Fraunhofer IMS

FRAUNHOFER INSTITUTE FOR MICROELECTRONIC CIRCUITS AND SYSTEMS

ANNUAL REPORT 2014

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Dear Readers, Friends and Partners,

A thing is a thing is a thing. That is how it used to be. Instead of pursuing a passive existence, objects and items from our daily life now play an active role in the »Internet of things« by being connected to the World Wide Web. That way, things become interactive and smart. They are able to be online, self-sufficiently exchange information, trigger actions and control each other due to their programmability, their storage capacity and their communication technology. Real and virtual worlds encounter and incorporate each other in the »internet of things«. At the same time, the economy is already on the verge of a fourth industrial revolution, which places higher demands on future production process. It has to be smart, changeable, efficient and sustainable. The future project »Industry 4.0« stands for the smart networking of product developments, manufacturing, logistics and the customer. Entire value chains are to be controlled and optimized in real time. These requirements face several new challenges, which the Fraunhofer IMS approached in 2014 with our usual energy.
We want to actively shape this industrial revolution with our developments and technologies, and together with our partners and customers, prepare ourselves for the future of production. The basis of any work is the institute's competencies. When a broad number of measurement procedures for process monitoring are necessary in the production line environment, Fraunhofer IMS sensor solutions can be deployed. In 2014, a wireless and energy-sufficient sensor system for extremely difficult industrial environments was developed. The system is, for example, deployed at coolant monitoring, measuring temperature and pressure at every injection molding tool in a coolant distribution system. A thermoelectric generator (TEG) supplies the energy for the sensor module using the difference in temperature between a coolant pipe and the warm surroundings. The project for this especially robust solution that is well-suited for industry was successfully completed in 2014. Another IMS development for highly-demanding industrial processes was realized in 2014. The »RLPS« (Reflow Soldering Process Sensor) monitors the temperature profile and provides assistance to assure the quality of the soldered assembly group. For wireless temperature measurements in vacuum-induction soldering machines, the sensor can be deployed for process control in temperature of up to 125 degree Celsius. The sensor system offers real-time, uninterrupted data communication and is characterized by robust, fail-safe operational mode compared with tethered systems.

Faster, more reliable, more efficient. The production processes of modern industrial facilities require a high level of perfection. The same is true for high-performance imaging. Together with the AIT (Austrian Institute of Technology GmbH), the Fraunhofer IMS has developed the world's fastest line scan sensor for highly sensitive optic surveillance tasks. With line frequencies from 200 kHz to 600 kHz, the »xposure« exceeds every sensor available on the market by a factor of two. As a »line scan camera«, the xposure offers entirely new opportunities to reliably scan surface structures, latent images, as well as security documents and holograms. This development is successful, last but not least, thanks to the exceptional cooperation between the Fraunhofer IMS and our valued customer, the AIT. At this point I would recommend you read the interview with Ernst Bodenstorfer from AIT, which can be found read on page 32 of this annual report.

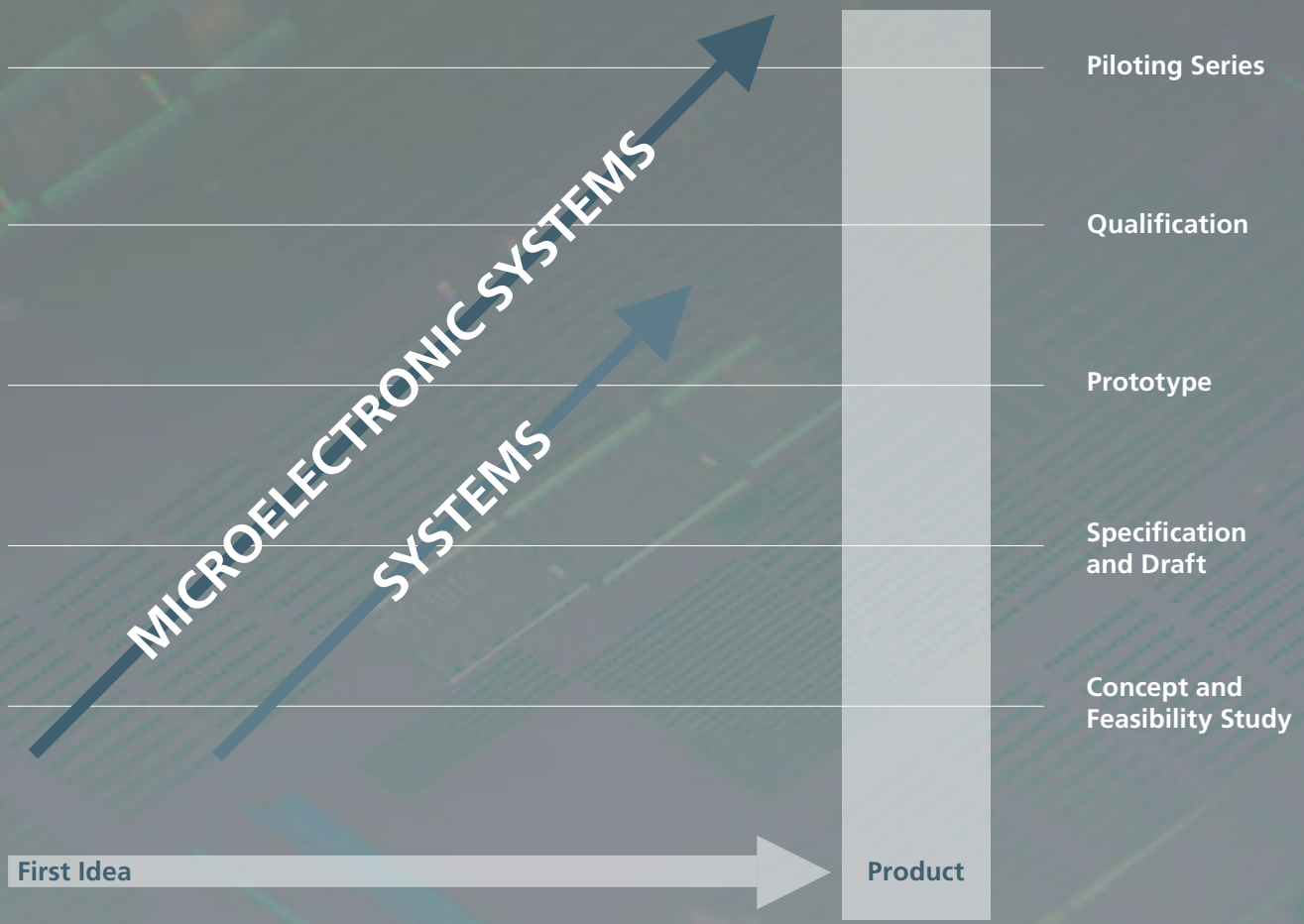
The project »Unihealth« is another example of a successful partnership – in this case cross-border. In cooperation with the Radboud-University Nijmegen and the University of Wageningen, as well as the Dutch SMEs, the Fraunhofer IMS developed a sensor based on a resonantly swinging membrane for the detection of allergens. Besides CMOS competencies, the IMS was able to incorporate its

know-how in microsystem technologies into the development. As a result, a CMOS-integrated, smart, ultrasensitive sensor with read out circuits could be developed, and the »proof of principle« could be demonstrated in 2014.
As you have surely noticed by reading this annual report, not only its visual appearance has changed, but the content has also been structured differently. To cover the broad spectrum of subjects and developments of our institute, we present projects chosen on a particular topic. In this report, you will learn more about our competencies concerning the topic »Building Technologies«. Safety and security of residents and users of facilities is in the spotlight of these projects presented. The »Home Guardian« sensor, for example, detects the current state of a window and offers protection against burglary. The RFID transponder system on the other side monitors the temperature in the particularly difficult environment of a switchboard and offers protection against potential fire. You can find out about these and other projects starting on page 18.

We, at the Fraunhofer IMS, not only have much to develop, but also to say. The continuously growing number of participants in the two workshops in the fields of high-temperature electronics and CMOS technology are proving this. First-class speakers and thrilling topics ensure high attendance. Also well-attended was the 6th inHaus-forum of the Fraunhofer inHaus-Center, »Effizienz beleuchten«, during which the first award for innovation was given. The common research project between the Fraunhofer IBP and the Nimbus Group GmbH won the award for their development of a noise cancelling office lamp. The awarded lamp is also part of the »Living Labs« of the Fraunhofer-in-Haus-Center, which were newly opened in 2014. The laboratory displays innovations for tomorrow's workplace on over 80 square meters.

Tomorrow is the keyword: In 2014, we applied to a broad number of calls for public R&D proposals, seizing our opportunity to generate projects within the framework of the EU-program »Horizon 2020« and ensuring to be well-positioned for the future. I would like to mention tomorrow in another context, too. In 2015, the Fraunhofer IMS celebrates its 30-year anniversary. We will look back full of respect on three decades of microelectronics in Duisburg and recognize once more how important continuous and persuasive work is for us, our customers, and last but not least the region's demands.
In the strategy audit that was conducted in 2014, we analyzed and rated our planning for the future of the institute together with external auditors. The result: we are well-positioned for years to come! Together with partners and customers, we want to continue to successfully achieve thrilling developments, especially in the field of »Industry 4.0«.

At this point, I would like to thank all of the institute's employees for their great work. I would also like to thank our customers for their trust and the good cooperation we have enjoyed. A thanks is a thanks is a thanks, and sometimes that's what it still is.



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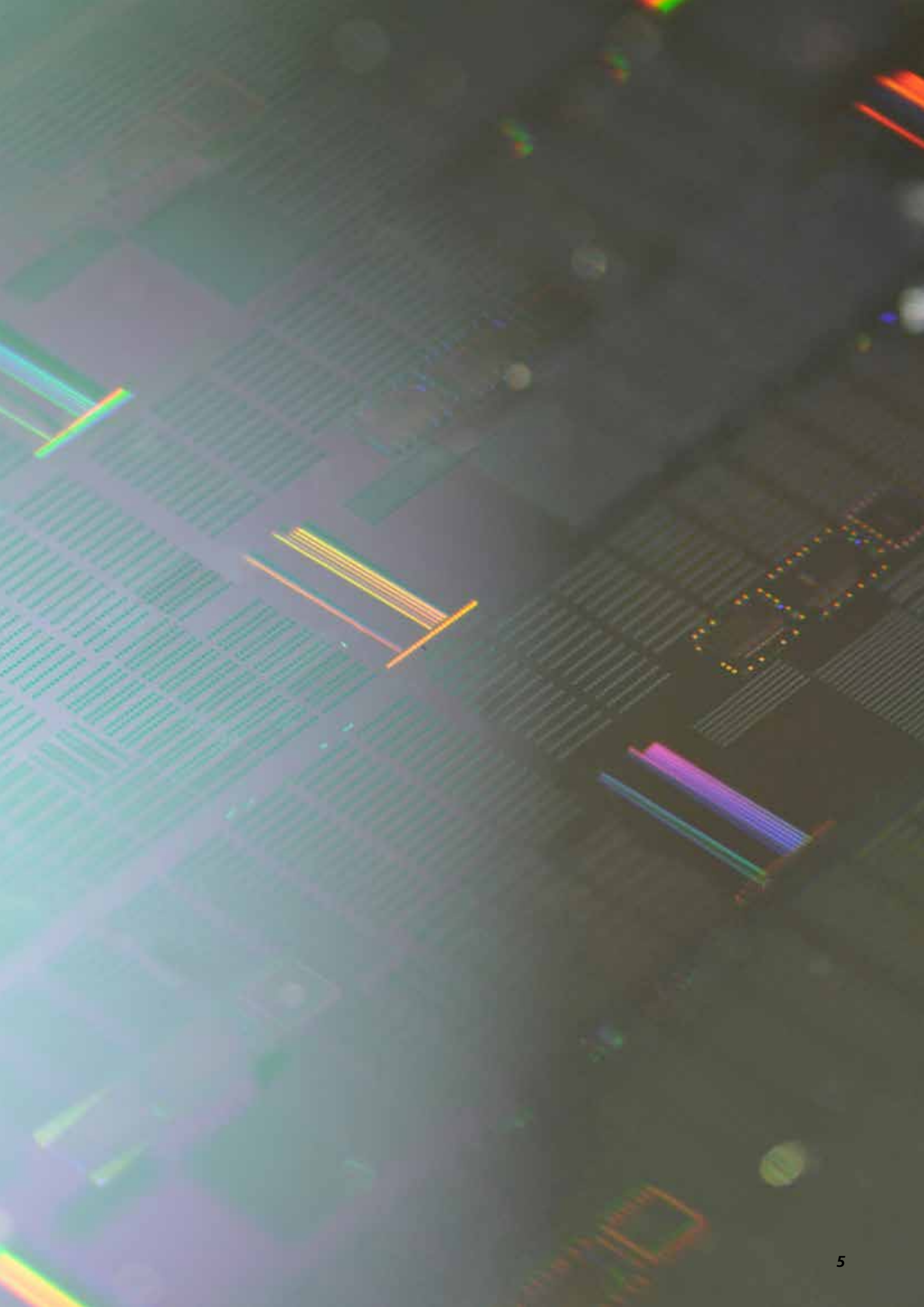


Our business units

- *ASIC and IC Design*
- *Wireless and Transponder Systems*
- *Electronic Assistance Systems*
- *Pressure Sensor Systems*
- *CMOS Image Sensors*
- *IR Imager*
- *Devices and Technology*
- *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.

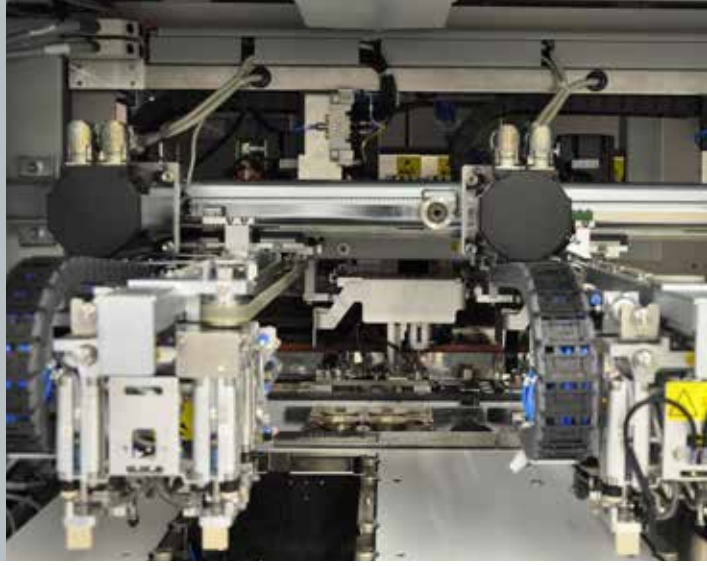
We accompany your development with concept and feasibility studies from the first moment – via specification and design, draft and fabrication of prototypes through to the product qualification. The pilot fabrication of your circuits and ICs is carried out by us as well. With us, you get microelectronics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

The 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 the 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	1,300 m²
Cleanroom class	10
Employees	150 in 4 shifts
Capacity	> 70,000 wafers/year

Test and assembly

Wafer size	200 mm
Cleanroom area	1,200 m²
Cleanroom class	1,000
Test	5 test systems
IC Assembly	Sawing & thinning of wafer, Chip-On-Board Die and wire bonding

Microsystems technology lab and fab

Wafer size	200 mm (0.35 µm)
Cleanroom area	600 m²
Cleanroom class	10
Capacity	5,000 wafers/year

Laboratories

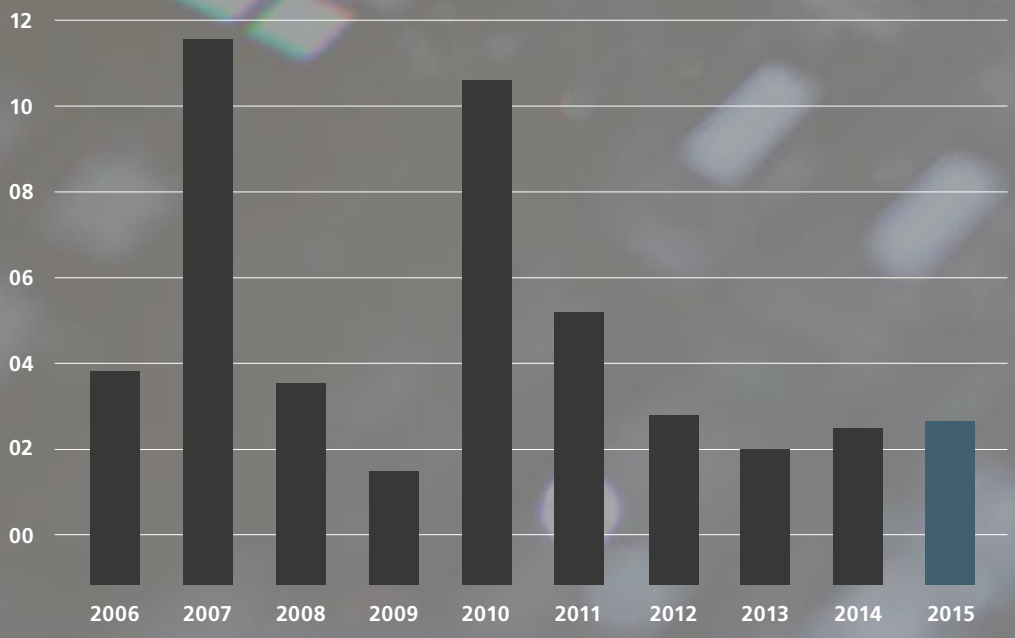
Biohybrid sensors	45 m²
inHaus center	3,500 m²
Laboratory space	800 m²
High-frequency measurement chamber	24 m²

TÜVRheinland® CERT ISO/TS 16949

TÜVRheinland® CERT ISO 9001

STAFF MEMBERS

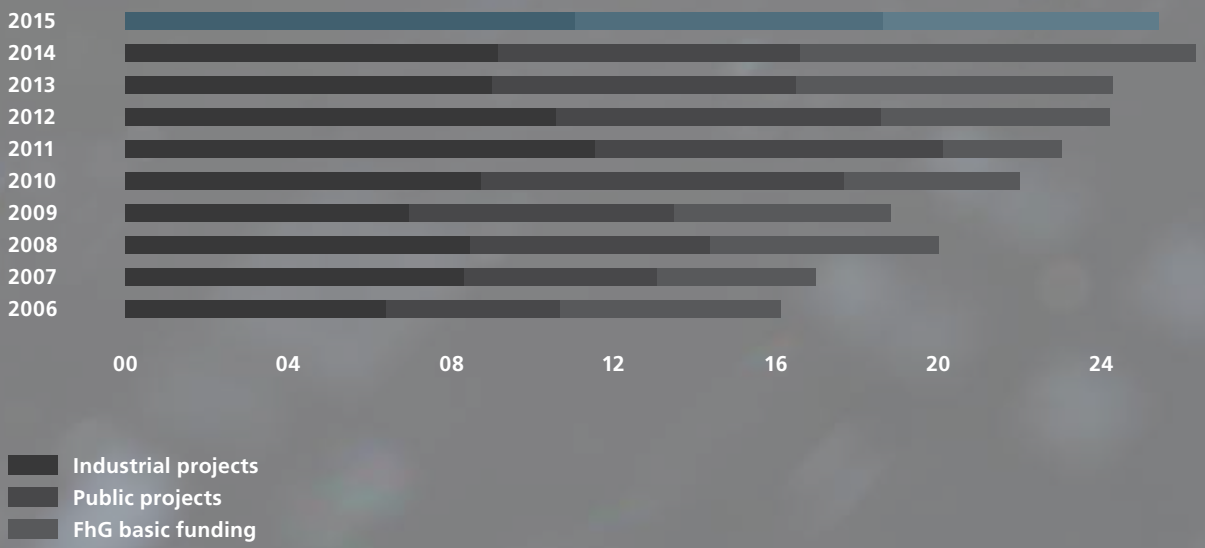
CAPITAL INVESTMENTS (in mio. euros)



»We are well-positioned for the years to come«

Prof. Dr. Anton Grabmaier

BUDGET (in mio. euros)



ORGANIZATIONAL CHART

IMS MANAGEMENT
Director / Prof. Anton Grabmaier
Deputy Director / Prof. Holger Vogt

FRONT END DUISBURG *Volker Gruber*	Manufacturing Control FE DU	Lithography
MICROELECTRONIC PRODUCTS *Dr. Franz Vogt*	Manufacturing Control IMS	Test
TECHNOLOGICAL RESEARCH AND DEVELOPMENT *Prof. Holger Vogt*	IR Sensor Systems	MST Lab and Fab
CMOS TECHNOLOGY AND DEVICES *Dr. Uwe Paschen*	Semiconductor Processes & Devices	
OPTICAL SENSOR SYSTEMS *Werner Brockherde*	CMOS Image Sensors	CMOS Photo Sensors
MICRO- AND NANOSYSTEMS *N.N.*	Pressure Sensor Systems	Biohybrid Systems
INTEGRATED CIRCUITS AND SYSTEMS *Prof. Rainer Kokozinski*	Mixed-Signal ICs	Concept Engineering
TRANSPONDERS, SYSTEMS AND APPLICATIONS *Martin Kemmerling*	Transponder Systems	High-Frequency Systems
INHAUS-CENTER *Volkmar Keuter*		
ADMINISTRATION SERVICES *Ralf Benninghoff*	Finances	Human Ressources

ADVISORY BOARD

Dr. Attila Bilgic
Krohne Messtechnik GmbH & Co. KG

Prof. Hubertus Feußner
Forschungsgruppe MITI

Prof. Frank-Hendrik Wurm
Universität Rostock

Dr. Stefan Dietzfelbinger
IHK Niederrheinische Industrie- und Handelskammer

Prof. Dieter Jäger
Universität Duisburg-Essen

Wolfgang Meyer
Sozialwerk St. Georg e.V.

Dr. Peter Rieth
Continental Teves AG & Co. oHG

Dr. Otmar Schuster
GEOhaus

Dr. Norbert Verweyen
RWE Effizienz GmbH

Sören Link
Stadt Duisburg

Angela Schöllhorn
Intel Mobile Communications GmbH

Michael Unger
Balluff GmbH

Dr. Hans-Jürgen Wildau
Biotronik SE & Co. KG

8 Business units

1 Innovation center

ASIC and IC Design 13

- *High Temperature Electronics*

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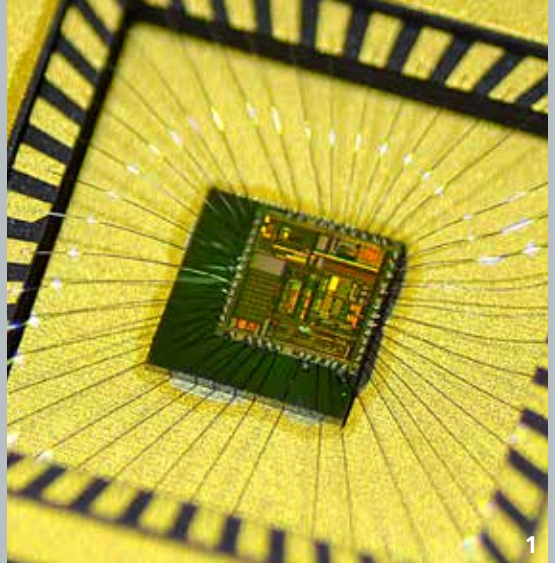
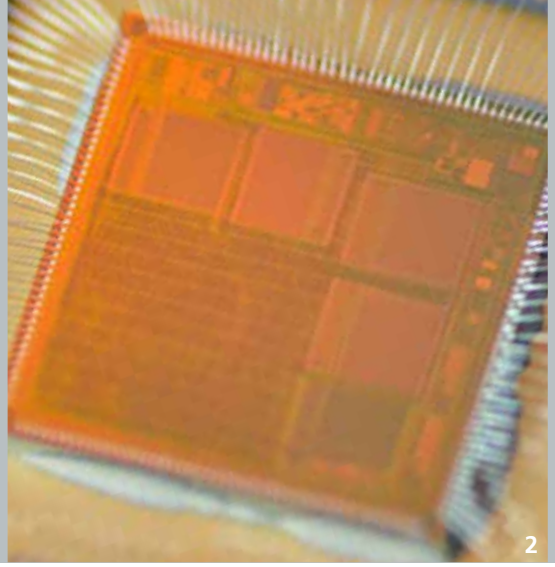
inHaus-Center 17





ASIC AND IC DESIGN

»From the concept up to the pilot fabrication« is the maxim of the 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« ASIC 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/technology

- *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°. 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° and above.

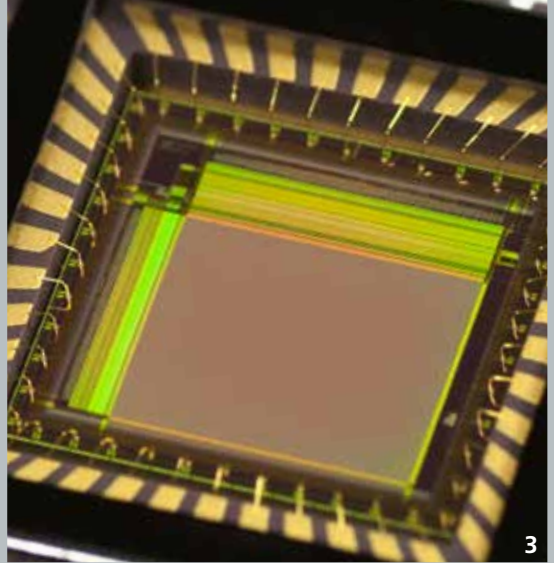
We can support your entry into the field of high temperature electronics with concept and feasibility studies. We also understand your customer-specific HT ASICs, including pilot fabrication and comprehensively support system integration, including the assembly aspects.

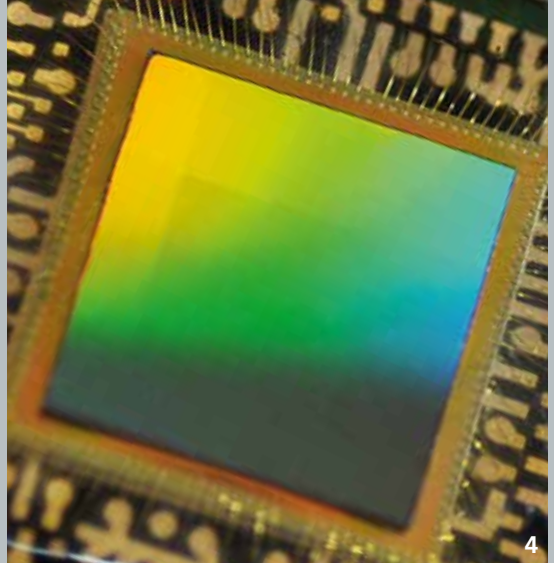
Supply and services/technology

- *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*

1 *MEMS accelerometer readout IC*

2 *HT micro controller*





DEVICES AND TECHNOLOGY

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 the 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*

IR IMAGER

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.

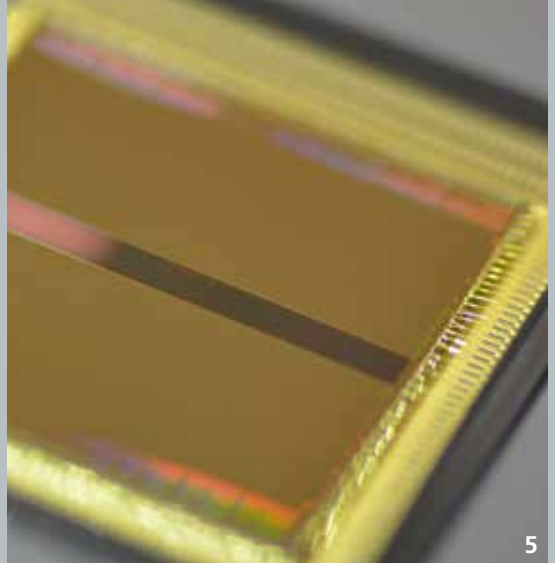
Similar safety aspects, e.g. personal security or measurement technology in process monitoring, are also important to the industrial sector. In the sensor system, the gas analysis is of increasing interest. Further applications include thermography in buildings or in medicine, but also border and building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

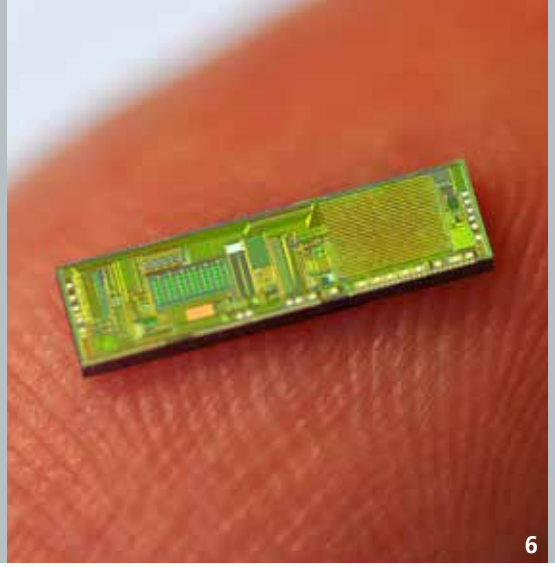
Supply and services/technologies:

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

3 *High frame rate eye sensor for Lasik surgery*

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 0.35µm »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 surface sensors*
- *UV- and XUV sensitive sensors*
- *Color filters and micro lenses*
- *Customized packaging and testing*
- *Pilot manufacturing in 0.35µm »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, the 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*

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.

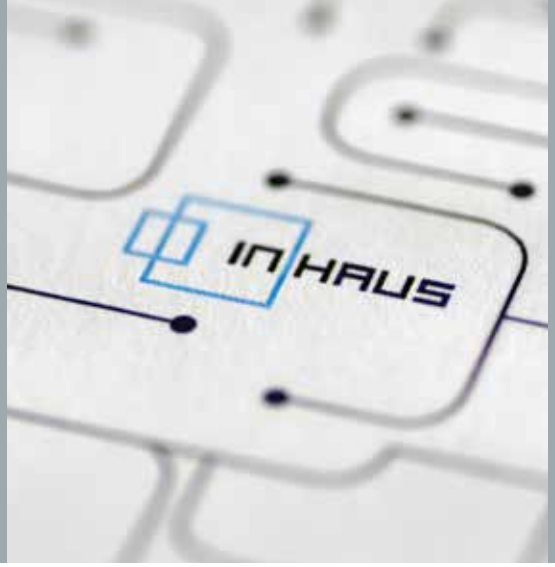
The wireless communication and power supply open up new application areas – e.g. in medicine to get measurement data from implanted sensors for diagnostic and therapeutic purposes. Other interesting application areas include the building sector and logistics.

Supply and services/technology

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

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

8 *HF transponder*



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 got 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.

The 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/technology

- *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 applicationoriented 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*

6 Selected projects

1 Main theme »Fraunhofer IMS building-technology know-how«

In this chapter:

Radio sensor with detective abilities 21

Infrared sensor technology – saves energy and warns of fire 22

How much energy do individual devices and plants consume? 23

Proven protection in proven steel 24

RFID technology in difficult environments 25

Secure insulation instead of only warm words 26

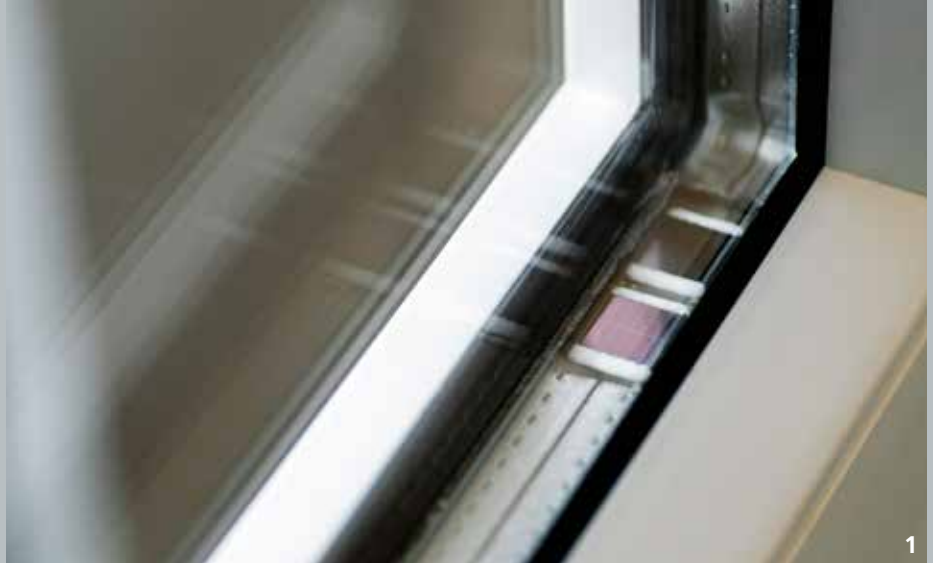
»FRAUNHOFER IMS BUILDING-TECHNOLOGY KNOW-HOW«

For 30 years scientists at the Fraunhofer IMS have worked on the development of microelectronic circuits, electronic systems, micro systems and sensors. Based on this broad know-how, access to technologies and high-level development accomplishments, the institute is a partner for industry that is recognized worldwide.

Divided into eight business units the Fraunhofer IMS dedicates itself to applied research-, and pre-development for products and their applications. The focus of our work is reliable, efficient and ready-for-market technologies and procedures, that can be applied in a broad number of business fields. Facilities, power supplies, mobility, production, medical engineering –

the spectrum of tasks and developments is as big as the passion and effort of our employees, who approach new challenges on a daily basis. To keep up with this broad range of tasks, projects are presented in detail according to selected topics in our annual report.

In this year's annual report, we present six different projects that involve technologies used in and around building facilities. With regard to our slogan »IMS building technology know-how.« the projects presented in this report are dedicated to residential or building security. Sensor solutions from the Fraunhofer IMS research laboratories ensure security in several ways: by providing protection against intruders, avoiding excessive energy costs, and providing fire protection and protection against ailing buildings or bridges.



RADIO SENSOR WITH DETECTIVE ABILITIES

The first project presented packs a punch, because it deals with a sensitive issue: residential burglary. When someone has forced their way into your private space, all of your furniture has been searched for valuables and your personal belongings have been touched by strangers, all of a sudden the entire home feels violated.

According to criminal statistics from the police, residential burglary has reached a new record high in Germany. The number of residential burglaries has rapidly increased since 2009 – over the past five years by a total of 33 percent! Currently, every three and a half minutes an apartment or house is broken into.

A new development from the »Wireless and Transponder Systems« business unit provides protection against unwelcome houseguests. Known by the name of »HomeGuardian«, a fingernail-sized radio sensor is fitted between the glass pane and the aluminum profile which can detect the state of a window – whether it is open, closed or tilted. The sensor draws the needed energy it requires from its surroundings and can be operated wirelessly and without a battery. »The challenge was to develop a wireless and maintenance-free sensor that detects the state of a window and transfers this data securely and reliably via radio transmission,« explains Gerd vom Bögel, Department Chief of the business unit »Wireless & Transponder Systems« at the Fraunhofer IMS. »Furthermore, the sensor had to be as small as possible and cost efficient«. The »HomeGuardian« – unlike other window sensors available on the market – pursues its detective duties entirely energy self-sufficiently and detects attempted break-ins by differentiating various fluctuations, which, for example, can be caused by a break-in attempt with a crowbar at the window frame. The goal, to develop an energy self-sufficient sensor to monitor the status of windows and doors, was preceded by the selection of a suitable energy harvester.

In this case a small but efficient solar cell makes it possible to operate the »HomeGuardian« which uses an energy management system, a cache and a particularly energy-efficient radio frontend.

In 2014, the development team demonstrated the smart window sensor with an exhibit at three different trade fairs. Whether it was at the »Security« fair in Essen, the »Electronica« in Munich or the »Euro-ID« in Frankfurt, the radio sensor always sparked great interest. The search for a suitable development partner is currently in process. Potential development partners for the Fraunhofer IMS could be manufacturers of insulated glass panes, who can mount the sensor in between the panes during the pane production process, or window manufacturers, who can fit the sensor into the frame. Furthermore, producers of facility automation systems or smart home solutions that bring the sensor to the market for retrofitting could also be suitable development partners. »We are planning on developing a demonstrator to verify functionality and feasibility, as well as further develop the prototype in the future,« according to Gerd vom Bögel. »A field test and subsequent qualification as a (pre-)series product will follow. After that we can work on new applications for this technology, such as in the industry.« There is a big future in store for the small sensor between the glass panes, which protects against unwelcome guests.

1 *The visible part of the window senor: solarcell between the panes of the insulating glass unit.*

2

INFRARED SENSOR TECHNOLOGY – SAVES ENERGY AND WARNS OF FIRE

While the »HomeGuardian« protects against intruders and, for example, makes possible a relaxed vacation for the homeowner, a new development from the business unit »IR-Imagers« of the Fraunhofer IMS is able to detect a possible fire just in time: infrared sensor technology operating at room temperature. To do that, short- to long-wave infrared wavelengths are monitored. The imagers, also called focal plane arrays, are one- or two-dimensional arrangements of IR-sensitive pixels. They are based on radiation-sensitive structures in silicon technology known as microbolometers.

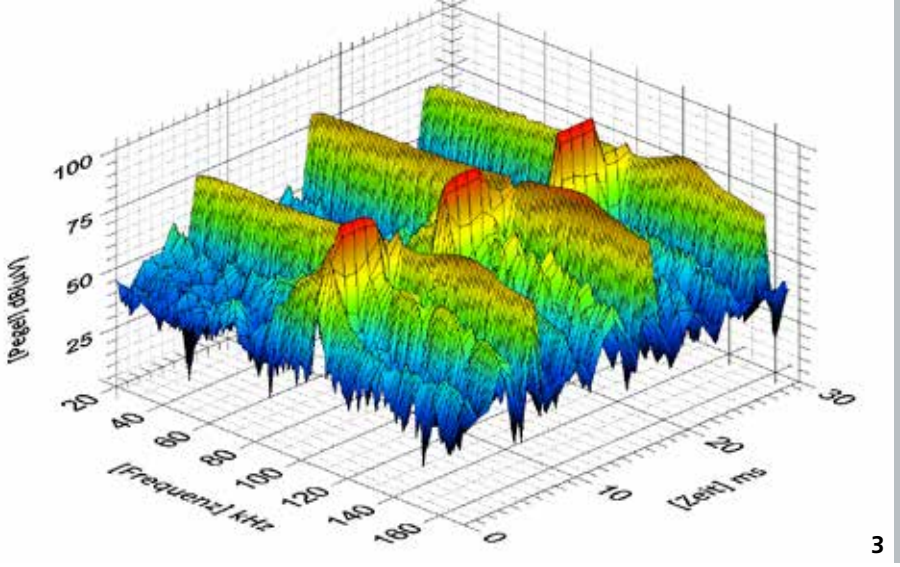
Complete image-capturing chips are produced by integrating CMOS read-out circuits on one chip. A field of application for these image capturing chips is the infrared sensor technology in facilities, which can be diverted into three fields of application: intelligent air conditioning, thermal facility surveillance and occupant counting. Low resolved IR detectors – approx. 32x32 pixels – which can measure the spatially resolved temperature, are used for these applications. Different from cameras used for the visual spectrum, there is no danger of infringing on privacy rights with these images.»IR detectors capture the emitted radiation passively and use it to derive the temperature. With these abilities, the detectors can regulate the air conditioning of rooms and buildings intelligently and add significantly to energy savings«, says Dirk Weiler, Department Chief of the »IR Imagers« business unit at the IMS. Therefore, the following scenarios are possible. Room temperature is regulated centrally. Whether there is currently a person in the room or where in the room that person might be is not taken into account. So if only the area of the room that a person uses is to be air-conditioned, energy could be saved in a targeted way. Air conditioning could be automatically lowered when a person left a room or a particular area. This special form of presence control could be extended to illumination. Current solutions in this field, such as motion detectors, sometimes switch off the light early by mistake, when a person is still in the room but no motion can be detected. These IR detectors can also be used for device monitoring. Before electronic devices and machines become inoperative, their temperature usually rises. This increase in temperature can be detected and recognized by the IR detectors. Fire detection devices that are fitted with an IR sensor can detect a potential fire at an earlier stage simply through the abnormally high temperature in a particular room, whereas smoke detectors rely on smoke that builds up during the course of a fire. This time advantage can reduce the consequences of a fire considerably. Domestic applications such as an oven or an iron can also be part of this field of thermic device monitoring.

»Did I switch off the oven?«, »Was the iron still on?« A lot of people ask themselves those or similar questions on their way to work or on vacation. Often, it is too late at that point and the danger of a fire is real. A domestic appliance that is still switched on can be detected via constant room surveillance when, for example, no one has entered the room for a longer period of time but the device is still emitting a high amount of heat.

In the future, many and different fields of application will be found for IR detectors. The fundamental conceptual work and development on a primary high-resolution IR imager with 320x240 pixels was done by scientists from the »IR Imagers« business unit in 2014.

According to Planck's law, every warm body emits electro-magnetic radiation. With a body temperature of 300K, the maximum wavelength of this radiation is approximately 10µm. The wavelength range from 8µm to 14µm is typically referred to as LWIR (long-wave infrared). Based on micro-bolometers, the IR-detectors act passively and don't need additional illumination such as that in the visible wavelength range.

2 *Infrared camera*



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HOW MUCH ENERGY DO INDIVIDUAL DEVICES AND PLANTS CONSUME?

As already depicted, by using IR detectors, a certain intelligence can be added to the air conditioning of buildings and a lot of energy can be saved. The next Fraunhofer IMS project presented also deals with energy savings. Since 2012, a developer team from the »Electronic Assistance Systems« business unit has been working full-time on »Nonintrusive Load Monitoring« (NILM), a system that will also become a BMWI research project in 2015, and whose core aim is to observe the energy consumption of individual devices.

»How can an electricity sum load profile be divided into its individual parts? That was the leading question our project was based on«, explains Timo Bernard, project leader at the IMS. »In contrast to the usual sub-metering procedures, a system is being developed that could separate the individual energy consumption of several devices and plants by using a single point of measurement«, says Bernard. The result of such a system is lower installation, maintenance and hardware costs compared to comparable sub-metering procedures. Furthermore, for the first time, the nonintrusive load monitoring system gives the building or facility operator broad access to device-specific analyses of energy consumption.

In contrast to other research groups that work on this subject, the developers at Fraunhofer IMS are pursuing a high frequency analysis of electricity and voltage signals approach as well as the utilization of a broad number of electrical characteristics for a reliable disaggregation.

Based on this approach, the first functioning disaggregation-algorithm for on/off-devices and permanent consumers was developed in 2014. The creation of a prototype for the recognition of finite state machines can be judged a success, just like the first positive tests of performance-bound emission interference as a disaggregation characteristic in 2014. Due to its energy consumption transparency and enhanced energy efficiency, this project is interesting for manufacturers of electricity measurement technology and energy contractors such as energy consultants for business enterprises, and not least for energy consumers in general, particularly operators of production facilities and buildings. »In the future, we want to expand our expertise in the field of NILM and take a leading position in Europe over the long-term.« reports Timo Bernard.

3 *Conductive emissions. 3D spectrum of a 19-inch LCD monitor as a potential feature for disaggregation*

PROVEN PROTECTION IN PROVEN STEEL

Once the home is secured against burglary, the danger of fire averted, and an energy-efficient air conditioning of the building guaranteed, nothing stands in the way of a relaxed short vacation. Just a few clothes hastily packed into a suitcase, and off you go on your way to the beach.
But on your way to the beach you'll have to drive over bridges and through tunnels.
The sixth and therefore last project on the topic of »building technology« leaves the residential and commercial built environment and focuses on early-stage detection of corrosion on reinforced steel in bridges, in tunnels or in parking garages. According to the Federal Ministry of Transportation, 6,000 out of 39,000 of Germany's bridges for long-distance traffic are ailing, whereas experts believe this number to be much higher.
A dramatic increase in heavy-duty traffic, which wasn't anticipated during the construction of those bridges, is often cited as the reason for these infrastructure issues. Older bridges in particular do not meet toady's requirements and are a potential risk due to the year of their construction and the technical standards at that time. Environmental impacts and delayed maintenance add to the situation. The consequence: many bridges are closed to trucks. Negative consequences for the economy can be anticipated, especially since the maintenance of long-distance traffic infrastructure is chronically underfunded. According to experts there is an annual shortfall of 1.3 billion euros. Regarding the current situation, the Fraunhofer IMS has, together with the two companies BS2-Sicherheitssysteme GmbH and Baustoffüberwachung BÜW, brought a simple and robust security- and surveillance system to market as part of a partnership project in 2014. The centerpiece of this development is sensors from the think tank of the »Wireless & Transponders Systems« business unit of the Fraunhofer IMS. These sensors detect corrosion in reinforced steel at an early stage because of invasive ions. Reinforced steel is a building material used in many highly-stressed construction projects such as bridges, tunnel walls, parking garages, cooling towers and supporting walls where it guarantees stability. However, this material is vulnerable to the intrusion of ions, which are soluble in surrounding water despite applicable standards and construction. This water could be seawater surrounding a quay, or dissolved de-icing salt on bridges or in parking garages. Once the reinforced steel becomes corroded, the stability of the construction is attacked and can even be severely endangered. Chipped concrete and cracks in the outer skin can be an indicator that it is already too late. A cost-efficient remediation for the construction issue is in many cases no longer possible. By detecting damage in time with sensors from the IMS, huge saving can be achieved, because at an early stage of corrosion, a cost-effective sealing can protect the construction for a longer period of time. These smart sensors are directly set in concrete into the specific component. The data is read out periodically and routinely during maintenance via RFID technology. With this development, a continuous monitoring of the state of corrosion can be implemented. This is a completely new approach, because to date there is no security or surveillance system for concrete constructions that can detect the state of corrosion. As part of the partnership project, the Fraunhofer IMS has designed and built the sensor-electronics and tested the system for the rough environments it will be operated in and for applicable guidelines. BS2-Sicherheitssysteme GmbH was the initiator of the project as well as the manufacturer and vendor of the new system. Baustoffüberwachung BÜW assumed the building chemical validation of the sensor principle.
»This project impressively showed how the interdisciplinary combination of three participating partners were capable of creating a market-ready, innovative product in a short period of time«, summed up Gerd vom Bögel, Department Chief of the »Wireless & Transponder Systems« business unit at the Fraunhofer IMS.
The product »CorroDec-2G«, which was developed by the consortium and brought to market in 2014, has several positive characteristics: the sensor can be installed easily and cost-effectively, has a long lifespan, and enables efficient corrosion monitoring with a mobile scanner whose utilization doesn't require expert knowledge. Even retrofitting is possible.

4 *Installed sensor »CorroDec-2G« before concreting*

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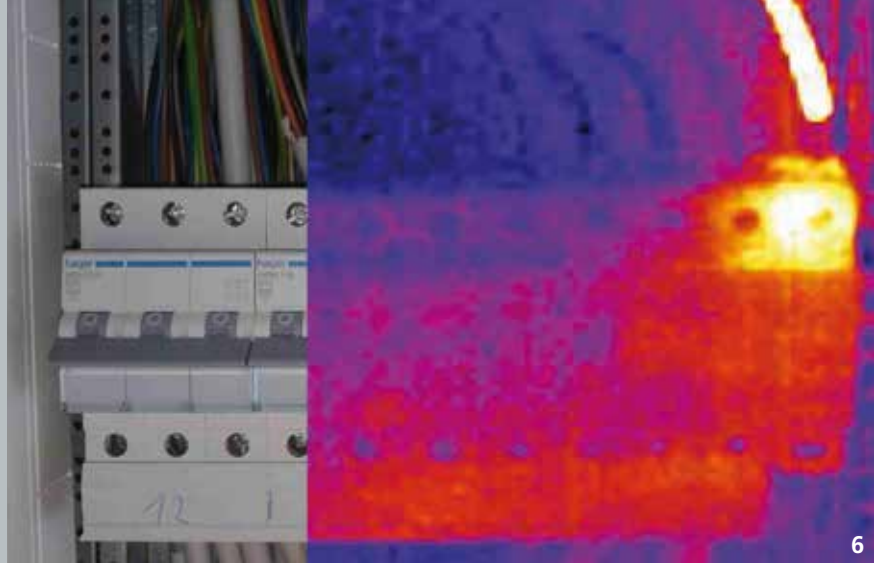

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RFID TECHNOLOGY IN DIFFICULT ENVIRONMENTS

RFID = radio-frequency identification; denotes a technology for transmitter-receiver systems for the automatic and wireless identification and localization of objects (product living creature) with radio waves

Recognizing fires at an early stage – this is a big and important subject the employees of »Wireless & Transponder Systems« business unit also work on. In contrast to their colleagues' IR sensors from the »IR Imager« business unit, RFID technology was used for the »Electrical Cabinet Monitoring« project.

This is a particularly difficult environment: a closed, metallic control cabinet. According to statistics, 32 percent of all fires occur in electronics-installations. Electronic control cabinets and switchboards with their active and passive electrical components have a particularly high potential for danger. Starting in the control cabinets, a fire can spread throughout the wires in a building due to the fire load. The main reasons for fires in electrical plants are malfunctioning or old connections. In order to prevent such fires, the scientists at the Fraunhofer IMS tackled the problem with sensor transponders and performed an analysis of field distribution in electrical cabinets. A specific antenna concept makes it possible for the transponder to be fitted onto the metallic bus-bar in the electrical cabinet. Several read-out antennas were skillfully arranged inside the cabinet so that the read-out of the transponder is possible in every position required. By using wireless temperature transponders, no wiring to the measuring point is necessary. With such an arrangement, 60 or more transponders can be operated in a single electrical cabinet! »With our solution, remote monitoring of electrical contacts is possible. That way, failures and fires in electrical cabinets can be prevented,« summarizes Andreas Hennig, Group Leader of »Wireless Sensors« at the IMS. »No dangerous manual labor is necessary on site. That is the unique characteristic of this development.«

This project, which was done for the Norwegian customer »OneCo A.S.« was successfully completed after a two-year lifecycle. With the already pre-existing demonstrator system, field tests were conducted, whose results will be the basis for the further development of a product series.

5 *RFID transponder with temperature sensor for the monitoring of electrical contacts*

6 *Unwanted heating caused by faulty electrical contact*

SECURE INSULATION INSTEAD OF ONLY WARM WORDS

Protection against burglary, energy savings, fire prevention – the Fraunhofer IMS projects presented so far display the know-how of the institute, using examples of micro-electronic systems and technologies whose field of application is found inside a building (residential- and commercial properties).
The projects that are concealed behind the research subject »Wireless Integrated Pressure Sensor for Quality Control of Vacuum Insulation Panel«, or in short »VIP Transponder«, approach possible solutions for the surveillance of the vacuum state in vacuum isolation panels as part of the external building insulation. Vacuum insulation panels insulate the building facade exceptionally well due to their low thermic conductivity and save much more space compared to standard insulation materials. They consist of a highly impermeable exterior and a porous material made up of silicic acid, which functions as a support body for the vacuum contained within the insulation panel. Vacuum is a very efficient thermic insulator; therefore the thermic insulation is 5 to 10 times higher compared to conventional insulation panels such as polystyrene.
However, the thermic insulation panels are very sensitive. In the case of foil penetration or faulty production, the highly impermeable foil loses its impermeability and the vacuum degrades. For example, the sensitive foil could simply be damaged in transit to a construction site. But how can the state of the vacuum be monitored to avoid mounting panels to a building's wall that have had their insulation qualities massively degraded due to damage? To counteract this, the state of the vacuum must be examined prior to installation in order to avoid the installation of any damaged panels and any resulting consequences, i.e. increased energy costs.
»In order to be able to determine the functioning of a panel at any given time, a pressure sensor-chip with a transponder interface was developed at the IMS,« explains Michael Görtz, Department Chief of the business unit »Pressure Sensor Systems«. »The sensor chip is built into a self-sufficient transponder with a few components and a coil and can, after being fitted into a recess in the support body, transmits the measuring data wirelessly through the foil.« A mobile scanner-hold on the exterior wall of the panel-provides the transponder with energy via a transmitter coil and receives the measuring data from the transponder. The sensor even draws the energy it needs from the scanner's radio signal through thin metal layers, and is therefore suitable for measuring the vacuum in refrigerator insulation. Low thermic conductivity is also important in such cold surroundings. Based on this solution, direct measurements of the internal pressure inside a vacuum insulation panel and an evaluation of the state of the vacuum before the installation are ensured.
The developments within the scope of »VIP Transponder« at the Fraunhofer IMS are especially interesting for manufacturers of vacuum insulation panels. Manufacturers of facade elements, general contractors in the construction industry and manufacturers of air-conditioned transport containers can all profit from this solution.

7 *Handheld reader unit-measuring sensor transponder*

8 *Sensor transponders*

At the beginning of all of these projects, of which six are presented in the annual report that display the IMS's know-how for building technologies, there are special challenges, ideas or visions that make the development of a system or product possible. Over the past three decades, the institute in Duisburg continually managed to differentiate itself from other research and development facilities, doing so through developments and specialized technologies. Together with partners and customers, in its eight business units the Fraunhofer IMS strives to persuade with technological solutions.

»FRAUNHOFER IMS FILLS CONSTRUCTION COMPONENT SUPPLY GAPS«

Elektronik Praxis, February 2014

»IMPLANT MONITORS INTERCRANIAL PRESSURE«

Medizin & Technik, February 2014

»SMALLEST HIGH TEMPERATURE MICROCHIPS FOR HIGH-RISK APPLICATIONS«

Springer für Professionals, April 2014

»SENSOR TO SIMPLIFY THE LIVES OF DIABETICS«

Der Westen, March 2014


11 in Pressure Sensor Systems
5 in Electronic Assistance Systems
2 in Wireless and Transponder Systems
5 in IR Imager
18 in Devices and Technology
31 in Biohybrid Systems
72
Publications in our fields of business in 2014

MOMENTS CAPTURED IN PICTURES

1

2

Since July, the new laboratory at the Fraunhofer-inHaus-Center has been in operation! The »office of the future« is displayed on 80 m² and shows innovations for the workplace of tomorrow.

3

A workshop on high temperature electronics at a forum for industry and academia in this field provided for a lively exchange. Besides interesting presentations on applications, circuits and systems, design, technologies and materials for HT applications, the participants were able to get in touch with users and technology providers.

The female scientists of tomorrow are welcome! Students between the ages of 17-18 were able to produce a unique wafer with a special Girl's Day logo in the MST cleanroom, and learned all about the processes and working conditions for microchip production.

The Fraunhofer IMS presented several devices, such as a device for monitoring intracranial pressure or the magnet ostrictive sensor at Electronica, the world's leading trade fair for components, systems and applications.

4

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Innovation award for its noise-canceling office lamp: As part of the inHaus-Forum, the Fraunhofer inHaus-Center recognized one of the communal research projects between Fraunhofer IBP and the Nimbus Group GmbH with the 2014 1st Place Award for Innovation.


9


6

About 20 journalists followed the invitation by the EnergieAgentur.NRW and joined a tour through the Fraunhofer-inHaus-Center, guided by Volkmar Keuter.


10


7

The 6th inHaus-Forum, titled »Illuminate Efficiency« offered its participants a diverse program with brief presentations and an inspiring panel discussion.


11

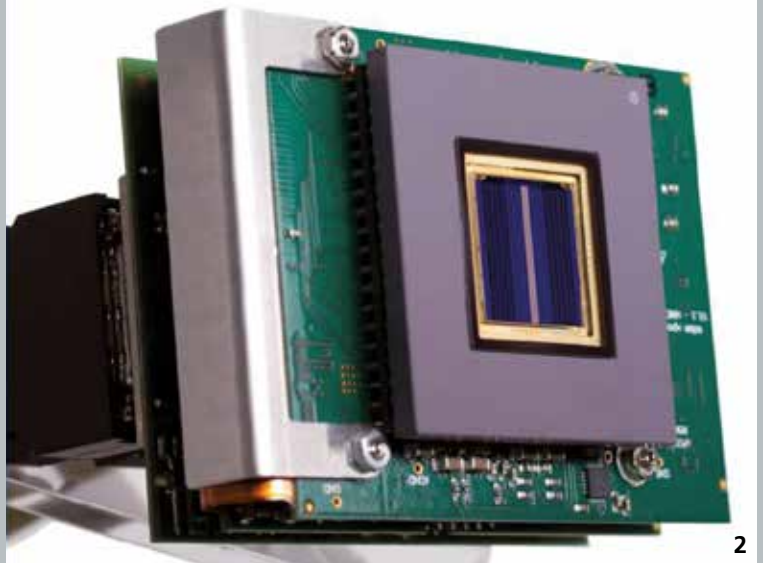

12

Over one hundred interested people visited the CMOS Imaging Workshop, which the institute was invited to for the seventh time in 2014. The workshop is a well-established event for experts in the field of optical sensors for Imaging based on CMOS technologies.

»The good discussion atmosphere between both partners was an important aspect of collaborating with the Fraunhofer IMS.«

Dr. Ernst Bodenstorfer

The native Viennese Ernst Bodenstorfer (born in 1968) studied electrical engineering at the Vienna University of Technology. He graduated in 1997. After that he worked for Infineon in Villach (1998-2000) and Vienna (2000-2004) on the development of microelectronics. Since 2004 he has worked for the High-Performance Image Processing research group at the AIT Austrian Institute of Technology GmbH.



2

JOINT EXPEDITION TO SUCCESS

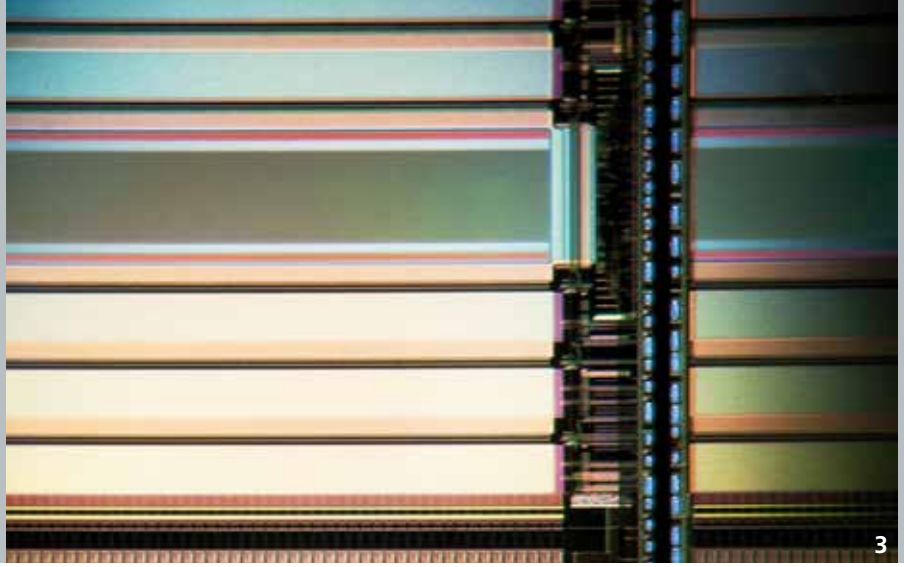
Together with the AIT (Austrian Institute of Technology), the Fraunhofer IMS has developed the fastest line scan sensor to date for highly sensitive optic inspection tasks and sets new benchmarks in the field of high-performance imaging.

The demands on modern industrial production plants are always expressed with superlatives. Whether it's paper, steel or textiles that are pacing along a plant's assembly line within the process of production – it always has to happen in the most reliable, most efficient, and fastest way possible. With such extremely high velocities, the number of products assembled by these plants is always on the rise. Customers expect non-stop production that ensures a constantly high level of quality. To keep up with requirements and challenges, technologies and solutions are necessary that enable an optical inspection of every single product. A broad number of optical measurement systems rely on high-speed image acquisition. Besides a high speed, a high sensitivity to light and high spatial resolution are required. The Fraunhofer IMS has developed, together with the AIT Austrian Institute of Technology, a high-speed sensor for line scan cameras with up to 2048 pixels per line. The maximum line frequency is 600 kHz for monochrome scanning and 200 kHz color scanning when the sensor lines are coated with red-, green-, and blue-transparent color filters for RGB color imaging. To give an example, the multi-line sensor developed enables color line scanning with an image resolution of 0.05 mm at a transport speed of 36 km/h. That way, the sensor can detect even the smallest surface damage, and is perfectly suited for surface inspection tasks like web inspection, printed circuit board inspection or wafer inspection. But there's more: with an image resolution of 0.4 mm at 300 km/h, the sensor can be used for inspection tasks in the field of high-speed surface inspection. For example, rail fractures can be detected at an early stage, by scanning the railway tracks for hairline cracks during the journey of an ICE, the German high-speed intercity express train.

In this interview, Ernst Bodenstorfer, AIT Scientist, High-Performance Vision research group, explains what's special about the xposure sensor, reports on the common development work with the Fraunhofer IMS and gives a forecast on future high-performance imaging.

Mr. Bodenstorfer, on which leading question and challenges was this project based?

The High-Performance Vision research group at the AIT Austrian Institute of Technology works on imaging solutions for inspection tasks with especially high transport speeds together with fine resolution. The majority of projects contain systems with fast line scan cameras, which, for example, scan the surface of railways, metal strips or treasury notes in order to detect defects at an early stage. All of these applications have one thing in common: speed is crucial in order to achieve the highest throughput possible together with the requirement that resolution can't be fine enough. We are continuously confronted with the demand for faster imaging systems together with an even finer image resolution. Therefore, we test the limits of what's technically feasible, especially with regard to image computing and -algorithms, but also line scan cameras, data transfer routes, optics and illumination. Several projects in the past could not be realized because there was no line scan camera available that was fast enough for the demands of our customers. Hence we decided to develop



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our own CMOS color line sensor, which is twice as fast as the fastest line scan camera available on the market. We reached this goal together with the Fraunhofer IMS in November 2014, when we introduced the sensor prototype and its full speed of 200 kHz color line rate to an expert audience at »Vision«, the world trade fair for industrial imaging in Stuttgart.

Please explain in a few sentences the unique features of the high-speed line scan sensor xposure.

The most important and unique feature of the sensor is its really high scanning speed. In the monochrome version it can scan objects at 600,000 line images per second, and in the color version it achieves 200,000 line images per second in RGB. Notable about this sensor is the fact that it is so low-noise that one can still achieve full image quality with customary illumination and lenses with an exposure time of a few micro seconds resulting from high line rates. This is possible because the sensor is fast and sensitive at the same time. Another important feature of the sensor is its pixel arrangement. It doesn't only have a single red-, green-, and blue-sensitive line of pixels, but integrates 60 light-sensitive lines. Depending on the requirements of an application, the number of lines that are read out can be configured. That way the sensor can, for example, be switched to area scan mode, thus supporting an operator during camera adjustments or enabling multispectral applications with up to 60 color channels. Furthermore, it's important to note that the color filters which are deposited on the sensor's surface cover the complete pixel lines, suppressing the disturbing Moiré-effect and coloring artifacts at bright-dark edges in the image. That is a huge advantage in comparison to the often used Bayer-pattern…

What does the development of the sensor mean to the AIT?

We at the AIT wanted to show that we can develop cutting-edge technology in Central Europe, in order to be capable of continuously responding to industrial demands into the future. That way we push technical possibilities in established application fields and open new ones.

Which application fields are currently planned for xposure and which are under consideration for the future?

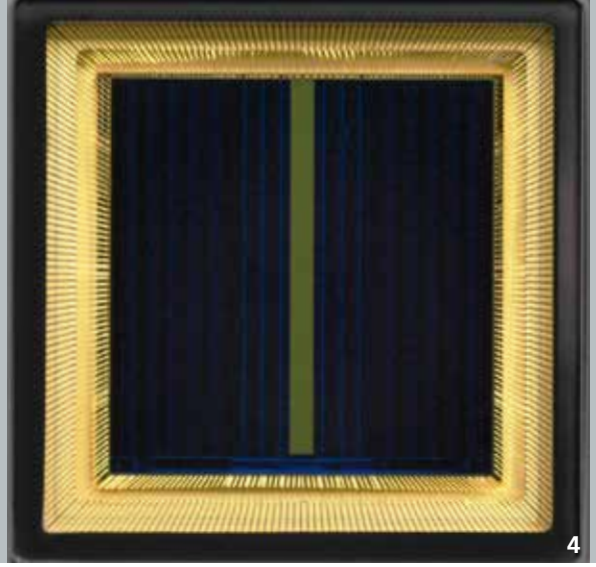
In industrial production, the assembly lines keep running faster while at the same time the products are becoming more and more complex. The sensor can be integrated into each of those assembly lines. Especially in the field of security printing, treasury notes for example, but also for packaging printing or label printing, the sensor will exploit new possibilities. Another field in which the sensor ensures decisive advantages is the inspection of infrastructure, such as rail- and highways. High resolution and velocity are the preconditions for security-critical applications.

AIT presented the high-speed sensor for the first time at the world´s leading trade fair for industrial imaging, »Vision«, in Stuttgart in November 2014. How was the feedback?

The feedback was extremely positive. Representatives from all of the major camera manufacturers visited our booth to inquire about this worldwide novelty. We could demonstrate the sensor at full recording speed and explain technical and performance data to an interested expert audience. The appreciation that was shown to the AIT and IMS for this development was clearly noticeable; some people were even surprised that a performance improvement like this was even possible.

How did collaborating with the Fraunhofer IMS work for you?

The good discussion atmosphere between both partners, which is crucial for any novel technology development, was an important aspect of collaborating with the Fraunhofer IMS. One could compare it to an expedition where the goal is given at the beginning, but not the path that leads you



there. The collaboration was always based on the awareness that both partners are pulling in the same direction, and each one bearing his part of the risk.

Which other common tasks and challenges are expected in this project?

The next common steps to be taken are the marketing and further development of the sensor in order to achieve market readiness. There are several other aspects besides the technical solutions, which influence the decision of producers in the imaging industry to make them add the sensor to their portfolio. Therefore it's important to find an industrial partner with whom we can actually transfer a new technology into an innovation that finds its place in the market.

How about a forecast on the future of high-performance imaging. In your opinion, what developments will be seen over the next few years?

Besides speed, line length will be an important parameter. There will be a need for longer lines for fast sensors like this in the future. Interface- and computer manufacturers are challenged in order to be able to compute this enormous amount of data, and if necessary, to store it. The amount of data will increase in the future. The topic 3-D, for example the inspection of surfaces, is already an issue today. Stereo and light field cameras enable new, innovative, solutions. These technologies will continue to rise to the performance requirements of computer- and software architecture. High performance imaging is, and remains, a thrilling subject.

Mr. Bodenstorfer, thank you very much for this interview!

1 *Silicon wafer with xposure sensor*

2 *Xposure camera system*

3 *Xposure CMOS line scan sensor*

4 *Photomicrograph of xposure*


Galileo Computing

1. Monographs

7th Fraunhofer IMS Workshop CMOS Imaging. (Workshop CMOS Imaging ⟨7, 2014, Duisburg⟩). Duisburg: IMS, 2014

Fraunhofer IMS Workshop High Temperature Electronics. (Workshop High Temperature Electronics ⟨2, 2014, Duisburg⟩). Duisburg: IMS, 2014.

2. Papers in Monographs

Durini, D.; Arutinov, D.: ***Fundamental principles of photosensing.*** In: High performance silicon imaging. Oxford [u.a.]: Woodhead Publ., 2014, pp. 3-24 (Woodhead Publishing series in electronic and optical materials; 60)

Durini, D.; Arutinov, D.: ***Operational principles of silicon image sensors.*** In: High performance silicon imaging. Oxford [u.a.]: Woodhead Publ., 2014, pp. 25-77 (Woodhead Publishing series in electronic and optical materials; 60)

3. Journal and Conference Papers

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