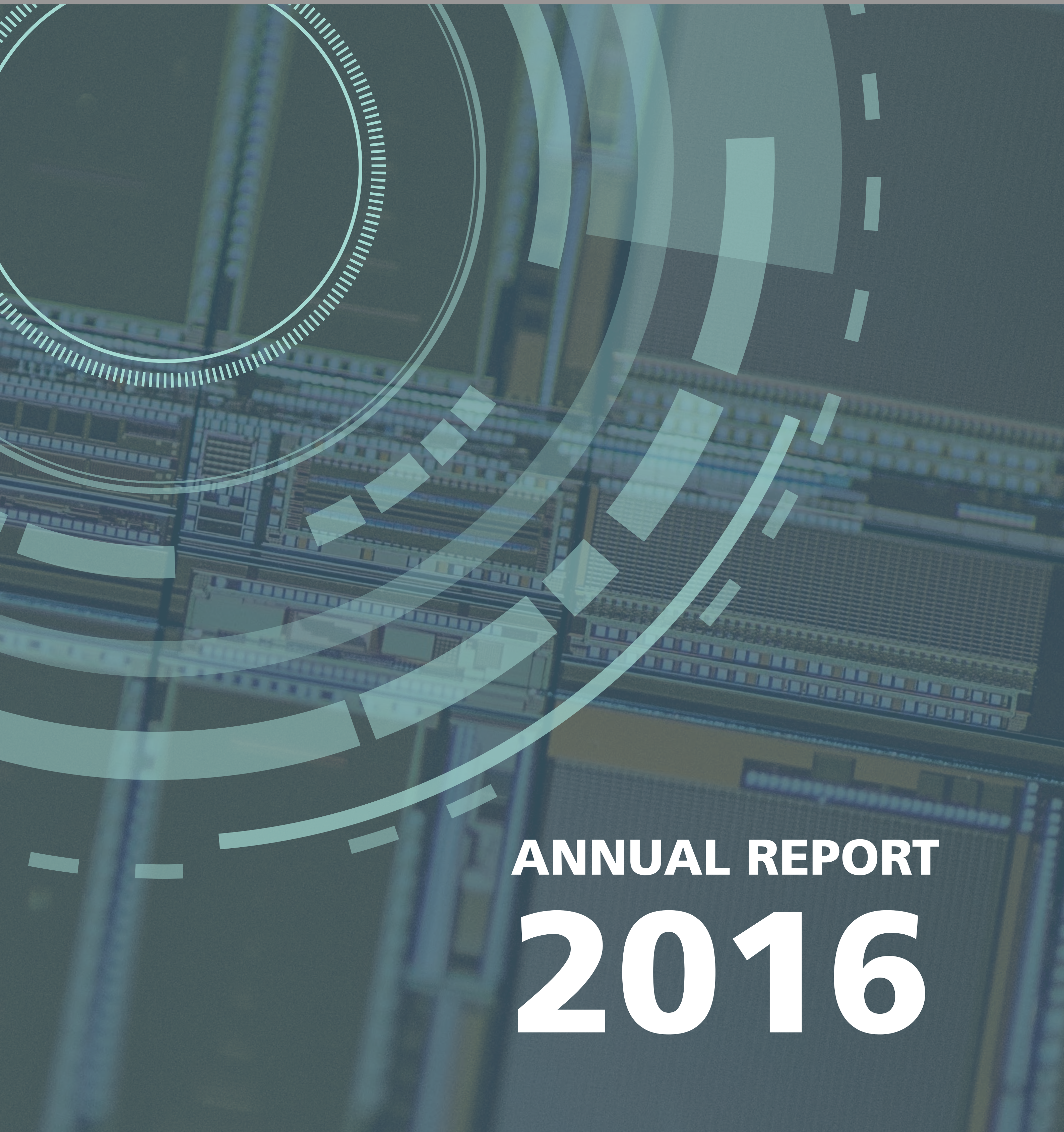
Fraunhofer

IMS

FRAUNHOFER INSTITUTE FOR MICROELECTRONIC CIRCUITS AND SYSTEMS



ANNUAL REPORT 2016

Contents

Dear readers,
dear friends and partners,

They are the sensory organs of today's industry and in a world of intelligent and linked products find varied and widespread application: modern sensors belong right at the beginning of the chain of technical information-processing and take an important strategic role, especially in industry 4.0. These sensors are also omnipresent in many other fields, such as in environmental monitoring or medical technology. The speed at which technical progress moves forward in this field is breathtaking: sensors today can measure, examine, sort, accelerate – and see!

In our Annual Report 2016, we focus on the various optical sensors and complex image-recognition systems which are researched and developed at our institute. Optical sensors are used for contactless presence and distance detection and to count and detect objects. They are a megatrend in the automotive industry, as the intelligent optical sensor systems are system-critical components in autonomous vehicles, making this an important and sustainable application field. Within microsystems technology, the optical technologies represent an extremely promising and dynamic future business segment that is characterized by strong growth prospects. With the following selection of seven research and product descriptions, we would like to give you, dear reader, an overview of our research and development focuses as well as a glimpse into the various practical application possibilities of optical sensor systems.

With our "COMS Imaging Workshop," that takes place every two years, we share our know-how in this field with interested participants from industry, the automotive branch and research. This workshop helps us remain in constant exchange with the industry's drivers of innovation. The core topics of the workshop that took place in May 2016 at our Fraunhofer-inHaus-Zentrum, with more than 100 participants, included SPADs, 3D sensors as well as testing and application in the field of ADAS (Advanced Driver Assistance Systems).

Besides intelligent image-recognition systems and optical sensor solutions, even high-temperature electronics belong to the emerging markets of today. At the end of November 2016, Fraunhofer IMS organized the third "High Temperature Workshop" to provide a platform for experts of industry, university institutions and research institutes. The workshop covered a wide range of topics related to high-temperature technologies. Beyond that, questions about high-temperature assembly were touched on and diverse industrial applications were presented.

In 2015 we celebrated our institute's 30th anniversary with a successful anniversary ceremony, and in 2016 we again had reason to celebrate: The institute's Fraunhofer-inHaus-Zentrum had its 15th birthday. The history of the Fraunhofer-inHaus-Zentrum began early in the year 1990, with the evolution of initial ideas and concepts at Fraunhofer IMS.

Later, five Fraunhofer Institutes formed a strategic alliance to work out "integrated house systems for resource-conserving living." This formed the technological core of the inHaus system integration as well as the network of business partners and institutes of the inHaus-Zentrum. The planning and subsequent construction phase on a 1000 m² lot close to Fraunhofer IMS was followed by the opening of the inHaus1 research facility in April 2001, a facility that focuses on our "Living" business unit. Shortly afterwards, initial plans for an expansion of research activities in the field of commercial buildings and a corresponding new research facility – inHaus2 – were developed. With the support of the EU, the German Federal Ministry of Education and Research (BMBF), the headquarters of the Fraunhofer-Gesellschaft, the federal state of North Rhine-Westphalia (NRW) and the city of Duisburg, and additional support from industry partners, the construction project got underway in 2007. The official opening of inHaus2 took place in November 2008.

Today, this think tank with its various practical application laboratories allows innovative systems and products to be developed, tested and demonstrated by means of collaborative research and development activities. The current focus is on the fields of energy efficiency, room and building systems and the (ongoing) development of smart measuring and energy systems. In 2016 the activities of the inHaus-Zentrum were centered on the development of future-oriented products and services for the health and care sector – always keeping the needs of the individual in mind. The 7th inHaus Forum in November 2016 was also focused on the topic of health. Under the motto "When Technology Promotes Healing – Physicians in a World of Web Therapy, Apps and Wearables," the program offered almost 90 guests a combination of exciting presentations and an innovative workshop that allowed participants to actively and creatively contribute. During the forum – which was attended by many doctors who have their own practices, scientists and university students – many interesting questions were answered and different aspects of "healing technology" and "wearable health care" were discussed.

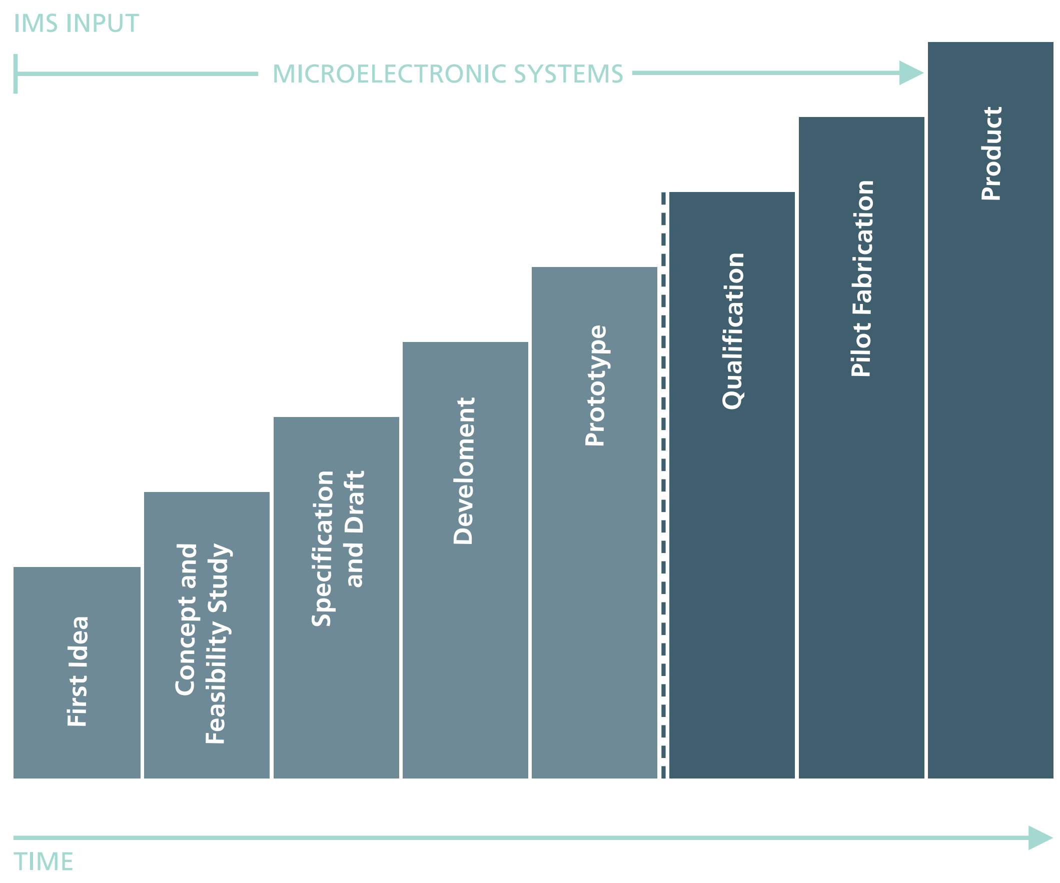
In closing, I would like to express my gratitude to all employees of Fraunhofer IMS for their work in 2016. Let us together meet the challenges of the upcoming business year with confidence, enthusiasm and a spirit of innovation.

A special thank you also goes to our customers, who confirmed their trust in us again this year. We are looking forward to continued successful collaboration with you!

Prof. Dr. rer. nat. Anton Grabmaier, director

In this chapter:

FROM CONCEPT TO PRODUCT



Our business units

- *ASICs*
- *Wireless and Transponder Systems*
- *Electronic Assistance Systems*
- *Pressure Sensor Systems*
- *CMOS Image Sensors*
- *IR Imagers*
- *Devices and Technologies*
- *Biohybrid Systems*

Step by step to project success

The way to a successful project is work-intensive and requires good planning. Step by step, the following project phases are passed through.

- *Concept and feasibility studies*
- *Specification and design*
- *Demonstrator development*
- *Prototype development*
- *Qualification*
- *Pilot fabrication (for microelectronic systems)*

Our technological core

- *Semiconductor processes*
- *CMOS and SOI technologies*
- *Microsystems technology*
- *Component and system developments*
- *Nano-(Bio)technologies*

YOUR IDEA – WE WILL IMPLEMENT IT

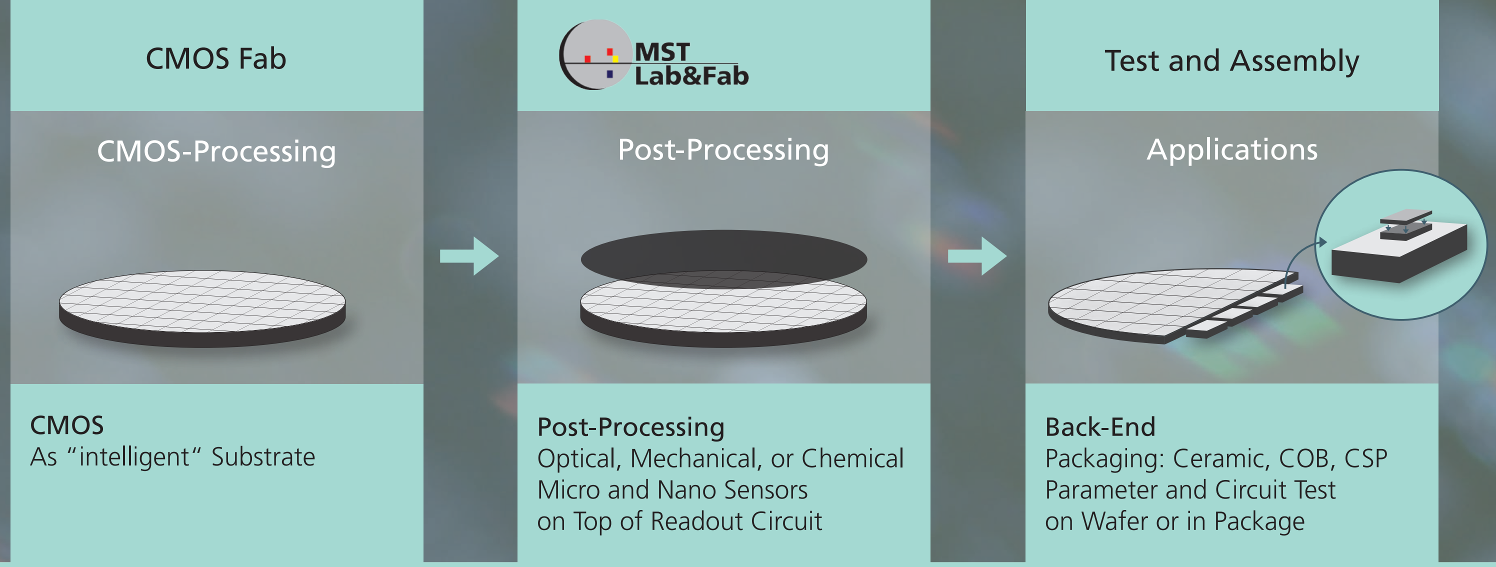
In the beginning there's your idea or vision for a new product, but you don't know if it is feasible, which costs you will have to face, if there are potential risks and which technology leads to the optimal product. As a research and development institute of the Fraunhofer-Gesellschaft, we offer you our support.

We accompany your development with concept and feasibility studies from the first moment – via specification and design, draft and fabrication of prototypes through to the product qualification. The pilot fabrication of your circuits and ICs is carried out by us as well. With us, you get microelectronics from a single source.

We provide our service and know-how across all industries. Our circuits and systems are especially used where it's all about the creation of unique selling points and competitive advantages for our customers. Then, our customer is able to serve his target market in an optimal way.

Quality pays off
Fraunhofer IMS has been certified according to DIN EN ISO 9001 since 1995. The certificate is valid for all divisions of the institute: research, development, production and distribution of microelectronic circuits, electronic systems, microsystems and sensors as well as consulting in these fields. The CMOS line is certified according to ISO/TS 16949.

Your project success is our mission.



FROM WAFER TO SYSTEM

At Fraunhofer IMS our field of attention has been, since its foundation in 1984, semiconductor technology and the development of microelectronic circuits and systems. The type and bandwidth of our infrastructure is extremely efficient; we have the experience and know-how in our eight business units. During our contract work we focus on strong, efficient and marketable developments. We offer comprehensive technologies and procedures which are applied in almost all industries. Application-specific adaptions to the requirements of our customers are the major focus of our work.

Infrastructure

CMOS line

Wafer size	200 mm (0.35 µm)
Cleanroom area	1300 m²
Employees	150 in 4 shifts
Capacity	> 50,000 wafers/year

Test and assembly

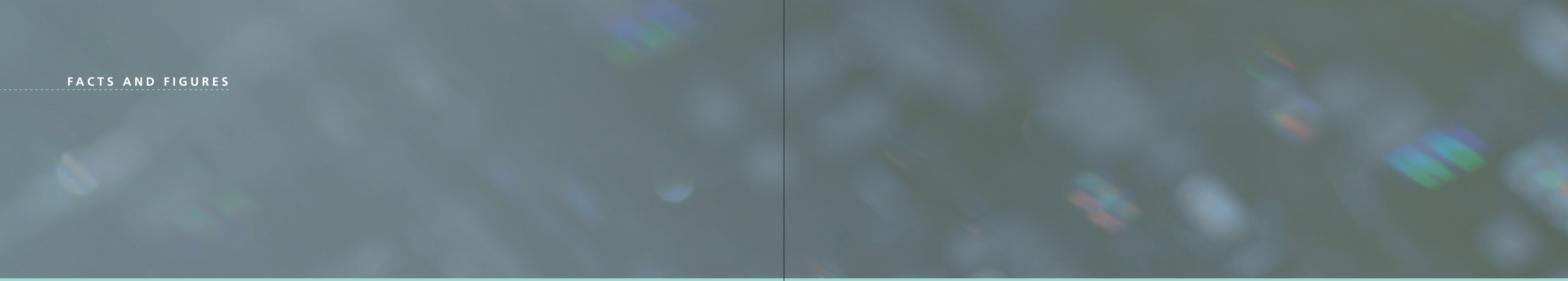
Wafer size	200 mm
Cleanroom area	1200 m²
Test	5 test systems
IC assembly	Sawing and thinning of wafer, Chip-On-Board Die and wire bonding

Microsystems technology lab & fab

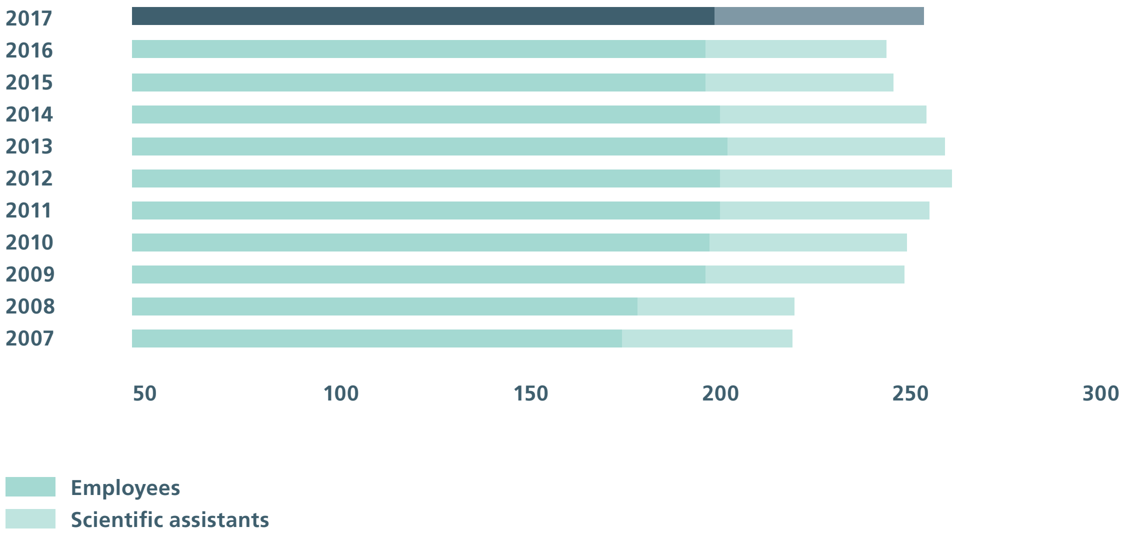
Wafer size	200 mm (0.35 µm)
Cleanroom area	600 m²
Capacity	5,000 wafers/year

Laboratories

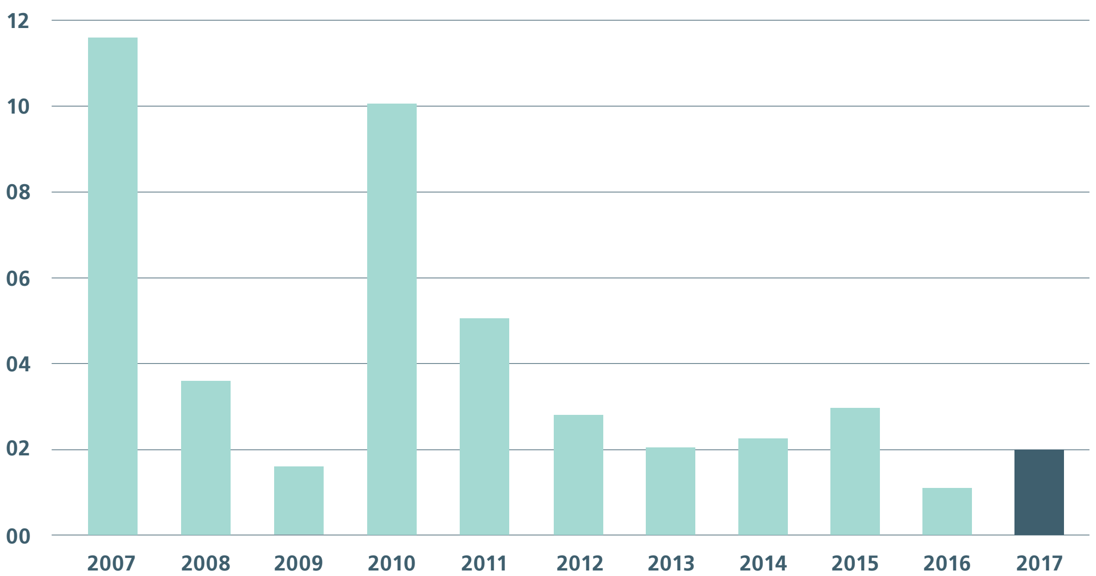
Biohybrid sensors	45 m²
inHaus-Center	3500 m²
Laboratory space	800 m²
High-frequency measurement chamber	24 m²



STAFF MEMBERS



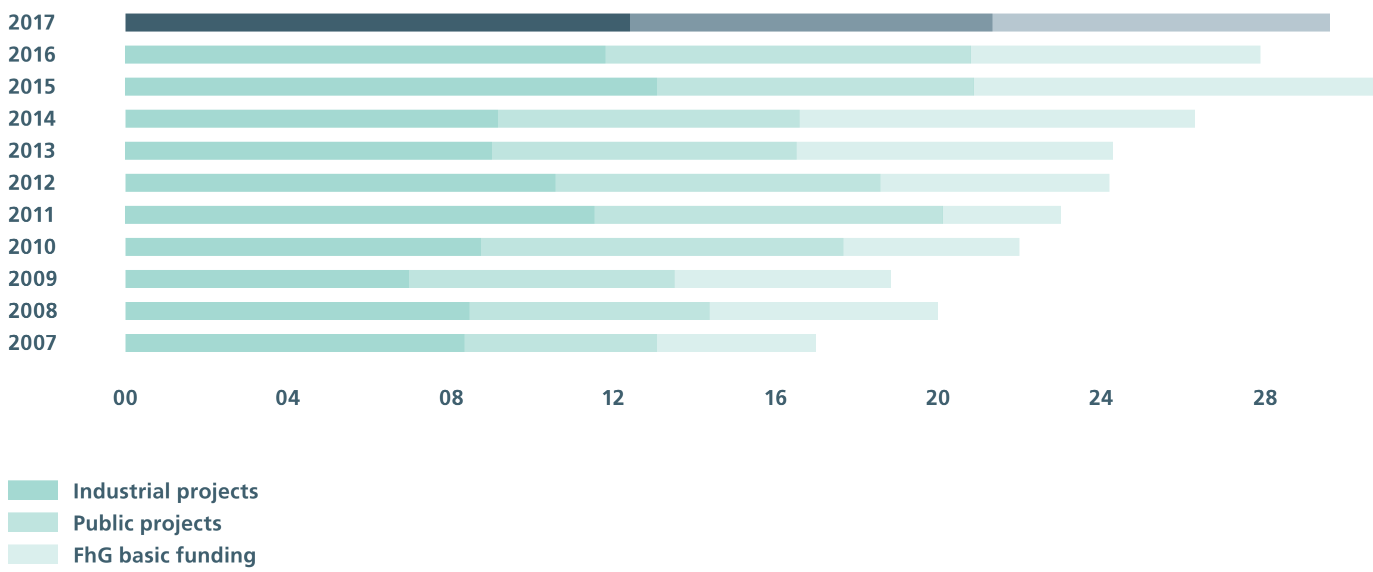
CAPITAL INVESTMENTS (in million euros)



"Let us together meet the new challenges in the coming financial year again with confidence, innovation instinct and full of beans."

Prof. Anton Grabmaier

BUDGET (in million euros)



ORGANIZATIONAL CHART

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Prof. Anton Grabmaier

DEPUTY DIRECTOR
Prof. Holger Vogt

PRESSURE SENSOR SYSTEMS
Görtz

CMOS IMAGE SENSORS
Brockherde

WIRELESS AND TRANSPONDER SYSTEMS
Dr. vom Bögel

ASICS
Dr. Vogt

ELECTRONIC ASSISTANCE SYSTEMS
Kemmerling

DEVICES AND TECHNOLOGIES
Dr. Goehlich

IR IMAGERS
Dr. Weiler

BIOHYBRID SYSTEMS
Görtz

INHAUS-CENTER
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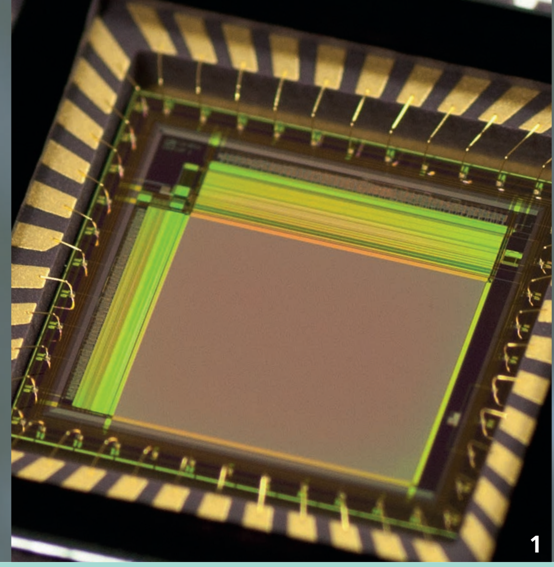
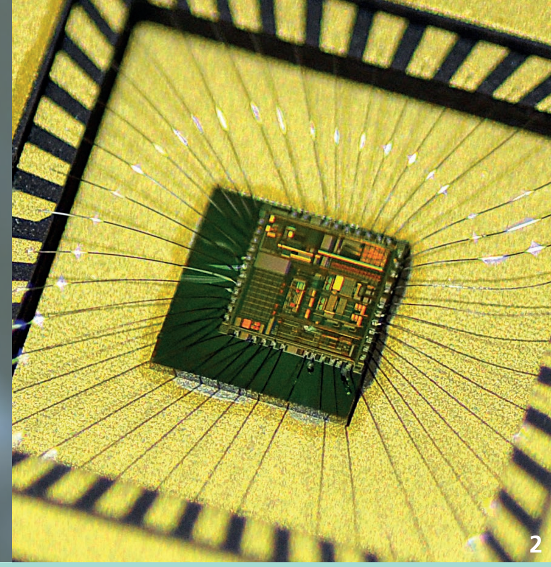
8 Business units

1 Innovation center





1 *High frame rate eye sensor for lasik surgery*

2 *MEMS accelerometer readout IC*

DEVICES AND TECHNOLOGIES

Our in-house CMOS line is the technological foundation of our institute. It provides professionally operated and acknowledged automobile quality in robust 0.35 µm technology on a 200 mm wafer. At Fraunhofer IMS, all of the processes are developed and augmented with additional process modules, such as special optical devices, pressure sensors or high voltage components.

Integrating new materials or micromechanical structures does not simply happen by accident, because a CMOS line needs to impose restrictions in order to maintain a high level of quality. That's why we assembled a separate microsystems-technology line (MST Lab & FAB) for the "post-processing".
CMOS wafers serve as an intelligent substrate. They contain control and readout circuits, signal processing and conversion, as well as external interfaces for wireless power and data transmission.

On these wafers, these substrates, layers and structures are separated in order to create new components. The overall aim of this development is compact, "intelligent" microsystems.

Supply and services/technologies:

- *MST process development*
- *Onto CMOS integrated microsystems*
- *200 mm (0.35 µm) wafer size*
- *CMOS process development and components*
- *SOI processes*
- *Development and consulting for the semiconductor industry*

ASICs

"From the concept up to the pilot fabrication" is the maxim of Fraunhofer IMS. We provide our customers professional analogue or mixed signal ASIC design solutions – from the concept up to verified silicon for "ready to use" ASICs products for the application in several areas.

In doing so, we support our customers with our large system know-how. In addition to implementations in various standard CMOS technologies, we especially allocate design and technology solutions for high temperature, high voltage and sensor systems applications.

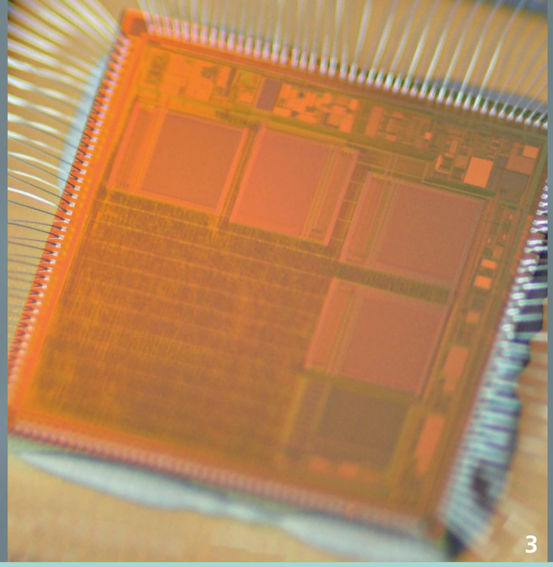
Special circuit parts or sensor system components are individually and custom-designed and integrated with standard components like sensor readout, signal processing, interface components or embedded micro controllers on an IC.

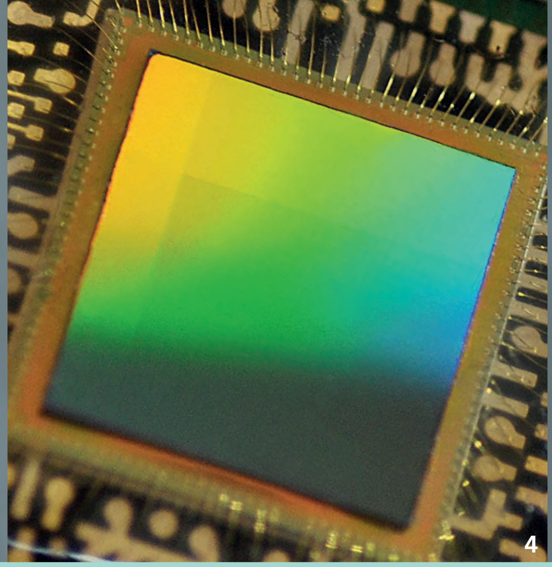
Supply and services/technologies:

- *Sensor interfaces*
- *Analogue ICs*
- *Signal conversion*
- *Digital signal processing*
- *Integrated sensors*
- *Customized packages and tests*
- *Energy-optimized solutions*
- *Pilot fabrication*

HIGH TEMPERATURE ELECTRONICS

Microelectronics is a key technology used in more or less any application. With increasing complexity and demand for performance in harsh for harsh environments, especially at high temperatures, standard electronics has reached its limits. Depending on the grade, integrated circuits are specified for a maximum operational temperature of up to 125 °C. Nevertheless, sensors and actuators are used





in industrial processes with high temperatures, while commonly deposited electronics are used, which requires additional space and results in a loss of performance.

Fraunhofer IMS's thin film Silicon-on-Insulator (SOI) CMOS technology makes it possible to overcome the abovementioned limits. Besides the CMOS-specific components, the technology is equipped with non-volatile memory based on EEPROM.
Based on this technology we realize integrated circuits for the extended temperature range of up to typical 250 °C and above.

We can support your entry into the field of high temperature electronics with concept and feasibility studies. We also understand your customer-specific HT ASICs, including pilot fabrication and comprehensively support system integration, including the assembly aspects.

Supply and services/technologies:

- *High temperature SOI CMOS technology*
- *Concept development and system specification*
- *Mixed signal integrated circuit design*
- *Application support*
- *Pilot fabrication in our CMOS facility*
- *Assembly*
- *Test and verification*
- *Reliability analysis*
- *Feasibility studies*

IR IMAGERS

Infrared imager "see" in a wavelength range from the near to longwave infrared. These thermal image sensors are called focal plane arrays and are one- or two-dimensional lines of IRsensitive pixels. They are based on radiation sensitive structures and use silicon technology, where CMOS readout circuits are integrated on a microchip. That's how complete image sensor chips are developed.

Our customer-specific applications are utilized in the automotive industry, where driver assistance, night vision and pedestrian detection are focal points of development.

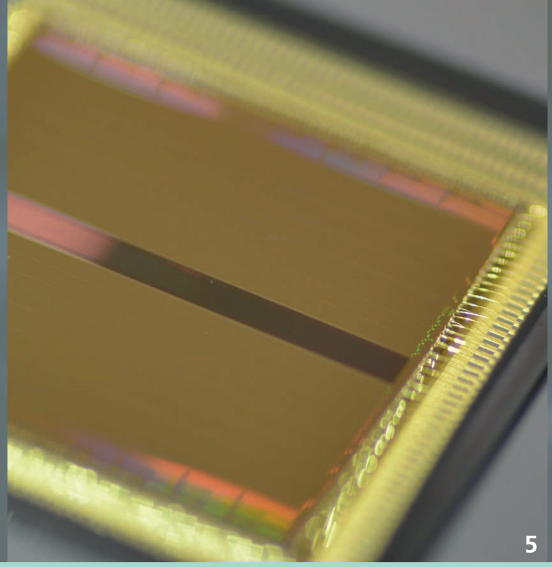
Similar safety aspects, e.g. personal security or measurement technology in process monitoring, are also important to the industrial sector. In the sensor system, the gas analysis is of increasing interest. Further applications include thermography in buildings or in medicine, but also border and building security.

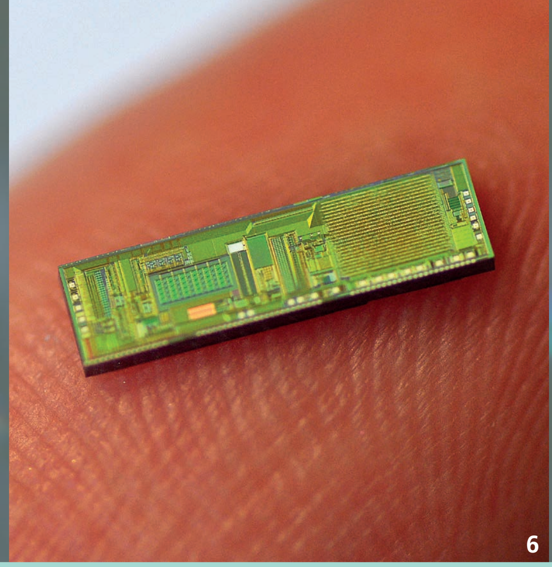
Supply and services/technologies:

- *Customized IR Imager*
- *Complete onchip signal processing*
- *Cost-effective chipscale packages*
- *IR development and pilot fabrication*
- *Customized packaging, testing and calibration*

3 *HT micro controller*

4 *Uncooled IR detector for thermal imaging*





CMOS IMAGE SENSORS

Optic sensors for image capturing based on CMOS technologies have reached a level that exceeds the performance and quality of established CCD sensors.

The development of specific photodetector components or the special treatment of the silicon surface has notably improved pixel attributes. Our experience with the design of CMOS photo detectors and image sensors, as well as their production and characterization, enable us to offer customized solutions.

Our customers benefit from a 0.35 µm "Opto" CMOS process optimized for imaging applications. "Pinned" photodiodes with low dark current and little signal noise and with color filters, micro lenses as well as stitching can be integrated. Our developments cover a broad spectrum from x-rays to EUV, UV and the visible spectrum up to infrared.

Supply and services/technologies:

- *Customized line and surface sensors*
- *Special pixels for time-of-flight, spectroscopy and more*
- *Stitching for large sensors*
- *UV- and XUV sensitive sensors*
- *Color filters and micro lenses*
- *Customized packaging and testing*
- *Pilot manufacturing in 0.35 µm "Opto" CMOS process*

PRESSURE SENSOR SYSTEMS

The trend in microelectronics is toward ever smaller sensors, even in pressure sensor technology. Our customer-specific developments are not only energy efficient and capable of high performance, but due to their minimal size, implantable in the human body if required. For this reason beyond classic applications for pressure sensors, new fields are opened up, particularly in medical engineering.

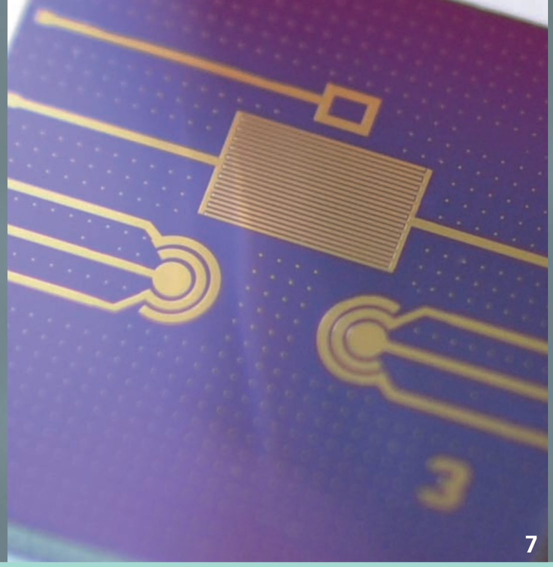
By producing these sensors as integrated capacitive pressure transducers in surface micromechanics, a connection with any kind of signal processing is possible. Our miniaturized pressure transponders can also be used for metrological applications in the industry or for measuring tire pressure in the automotive industry. Due to the integration of the sensor and signal in one ASIC, Fraunhofer IMS is able to respond to all possible requirements and applications and can offer customized solutions for the future.

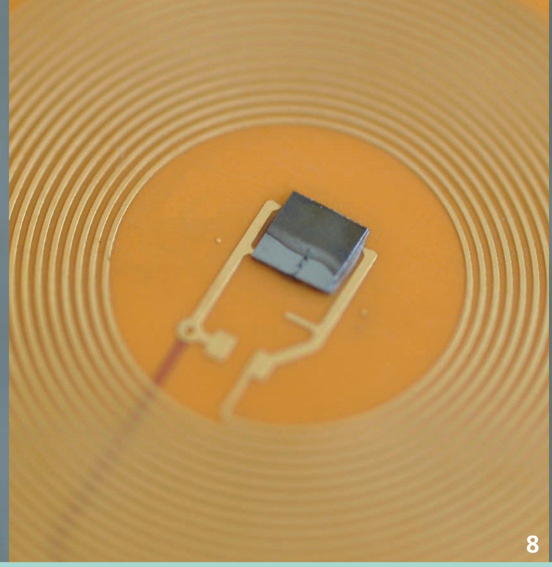
Supply and services/technologies:

- *Customized development of capacitive pressure transducers*
- *Measuring range from only a few mbar up to 350 bar*
- *Extremely high precision*
- *Transponder ability due to low energy requirements*
- *Integrated temperature sensor*
- *Customized packaging, testing and calibration*
- *Customizable digital and analog interface to meet customer demands*

5 *xposure CMOS line scan sensor*

6 *Pressure sensor for medical implants*





7 Integrated multi-parameter sensor chip for in situ monitoring of biotechnological processes

8 HF transponder

BIOHYBRID SYSTEMS

The markerless identification of biological and chemical substances without extensive laboratory work is crucial for progress in medical engineering. Sophisticated measurement technology is replaced by miniaturized systems that, detect substances via a biosensor (immuno or electrochemical) by their electronic reaction.

We offer the development of these highly sensitive detection systems, which are a cost-effective and fast alternative to optic analysis in the laboratory. These nano systems can also be integrated into more complex biohybrid systems, such as lab-on-chip, if required. This is particularly interesting for customers in the field of medical engineering, who can offer simple ways for real-time examinations via non-invasive, permanent diagnosis and monitoring systems in the future.

This is possible because bioelectronic sensors can also detect medical and physical parameters. These functions are also interesting for the food industry, which can profit from the simple and fast detection of biological-chemical alterations in their products.

Supply and services/technologies:

- *Customized biosensor systems (e.g. glucose, lactose)*
- *Markerless and quantitative sensor technology*
- *Real-time monitoring in body fluids*
- *Customized electrochemical sensor technology*
- *Customized immuno sensor technology*
- *Customized packaging and testing*

WIRELESS AND TRANSPONDER SYSTEMS

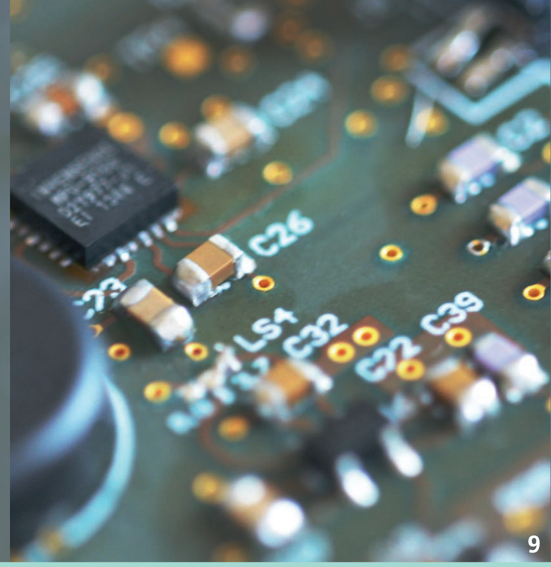
Industrial production and processing processes can only supply high quality products and operate cost-effectively if the machines are optimally adjusted, if they have not had much wear and have proven durabile. For performance to these requirements it is indispensable to have measurement data that help to optimize the machine settings, to determine the maintenance requirements, to control the manufacturing steps and to make quality recordings.

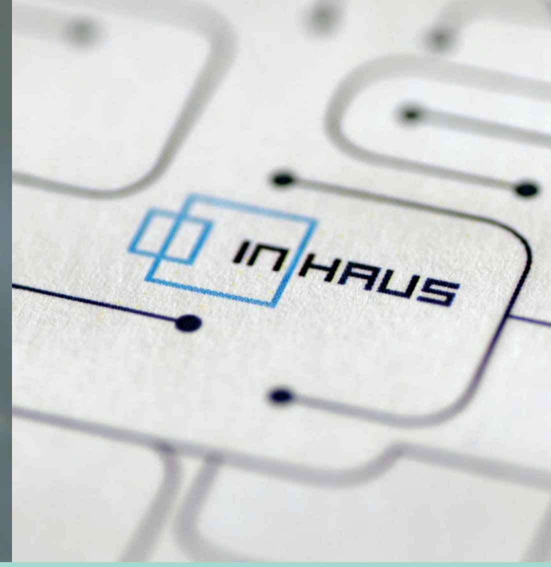
Transponder systems – especially sensor transponder systems – and sensor networks feature an excellent technological basis for the registration of identification and sensor data.

The wireless communication and power supply open up new application areas – e.g. in medicine to get measurement data from implanted sensors for diagnostic and therapeutic purposes. Other interesting application areas include the building sector and logistics.

Supply and services/technologies:

- *Active and passive systems*
- *Sensor transponder integration*
- *Customized adaption*
- *Radio frontends for LF-, HF- and UHF-frequencies*
- *Systems with high ranges*
- *Systems for "difficult" environments*





ELECTRONIC ASSISTANCE SYSTEMS

People spend a large part of their lives in rooms and buildings. This includes not only their private lives, but also special care as they get older – at home or in nursing homes – as well as their entire working lives. Here, operating costs, a flexible adaptation to user requirements and the feel-good factor are becoming increasingly important.

In our inHaus-Center, supportive solutions for residential and building environment (AAL – Ambient Assisted Living) for our customers are developed and tested. The installed products for facility management in commercial buildings are subject to strict criteria for economic efficiency and sustainable energy efficiency.

Fraunhofer IMS offers novel assistance systems for more efficiency in the nursing and hospital area. Innovative solutions in the area of energy and facility management up to solutions for the next generation office are the development priorities of the Electronic Assistance Systems business unit.

We provide our service and know-how across all industries. Our circuits and systems are used especially where it's all about the creation of unique selling points and competitive advantages for our customers. Then, our customer is able to best serve the target market.

Supply and services/technologies:

- *Hardware- and software development*
- *Planning and consulting*
- *Building integration and practical tests*
- *Heterogeneous interconnection (also wireless)*
- *Field tests for longterm monitoring*

INHAUS-CENTER

The Fraunhofer-inHaus-Center is a unique Europe-wide innovation workshop for application-oriented and close-to-the-market research for intelligent room and building systems. The inHaus-Center bundles the potential of several Fraunhofer Institutes and more than 120 business partners for the collaborative development, testing and implementation of innovative technology, product and system solutions for residential and commercial buildings. Focused on a broad variety of applications, such as Business Office, Hotel, Resources, Residential Living and Health&Care, new concepts for rooms, innovative building materials as well as intelligent building technologies and electronic assistance are developed here in order to access new markets.

Innovative components, system solutions and services with new utilization effects by combining design, materials, building technology, microelectronics and information technology for rooms and buildings are called smart buildings and smart homes. These future-oriented solutions lower energy consumption and costs while increaseing security and lowering facility management expenditures. The Fraunhofer-inHaus-Center offers its clients a targeted range of system solutions such as know-how, services and facilities. This ensures that ideas are generated efficiently, conceptualized, prototyped, tested and demonstrated.

Research and development focus on these subjects:

- *Building/planning with IT support*
- *Energy transparency/ -energy efficiency*
- *Logistics and operational processes*
- *Interaction between people and technology*
- *Multifunctional component building systems*
- *Sustainable construction*
- *Performance-oriented rooms*
- *Security and safety*
- *Electronic assistance*

9 Bicycle fall detection PCB

7 Selected projects

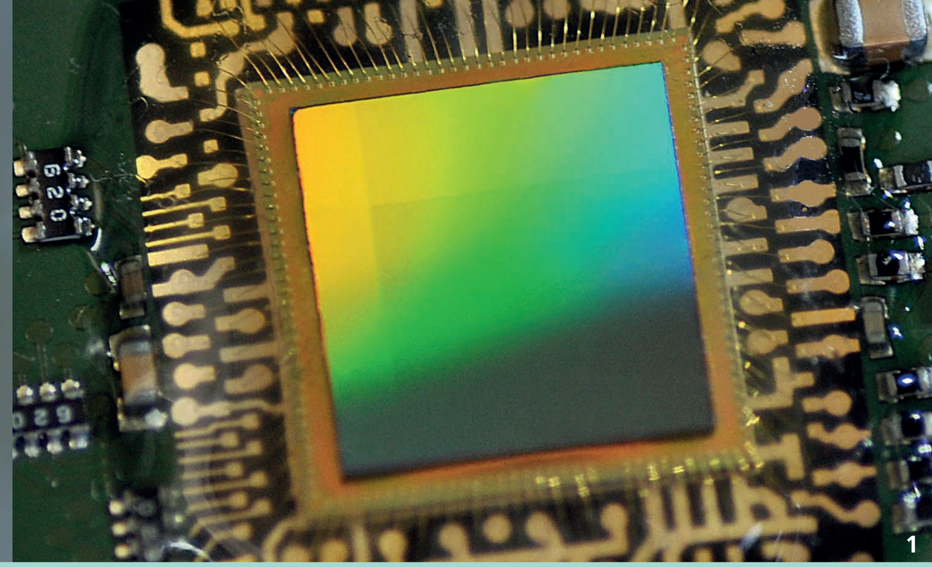
1 Main theme “optical sensor solutions”

In this chapter:

EYE 4.0 – SEEING INTO THE FUTURE WITH OPTICAL SENSOR SOLUTIONS

Diagnostic radiology, autonomous driving, and counting salmon admittedly don't have much in common, at first glance. With all three of these applications, however, there is one thing that is especially important: the correct tracking and detecting of objects under difficult conditions. Objects that are for example situated in murky waters, hidden in the human body or that need to be quickly and accurately detected while travelling at great speed need to be recorded in a quick, safe and efficient manner. In our age of intelligent, integrated sensor systems, optical sensors and smart image-recognition systems will in the future increasingly take over those visual tasks that the human eye is not especially good at doing. Optical sensor systems for example provide information about the size of salmon populations, allow medical insight into the human body and recognize obstacles well enough in advance while driving. The following seven product descriptions provide a short overview of where and how these optical sensor systems are used.

Light-sensitive semiconductors serve as the sensory eyes. In practice they measure with optical applications the brightness values and therefore enable image-recognition algorithms that can e.g. recognize structures in imaging processes, recognize and decipher traffic signs and other users of the road, determine fluid concentration, identify barcodes or even count salmon. This automation process reduces the risk of human error as well as the amount of work. Driven by the World Wide Web, real and virtual worlds are growing together to form an "Internet of Things" (IoT), a megatrend of the present and future, together with trends such as industry 4.0, energy, mobility, health and residential living. Tiny, intelligently-linked sensors are thus very much on the rise. In the field of microsystems technology, optical technologies are a sustainable research focus that is increasingly gaining importance.



THE SECOND GENERATION OF DIGITAL UNCOOLED IR IMAGE SENSORS

It's a question of seconds. In case of a fire within a building, the fire department not only has to fight the fire as quickly as possible, but also to search for persons possibly still in the building. Strong smoke emission often complicates this search enormously, so that sometimes, at levels of very low or even zero visibility, much precious time is lost. Inserted into thermal imaging cameras, infrared detectors allow image recordings under poor optical conditions that can, for example during a fire-fighting operation in smoke-filled rooms, expedite the search for persons as well as the source of the fire.

In the business unit "IR Imagers" at Fraunhofer IMS, researchers have been working for years on infrared sensors, working with medium to long infrared wavelengths. The imagers, also called "infrared focal plane arrays" (IRFPA), are two-dimensional arrangements of scalable pixels. They are based on radiation-sensitive structures in silicon technology, the so-called microbolometers, and work in the wavelength range of 8 – 14 µm (LWIR). On a chip with integrated CMOS-readout circuits, this results in complete image sensor chips. The IMS has been able to optimize the electro-optical performance, so that in particular the NETD value and the percentage of defect pixels can be reduced.
In the framework of a separate project, the researchers want now to develop a second generation of digital uncooled infrared image sensors for thermal radiation for industry customers of IRFPAs, with less than one percent defect pixels and a thermal sensitivity of under 60 mK.

These uncooled image sensor chips are used for passive detection of long-wave infrared radiation (LWIR), so that they enable visibility in the dark, with low sun, fog, smog and smoke. "Due to the passive measurement there is no active illumination necessary as it is in the visible range, since warm objects glow by themselves" explains Dr. Dirk Weiler. For the leader of the business unit "IR Imagers" at Fraunhofer IMS the potential users of uncooled IRFPAs consist of manufacturers of thermal imaging cameras for imaging thermography, of manufacturers of night vision assistance systems in the framework of autonomous driving and of manufacturers of fire department cameras for the detection of ember clusters and persons in smoke-filled buildings. Initial successes in the development of the second generation of uncooled IR image sensors have already been reported in 2016. "With an excellent thermal resolution of less than 40 mK, Fraunhofer IMS is already now in the leading group for commercially available IRFPAs," according to Dr. Weiler. "Moreover, we have already established a convincing image quality without the usual two-point correction of long-wave infrared radiation in an IRFPA camera as an evaluation system."

For the future, reliability studies by the quality management unit are planned, with subsequent series production. In addition to that, the team around Dr. Weiler is adapting the existing read-out electronics to the new IRFPA-generation and implements pixel-by-pixel strengthening and offset correction into the evaluation-camera as a basis for radiometric measurements. With scaled pixels, the Fraunhofer IMS is working on innovative 12 µm microbolometer structures that are necessary for a significant size reduction of the microbolometer.

1 *Uncooled Infrared Imager*

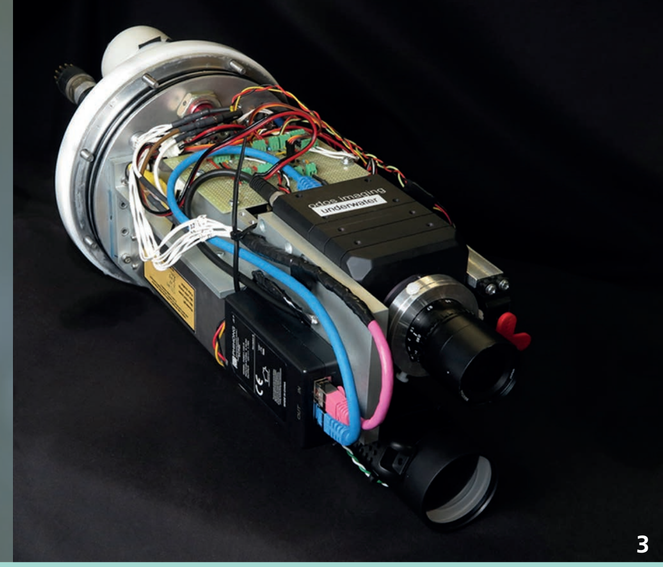
"HONEST" IMAGES FOR AN OVERALL OPTICAL IMPRESSION

The infrared detectors of the business unit "IR Imagers" ensure therefore more transparency in the most diverse applications. Much of what they recognize cannot be seen with the human eye; that is why IR detectors are e.g. also used in thermal device monitoring. Before electrical devices and machines for example fail because of a defect or wear-and-tear, their temperature often increases. This warming can be recognized early by the IR detectors, so that a cost-intensive failure can be prevented through appropriate measures.

How can an IR image sensor be evaluated, however, if no image can be seen on-site? To demonstrate the quality of the image-sensor chips in the specific application environment, researchers of the area of "Electronic Assistance Systems" have now developed – additionally to the IR detectors – an IRFPA camera as an evaluation system, showing once again the smooth cooperation between chip- and system-designers at Fraunhofer IMS. With the use of this camera for uncorrected image recording of temperature distribution, the operating system and efficiency of the infrared detectors can be tested and demonstrated, because the efficacy of IR image sensors of the IMS is best illustrated through the optical overall impression. Traditional component tests inform the researchers during the development of numeric measurements on the basis of an artificially standardized environment, e.g. the "noise equivalent temperature difference" (NETD), and need to be supplemented by an optical overall impression. The motivation for the development of the new camera comes from the evaluation of the IR detectors on the basis of the overall optical impression. In contrary to measurements of a standardized environment the new developed camera produces "honest" images in which the pixel errors are not initially offset. Furthermore, the use of the camera is especially advantageous for the user: "With the EVAL camera we would like to give the costumer the possibility to use the infrared detectors in the specific application environment and to evaluate the images acquired" says Martin Kemmerling, business field leader at Fraunhofer IMS, about the newly developed infrared-camera. The customer can thereby convince himself of the early-stage error-free detection of undesired hotspots on machines and devices.

But there is more to it than that: the EVAL camera, which was already presented in 2016 at different fairs – thereby generating many interesting contacts – also functions as a reference design for the integration of infrared image sensors in an evaluation system. Out of this reference design, consisting of circuit diagrams and the layout, customer-specific sensor solutions can be derived with minimum adaption and cost. This enables scientists of Fraunhofer IMS in Duisburg to develop and provide application-specific evaluation circuits for their customers – and this with significantly less expenditure than it was so far possible without the camera. Summarizing a further advantage of the camera, Martin Kemmerling says, "Because the function blocks of the camera algorithms are located in a programmable component (FPGA), the functionality can be adjusted to the specific wishes of the customers with little expenditure and without changing of hardware."

2 *EVAL infrared camera*



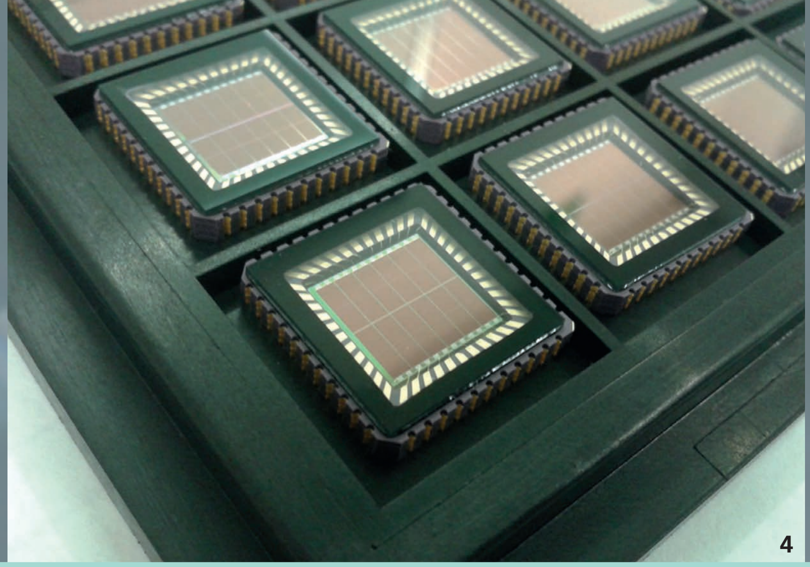
CAMERA SYSTEM FOR THE USAGE IN MURKY WATERS

In order to check the levels of and preserve the stocks of wild salmon in Alaska, they are counted anew every year. All relevant rivers therefore need to be monitored and the fish passing through need to be systemically registered. An important part of this is taken over by the salmon counter, who from special blinds along the river records the fish via hand-click counter. For this tedious work underwater video cameras could provide remedy. For several underwater inspection tasks, cameras are already used, e.g. in measuring and mapping of the seabed or in the inspection of civil buildings such as dams and bridge foundations. The quality of the imaging of customary cameras, however, suffers from stirred-up mud and other turbidity of the water. Within the EU framework program "Horizon 2020" a research consortium, under the project name "UTOFIA" (Underwater Time of Flight Image Acquisition system), has been composed in order to use the latest technologies in the fields of imaging, lighting and processing to create a new future platform for the underwater operation of camera systems. The partner consortium consists of, besides Fraunhofer IMS, the Norwegian research organization SINTEF, the companies Subsea Tech from France, Odos Imaging from Scotland, and Bright Solutions from Italy, as well as the Danish university DTU Aqua, and the Spanish technology center AZTI.

"The aim of 'UTOFIA' is to develop a compact and cost-efficient underwater-imaging-system for murky surroundings that then can be used for important applications such as, e.g. surveillance of marine life and aquacultures, fisheries, litter detection in oceans and harbor areas, and seabed mapping," summarizes Dr. Adrian Driewer, project manager at Fraunhofer IMS. "ToF" cameras are 3D cameras that measure distances with time-of-flight methods. For this purpose, the field-of-view is illuminated by means of a light pulse and the camera measures for every pixel the time that the light needs to get to the object and back; this time is directly proportional to the distance. The camera therefore provides for every pixel the distance of the overlying object. Compared to laser scanning, this procedure offers the advantage that a whole field-of-view can be recorded in one shot and does not need to be scanned, which leads to faster image recording. By applying this so-called range-gating, most of the backscattering contribution is removed. High contrast images with a greater range are thus possible even in bad water conditions. Within the scope of the project, several specific challenges for underwater camera operation must be addressed. Due to the absence of natural light below a shallow surface, the usage of special light sources is required. Underwater environments often contain small particles that scatter the light and reduce the effectiveness of the lighting used. The absorption of visible light by the water reduces also the light intensity that is recorded by the camera, leading to low contrast and a decreased visible range. In addition to these optical challenges, the hardware needs to be designed to handle high pressure as well as corrosive seawater. Due to the range-gating, the system developed in the three-year project extends the visible range by the factor 2 to 3 compared to conventional imaging systems while simultaneously providing 3D video information. Underwater objects can thereby be more easily identified and their size can be measured with significantly higher precision. The "UTOFIA" system will close the existing gap between short-range, high-resolution conventional video cameras and long-range sonar systems with low resolution. In comparison with sonar devices currently available on the market, the system is convincing due to its low acquisition costs and simultaneously offers a larger range of functions than inexpensive video-based systems. For this purpose, Fraunhofer IMS, with the support of SINTEF, performed measurements on a test imager which were used to determine the optimal pixel structure for underwater range-gating. With these pixels the researchers from Duisburg manufactured an image sensor with QVGA resolution (320 x 240) and confirmed the functionality. The image sensor will now be integrated over an interface PCB of the image sensor into the camera of the project partner Odos Imaging. In order to ensure the interaction between the components, IMS has designed, developed and tested an associated interface board. After the successful testing of two prototypes, the project consortium will develop a version of the underwater camera ready for the market by the end of the project in 2018.

3 *Second prototype of the UTOFIA system without outer housing*

For additional information on "UTOFIA," see www.utofia.eu



4 *Photo cell modules for PV applications*

MINIATURIZED SOLAR CELLS: LOW IN MAINTENANCE, COST-EFFECTIVE AND EFFICIENT

Solar cells – not on a rooftop, but as a miniature world on a chip: The Fraunhofer IMS is making this idea come true, in the form of an energy-autarchic sensor node with integrated silicon solar cell. The solar cell supplies the energy required for the electronic components from the surrounding light (energy harvesting). A first generation of miniaturized thin-film solar cells has already emerged as part of an industry collaboration project. Now, in the second generation, Fraunhofer IMS is developing miniaturized crystalline solar cells with a significantly higher efficiency. This efficiency is greatly increased by a special anti-reflection coating of AZO (aluminum-doped zinc oxide). The miniaturization of sensor nodes, which blend in inconspicuously with the surrounding, are achieved through a high integration density: the autonomous sensor node can contain, e.g. a control unit, a sensor, an energy storage element, and a wireless interface.

“Our vision is: the miniaturized sensor nodes need to be low in maintenance, easily produced and therefore cost-efficient,” says Dr. Andres Goehlich, head of the department CMOS and microsystem technology (CMT). And not to forget: “Of course it needs to be smart as well.”

Low in maintenance: Usually batteries used for sensor nodes need to be exchanged regularly. “We avoid this expense with self-sustaining sensor nodes that harvest their energy from light,” explains Dr. Christopher Krause, who leads the project at Fraunhofer IMS.

Cost-effective: This is realized through the usage of semiconductor technology. The 200-mm-wafer serves as a substrate on which hundreds or thousands of solar cells can be placed.

Smart: Additional components can be integrated into the silicon substrate to allow intelligent solutions – for example a camera with signal processing, or perhaps pressure or moisture sensors. As the following examples show, this makes diverse and flexible applications possible:

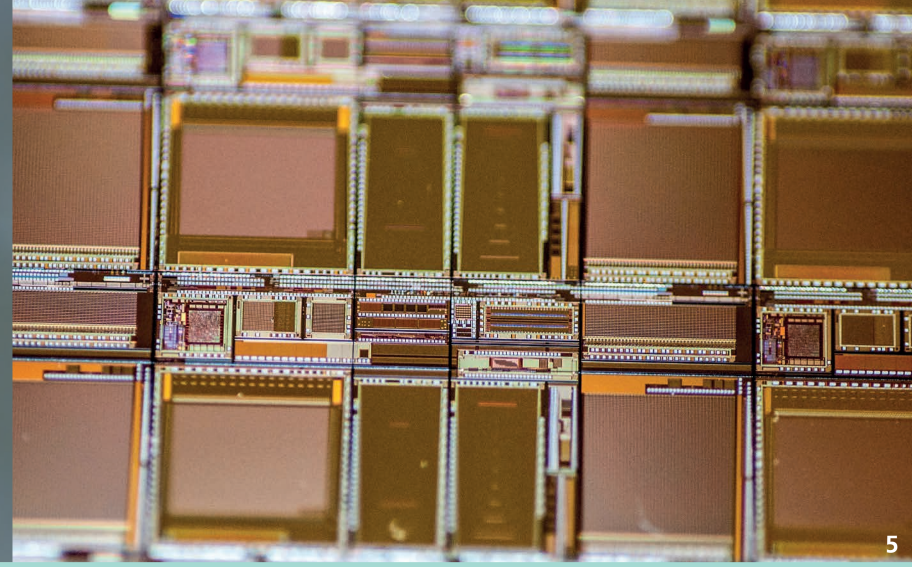
Building technology: Left the house and forgot the wide-open window? Miniaturized sensors powered from solar cells could check the window position – and pass on the information to the residents via a cell phone app; an app that would also serve well as burglary protection. Even the control of air-conditioning systems and surveillance of indoor climatic conditions are conceivable: The carbon dioxide content in the air is measured and transmitted to a central unit that could e.g. increase air circulation. Infrared or motion sensors could register the presence of people in a certain room and, if needed, switch on the air conditioning. The great advantage here is the elimination of wiring – making retrofitting much cheaper.

Industry: In the context of industrial automation, energy-autarchic sensor nodes can wirelessly keep track of machines. In large industrial plants, sensors can for example measure the maintenance cycles of gear-boxes and the load profile of machines. They can also determine which vibrations the machine was subjected to – and pass all this data on to a central control unit that reacts appropriately. This early information can prevent the breakdown of machines and save money. The sensor node can also be used in larger companies to locate industrial robots.

Health care: Portable autonomous nodes can provide relief for patients, e.g. a sensor in a wristband can allow the patient free movement while measuring e.g. the patient’s vital functions. Also, energy-autarchic sensors within a bandage can measure the inflammation values of the patient (intelligent wound dressing).

Agriculture: In this field the sensors can for example measure the soil moisture and according to that regulate the irrigation.

In this manner the small, unobtrusive, mobile sensor nodes provide clever solutions in the fields of health, smart living and the navigation of logistics and industrial processes.



5 *SPAD sensor chips are realized within CMOS technology*

SECURE AND FAST DISTANCE MEASUREMENT IN AN INDUSTRIAL ENVIRONMENT

An important method for optical distance and speed measurement is “LiDAR” (light detection and ranging). This method, closely related to radar, uses laser beams instead of radio waves. The reflected laser light from the object surface enables the determination of speed and position. In this process the measurement quality of LiDAR systems depends largely on the choice of the optical detector that records the reflecting laser beams. The researchers of the business unit “CMOS Image Sensors” are working on the optimization of these optical sensors for LiDAR. In particular regarding the optimization of the distance measurement, there are three central questions that play a significant role in research and development work around the “LiDAR” method. These questions are currently being dealt with by Dr. Jennifer Ruskowski, head of 3D sensors, and her team.

1. To make the distance measurement more reliable, how can ambiguous measuring signals be avoided already on the basis of the sensor principle?
2. How can the image processing effort be reduced, to generate faster measurements in real-time and to reduce system costs?
3. How can sensors be manufactured that have a high measuring dynamic and that have on the one hand very few photons and on the other hand can detect a high signal rate, without in this last case going to saturation?

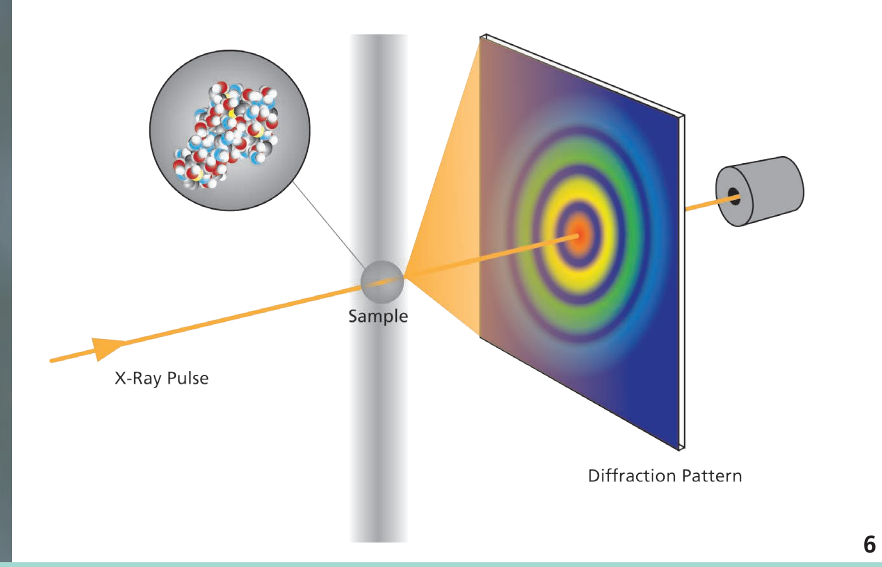
Dr. Jennifer Ruskowski explains the intention of the in-house research project at Fraunhofer IMS: “With the working out of solutions to these questions, we would like to enable the usage of our sensors especially in the industrial environment, so that in the future improved sensors bring an increase of security and an optimization of workflows between robots used in the factory and people who work there.” For example, even the usage of LiDAR sensors as an alternative to light curtains is possible, in which employees are warned and machines are stopped if employees enter dangerous production areas. In addition to this, further processes in the factory automation area can be supported, such as the measuring of volume, detection of pallets or in automated robotics within logistic processes.

To design the distance measurements faster and more securely and to manufacture sensors with a high dynamic measuring range, at Fraunhofer IMS particularly light-sensitive photodiodes (single-photon avalanche diodes, short: SPAD) are being developed and implemented as optical detectors. With these, high accuracy measurements in real-time are achieved. The Fraunhofer IMS thereby directly integrates the diodes into an in-house CMOS process. This is a clear advantage, because due to fusing of optical sensor and read-out chip, extremely compact detectors can be generated.

To achieve solutions for the above questions, new circuit technology and read-out circuits are currently being developed that enable a reliable readout of the data in digital form. Furthermore, an adaptive context-specific programming of the sensor allows an improvement of the signal-to-noise-ratio from up to a factor of nearly 10. Here, signals from ambient light can be suppressed and the object distances can be detected more reliable (question 1).

A fast real-time measurement (question 2) also becomes possible through the usage of SPADs. In the first step, 50 frames per second is the target for the LiDAR overall system. Because of the direct measurement, the distance values are coming digitally out of the sensor, so that, e.g. the evaluation of various images is no longer necessary to generate the distance values. Moreover, SPADs have a high dynamic (question 3); these sensitive detectors are even able to detect single photons. Additionally SPAD detectors can never saturate because of their technical nature.

SPAD detectors with extremely good optical characteristics were already developed in 2016, and for the future a next iteration of SPAD detectors with higher resolution and the further development of read-out circuits is planned. Beyond that, handy camera modules are in the planning, so that potential customers can test new sensors. “Currently we are further developing new technologies with customers, among others, in the automotive sector and these technologies will also soon be used in industrial applications,” says Dr. Jennifer Ruskowski.



DEPFET DETECTORS FOR UNPARALLELED RESULTS

More than 120 years ago Wilhelm Conrad Röntgen discovered X-rays, later named after him. Since then, electromagnetic waves have been used worldwide in diverse scientific areas, for example in biology, medicine, and physics as well as nanotechnology and photonics. Thanks to the short wavelength of X-rays, single molecules or atoms can be observed. Thanks to this, in the 1950's X-rays significantly contributed to the discovery of genetic information and the double-helix structure of DNA. This revolutionary breakthrough shows how close structure and function of biomolecules are intertwined with each other. Since then, new and exciting research fields have continued to open up. In space, e.g. the chemical composition of various planetary surfaces can be examined and in nanoelectronics the material characteristics of magnetism can be investigated.

To examine the structure of complex molecules, highly luminous X-ray light sources are needed. Free-electron lasers (FELs) are the fourth and newest generation of accelerator based light sources. They are based on linear electron accelerators and they can shine 10^{20} times brighter than the X-ray tubes used for medical applications. Their light flashes are extremely powerful, ultra short and have spatial coherence (the light waves of the laser oscillate in step and strengthen one another).

To be able to make use of the enormous radiation of FEL light, the development of a new type of detector is absolutely essential. DEPFET detectors are extremely fast imaging pixel detectors with an excellent energy resolution, and with especially high radiation intensity. Sensors and detectors with integrated electronics for ionizing radiation find application in basic and applied research as well as in industrial analytics and quality control. A DEPFET detector is an electronic semiconductor component, a special type of field-effect transistor to detect light and particle radiation. DEPFET stands for "depleted p-channel field-effect transistor," which in turn means "field-effect transistor with p-channel on a fully depleted substrate." Here, depleted means that all free charge carriers are extracted through very high voltage, leaving only charge carriers of incident radiation.

A DEPFET cell consists of an operationally fully depleted silicon substrate and a field-effect transistor embedded into this same substrate. The fully depleted substrate constitutes the sensitive area for the radiation. The field-effect transistor serves for a first pre-amplification of the signal. With DEPFET detectors, the first amplification level is integrated in each pixel. This leads to a very small input capacity and therefore to a very good noise behavior of the detector.

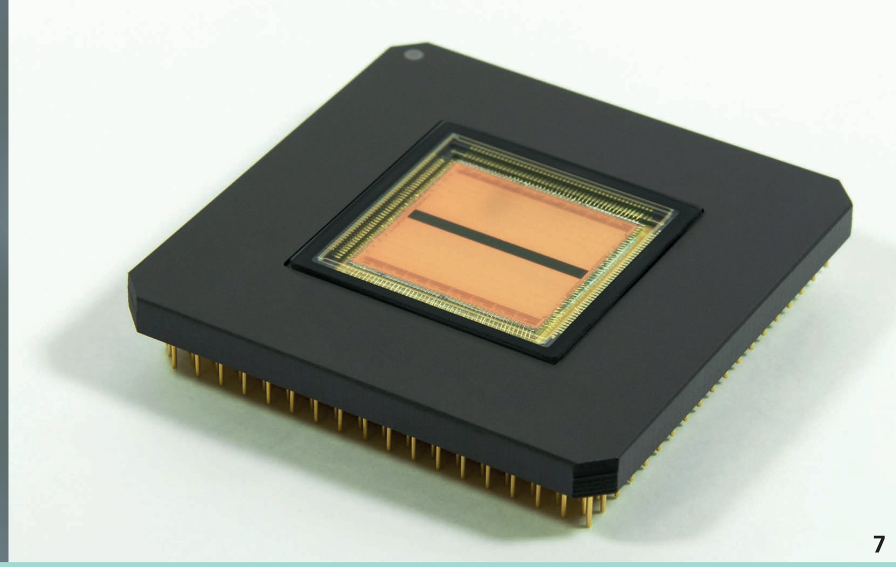
Until now, these special low-noise detectors have been only produced in the research laboratory. Together with PNSensor GmbH, Fraunhofer IMS researchers are currently developing a manufacturing process for DEPFET detectors with industrial quality standards.

PNSensor explores and develops modern radiation detectors and has already implemented, tested and proved the functionality of DEPFET detectors. Now, in this shared project a new technology for the manufacturing process is to be developed.

"The manufacturing of DEPFET detectors within a CMOS line guarantees high process stability with short processing times and, at the same time, reduced costs. Moreover, the CMOS process provides the developers with a number of new design options for the DEPFET. This allows detector and amplification characteristics to be greatly improved and new applications to be tried and tested in experiments of basic and applied research," explains Julia Hauser, project leader at Fraunhofer IMS, when giving an overview of the advantages of this joint project. The greatest challenge is the development of double-sided processing of DEPFET sensors and the definition of a suitable CMOS-compatible process sequence. This is because both wafer-sides need to be processed – an especially tricky challenge: "This process is highly complex, because 23 layers need to be considered and the processing of both wafer-sides presents a special challenge," says Hauser. Furthermore, the actual manufacturing of the components in the clean room at Fraunhofer IMS is also an essential milestone during the project. Preliminary technological tests for the double-sided processing of highly-purified silicon have already been completed and in the year 2016 the transfer of a DEPFET process into the CMOS line at Fraunhofer IMS was successfully executed, allowing the first DEPFET test structures to be produced at the Duisburg institute. For this, the researchers achieved at room temperature a leakage current level of < 10 nA/cm², which is very well-suited for the planned application. The leakage current shows how much residual charge remains in the depleted substrate. These residual charges can occur due to defects in the substrate or during the wafer processing. Only with a low leakage current, the charge of the X-ray radiation that needs to be detected is verifiable and does not vanish in the leakage current.

The fabrication of 40 large-scale sensors is being pursued within the framework of the project; currently researchers are working on the development of large-scale sensors with an active area of 18 cm². "The project provides an important research contribution in the field of detector development. The planned short processing time enables fast iterations in the development of new designs. In addition, this also serves as a pioneer project for research institutions in detector production," explains Julia Hauser, speaking of the use of DEPFET detectors e.g. as X-ray sensors in the free-electron laser "European XFEL." The international project is currently working on the "European XFEL," a laser that generates ultrashort laser light flashes in the X-ray range: 27,000-times per second and with a light intensity that is a billion times higher than the best conventional types of X-ray radiation sources – for unparalleled results!

6 *Detector for X-ray scattering experiments*



7

EXTREMELY FAST LINE SENSORS: ALLOWING A BETTER LOOK INTO THE EYE

Just as every person values good eyesight, every ophthalmologist values getting a good, clear look into the eye of a patient. This is important because the human eye is a highly-complex sensory organ that can give crucial clues regarding the patient's overall health. For instance, an ophthalmologist is able to recognize first effects of high blood pressure or diabetes by the condition of blood vessels at the ocular fundus. Its extremely fine capillaries, not visible to the naked eye, provide information about the state of the patient's blood circulation and thus of overall vascular health. The retinal vessels belong to the cerebral circulation system and their condition allows conclusions to be drawn regarding cerebral blood flow and cerebral pressure – important factors when, e.g. trying to prevent a stroke. In ophthalmology, optical coherence tomography (OCT) is often used for such examinations. Within OCT, the extremely fast line sensor "xposure" – developed by Fraunhofer IMS together with the Austrian Institute of Technology (AIT) – guarantees ophthalmologists a better look into the eye. But how exactly is the rapid multi-line sensor used?

Besides mere morphological imaging, OCT also provides the possibility of functional imaging. With this imaging process, variables such as metabolic activity or the blood flow of capillaries in the eye can be measured. Optical coherence tomography is a new, cost-efficient technology using infra-red light that offers very good intravascular depth resolution and allows for easy, fast, and cost-efficient measurement. It is easy to understand why worldwide, according to estimates, one retinal scan is performed every second!

As an examination method, OCT is used even more frequently than ultrasound. Depending on the diagnosis, larger fields of view of the eye need to be recorded; but here, the frame rate may not be further lowered. The compliance with these parameters is especially important so as to keep the examination as short and pleasant as possible for the patient. The patient's eye needs to be very brightly illuminated for a few seconds, to keep motion artifacts in the image caused by microcellular activities as low as possible. If the motion artifact concentration is too high, the OCT-generated image can no longer be used for a diagnosis. Such intense illumination is required for the high number of sectional images, the so-called A-scans that are needed for a volumetric scan of the eye, and due to the limited sensitivity of currently available camera systems. This is exactly where the development by the Fraunhofer IMS starts: The researchers of the Duisburger Institute, together with the Austrian Institute of Technology (AIT), designed a high-speed multi-line sensor based on CMOS with 2048 x 60 pixels. This "xposure" line sensor was then built into an AIT line-scan camera and made available to the medical faculty of the University of Vienna for an OCT testing setup, to test the volumetric scans with greater resolution and lower illumination. The medical faculty then did so-called "Line Field Swept Source OCT System" testing. Here, the line-field procedure simultaneously performs a deep scan for all 2048 pixels along one line of the sensor. Due to the high line rate of 600 kHz, the sensor allows A-scan rates in the eye of up to 4 million deep scans per second, meeting the requirements of future OCT procedures where less intense illumination will make this eye examination far more comfortable for the patient.

The OCT procedure is very complex. The procedure is based on white-light interferometry – a contactless, optical measuring method – which detects the interference that occurs by the overlapping of the reference light with the backscattered sample light in the interferometer, thereby enabling the extraction of the sample depth-profile. For this purpose, the "time-domain" OCT travels through the reference arm and interferences occur within the coherence length of a few micrometers. The "fourier-domain" OCT detects the interference spectrum, which captures the entire depth information with only one shot. For 2D and 3D images, the ray is laterally deflected over the sample. This procedure, also called retinal scan, happens in a non-invasive manner and in three-dimensional presentation with a resolution of a few micrometers in all three dimensions.

With "xposure," the 60-line high-speed sensor developed by Fraunhofer IMS together with the Austrian research institute AIT, highly sensitive optical inspections are possible, finding application not only in the medical field, but also in industrial production processes or in security printing.

The know-how is extended through the collaboration with the Center for Medical Physics and Biomedical Technology of the Medical University of Vienna. Its focus of research lies among other things on the development of non-invasive vascular imaging processes and instruments for highly-sensitive quantitative perfusion monitoring, as well as on the development of novel technologies for a high-resolution optical microscopy.

What are the plans for the future? Dr. Olaf M. Schrey, project leader and researcher in the field of optical sensor systems at Fraunhofer IMS explains: "With 2048 laterally resolved pixels, the 'xposure' system will in the future allow for significantly more reliable early diagnoses. Previous OCT systems had noticeably lower lateral resolution, typically 512 pixels, making reliable diagnoses more difficult." Besides the increased speed, Dr. Olaf M. Schrey sees further market potential in the increased diagnostic accuracy of ophthalmological examinations. "Further, it is planned that 'xposure' will be used in virtual surgical preparation in the treatment of macula degeneration via 'retinal 3D OCT'."

7 *xposure Ultra High Speed Sensor for OCT applications*

HAPPY BIRTHDAY

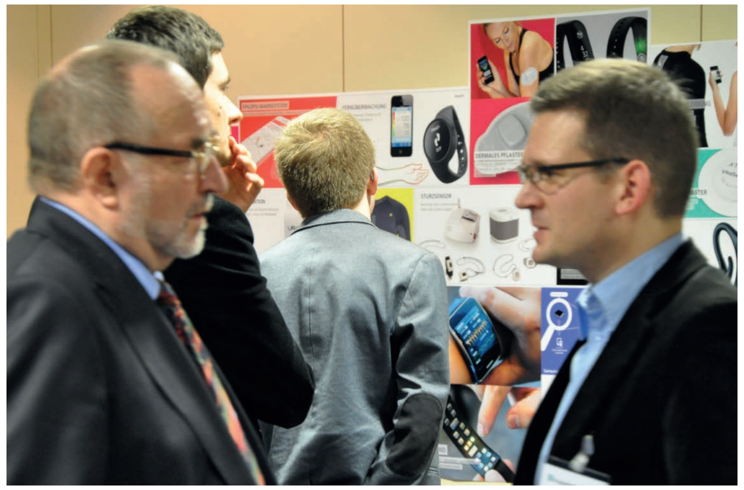
15 years of inHaus-Center – 15 years of cooperative research and development in a creative think tank. The state premier of NRW, Hannelore Kraft (on the left), congratulated Dr. Nina Kloster (management inHaus-Center) on the occasion of the 15th anniversary of the Fraunhofer-inHaus-Center.

"CMOS IMAGING WORKSHOP"

The subjects of the "CMOS Imaging Workshop" were SPADs, testing and application of ADAS (Advanced Driver Assistance Systems) as well as general 3D sensor technology. Of particular interest to the nearly 100 participants were the application possibilities and technical refinements of SPADs.

IN DIALOG WITH THE CUSTOMER

The Fraunhofer IMS places great value on the presentation of its developents as well as the direct dialog with the customer on the various application possibilities. Therefore the institute is regularly present at well established trade fairs for microelectronics. In 2016 the institute was present at the BIO-Europe in Cologne and the Vision in Stuttgart, the world's leading trade fair for image processing.

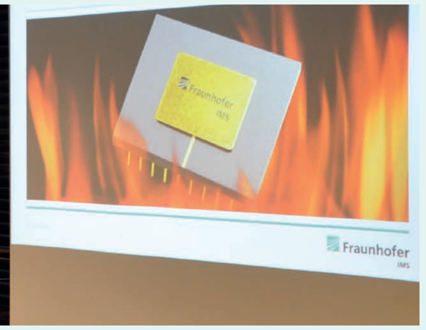


"WHEN TECHNOLOGY HELPS HEALING"

Under the sign of health – the program of the 7th inHaus-Forum "When Technology Helps Healing" offered the nearly 90 participants of the event a combination of exciting speeches and an innovative workshop in which the visitors could make creative contributions.

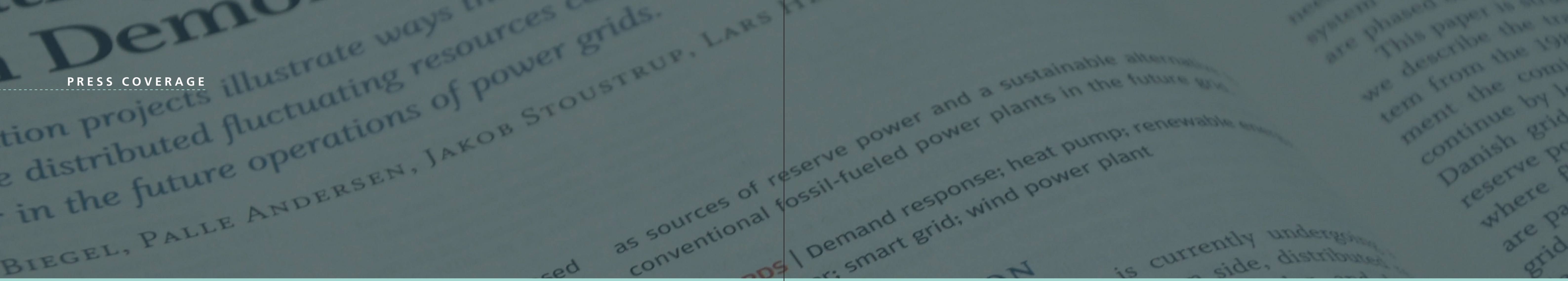
"GIRLS' DAY"

Opening up the doors for the scientists of the future: The Fraunhofer IMS attended the nationwide day of action "Girls' Day" and gave 18 female students of various regional schools a look behind the scenes of the research institute.



"HIGH TEMPERATURE WORKSHOP"

The workshop offered its participants the possibility of establishing contacts and discussing the technological aspects of high temperature applications. An accompanying exhibition also showed new products and technology from the field of high temperature electronics. Due to the positive feedback, the Fraunhofer IMS is going to continue organizing this workshop series; the next event will take place in the fall of 2018.



"INTELLIGENT CELL IMPLANTS CONTACT THE NERVOUS SYSTEM DIRECTLY"

phys.org, December 2016

"ULTRASENSITIVE SENSORS ENSURE OPTIMUM SIGHT CONDITIONS"

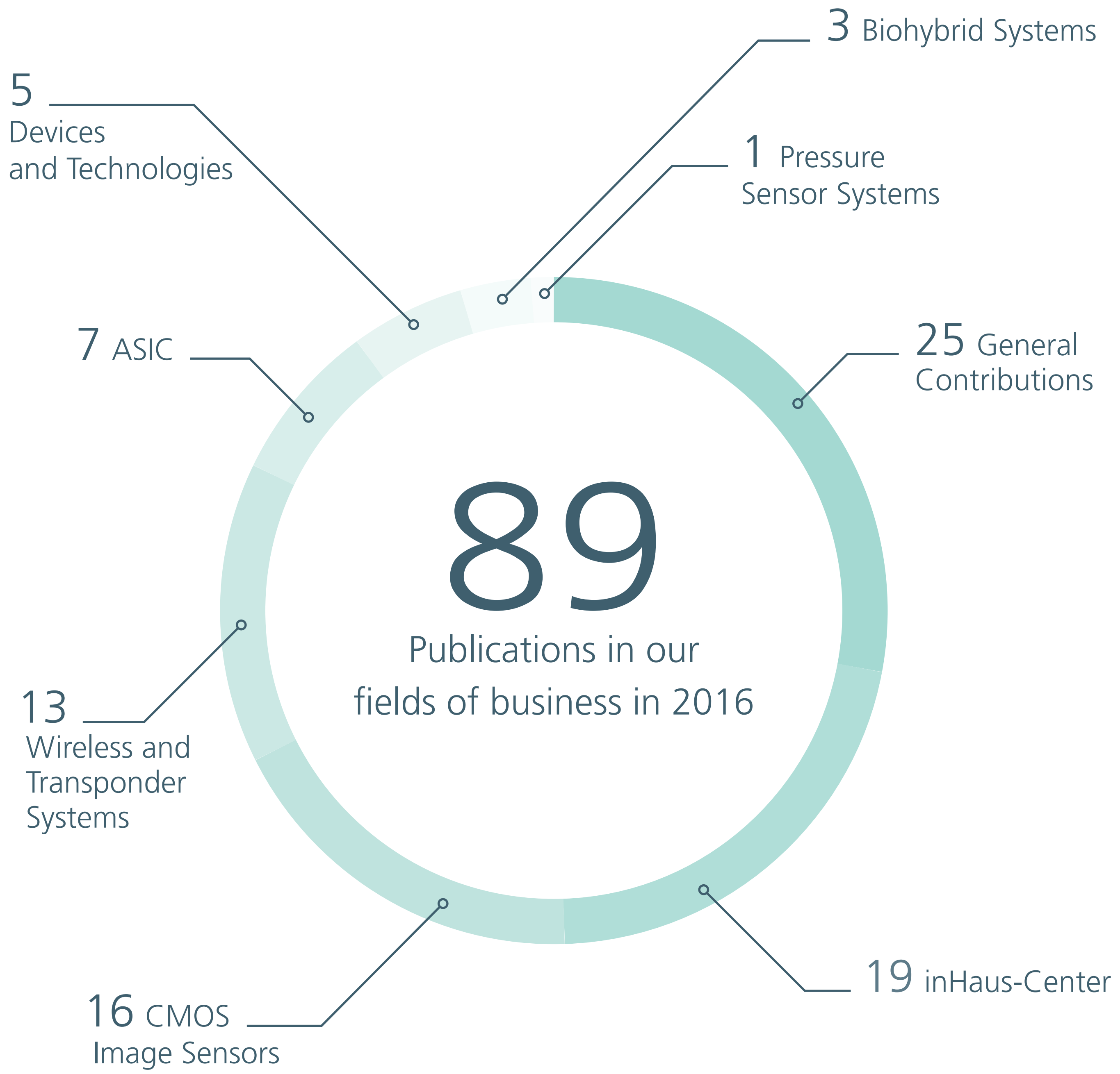
ScienceDaily, October 2016

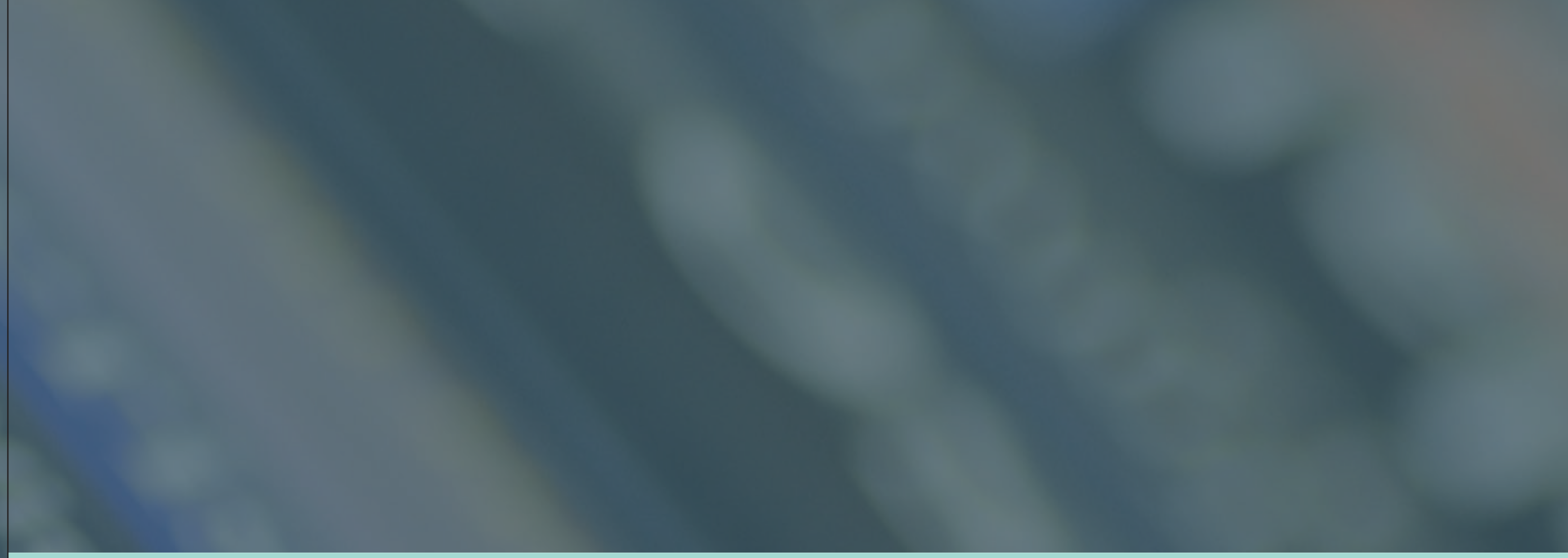
"SMART METERS TO USE ALGORITHMS TO ANALYZE ELECTRICITY CONSUMPTION"

phys.org, December 2016

"RFID SENSORS PROVIDE EARLY WARNING OF FIRE HAZARDS"

Technik+Einkauf, June 2016





1. Papers in Monographs

Durini, Daniel; Paschen, Uwe; Schwinger, Alexander; Spickermann, Andreas: ***Silicon based single-photon avalanche diode (SPAD) technology for low-light and high-speed applications***. In: Photodetectors: Materials, Devices and Applications. Cambridge [u.a]: Woodhead Publ. (2016), Chap. 11: pp. 345 - 371.

2. Journal Papers

Dogan, Özgü; Walk, Christian; Weidenmüller, Jens; Gembaczka, Pierre; Stanitzki, Alexander; Görtz, Michael: ***Development of a system concept for miniaturized cardiovascular multi sensor implants***. (Eurosensors <30, 2016, Budapest>). In: Procedia Engineering 168 (2016), pp. 159 - 162. DOI: 10.1016/j.proeng.2016.11.194.

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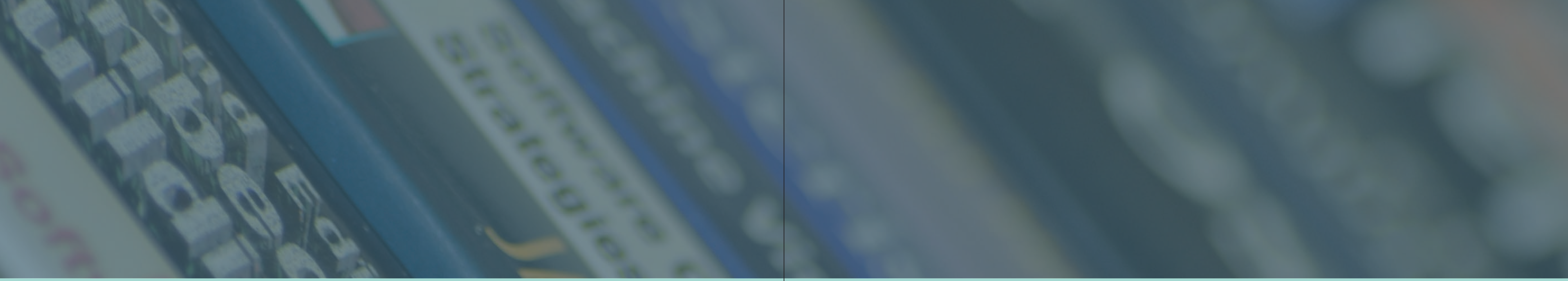

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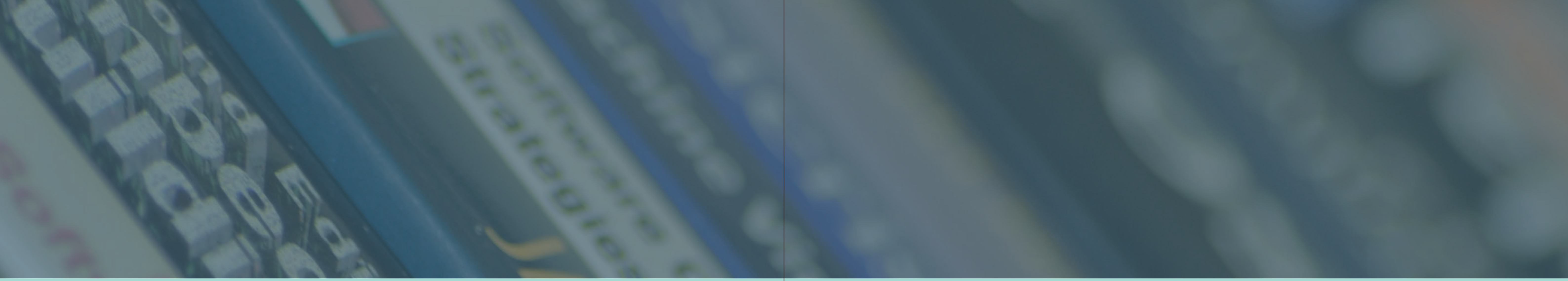

4. Oral Presentations

Aschauer, Stefan; Hauser, Julia; Weyers, Sascha; Schlosser, Dieter; Kalok, David; Holl, Peter; Hartmann, Robert; Lutz, Gerhard; Majewski, Petra; Strüder, Lothar: ***Properties of DEPFET active pixel sensors fabricated in an industrial*** CMOS foundry. IEEE Nuclear Science Symposium and Medical Imaging Conference (29.10.-25.11.2016): Strasbourg, France, 03.11.16.

Brockherde, Werner: ***Optische Sensoren für Sicherheits-anwendungen in Standard CMOS Technologie***. Angewandte Forschung für Verteidigung und Sicherheit in Deutschland (22.02.-24.02.2016): Bonn, Germany, 23.02.2016.

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Mross, Stefan; Zimmermann, Tom; Vogt, Holger: ***Multi-sensor patch with wireless data transmission for in-situ monitoring of bioprocesses in single-use bag bioreactors***. 26th Anniversary World Congress on Biosensors (25.03.-27.03.16): Gothenburg, Sweden, 26.05.2016.

Pieczynski, Janusz; Hirmer, Raimund; Figge, Martin: ***Plasma Damage Messungen zur Prozess-Charakterisierung und Verifizierung der Antennen-Regeln***. VDE-ITG Fachgruppe 8.5.6 fWLR / Wafer Level Reliability, Zuverlässigkeits - Simulation & Qualifikation (03.05-04.05.2016): Hannover, Germany, 03.05.2016.

Vom Bögel, Gerd; Schmidt, Philip; Hennig, Andreas; Kemmerling, Martin: ***Energieautarker Fenstersensor – ein kabelloser und wartungsfreier Sensor zur Zustandsüberwachung und Einbruchserkennung in Wohngebäuden***. 8. GMM Workshop Energieautarke Sensorik (EAS) (25.02.-26.02.2016): Renningen, Germany, 25.02.2016.

5. Posters

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Kahnert, Stefan; Lennartz, Klaus; Goehlich, Andreas; Greifendorf, Dieter; Schreiber, Fedor; Kirstein, Uwe; Bartels, Frank; Janzyk, Udo; Rennings, Andreas; Erni, Daniel; Küppers, Ralf; Vogt, Holger: ***Development of a microchip based cell sorting device***. BIO. NRW.academy "From Mice to Men" Henkel AG: Düsseldorf,Germany, 02.05.2016.

6. Patents

6.1 Granted Patents

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7. Theses

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Mross, Stefan: ***Integrated multi-sensor system for parallel in-situ monitoring of biotechnological processes***. Duisburg, Essen, Univ., Diss., 2016.

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7.2 Master Theses

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