electrical and mechanical connection on wafer-level for MEMS sensors based on metal-filled vias. Fraunhofer ISIT will focus on technologies like silicon DRIE, side wall passivation and metallisation, trench filling, electroplating and bonding techniques. This process tool box will be completed by a redistribution-wiring module.
These technologies have to be compatible with the bonding and bumping technologies described below.

Bonding Technology for Vacuum WLP

A reliable packaging is one of the key requirements on the way to commercial MEMS products. In many cases it must be hermetic to ensure a long lifetime of the device. It should be small and cheap. At the same time it must be strong enough to withstand common operational and post processing demands. At Fraunhofer ISIT the emphasis will be on innovative wafer-to wafer bonding techniques using narrow-width metallic sealing layers. Several process options are available. Beside Au-Sn solder bonding at about 300°C and CuSn with a bonding temperature at about 250°C Transient Liquid Phase (TLP) bonding is a further advanced type of solder bond technology that can form high-quality hermetic

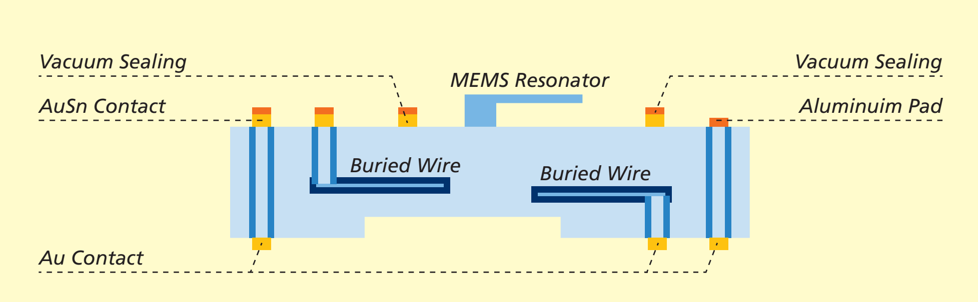


Figure 4: Basic elements of a MEMS to MEMS TSV tool box

Material System	Bonding Process	Remelt Temp.
Copper - Tin	4 min at 280 °C	> 415 °C
Gold - Tin	15 min at 260 °C	> 278 °C
Gold - Indium	0.5 min at 200 °C	> 495 °C
Nickel - Tin	6 min at 300 °C	> 400 °C

Table 1: TLP Bond results reported in the literature adapted from:

[1] C. C. Lee, et Al „A new gold-indium eutectic bonding method," in EPMS VI, 1992, pp. 305-10

[2] W.C. Welch III and K. Najafi, "Nickel-Tin Transient Liquid Phase (TLP) Bonding for MEMS Vacuum Packaging," Transducers '07, Lyon, France, June 2007

[3] G. Humpston, Principles of Soldering. Materials Park, OH: ASM International, 2004, pp. xii, 271

seals at low temperature. TLP bonded wafers can survive temperatures much higher than the formation temperature (see table 1),. Aside from robust thermal performance, TLP bonds can be formed with low cost processes and can seal non-planar surfaces during bonding; this last feature makes them an attractive choice for applications requiring lateral feed throughs. Fraunhofer ISIT will explore this technology with respect to its application to wafer level packaging of inertial sensors, which needs reduced pressure in cavity.

Fine Pitch Bumping for Chip to Chip Connection

Wire bonding is an effective but size consuming technology to realize first electrically functional demonstrators and to get first electrical measurements knowing that the wire bonds might deteriorate the sensor performance with respect to parasitic capacitances. Advanced interconnect technologies like flip chip technology will be used to realize ultra-compact modules with a significantly reduced pitch (even below 150 µm) for contact pads. For such small interconnect dimensions, an innovative bump technology has to be provided. Electroplated Cu pillars as an interconnect technology will be investigated. As soon as a TSV technology for MEMS (see above) is available, this interconnect technology can be used to mount the MEMS dies directly on other MEMS or on the substrate. The principle process sequence for electroplated pillars Fraunhofer ISIT will apply in the project begins with the sputter deposition of a seed layer and a subsequent lithography process for a thick photo resist. After galvanic growth of e.g. Cu and Sn the photo resist is removed as well as the exposed seed layer by ion milling or wet chemical etching. Challenging for this process development is the compatibility with the former process steps and the need not to deteriorate the performance of TSVs and WLP.

The above work packages are closely related to the work packages of project partner Bosch and the respective schedules are synchronized.

EPAMO – A NEW EUROPEAN RESEARCH PROJECT ON RF-MEMS FOR MOBILE COMMUNICATION

In April Fraunhofer ISIT has started a new European research project as a partner of the EPAMO consortium lead by EPCOS AG Munich. The ENIAC project is entitled "Energy-Efficient Piezo-MEMS Tunable RF Front-End Antenna Systems for Mobile Devices".

Current and future wireless communication systems need to cope with the increased number of frequency bands and advanced mobile phone standards like LTE supporting high data rates. At the same time mobile phone systems have to become more energy efficient in order to contribute to the Grand Challenge "CO_2-reduction". One major limitation of today's mobile phones is the poor impedance matching of the antenna to the RF-front-end section of the mobile phone leading to overall poor antenna efficiency.

Different user cases (e.g. shielding of RF radiation by hand / head / environment effects, e.g. usage of mobile phone in a car), a strong miniaturization need in form factors of antenna systems, and the increase in frequency spectrum to be covered by the antenna system (700 to 2600 MHz later up to 3600 MHz) result in an overall poor energy efficiency of today's RF-sections of mobile phone systems, lead to a significant number of dropped calls, and limit the overall capacity of mobile phone networks with respect to the number of users and / or data volume to be transmitted.

In addition the ongoing trend towards higher miniaturization and integration is an ever increasing challenge in the design of complex RF systems e.g. due to critical RF interaction on signal lines. By introducing tunable RF elements, the overall system architecture can be simplified leading also to a significant cost reduction for future RF-systems. Therefore the development of tunable RF components is a key enabler for future highly advanced RF systems and essential to strengthen the leading position of the European RF-community and industry in the worldwide competition.

The EPAMO project will address the four main challenges of providing future high performance RF-systems, energy efficient mobile communication systems, highly miniaturized and integrated RF components, and cost efficient solutions to the mobile phone industry by exploring and implementing multiple innovative process and testing technologies to realize an adaptive antenna front-end system for 4G mobile phones. Due to closed-loop antenna tuning the radio power levels can be reduced in the mobile phone by more than 50%, in the base stations a saving of at least 10% is possible. Knowing that the data volume will continuously increase, the EPAMO project will help to utilize the installed mobile phone infrastructure in a more efficient way and to reduce the number of new base stations to be installed to cover the future data traffic. In total it is estimated that the implementation of this technology has a global energy-saving potential of more than 10.000 GWh per year referred to a constant data volume to be transmitted.

EPAMO has the objective to explore the potential of unprecedented ultra-high density RF-MEMS switch arrays to be integrated in an energy-efficient agile RF transceiver with reconfigurable antenna. Compared to today's approaches for RF-MEMS switches utilizing electrostatic actuation, key cross-cutting More-than-Moore and heterogeneous integration technologies are high-force piezoelectric MEMS actuators based on Lead Zirconate Titanate (PZT) thin films, high reliability metallic contact switches, and low-loss silicon and composite glass-silicon 8" wafer substrates. With this technology it will be possible to realize galvanic switches

compared to today's capacitive switches extending the application field for RF-MEMS switches significantly.
Fine pitch through-wafer vias will allow a high-density 3D system integration in ultra-small RF module substrates with integrated components. The project covers the whole development process including simulation / modeling, design and layout, material development, process technology development, device measurement and evaluation, and reliability / quality testing. Tests will be performed on wafer level, on component level, on module level, and on system level.

In this ambitious R&D project Fraunhofer ISIT will focus on the development of a high-density RF-MEMS (Radio-Frequency Micro-Electro-Mechanical Systems) switch array to be integrated in the reconfigurable antenna module. As described elsewhere in this annual report, during the last years ISIT has developed a magnetron sputtering technology for thinfilm PZT layers with high piezoelectric coefficients. The challenges in EPAMO will be to implement this process step into a complex surface micromachining technology and moreover to design and fabricate ohmic RF-MEMS switches with high contact forces, high speed and low power consumption. To meet the long-term reliability specifications the work plan also addresses also the integration of durable contact materials and advanced waferlevel packaging technologies.

EPAMO is funded in the framework of the ENIAC Joint Undertaking (JU), a European public-private partnership focusing on nanoelectronics. EPAMO gathers the competences from 16 partners: Epcos AG (Munich), Fraunhofer ISIT (Itzehoe), Fraunhofer IZM (Oberpfaffenhofen), EPCOS Netherlands B.V. (NL), VTT - Technical Research Centre of Finland, Silex Microsystems AB (SE), Boschman Technologies B.V. (NL), Picosun Oy (FI), Plan Optik AG (Elsoff), Okmetic Oyj (FI), University of Twente (NL), Christian-Albrechts-Universität (Kiel), SolMateS B.V. (NL), aixACCT Systems GmbH (Aachen), TNO (NL) and MASER Engineering B.V. (NL).

The project runs from April 2011 till March 2014 and has an overall budget of 13.3 Mio Euros. The Fraunhofer Society will receive a funding of 1.45 Mio Euros of which 83.3 % is funded from the German Federal Ministry of Education and Research (BMBF) and 16.7 % from the ENIAC JU.

eniac
JOINT UNDERTAKING
EPAMO

HIGH THROUGHPUT OPTIMIZATION OF MEMS WAFERLEVEL-ENDTEST BY USING FPGA-MODULES

Since many years the Fraunhofer Institute for Silicon Technology ISIT is engaged in the continuous miniaturisation of many kinds of mechanical sensors and actuators.
The base technology used is the so called surface micro machining technology on silicon wafers, where the principle steps are shown in figure 1.

Based on this technology the partners from MAXIM, formerly SensorDynamics AG are producing inertial sensors i.e. accelerometers and gyroscopes for the automotive industry and consumer applications. Due to the constantly falling cost of production and therefore prices for these products, many new applications arose. The consumer market shows many interesting areas like picture stabilisation in cameras, virtual reality systems, computer control inputs and bluetooth applications.

Actual sensors have a dimension of only 2 mm by 3 mm, that results in an amount of roughly 3400 sensors on a wafer with 200mm diameter. These wafers have to be tested after the last step of production to check various characteristic parameters of each device. As an example the function of a gyroscope, see figure 2, is mainly defined by its resonance frequency for the different spatial axes. Additional tests measure the cross coupling effects and the quality factor of the resonances. Finally each sensor will be tested to find leakage currents with an accuracy down to 1nA.

A complete test can take up to 20 seconds, depending on the amount of spatial axes of the individual inertial sensor.
The maximum effort of the test system is reached by so called 6D-inertial measurement unit (6D-IMU), i.e. a 3D-accelerometers as well as 3D-gyroscope integrated on single die. For the measurement of all necessary parameters the following hardware demands are:

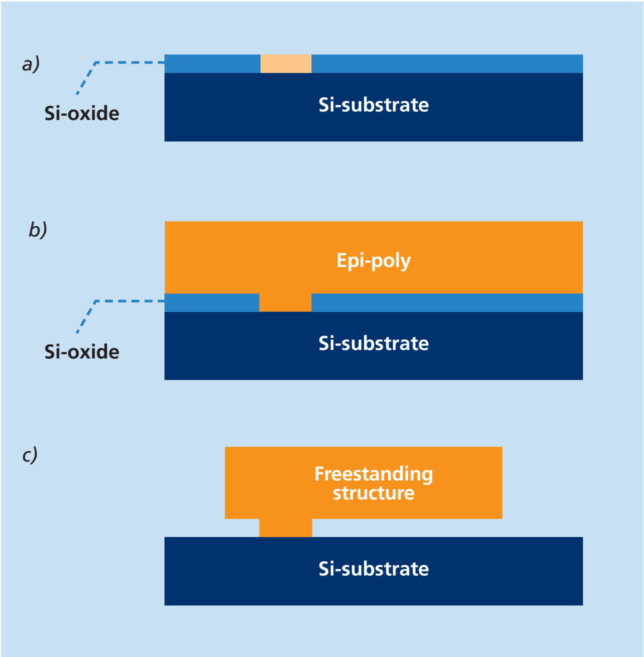


Figure 1: Schematical process steps of a surface micromaching technology

- 2x 2 signal generator for each subdevice
- 2 synchronous demodulators for each subdevice
- Fast Fourier transformation (FFT) with an accuracy of smaller 1 Hz at a bandwidth of 2 kHz
- Peak detection
- AC/DC-measurement

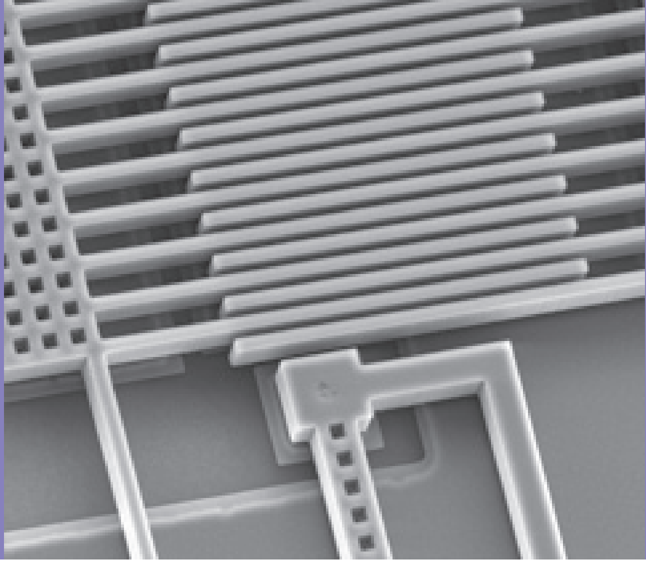


Figure 2: Detail of a micro machined gyroscope realised with surface micromachining technology

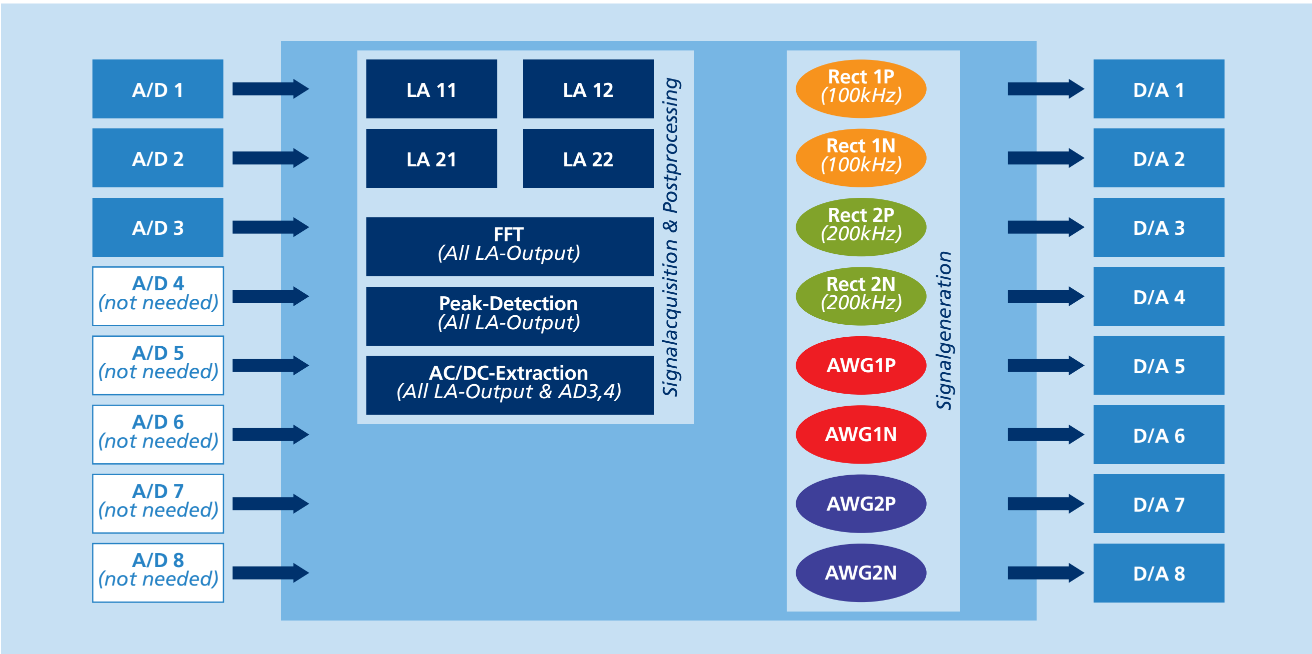


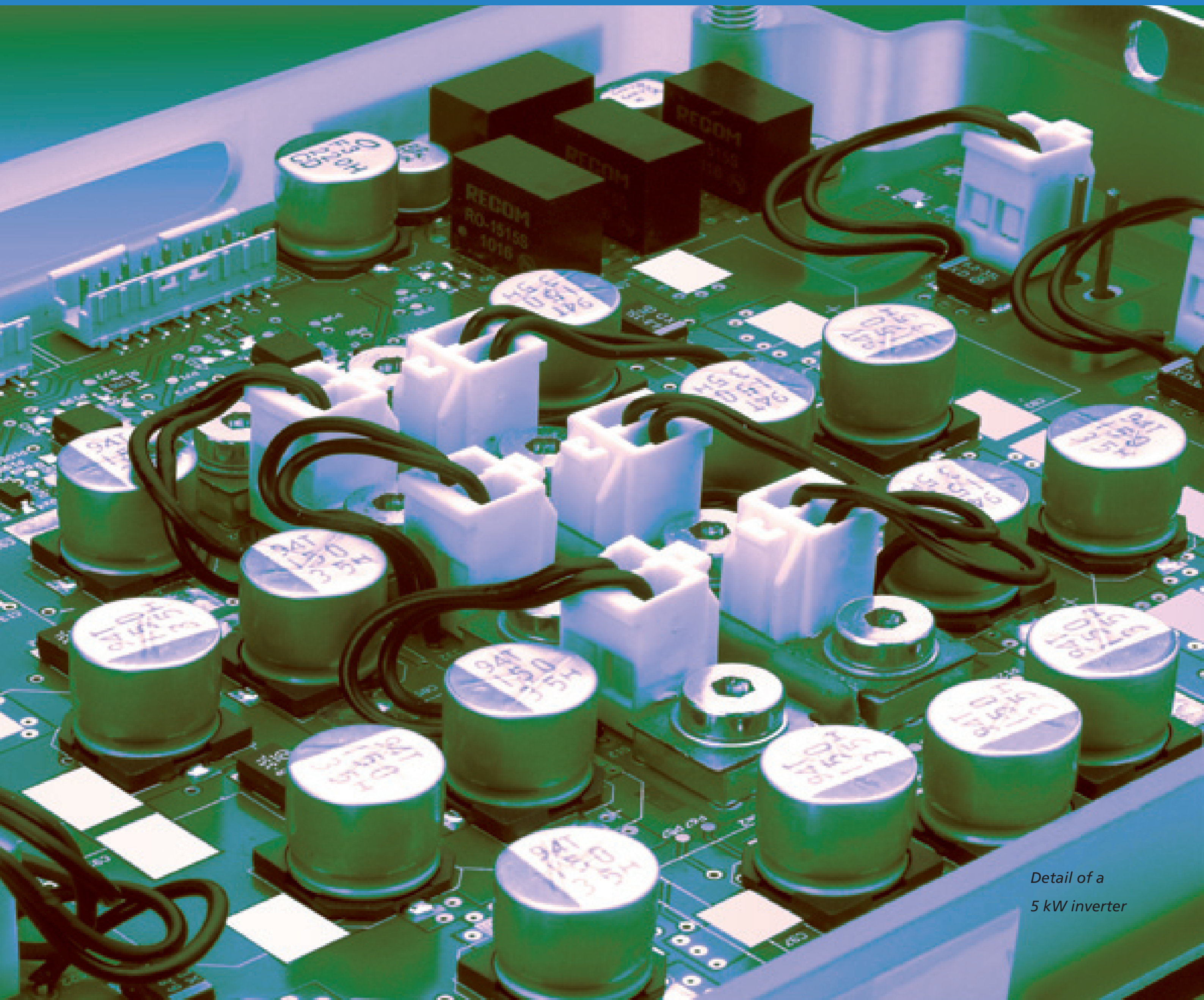
Figure 3: Block diagram of the most important components of the FPGA-module

Since several years Fraunhofer ISIT has intensified its activities to increase the performance of such wafer tests. To increase the throughput on a single wafer prober the target is to decrease the measurement time for a single sensor and so for a complete wafer while keeping the precision of each test procedure. To achieve this the complete test measurement algorithms are written using the software LABVIEW and taking a flexible FPGA board from the company National Instruments. The PXI-7854R board has a Virtex 5 LX110 FPGA-processor that is powerful enough to realise all the digital signal algorithms, see figure 3. In addition all stimuli are generated with this FPGA and are switched to eight analogue outputs to the device under test (DUT).

The complete software flow is realised by a state machine implemented within the FPGA which leads to a test time of less than 8 s/DUT (6DOF-IMU). The used HW/SW-architecture has an additional benefit: Due to the fact that most of the algorithms are implemented in a single FPGA-board, the test-time can be further reduced by adding additional FPGA-Boards to test more devices in parallel. Actually up to four DUTs can be measured at the same time that results to a measurement time of less than 2 hours per wafer.

REPRESENTATIVE RESULTS OF WORK

IC TECHNOLOGY AND POWER ELECTRONICS



Detail of a 5 kW inverter

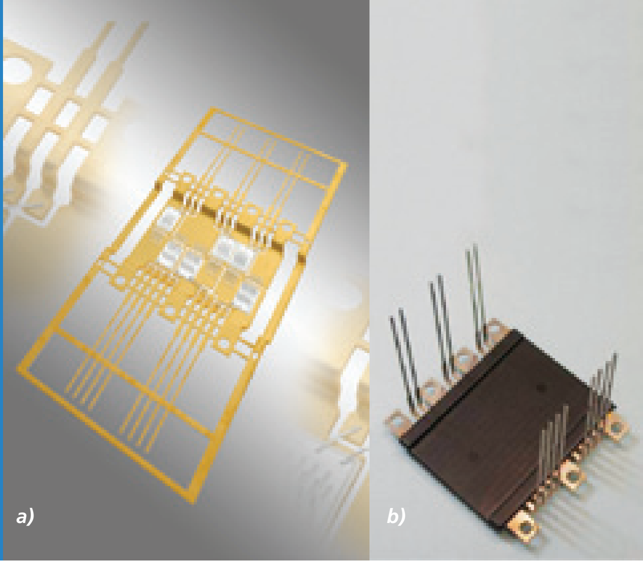


Figure 1: Leadframe with PowerMOS devices mounted by Ag sintering (a) and module after molding (b)

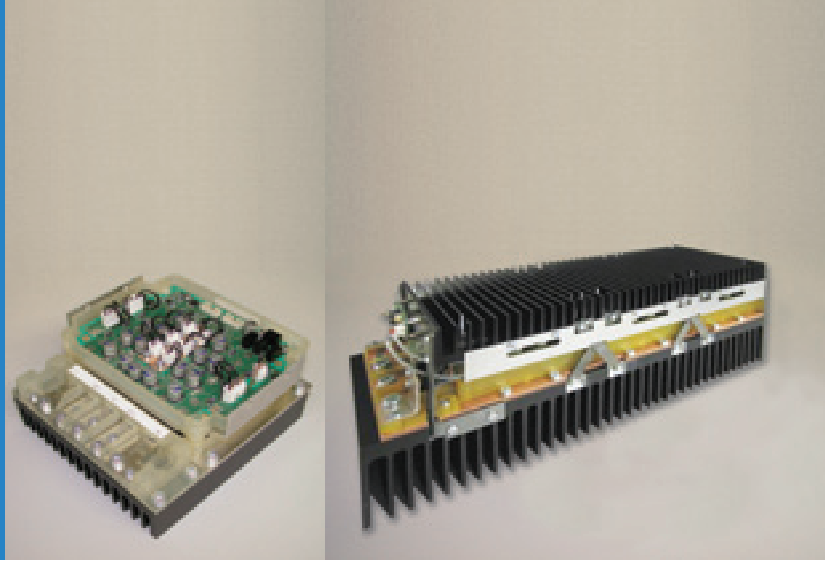


Figure 2: One 5 kW inverter and three inverters in parallel for output power of 15 kW

COMPENTENCE CENTRE OF POWER ELECTRONICS SCHLESWIG-HOLSTEIN (KLSH): STATUS AND PERSPECTIVE

The Fraunhofer Society and the federal state Schleswig-Holstein initiated the Compentence Centre of Power Electronics Schleswig-Holstein (KLSH) in 2008. The intention was to generate a local network, which offers a common platform to companies, universities and institutes, engaged in the field of power electronics. The regional existing expert knowledge, especially of small and medium sized companies, is focussed. The interaction of developers and users of power electronics is promoted as well as the exchange of the complementary requirements along the whole value added chain of a power electronic system.

As start up, a project was initiated with the objective to develop a power converter for industrial application which is optimized with respect to costs, reliability, lifetime, power density and efficiency. For this purpose a complementary team of industries, universities and institutes located in Schleswig-Holstein was established. The project members were:
Vishay Siliconix Itzehoe GmbH for semiconductor production, Danfoss Silicon Power for assembly technologies, Jungheinrich and JENOPTIK/ESW, Wedel as users of electric motor traction. These partners were supported by the following institutes: Fraunhofer ISIT, Itzehoe, universities of applied science Westküste and Kiel (FHW, FHK) and Christian-Albrechts University (CAU), Kiel.

The main benefit is, that this team covers the entire value added chain starting from semiconductor devices up to the final power electronic systems. This enables the consortium to optimize first the total system and to derive then the specifications for the different subsystems. As an example, the layout and dimensioning of the PowerMOS device was not specified before the final layout of the power module was defined.

The development of the PowerMOS device was carried out in collaboration with Vishay based on a qualified production technology. The chip was designed for a nominal current of 150 A with a breakdown voltage of 60 V.
The On-Resistance was measured in the range of 0,8 mOhm which was predicted by device simulations. The threshold voltage was increased to 5 V to improve turn off stability. Chip geometry and the pad configuration were defined according to specifications of the optimized power module. Backside metallisation was adapted to allow a chip assembly by silver sintering.

To enable advanced assembly methods a Ni/Au front side metallisation was applied feasible for soldering and sintering techniques. As a special feature of the PowerMOS device a diode structure was integrated to be used as a temperature sensor. The temperature characteristic of the integrated sensor exhibits excellent linearity with a slope of 1,9 mV/°C.

The active PowerMOS chips were mounted within power modules. For the power modules used here a special layout for a B6-bridge was designed. Based on extensive simulations from the university partners the design minimises stray inductance by avoiding loops and keeping current paths short. Additionally current paths of opposite direction are designed in close proximity to further reduce inductances. The PowerMOS devices were mounted on a copper leadframe using a silver sintering process for good thermal contact and to improve lifetime and reliability of this electronic backside contact. Front side contacts were assembled by standard aluminium thick wire bonds.

An optimised gate driver and control circuit was designed, assembled and tested by the CAU university group. The final driver circuit has the following features:

- supply voltage 16-36 V,
- separate gate driver for each single MOSFET,
- electrically isolated high-side-potentials,
- detection of bridge short-circuit faults,
- detection of too low supply voltage,
- level adaptation by module integrated temperature sensor,
- recharging of intermediate circuit,
- output of current measurements,
- active Gate control for MOSFET switch off,
- low variation in signal delay for high synchronisation of switching of parallel MOSFETs.

The mechanical concept was developed by the FHK.
The objective of the consortium to design a cascadable 5 kW inverter was realized by using two independent busbar systems. The intented multiplication of the output power (e.g. 10 kW or 15 kW) can simply be done by paralleling the inverters via the screwable copper plating. All design steps, starting with power modules and ending with cascaded inverters, were assisted by intensive thermal simulations of the FHW.

Several prototypes of traction inverters have been build and tested extensively. One traction inverter was build into a commercial lift truck to evaluate parameters during operation in a real working environment. Using the finished traction inverters temperature runs has been determined at various positions in the inverter at constant current loads. Using only passive cooling by ambient air the initial specification of a maximum temperature increase at the Power MOSFET of ΔT=55 K at a constant current load of 130 A for 60 min. has been met exactly. For higher current loads of 250 A and 300 A a temperature increase well below the initially allowed specification was determined. From these results it can be

Figure 3: KLSH team with lift truck having installed the optimized 5 kW inverter

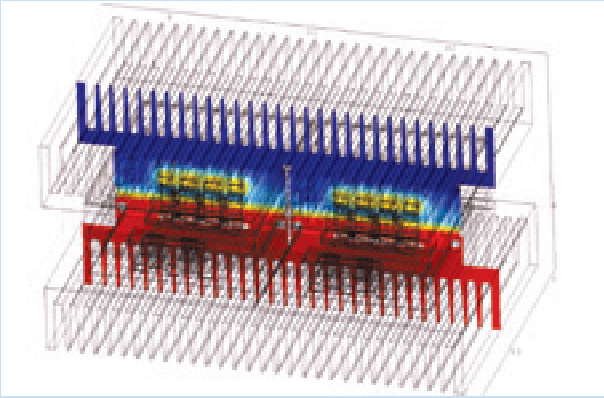


Figure 4: Thermal simulation of a 10 kW inverter

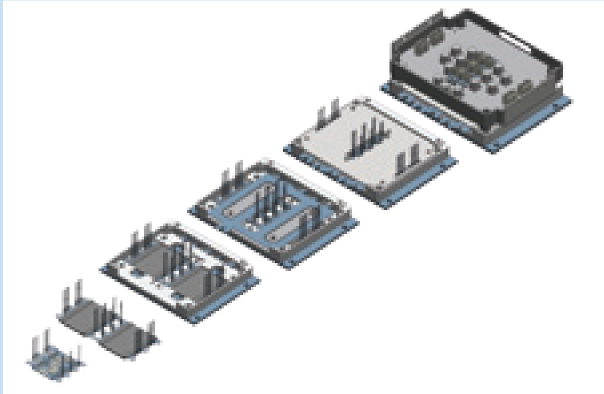


Figure 5: Mechanical concept and assembling of a 5 kW inverter

estimated that the custom made PowerMOS chips are able to sustain a constant current of 400A for up to five minutes within the allowed temperature specifications. Due to power limitations of the available measurement stations these maximum current values could not be tested experimentally. Clearly initial temperature specifications have been surpassed with the optimised power modules and traction inverter. The Efficiency factor of the output stage was determined to 98% at nominal rotational speed value. Including power consumption of the overall control electronics efficiency is reduced to 96%. These values exceed the parameters of existing traction inverters and clearly exceed the initial design parameters from the start of the project.

First investigation indicate, that an active power management has the potential to reduce current load for the battery. Braking energy is recharged into the system and can be used for the next acceleration. As result, the voltage variation at the battery clamps is reduced from 6V to 2V during operation. Moreover, this custom made setup of power modules with integrated temperature sensors has allowed Jungheinrich to resolve the change of junction temperature as result of single load changes during operations. Probably this deepened information of inverter conditions can be used in the future for further improvements of driver and control circuits.

The presented achievements will be continued in a regional R&D partnership. One of his objectives is more soft skill oriented; here a contact point to participants of modern energy management and efficient power electronics as well as the training and qualification of students and trainees is offered. Furthermore, specific research projects will be accomplished linking basic and applied research to their industrial implementation. In summary, the competitiveness of the involved companies will be enhanced to create the background for new and secure employments.

ZUKUNFTSprogramm Wirtschaft Investition in Ihre Zukunft

VISHAY. JENOPTIK GERMANY ESW JUNGHEINRICH Danfoss

FACHHOCHSCHULE KIEL Hochschule für angewandte Wissenschaften University of Applied Sciences

CAU Christian-Albrechts-Universität zu Kiel

FHW Fachhochschule Westküste Hochschule für Wirtschaft & Technik

Fraunhofer ISIT

APPLICATION SPECIFIC IGBTS FOR NEW ASSEMBLY TECHNIQUES

Energy efficiency, energy reduction and environmental conservation are intensively discussed themes in our society. In this context power electronics is the key technology for energy controlling wherever electrical energy is generated, directed, or converted. Electronic components like FS-IGBTs (**F**ield-**S**top **I**nsulated **G**ate **B**ipolar **T**ransistors) used in power modules work with minimal switching losses and the lowest on resistance possible to reduce the thermal dissipation loss.

Fraunhofer ISIT is developing application specific IGBTs for a new kind of high reliable "Ultra-Compact Power Modules" (UltiMo) which are supposed to be cooled within a closed cycle cooling system. Power modules are designed for a continuous operation temperature of up to $T_{J(op)}$ = 150°C, with a specified highest IGBT junction temperature of $T_{J(max)}$ = 175°C. In automobile applications, for example, the cooling water temperature is about 90°C at stationary condition. The application of advanced power modules is not restricted to automobiles since they are useful wherever a handling of high power densities is required. Power loss during IGBT operation always requires a very effective cooling. In most instances, module assemblies are cooled on one side only by use of a heat sink which is strongly reducing the potential ampacity of the IGBTs. Additional water cooling is improving the power dissipation throughout the DCB (stack of Cu/ceramic/Cu) and base plate. The specific feature of the new "Ultra-Compact Power Modules" is to provide an effective cooling on both IGBT sides in conjunction with overall reduced module dimensions and low thermal resistance paths from the IGBT to the upper and lower heat sink.

IGBTs with copper/tin (Cu/Sn), nickel/silver (Ni/Ag) or nickel/gold (Ni/Au) terminations which could be sintered or soldered on both sides directly to DCB contacts are actually not available on the market. Therefore special IGBTs are needed in terms of geometry and pad configuration as well as front side metallization schemes.

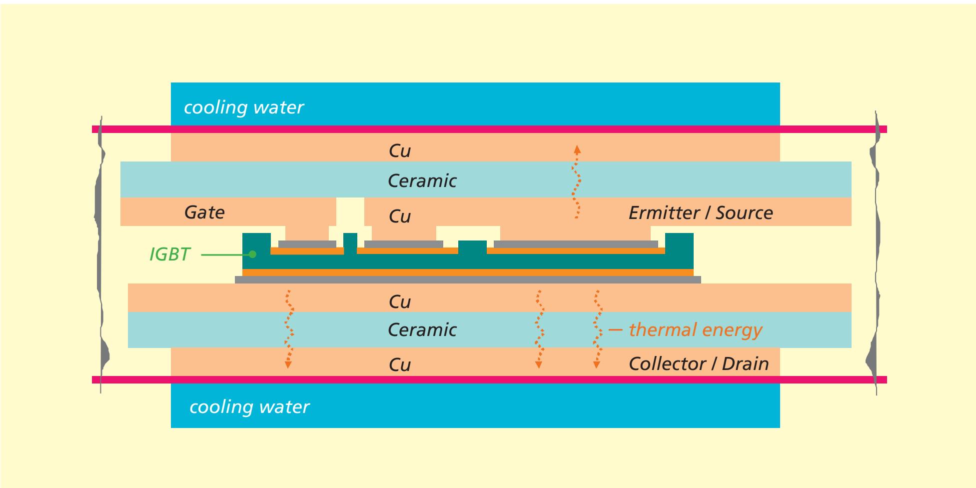


Figure 1: Cross section of an "Ultra-Compact Power Module" sandwich assembly of DCB (Cu/ ceramic/Cu) and corner gate IGBT. All IGBT terminations are sintered or soldered to copper coated ceramic

Fraunhofer ISIT therefore is fabricating IGBTs with modified AlCu metallization for the assembly as outlined in figure 1. This arrangement of DCB/IGBT/DCB enables an effective heat transfer to the liquid coolant throughout the DCBs.
The junction temperature is reduced due to the improved heat flow at low thermal resistance and thus the IGBT can perform at higher power density. In addition, the new structural design is minimizing parasitic commutation inductivities since the dimension of current carrying metal lines can be reduced according to chip thickness and connecting layer requirements.

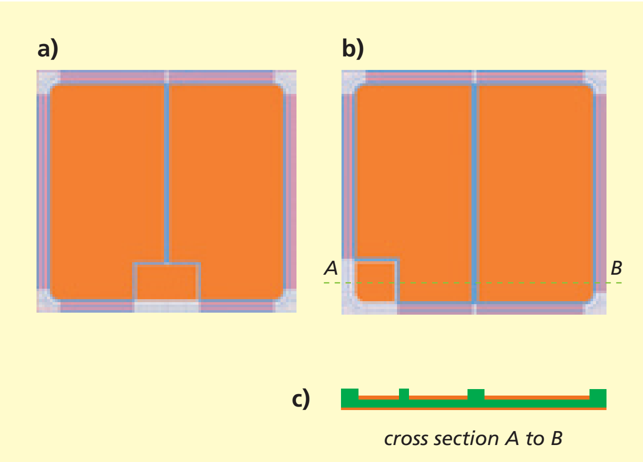


Figure 2:
Layout of 600 V IGBT, 75 A
(a) edge gate IGBT
(b) corner gate IGBT
(c) General sketch of a corner gate IGBT cross section (A to B)

Fraunhofer ISIT realized two customer-specific designs for 600 V/ 75 A FS-IGBTs, one providing components with an edge gate contact and another one with a corner gate contact as displayed in figure 2(a) and 2(b). The IGBT wafer thickness is 70 µm, the chip size is about 6 x 7 mm^2.

On base of experiences in process and device simulations a set of basic static parameters has been defined prior to mask design and IGBT fabrication. The wafer processing is divided into front-side processes and rear side processes. While processing the front side of the IGBT, the active areas including the MOS-trench structures and the edge termination structures are defined. The principal sketch displayed in figure 3 shows the basic cell structure of the active IGBT area. The front side processing finishes with the final metallization structure depending on customer requirements. An overview for approved metallization stacks is given in table 1.

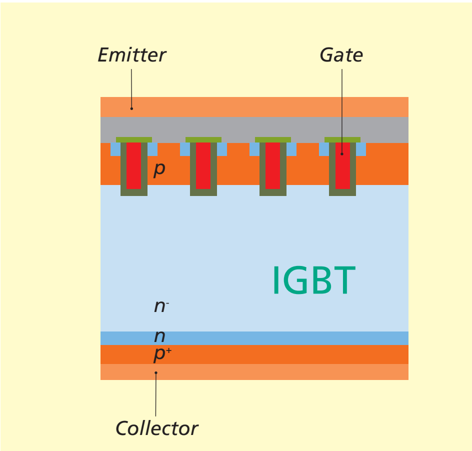


Figure 3: IGBT cross section

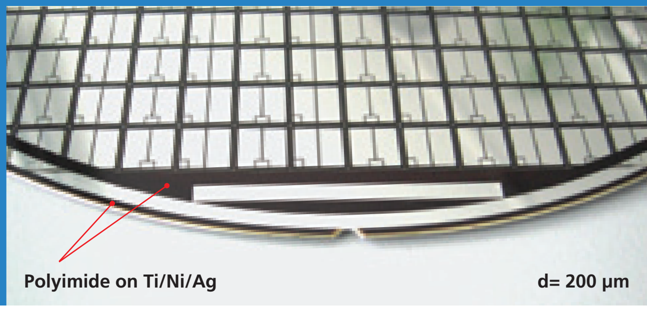


Figure 4: AlCu/Ti/Ni/Ag wafer- surface with Polyimide insulation of 20 µm thickness

Front side Emitter metal	**Ni/Au** electroplating 2 µm / 70 nm	**Cu/Sn** galvanic 2 µm / 5µm	**Ti/Ni/Ag** thermally evaporated 50 nm / 100 nm / 1 µm
Rear side **Collector metal**	**Ti/Ni/Ag** 50 nm / 100 nm / 1 µm, thermally evaporated		

Table 1: Front side emitter on 20 µm Polyimide (PI) and rear side collector metallization

The Ni/Au or Ti/Ni/Ag metallization stacks are suitable for sintering processes, the Cu/Sn surface is prepared for Transient Liquid Phase Bonding. All mentioned front side metals can be used for soldering processes except pure AlCu which requires wire bonding. An additional polyimide layer is useful for high voltage applications since polyimide reduces the field strength and enhances the insulation around the edge termination. In particular this is important for sandwich assemblies as shown in figure 1. As an example an AlCu/Ti/Ni/Ag coated wafer with polyimide insulation is shown in figure 4.

The rear side processes are performed after temporarily bonding the IGBT substrates upside-down onto carrier wafers. The method of temporarily bonding is used for the mechanical stabilizing of the IGBT wafers while grinding them down to the target thickness of 70 µm. Subsequently, the rear side p^+-emitter and the field-stop layers are implanted and then activated by laser annealing. During laser annealing only the implanted surface is molten by laser pulse energy.
The heat transfer is limited to a depth of a few µm so most of the Si substrate remains cold. After rear side metallization the

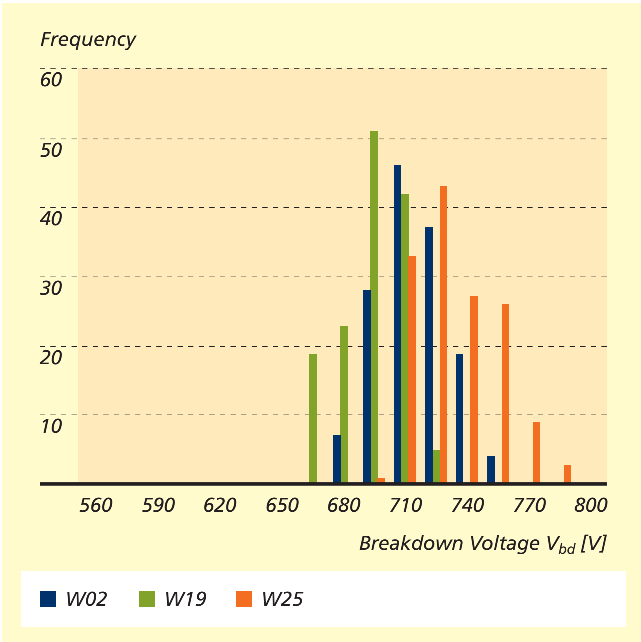


Figure 5: Failure frequency vs. breakdown voltage for three different wafers. At breakdown the current I_{CE} exceeds 250 µA, V_G = 0 V

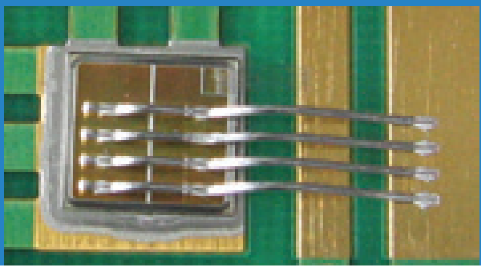


Figure 6: PCB with soldered and wire bonded IGBT, prepared for high current dynamic testing

wafer is de-bonded from the carrier wafer. Now it is ready for first static measurements on wafer level by connecting the wafer with prober-needles. As shown in figure 5 the mean breakdown voltages V_{bd} measured on different wafers are about 700 V to 730 V with a small standard deviation of ±20 V. A low gate leakage current of less than 50 pA was measured within the temperature range of 25°C to 150°C. The IGBT leakage current under blocking condition at 600 V exhibits values below 1 µA at T = 25°C. The temperature coefficient for the threshold voltage was determined to -17 mV/K within the temperature range of T_j = 25°C to 150°C.

Dynamic parameters at high voltage and current can only be measured on assembled IGBTs. Therefore the IGBTs have been soldered and wire bonded to PCBs (printed circuit boards) as shown in figure 6. The output characteristic (IC vs. V_{CE}) of the IGBTs for a gate voltage range of 6 V to 18 V is displayed in figure 7. At a nominal current of 75 A a saturation voltage of V_{CEsat} = 1,5 V is determined.

The project "development of customer-designed IGBTs for both side solder- /and sinterable assembly technologies" is founded by the federal government ministry BMBF within the project UltiMo as part of "Leistungselektronik zur Energieeffizienz-Steigerung" (LES), conveying program "IKT2020".

Overall eleven project partners are working on this project jointly, eight Industrial companies and three Fraunhofer Institutes.

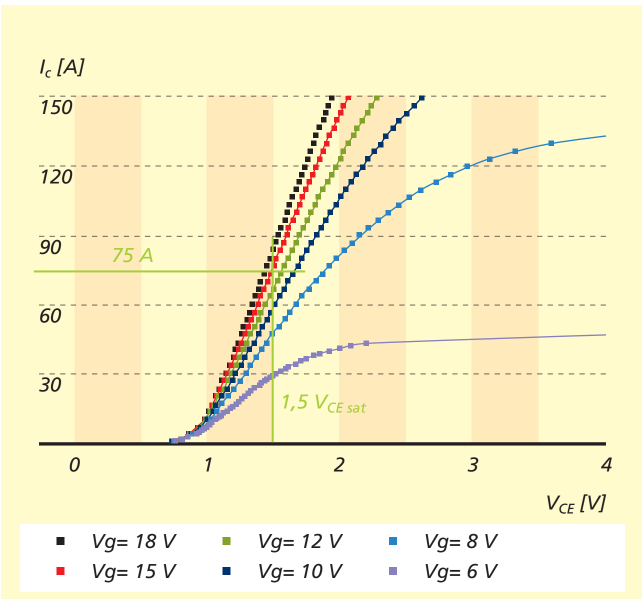


Figure 7: IGBT output characteristic at T_j = 25° for V_G = 6 V to 18 V. The saturation voltage amounts to 1,5 V

BIOTECHNICAL MICROSYSTEMS

Disposable cartridge with automated sample collection

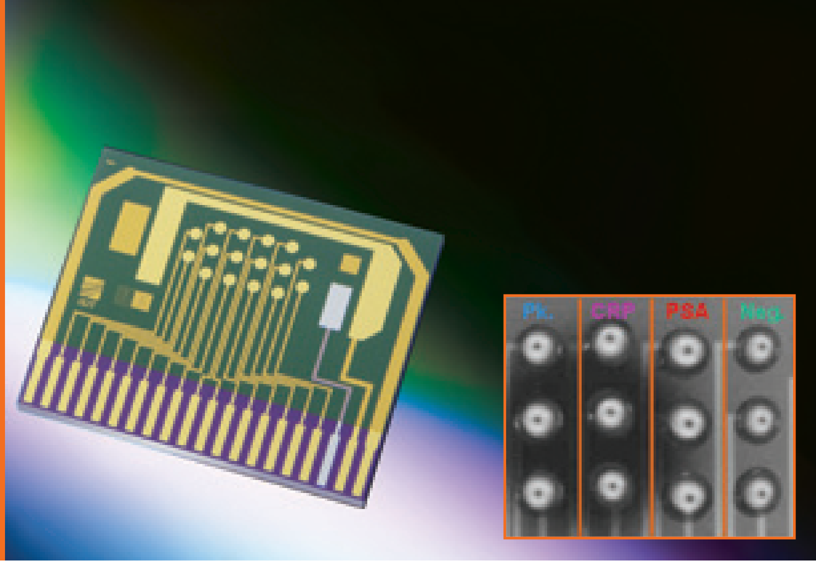


Figure 1a: Picture of the array chip with 16 positions

Figure 1b: Spot layout for CRP/PSA measurement with included controls (Pk: positive, Neg: negative)

THE FRAUNHOFER IN-VITRO-DIAGNOSTIC-PLATFORM WITH ELECTROCHEMICAL DETECTION

Standard diagnostic tests are currently done in central medical laboratories. Therefore mainly whole blood samples are collected from patients in amounts of millilitres and are sent to these labs for automated measurements. Caused by this many patients have to wait for days to get their results which in general is no problem, but in urgent cases this lack of time is too long. To shorten this, the point-of-care-diagnostic directly at the doctor´s place is of high interest. The used measurement devices are characterized by some specific features: They have to be portable, fast, reproducible and also inexpensive. The Fraunhofer in-vitro-Diagnostic-Platform (ivD) combines these features as a result of the profound knowledge of eight Fraunhofer Institutes: Fraunhofer IBMT as the coordinator, IPA, IZM, ENAS, IAP, IPM, IGB and ISIT. The whole project was founded by the Fraunhofer Society as a so called MAVO and continued as a so called WISA.

The ISIT specific ivD-platform consists of a portable electrochemical detection device and disposable plastic cartridges. These cartridges are built up in a modular way by combining injection moulded plastic parts with electronic circuit boards. They are able to detect DNA as well as proteins. These cartridges consist of all needed fluidic parts like reagent reservoirs, gel based electrochemical micro pumps, channels and an air bubble trap. The cartridges were developed by ENAS, IZM and IPA. According to the application it could be chosen between two different detection technologies: The electrical array biochips from ISIT and an optical detection technology (TIRF; total inner reflection fluorescence) from IPM.

The electrical array biochips are included for qualitative and semi quantitative detection. In the portable detection device all related electronic parts are integrated.

The used model application is the detection of the marker molecules CRP (C-Reactive Protein) and PSA (Prostate Specific Antigen) together in one assay on the biochip including the positive and negative control. These measurements were done in parallel at the partner institutes with the different detection technologies.

At Fraunhofer ISIT these ELISA-like assays were evaluated by measurements directly in the cartridges. 12 positions of the biochips were used (see figure 1a). The anti-CRP- and PSA-antibodies were spotted by an automated microdispensing device onto 3 chip positions each. They immobilized via thiol links and adsorptive forces directly at the gold electrodes surface. Another 3 positions were covered with a mouse antibody for positive control and another 3 positions were covered with a nonbinding protein (BSA) for negative control (see figure 1b). After incubation and washing steps the spotted chips were glued into the cartridges. The whole assay procedure including the electrochemical detection of an enzyme generated redox active product was performed by the detection device. This device automatically addresses the cartridges pumps regarding to the given assay program: At first the sample was pumped over the chip and during incubation CRP and PSA molecules bound specifically to the immobilized antibodies. In case of a positive CRP and PSA sample, added monoclonal anti-CRP- and anti-PSA antibodies acted as high specific detectors. An anti-mouse-enzyme conjugate was used as a label. It bound to the positive control positions and to bound detector antibodies

Figure 2a: ivD-cartridges equipped with microfluidics and chip

Figure 2b: portable detection device

at the CRP/PSA positions while the BSA positions left unbound. After this labelling step a substrate was added which was converted by the label enzyme into its redox active form. It could be measured specifically for each position in a stopped flow modus. The resulting current slopes were directly proportional to the CRP and PSA amounts in the sample. Up to hundred tests were performed in these cartridges to evaluate the whole system (see figure 2a).
At first the cartridges equipped with a spotted biochip were filled with the needed reagents. A typical volume of one cartridge reservoir was 150 µl for the washing buffer and 90 µl for reagents. Then 50 µl of sample was added and the cartridges were put into the detection device (see figure 2b).

Cartridge based measurements are shown in figure 3a and 3b. In comparison to the department's standard biochip device the ivD-cartridge system showed in general lower and more inhomogeneous signals. This depends on adsorption effects of reagents in the injection moulded cartridge parts and fluidic effects. After using the control positions for standardization the results were comparable to the assay performed with the standard biochip device. In both systems 1 ng/ml CRP and 1 ng/ml PSA could be detected during 20 minutes as the sensitivity limit.

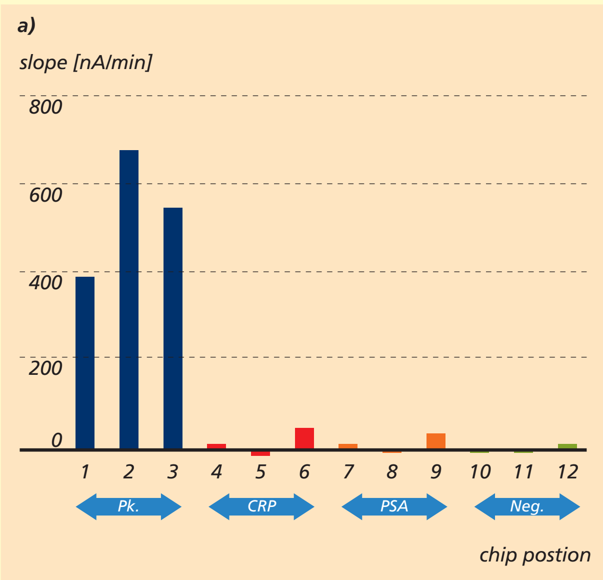


Figure 3a: CRP/PSA negative sample

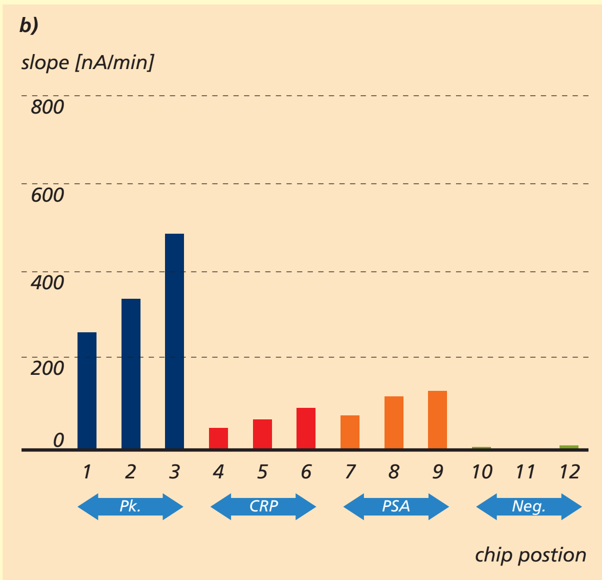


Figure 3b: Sample with 10 ng/ml CRP and PSA

Point-of-Care diagnostic system

REPRESENTATIVE RESULTS OF WORK

MODULE INTEGRATION

RFID transponder with embedded chip module in polycarbonate

Figure 1: Gyro modul: Sensorchip and ASIC in open cavity package

CUSTOMIZED PROTOTYPE ASSEMBLY OF ANGULAR RATE AND ACCELERATION SENSORS

Introduction

Fraunhofer ISIT has long background in the joint developement of advanced inertial sensors together with industrial partners. In the last two years ISIT extended the packaging concepts. The dual cavity sensor was introduced, combining angular rate and acceleration sensors in the same chip. With the new 200 mm wafer process technology, the devices are built and provided for first customer evaluation and qualification.

At the end of the development process the sensors have to be mounted with ASICs into open cavity packages for testing and qualification. There are tests for hermeticity, shock robustness, humidity, vibration and electrical characterizations. Depending on the application the package type, adhesive and bond-diagram have to be adapted. This variety demands a very flexible partner to perform the customized build ups. Fraunhofer ISIT is able to accomplish the sensor assembly requests in the packaging laboratory with state of the art equipment.

The standard Build Up

When the order for assembly arrives, all needed parts are checked for availability. If there is a deviation from the standard, the build up has to be checked for feasibility. The process starts with the cleaning and activation of the packages, ceramics or open cavities, in an O_2 plasma oven. The activation is necessary to improve the adhesion. The adhesive dispensing and die placement has to be performed in a defined time window. Otherwise the plasma activation has to be repeated. After the cleaning the adhesive is dispensed, the pattern and the amount of glue are depending on the die geometry. The dispensing and die placement are performed manually. Normally the sensor and the ASIC can be applied in one step that is depending on the curing temperature and time of the used adhesives. The placement accuracy is so good that the pattern recognition of the following machines finds the marks automatically. The patterns on the dies and the position of the pads in the package are good reference marks for orientation. After the curing the assemblies return into the plasma oven, to activate and clean the bondpads. In the next step the dies are wirebonded. Therefore it is necessary to have an exact bondplan to avoid electrical shorts and other connection mistakes. Today Fraunhofer ISIT performs the bonding with a H&K Bondjet 715M Ultrasonic Al-wirebonder, but there are tests to transfer the interconnection to a Palomar Thermosonic Au-wirebonder to get a step closer to the high volume production process. Sometimes the requested assemblies are stacks which means after the first level is completed, adhesive is dispensed on top of the ASIC and a sensor is placed on it. After curing the bond pads have to be activated and bonded. The last optional step is to fill the assembly with special silicone to protect the bondwires. At the end a lid is applied.

Special build ups

Previously the standard process for an inertial sensor assembly was described but Fraunhofer ISIT is also able to check the feasibility of customer specific assembly constructions and to realize them. It is possible to add parts under or on top of the dies to control the self resonance frequencies. If the package is big enough SMD or other components can be added. The bonding-diagram can be varied from assembly to assembly. Each die can be applied with a different adhesive. Nearly all kind of packages are possible to handle. Dies can be modified with soft "feet" for better decoupling from the package and many other variations are possible.

OPTIMIZATION OF SELECTIVE SOLDERING PROCESSES IN APPLICATIONS FOR POWER ELECTRONICS

Introduction

The increasing importance of electronics in different application areas leads to an increase in the complexity of the modules and results in increased demands on the joining technology and its associated processes. Coupled with the trend towards electric mobility are high currents and frequencies which have a significant impact on component selection and design of printed circuit boards.

Thick copper PCBs with copper layer thickness up to 400 microns and more in connection with large, highly heat-demanding components are essential for assembling power electronics. In addition with leadfree SnAg(Cu) selective soldering processes poor through hole filling, copper leaching, wetting defects and damage to adjacent components and the inner layer vias and attachments within the circuit boards are frequently observed defects.

In the government financed research project „Process optimization for selective soldering in applications for power electronics“ (AIF Research Project 161.74 N) different selective soldering processes were investigated systematically by the Fraunhofer ISIT together with the Fraunhofer IZM for their suitability for processing of THT (Through Hole Technology) components on printed circuit boards with thick copper layers. Soldering parameters and process boundaries have been developed. The influence of various heat traps was worked out by means of temperature measurements and series of soldering tests. The results have been incorporated in an application recommendation.

Realized studies

A 4-layer FR4-Printed Circuit Board (PCB) with a representative sample of typical power electronic components and up to 1 mm total thickness of copper was designed in three buildup sequences:

PCB V1: 4x70 µm Cu thickness (outer and inner layers),
PCB V2: 2x70 µm Cu thickness (outer layers), 2x200 µm Cu-thickness (inner layers),
PCB V3: 2x70 µm Cu thickness (outer layers), 2x400 µm Cu-thickness (inner layers).

Three different types of heat traps (HT) were realized:

HT1: single, clearance and line width each 800 µm,
HT2: double, clearance and line width each 800 µm (see figure 1)
HT3: same as HT1, clearance 1600 µm.

At some component types „thermal vias“ in the form of eight through holes were attached to the connector annular ring to improve the through thickness heat transfer.

Soldering Tests

Laser Beam Soldering

Laser beam soldering tests were performed in cooperation with the company Wolf Production Systems, carried out with a laser soldering machine type LLW03. By using six laser sources, each with separate rates up to 10 watts of laser power, which act in different directions on the solder land, the soldering tool can be optimally adapted to the connector land geometry. The distribution of the laser energy to a plurality of light sources reduces the radiation intensity and the danger of damaging units of the assembly.

It was found very quickly that satisfactory soldering results couldn't be reached without preheating. Therefore the boards were preheated up to 90° C and then soldering experiments were performed with a laser power of about 45 W and soldering time between 0.6 to 1.3 seconds.

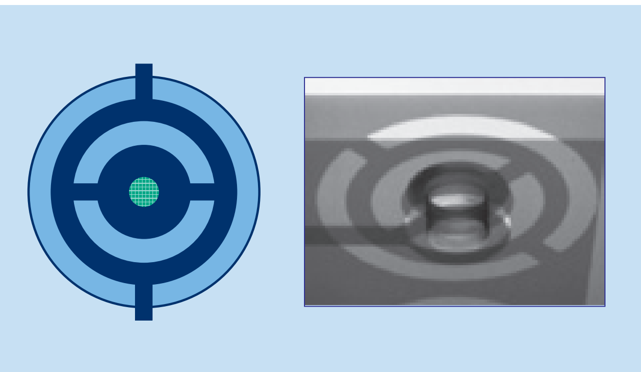


Figure 1: Heat Trap [HT2]
Left: schematic, right: XRAY

Soldering Iron

For the experiments, an automated soldering iron type Vario-A16-fra from the company ATN (Automatisierungstechnik Niemeier GmbH) was used. The solder feeder position was adapted to reach good heat transfer from the soldering tip to the component pin and the solder land as well.
A bottom heater (hot gas as well as infrared) was installed and soldering tests were performed with a soldering tip temperature of 350° C and 400° C using soldering times up to 20 seconds.

Selective Wave

Main experiments were carried out with a Versaflow 3 from Ersa. A SAC305 solder material was used. The soldering tests were performed at three different solder bath temperatures 285° C, 300° C and 320° C. The contact time per soldering joint varied between 0.5 to 6 seconds.
The preheating was operated at a temperature of 125° C for a duration of 100 seconds. In addition single tests were carried out with a selective wave soldering module from the company EUTECT.

Evaluation of Soldering

Solder joints were visually inspected using a stereo microscope and evaluated using the acceptance criteria of the IPC-A -610 Revision E for class 3 electronic products.
Acceptance criteria were the circumferential wetting of the solder land on solder source side and solder destination side as well as the complete vertical fill.

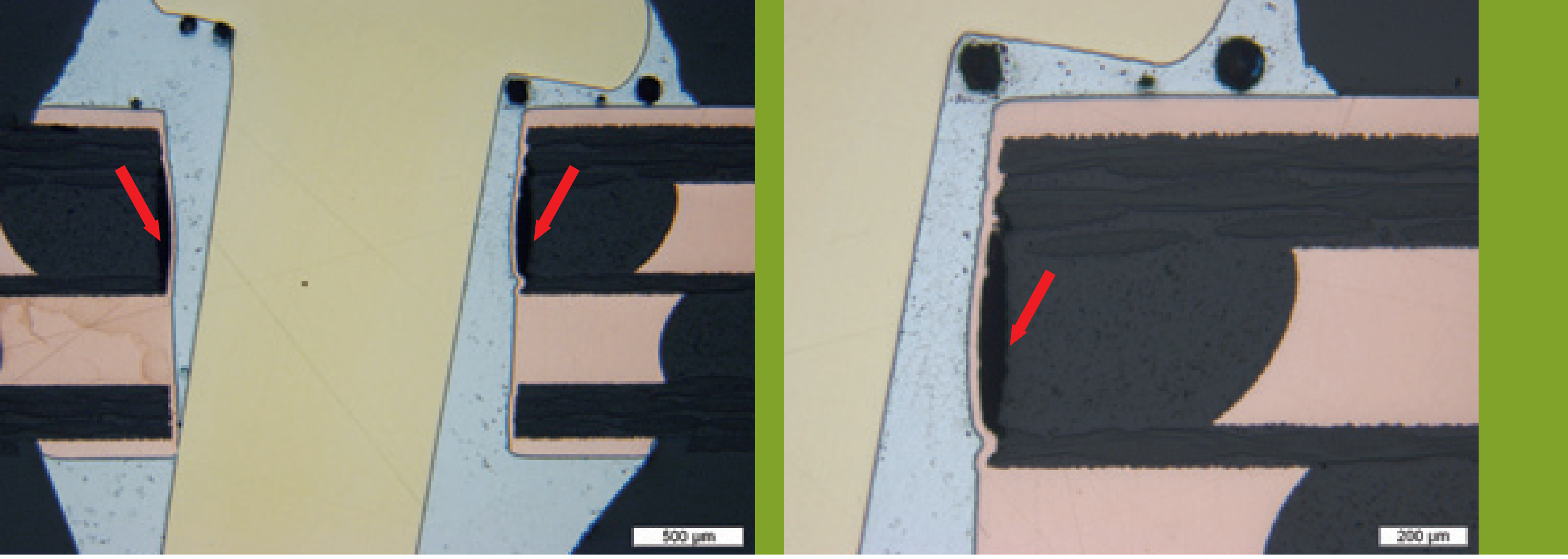


Figure 2: Extreme resin recession and distinct deformation of the copper plating

Experimental Results

Laser Soldering

In particular, using laser soldering shows that small changes in pad layout, connectivity options, or material variations lead to significantly varying results. This means that there is only a small process window available to supply sufficient heat to the solder joint without damaging the printed circuit board. The results obtained with the laser soldering system can be summarized as follows:

- With the laser soldering process the PCB V1 is limited solderable.
- Increasing thermal mass of the components or the PCB (having thicker copper layers) process problems begin, showing incomplete vertical fill, wetting problems and assembly damage.
- The PCB V2 and V3 are unsuitable for the laser soldering process.
- Due to assembly tolerances there is a big fluctuation in the soldering result (good / bad) although using nearly identical process parameters.
- The process window is narrow and difficult to be met.

Soldering Iron

Even on the PCB V1 the soldering of pins with 1.0 mm diameter without bottom heating shows incomplete vertical hole filling. Using a bottom heating with a PCB temperature of 90° C on the solder side a complete vertical fill of solder is then obtained even with a full-scale attachment to the internal layer. Soldering PCB V2 the result is unsteady even using a soldering tip temperature of 350° C and a PCB temperature of 110° C. When using processing times of about 10 s, both almost complete filling of the via is possible, as well as incomplete filling. Only pins without inner layer attachment can be handled well with a PCB temperature of 100° C and a process time of 9 seconds. The PCB then tends to increase resin resession. Increasing the tip temperature to 400° C pad-lifting and laminate cracks were observed. A full-scale connected via achieves no more complete wetting even using PCB temperature of 160° C and a processing time of 12 s.

Efforts to achieve complete filling of the vias at PCB V3 and full-scale connected vias showed no success although using PCB temperature of 180° C. Also extreme resin recession and distinct deformation of the copper plating is observed (see figure 2).

Using the automatic soldering iron process limits are visible when trying to solder PCB V2 and V3. Good wetting is only to achieve with significantly higher preheat temperatures up to 180° C and / or 400° C soldering tip temperature but for the price of damaging the substrate. Trying to solder high-mass components no satisfying results were obtained. Thus, the automatic soldering iron for thermally massive structures (massive components or thick copper printed circuit boards) is not suitable.

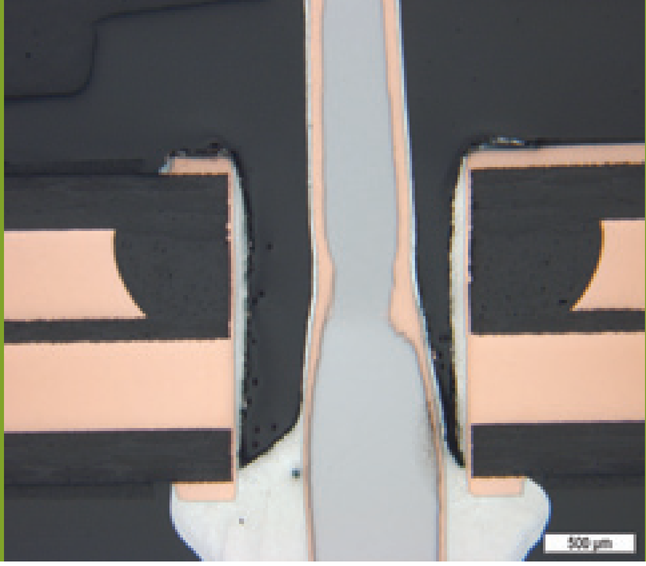


Figure 3: Poor wetting

Figure 4: Good wetting

Selective Wave Soldering

The results for the experiments with the selective wave can be summarized as follows. Regardless of the type of component, the copper layer thickness and the PCB layout, it should be noted that for these configurations selective soldering without preheating is not applicable. A preheat temperature of 125° C with a preheating time of 100 seconds has been shown in tests satisfactory results. The importance of preheating is also confirmed by temperature measurements during the soldering tests which showed clearly that the preheating has a significant influence on the final solder joint temperature. Looking at the parameters soldering temperature and soldering time, which were at least necessary to achieve a complete hole filling with selective wave soldering, clear relationships are found.

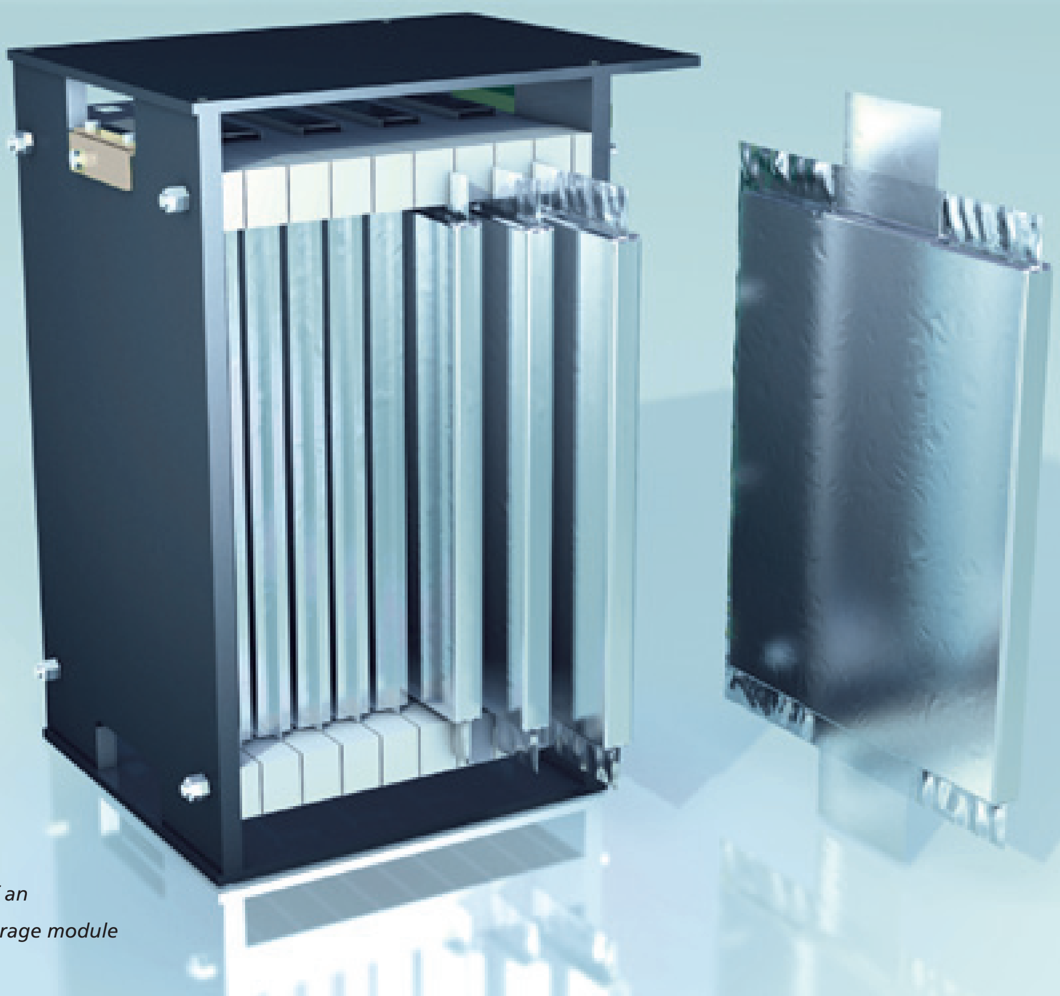
As expected, and applying to all components, the PCB V3 with copper layer thickness of 400 microns is most difficult to be soldered and in combination with the full scale connected terminals no satisfactory soldering result can be achieved (see figure 3). A significant influence is also apparent by the choice of the heat trap. Regardless of the shape of the component, using the heat trap 2 the best soldering results are visible, see fig. 4. Additional application of thermal vias in the pad of the plated through hole can enhance the heat transfer and reduce the soldering temperature and time. The effect of heat traps on the solder joint temperature at the terminals and thus on the soldering quality is also confirmed by the temperature measurements that were made. However, as already mentioned above, again the additional thermal vias are not sufficient to reach a complete vertical fill of supported holes which are fullscale attached to a 400 micron thick layer. Such a combination has to be avoided.

Summary

From the obtained results it can be concluded that using the selective wave soldering sophisticated assemblies from the field of power electronics can be processed in such a way that good soldering results are achieved without a significant degradation of PCBs.

Particular attention is to be paid to the PCB layout. By connecting the pads using heat traps and additional insertion of thermal vias, significant improvements in the soldering results are achieved.

INTEGRATED POWER SYSTEMS



Subunit of an energy storage module

STATIONARY ENERGY STORAGE SYSTEMS BASED ON LITHIUM-POLYMER-BATTERIES: TECHNOLOGY DEVELOPMENT BY FRAUNHOFER ISIT

Caused by the dramatic incidents in Fukushima, Japan, the past year saw a distinct change in the energy policy of Germany (see figure 1). The share of renewable energy, including solar and wind power will increase significantly in the coming decades. One of the biggest challenges for this strategy is the required expansion of the power grid.

Using local, stationary energy storage systems can help to overcome this problem.

The economics of battery storage in the application described here is decisively dependent on the lifetime and the number of cycles which can be achieved. In energy storage systems

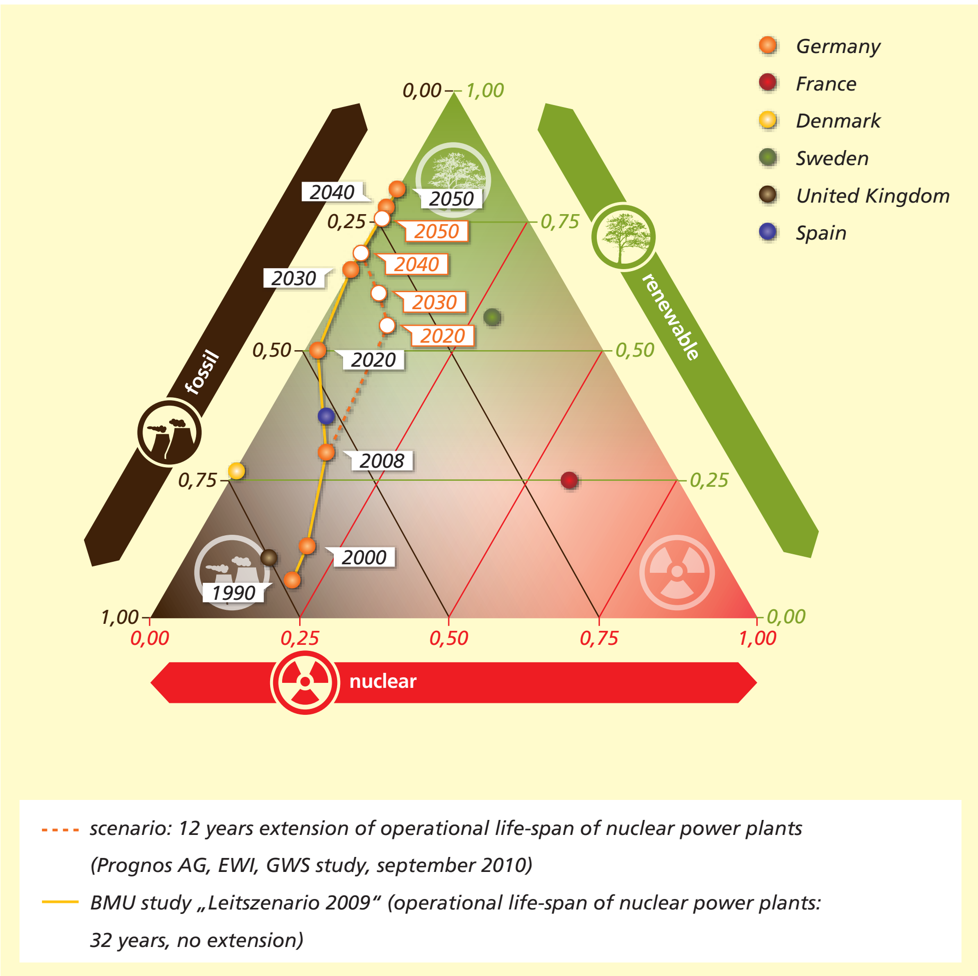


Figure 1: Energy Scenario, Germany

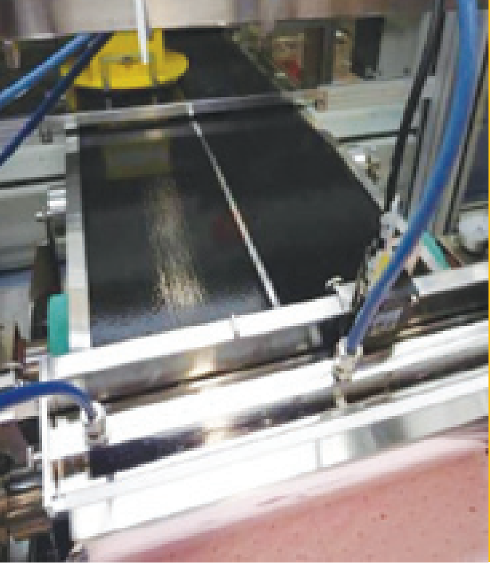


Figure 2 Electrode coating process (width 400 mm)

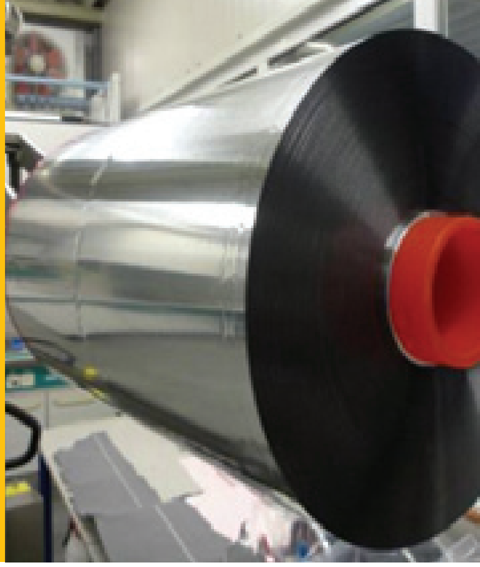


Figure 3: Electrode Coil Produced by Fraunhofer ISIT

Figure 4: Storage unit "Black diamond 5000", Dispatch Energy

for photovoltaic applications a calendric lifetime of about 20 years is required and in grid-connected systems a very high number of cycles have to be achieved. These requirements imply the use of an electrochemically robust system with highly reversible charge and discharge processes and a careful management of the electrical operating conditions of the storage unit. The department of Integrated Power Systems at Fraunhofer ISIT therefore developed a cell chemistry that addresses in particular these key-points.

Conventional battery systems operate predominantly with cells on the basis of carbon anodes and metal oxide cathodes but this combination cannot offer the required safety and lifetime. For several years lithium-titanate ($Li_4Ti_5O_{12}$), LTO, has been investigated at Fraunhofer ISIT as anode material. It is characterized by a high stability and intrinsic safety, but the energy density is comparatively low. Fortunately the energy density is of less importance for stationary storage systems. At the cathode side lithium-iron-phosphate ($LiFePO_4$) is used - well known for some time and already used in commercial lithium batteries. Like LTO it also features a significantly increased safety.

In 2010 Dispatch Energy GmbH was founded in Itzehoe as a manufacturer of stationary battery storage systems based on lithium-polymer batteries for the photovoltaic market. The lithium cell technology for this application has been developed by the department of Integrated Power Systems in cooperation with Dispatch Energy. Based on pre-existing know how and using the Fraunhofer ISIT coating facility, the manufacturing technology and recipes of anode and cathode electrodes had to be adapted to a continuous direct coating process. Using a new combination of electrode binders and solvents IES succeeded in developing a stable and cost effective process which can later be transferred to Dispatch Energy.

In late 2011 a second project with Dispatch Energy was started in order to increase the quantity of the electrode foils and to stabilize the manufacturing process at a high throughput. Among other measures the coating width was doubled which allows a significantly increased coating rate (see figure 2). For the successfull completion of this project, a new slurry preparation system will be obtained in 2012 in order to increase the foil output at high quality. Dispatch Energy GmbH will offer complete storage systems starting in 2012 (see figure 4).

FSEM: FRAUNHOFER ISIT-RESULTS OF CHARACTERIZATION OF MATERIALS FOR RECHARGEABLE LITHIUM-BATTERIES DEVELOPED AT FHG IN HALF CELL AND FULL CELL CONFIGURATION

The department of Integrated Power Systems at Fraunhofer ISIT has been active for over 10 years in developing rechargeable lithium polymer batteries with an emphasis on special user-specific needs. In the framework of "Fraunhofer Systemforschung Elektromobilität" (FSEM) advanced materials have been synthesized and characterized in half-cell- (HC) and full-cell (FC) configuration.

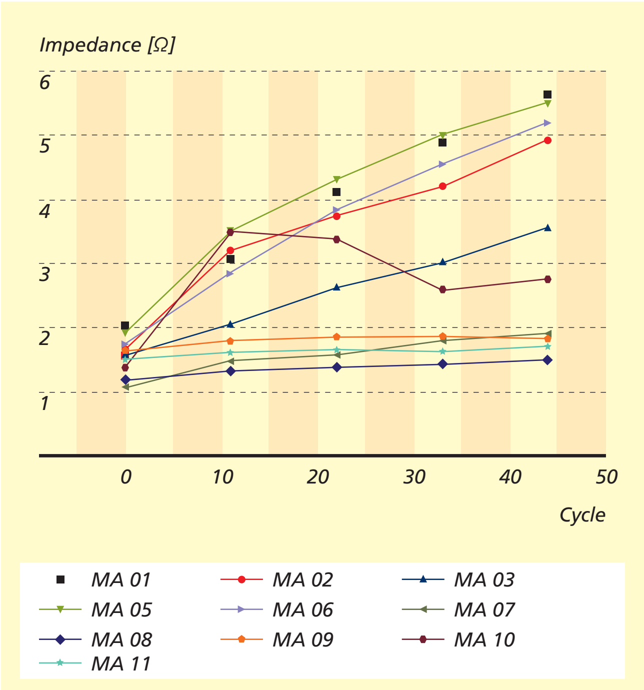


Figure 1: Cells with graphen based coating (MA 07 – MA 11) showed after 45 full cycles a significant lower impedance compared to cells with a standard collector-coating (MA 01 – 06)

The work necessary for optimizing of electrochemically active foils has been carried out at laboratory scale. The electrochemical characterization of the electrode foils are initially done in half-cells. Next, small and scalable full-cells have been manufactured to determine the properties of the full system consisting of the anode, cathode, and separator.

Finally all materials provided by the FHG-partners and the processes developed at Fraunhofer ISIT in the framework of FSEM have been integrated in order to achieve optimized demonstrator cells (C= 220mAh) showing the following features:

- graphen-based conductive collector coating reducing cell impedance (IWS)
- High power NCM-cathode material (IKTS)
- Carbon-nano-tubes (CNT) improving electronic conductivity (IWS)
- Ion conductive ceramic filler for improvement of separator functionality (IKTS)

Cells (see figure 1) with the innovative graphen based collector coating (MA 07 – MA 11) showed a significant lower cell impedance after cycling compared to cells with standard coating (MA 01 – 06). This in turn allows for a better load capability even with aged cells.

Full cells containing the proprietary NCM for Fraunhofer IKTS showed a better high power performance than cells with reference cathode material of the same chemical formulation provided by a renowned commercial supplier of cathode materials (see figure 2).

Moreover, the integration of all the proprietary materials developed at FHG and integrated at Fraunhofer ISIT into fully functional prototype cells resulted in a cycle stability comparable with or superior to mature commercial materials (see figure 3).

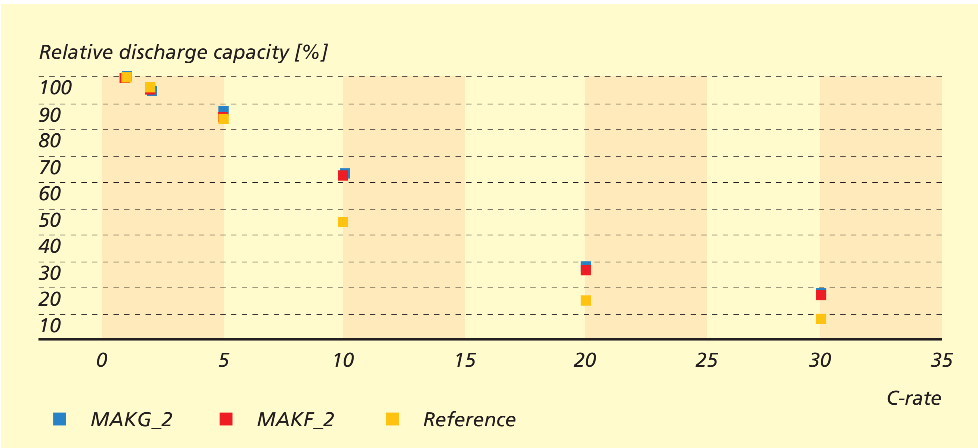


Figure 2: Load capability of cells with IKTS-cathode material (MAKG_2, MAKF_2) compared to a commercial reference material (Reference)

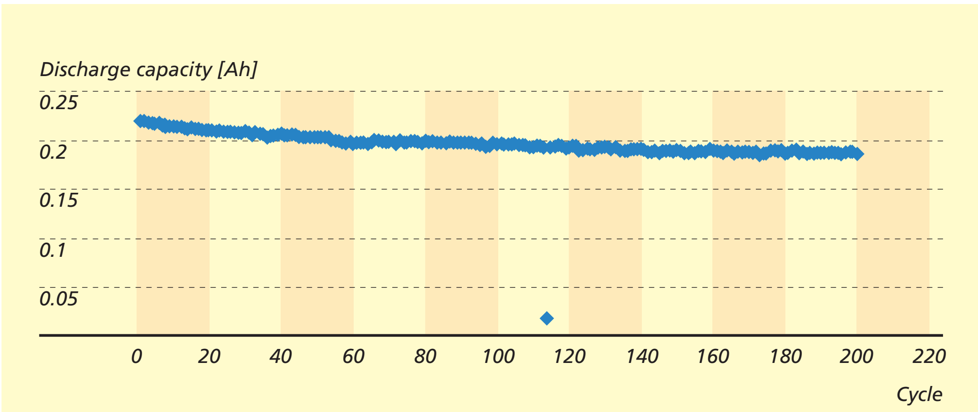
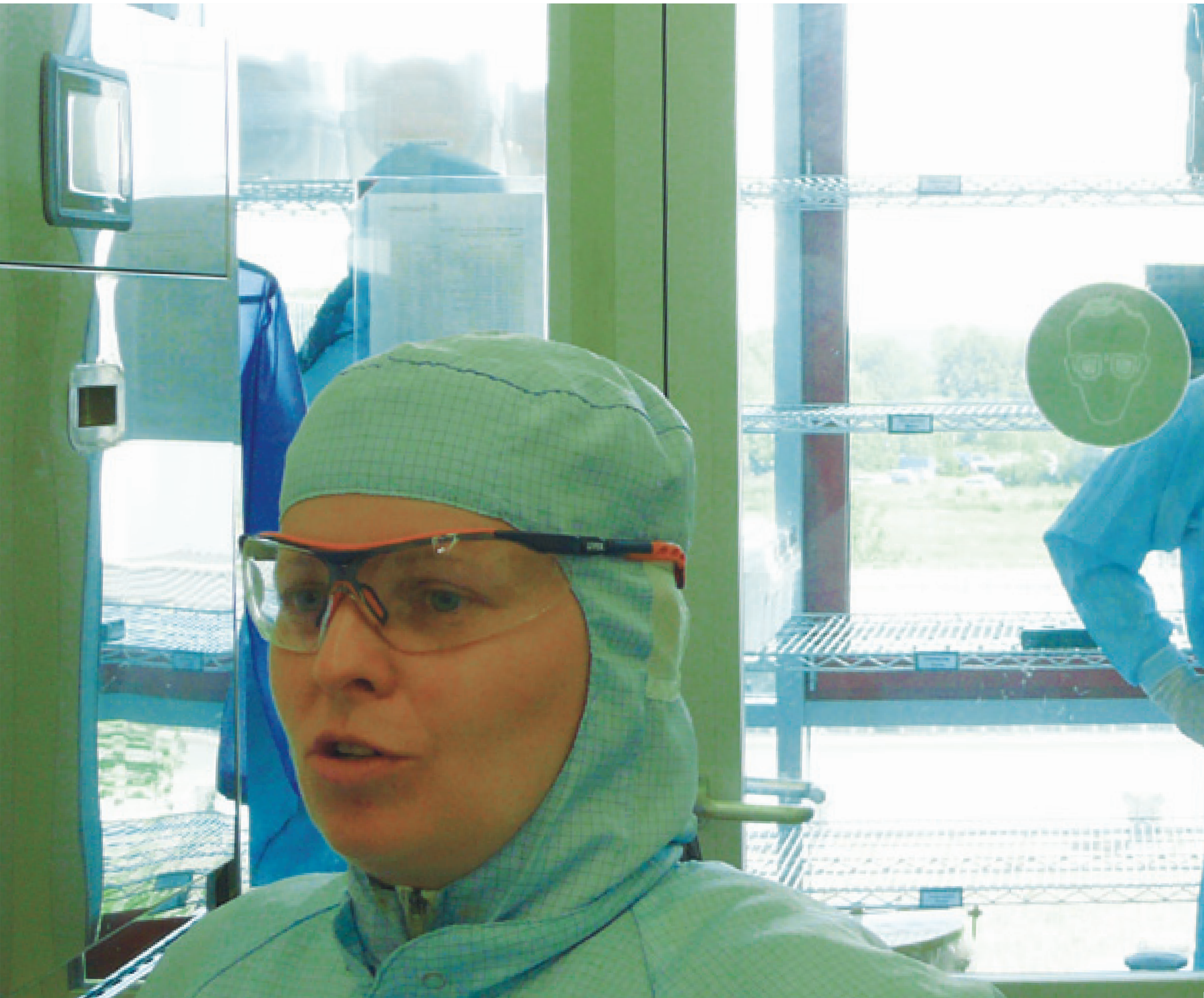


Figure 3: Cycle stability of a full functional MALION prototype (full cell) containing all proprietary materials developed at Fraunhofer

Components and Lithium polymer secondary batteries with different form factors



IMPORTANT NAMES, DATA, EVENTS

LECTURING ASSIGNMENTS AT UNIVERSITIES

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Slovac Academy of Sciences, *Bratislava, Slovakia*

University of Cardiff, *Great Britain*

Fachhochschule Vorarlberg *Dornbirn, Austria*

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Technische Universität Dresden, Institut für Halbleiter- und Mikrosystemtechnik

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Fachhochschule Kiel

IMEC, *Leuven, Belgium*

Fachhochschule Lübeck

Westfälische Wilhelms-Universität, *Münster*

University of Neapel, *Italy*

Sintef ICT, *Oslo, Norway*

École Polytechnique, *Paris, France*

University of Perugia, *Italy*

University of Pisa, *Italy*

Universität Rostock

Süddänische Universität, *Sonderburg, Denmark*

IMS Chips, *Stuttgart*

VTT, Technical Research Center of Finland, *Tampere, Finland*

FBK, *Trento, Italy*

University of Turin, *Italy*

University of Twente, *Netherlands*

Fachhochschule Wedel

Institut für Polymertechnologien, *Wismar*

TRADE FAIRS AND EXHIBITIONS

Arab Health 2011
in Cooperation with Norgenta; Norddeutsche Life Science Agentur, January 24 – 27, 2011

BATTERY JAPAN, 2011
2nd International Rechargeable Battery Expo, in cooperation with Fraunhofer Netzwerk Batterien, March 02 – 04, 2011, Tokio, Japan

New Energy 2011
March 17 – 20, 2011, Husum

SMT 2011
Hybrid Packaging System Integration in Micro Electronics, May 03 – 05, 2011, Nürnberg

Control 2011
International Trade Fair for Quality Assurance, May 03 – 06, 2011, Stuttgart

PCIM 2011
International Exhibition & Conference, Power Conversion Intelligent Motion, May 17 – 19, 2011, Nürnberg

Transducers 2011
The 16th International Conference on Solid-State Sensors, Actuators and Microsystems, June 05 – 09, 2011, Beijing, China

Sensor 2011
The Measurement Fair, June 07 – 09, 2011, Nürnberg

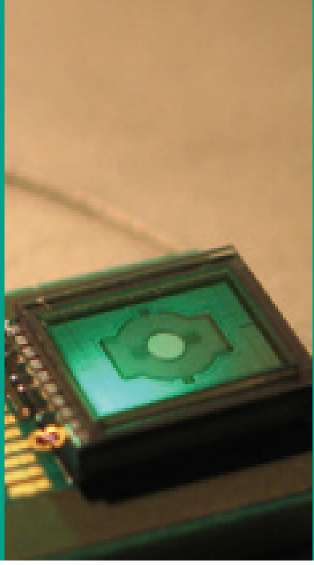
MST Kongress 2011
October 10 – 12, 2011, Darmstadt

Jobaktiv Metropolregion Hamburg 2011
Akademiker im Norden, October 19, 2011, Hamburg

Vision 2011
International Trade Fair for Machine Vision, November 08. – 10, 2011, Stuttgart

Productronica 2011
19. International Trade Fair for Innovative Electronics Production, November 15 – 18, 2011, München

Medica 2011
November 16 – 18, 2011, Düsseldorf



MISCELLANEOUS EVENTS

Aspekte moderner Siliziumtechnologie
Public lectures, monthly presentations, Fraunhofer ISIT, Itzehoe

Praxisorientierte Prozessoptimierung in der elektronischen Baugruppenfertigung
Seminar: February 07 - 11 and December 05 – 09, 2011, Fraunhofer ISIT, Itzehoe

ISIT Presentation in framework of „Macht mit bei Mint – Zukunftsberufe für Frauen"
Information day for schoolgirls, initiated by Volkshochschulen Kreis Steinburg, February 08, 2011, Fraunhofer ISIT, Itzehoe

Die beherrschbare Baugruppenfertigung
Seminar: February 23 – 25 and October 05 – 07, 2011, Fraunhofer ISIT, Itzehoe

Der optimierte Rework-Prozess
Seminar: March 23 – March 25 and November 23 – 25, 2011, Fraunhofer ISIT, Itzehoe

26. CMP Users Meeting
April 15, 2011, Fraunhofer ISIT, Itzehoe

Ministerpräsident Carstensen überreicht Bewilligungsbescheid für den Ausbau des Fraunhofer ISIT
Festive event on the occasion of the presentation of the approval notification in the amount of € 27.45 million for the expansion of the Fraunhofer ISIT. Speaker: Peter Harry Carstensen, Prime Minister of Schleswig-Holstein, June 15, 2011, Fraunhofer ISIT, Itzehoe

Microscopy Conference 2011
ISIT Posterpresentation, August 28 – September 2, 2011, Kiel

Open Day of Hightech Itzehoe
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J. Lähn
Fortführung der Temperaturmessungen in Konvektions- und Kondensationslötsystemen. ISIT-Seminar: Temperaturmesstechnik, Itzehoe, September 27, 2011

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Hochstromleiterplatten und geeignete Verbindungstechniken. ISIT-Seminar: Die beherrschbare Baugruppenfertigung, Itzehoe, February 23 – 25, 2011

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Zuverlässigkeit von Baugruppen. ISIT-Seminar: Die beherrschbare Baugruppenfertigung, Itzehoe, February 23 – 25, 2011

M. H. Poech
1) Werkstoffe der AVT I.
2) Werkstoffe der AVT II.
3) Passive Bauelemente, Schaltungsträger, Kühlkörper.
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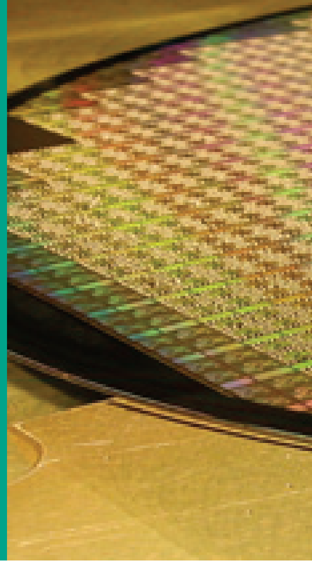

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1) Modellierung der thermischen Vorgänge im Reflow-Lötprozess.
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Baugruppen- und Fehlerbewertung , Inspektionskriterien, bleifreie Lötstellen. ISIT-Seminar: Die beherrschbare Baugruppenfertigung, Itzehoe, February 23 – 25, 2011

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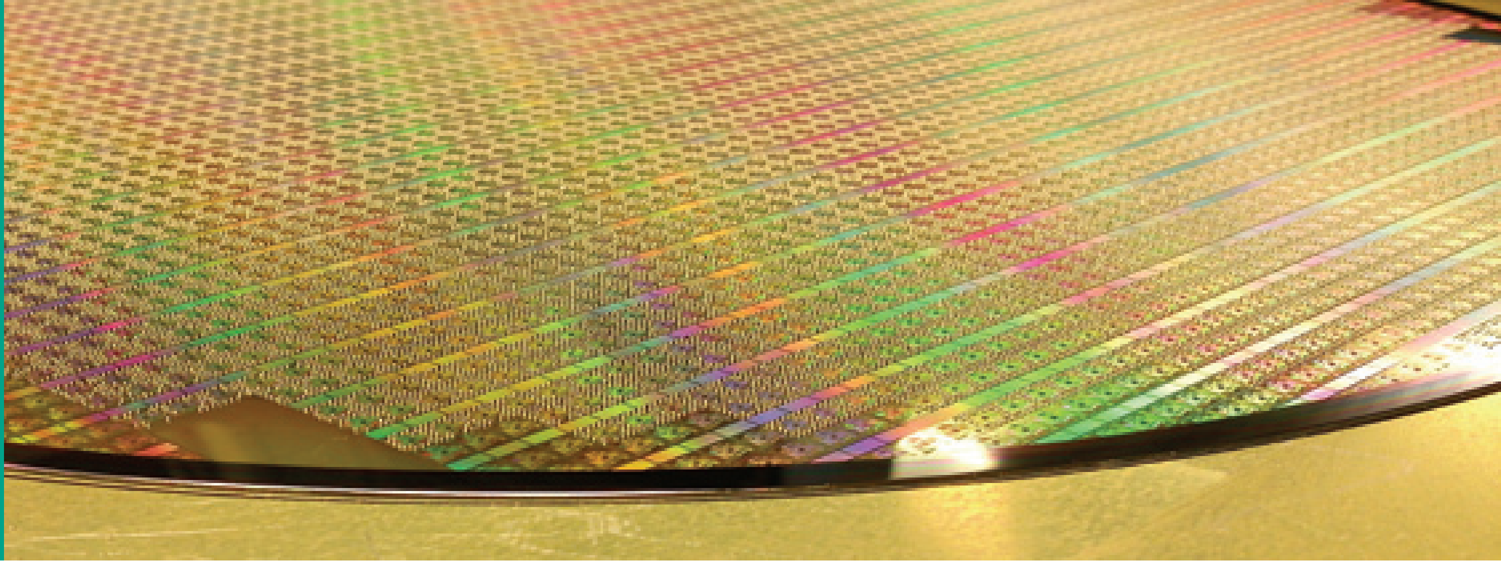

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Wie komme ich zu einem Reflow-Lötprofil. ISIT-Seminar: Temperaturmesstechnik, Itzehoe, September 27, 2011

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Performance Investigation on Lithium-Ion Cells with Different Electrode Thicknesses for Application in Wafer-Integrated Microbatteries. 220th Electrochemical Society Meeting, Battery Systems Symposium, Boston, USA, October 09 – 14, 2011

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Yassin Bouslama
Untersuchungen zur Verbesserung des aktiven Cell balancing eines Batteriemanagement-systems. Bachelor's thesis, FH Flensburg, September 1, 2011

Dörte Carstens
Erstellung eines datenbankbasierten Statistik-Reporting-Tools zur produktionsrelevanten Bewertung von Testdaten auf Waferebene. Bachelor's thesis, FH Flensburg, September 1, 2011

Maria Claus
Entwicklung einer metallischen Niedertemperatur-Verbindungstechnik für Siliziumwafer. Master's thesis, CAU Kiel, November 18, 2011

Nils Heitmann
Ein energiesparendes Batterie-Management-System mit Ethernet, Bachelor's thesis, FH Wedel, September 2011

Arne Krudopp
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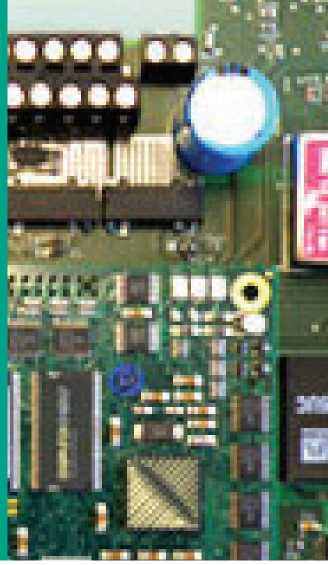

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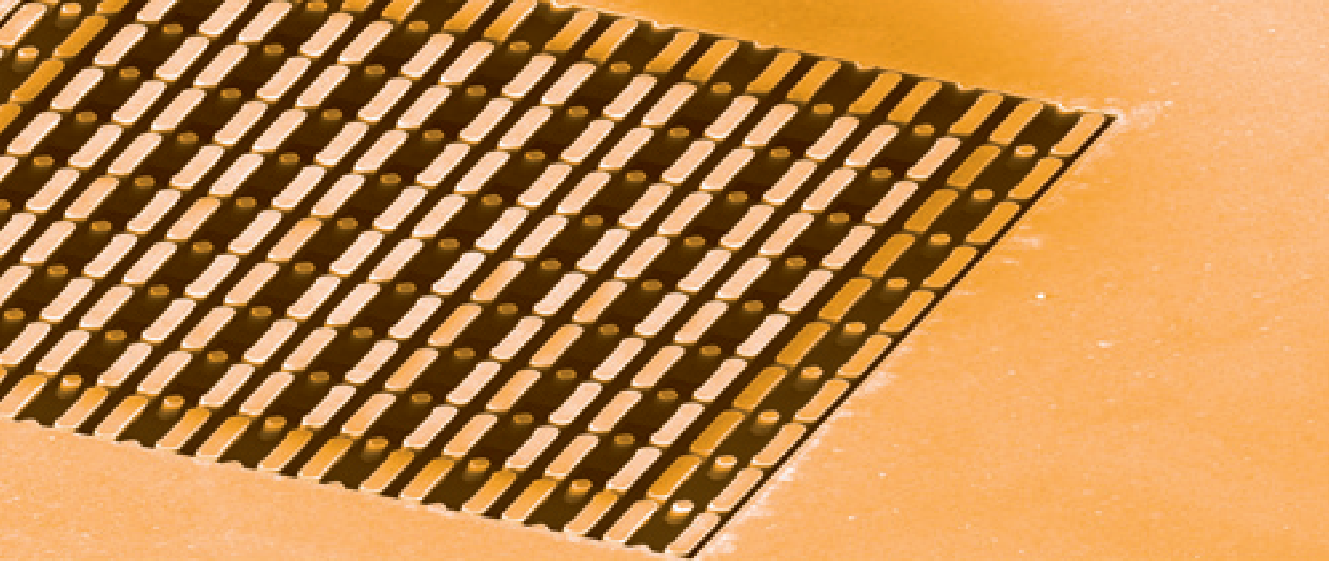

OVERVIEW OF PROJECTS

- Kompetenzzentrum Leistungselektronik Schleswig-Holstein
- Ultrakompakte Leistungsmodule höchster Zuverlässigkeit ULTIMO
- Simulationsstudie für Fast Recovery Dioden
- Energie-Effiziente Elektrische Antriebstechnik: Neue Umrichterkonzepte
- Lochmembranen im sub-0,5µm Bereich
- Entwicklung neuer Ansätze für RC-IGBTs
- Super Junction PowerMOS
- Ultrathin Trench IGBTs on sub-100 µm Si-Substrates
- Untersuchung von Ceroxid-Dispersionen für CMP
- Entwicklung von poly-Si CMP Prozessen für die MEMS Herstellung
- Energy-Efficient Piezo-MEMS Tunable RF Front-End Antenna Systems for Mobile Devices (EPAMO)
- 9 D Sense; Development of Magnetic Field Sensors

- Untersuchung an mikromechanischen Drehraten-Sensoren
- Entwicklung von kapazitiven HF-Schaltern
- Entwicklung von piezoelektrischen Schichten für Si-Mikroaktuatoren
- Herstellung mikrooptischer Linsenarrays aus Glas
- Mikrolinsen aus Borosilikat-Glas
- RF-MEMS Packaging
- High Volume Piezoelectric Thin Film Production Process for Microsystems, Piezo Volume
- Entwicklung von PZT-Schichten
- Mikroscan-Systeme für Display Anwendungen
- Herstellung mikrotechnischer analoger Ablenkeinheiten
- Magnetoelektronische Sensoren (Sonderforschungsbereich 855 der Uni Kiel)
- Entwicklung von LIDAR Systemen, MiniFaros
- Development and Fabrication of 256k CMOS Blanking Chips for Maskless Lithography

- Development of an ASIC for the control of BLDC-motors
- Dünnfilm Transducer PIETRA
- Silizium basierte Hochtemperatur-Thermogeneratoren auf 8“ Wafer-Level (SIEGEN)
- Zero- and first-level packaging of RF-MEMS (MEMSPACK)
- Parallele Vermessung von mikromechanischen Inertialsensoren auf Waferebene
- 3D-Signage
- MEMS-Chromatographiechip für portable Analysesysteme MiChroChip
- Zellfreie Bioproduktion
- ivD-WISA, in vitro Diagnostik Plattform
- Zuverlässige Kontaktierung von Höchstleistungs-bauelementen in der Leistungselektronik durch innovative Bändchen- und Litzenverbindungen (MAXIKON)

- Produktionsgerechtes reaktives Nanofügen zum hermetischen Versiegeln von Mikrosensoren auf Waferebene (REMTEC)
- MIT-Modularer In-Mould Transponder
- ZIM-Projekt im Rahmen des Konjunkturprogramms II der Bundesregierung
- Glassfritt Vacuum Wafer Bonding
- Glaslotbonden mit strukturierten Capwafern und Musterwafern
- Wafer Level Packaging
- Process Development for Hermetic AuSn Vacuum Sealing of IR Sensors on Wafer Level
- Wafer Level Balling for 100 µm up to 500 µm Spheares
- Neon Ultra Fine Leak Test for Resonant Micro Sensors
- Solder Flip Chip on Flex
- Prozessoptimierung beim Selektivlöten für Anwendungen in der Leistungselektronik

- *Zuverlässige Kontaktierung von Höchstleistungsbauelemente in der Leistungselektronik durch innovative Bändchen-Litzenkontaktierung (MAXICON)*
- *Entwicklung von modularen In-mould Transpondern (MIT), Transponder für Einwegkisten*
- *Zuverlässige Ag-sinterkontaktierte Halbleiterbauelemente für die regenerative Energietechnik (ZuSi)*
- *UV-Detektoren AlGaN (AGNES)*
- *Hochzuverlässige Stromrichter für Windenenergieanlagen (HiReS)*
- *Tiefsee-Inspektions- und Explorations Technologie (TIETeK)*
- *Qualitätsbewertung an bleifreien Baugruppen*
- *Lötwärmebeständigkeit und Zuverlässigkeit neuer Konstruktionen im manuellen Reparaturprozess bleifreier elektronischer Baugruppen (AiF-Projekt)*
- *Prozessoptimierung beim Selektivlöten für Anwendungen in der Leistungselektronik*
- *Assistance for Electronics Manufacturers in the Transformation to RoHS Compliant Products and Processes*
- *Untersuchung zu den thermischen und prozesstechnischen Eigenschaften von Flussmitteln für bleifreie Lötlegierungen auf hochzuverlässigen Baugruppen*
- *ZuSi- Zuverlässiger Ag- sinterkontaktierte Halbleiterbauelemente für die regenerative Energietechnik*
- *Ionische Liquide für elektrochemische Applikationen (IL-Echem)*
- *Amagnetische Lithiumzellen*
- *Flottenversuch Elektromobilität*
- *Hochenergie-Lithiumbatterien für die Zukunft- HE-LION*
- *Hochleistungslithiumbatterien mit Nanopartikeln in Core-Shell-Technologie LINACOR*
- *Entwicklung einer Zelltechnologie für Solarstrom-Zwischenspeicherung*
- *Hochenergie-Lithiumbatterien für die Zukunft (HE-LION)*
- *MALION (FSEM_I)*
- *European Li-Ion Battery Manufacturing for Electric Vehicles (ELIBAMA)*

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