Fraunhofer

IMS

FRAUNHOFER INSTITUTE FOR MICROELECTRONIC CIRCUITS AND SYSTEMS

ANNUAL REPORT

2017

Content

Dear readers,
dear friends and partners,

they have always been an elementary component of our work at Fraunhofer IMS: The interdisciplinary leading projects within the Fraunhofer Gesellschaft, on which we worked especially intense in 2017. Therefore we got the opportunity to promote our main topics as well as to cooperate closely with other Fraunhofer institutes. This way we face the current challenges together and combine our competences for the German and European industry. The overarching goal is to transform scientific ideas into marketable products and to develop concrete solutions. As the topics are always oriented towards the needs of the economy, we incorporate our industrial partners in the projects early on. One of the leading projects, in which Fraunhofer IMS is involved intensively, is “QUILT” (Quantum Methods for Advanced Imaging Solutions). Together with five additional Fraunhofer institutes, as well as with scientific and industrial partners, we are working on the area of quantum research – one of the most important scientific fields of our time. The goal is to establish quantum technologies as a core competence of the Fraunhofer Gesellschaft and to be prepared for the future. Especially in the area of quantum imaging we are already excellently positioned – and this position is supposed to be reinforced by QUILT. For this purpose Fraunhofer IMS is going to contribute “Imagers” as a core topic.
An additional leading project, in which Fraunhofer IMS got in the leading position, is entitled “eHarsh”. The goal of this project is the development and provision of a technology platform. On the basis of this platform, sensor and electronic systems for application in extreme environments of industrial processes, for example high operating temperatures, mechanical stress or humid and chemically aggressive environments are to be developed and manufactured. It is a special honor for us to be in a leading role of this project and I am entirely confident in its success. As there were many more industrial and leading projects in 2017, these are only two examples of our research activities.

The year 2017 has also been special for us, because we became an official part of the Forschungsfabrik Mikroelektronik Deutschland (FMD). Eleven institutes form the network of microelectronics of the Fraunhofer Gesellschaft in combination with two Leibniz institutes that build the virtual research factory with the goal to lay the foundation for future microelectronic competences. Therefore, Fraunhofer IMS received 25.5 million Euros from the investment program by the German Federal Ministry for Education and Research (BMBF), which are going to be invested primarily into new machinery and the structural development within the research factory.
We want to research increasingly on intelligent sensor chips and develop novel construction elements. To be a part of this unique network makes me proud and I am glad to be able to strengthen our position as an attractive partner for national and international economy. Due to the support of BMBF within the framework of FMD, we are even more powerful to increase the condition of our core issues and to offer our customers sustainable solutions.

A topic that I want to highlight especially is the further development of the LiDAR technology at Fraunhofer IMS. The LiDAR system works with light to measure distances and generates high-precision 3D-images of its environment in VGA resolution. In particular this technology combines the advantages of other 3D processes and is characterized by its very accurate spatial assessment, fast measuring times in real-time and a depth of focus, which is comparable to RADAR. Disturbing environmental influences, like snow, rain or too much sun exposure as well as weak signal strength, have been problematic. The scientists of Fraunhofer IMS are researching intensively on new sensor concepts that are able to defy these problems – and they can already showcase first successes. In the future, this technology is going to make the receiving of even more secure measurements possible, so that LiDAR is able to replace the human eye almost equally, for e.g. in cooperative robotics.

In this year, there has also been a new impulse for our innovation factory, the Fraunhofer inHaus-Center. Wolfgang Gröting is a proven expert in the area of innovation management and the new director of the innovation center. He predicts the future focus areas of his work in subjects like health, healthy ageing and care. Also, topics in the area of smart home are going to be of great importance under his management. In the last 20 years, Wolfgang Gröting has been in leading positions at Siemens and Philips and I am glad that we could win him over for the inHaus-Center.

In our annual report 2017 we present, as usual, a few highlights from the past year – this time the focus is placed on the area of industrial sensors. But, our general leading theme micro sensors is a part of our highlights as well. Additionally, you will discover the additional value our research and development has to offer. A selection of projects on the topic of “industrial sensors” can be found beginning on page 18 of this annual report.

From an economical point of view we can look at an overall positive annual balance. Industrial revenues have increased significantly compared to the previous year, whereas the public revenue from the federal government, the state and the EU has become weaker. Overall, we are very satisfied with our economic success and are optimistic about the future.

Special thanks are directed, of course, to all employees of the institute. You have been doing excellent work that I am very proud of. Further I would like to thank all our customers and partners for a trustful cooperation. I am sure that together we can achieve a great deal in the next year as well and shape the future together.

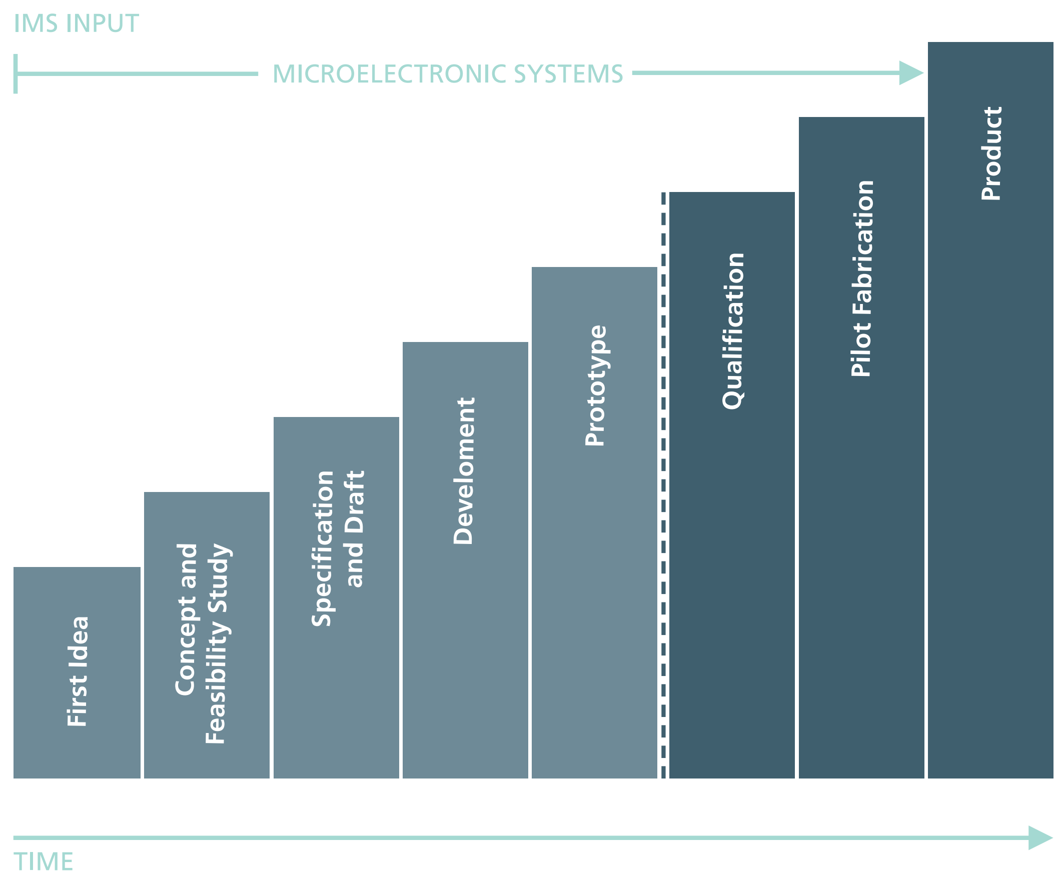
I am looking forward to a successful year 2018!

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

Anton Grabmaier

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

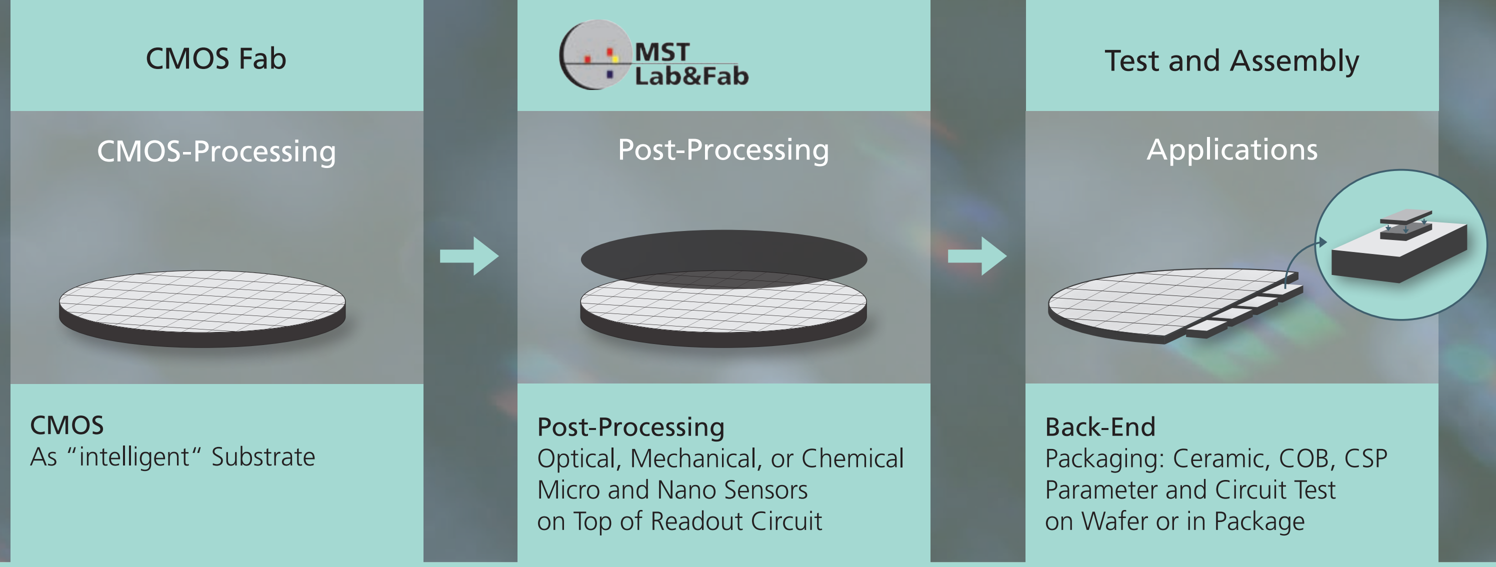
In the beginning there's your idea or vision for a new product, but you don't know if it is feasible, which costs you will have to face, if there are potential risks and which technology leads to the optimal product. As a research and development institute of the Fraunhofer-Gesellschaft, we offer you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

Frontend

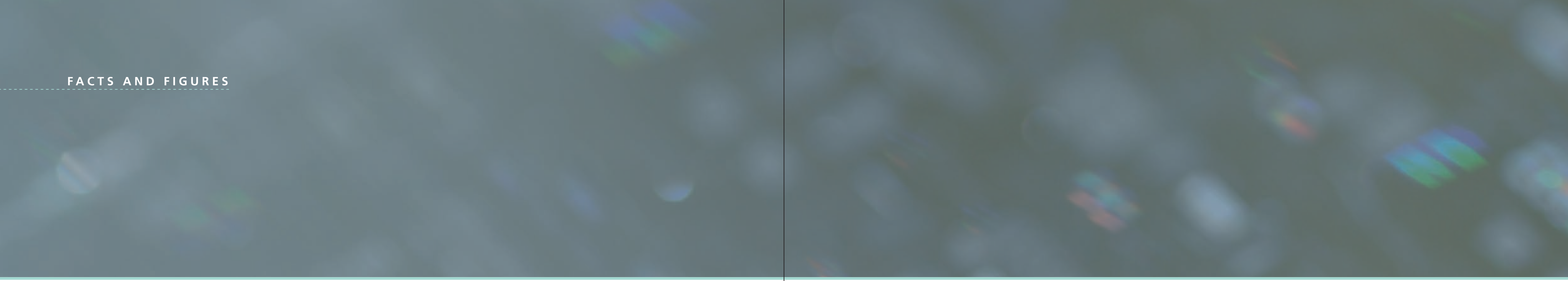
CMOS line	
Wafer size	200 mm (0.35 µm)
Cleanroom area	1300 m²
Employees	150 in 4 shifts
Capacity	> 50,000 wafers/year

Microsystems technology lab & fab	
Wafer size	200 mm (0.35 µm)
Cleanroom area	600 m²
Capacity	5,000 wafers/year

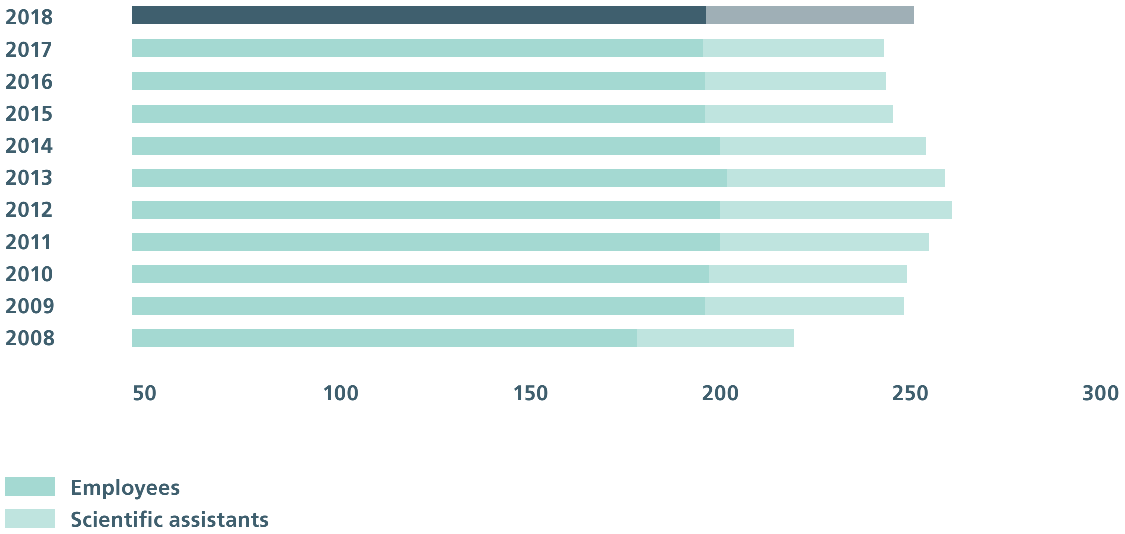
Backend

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

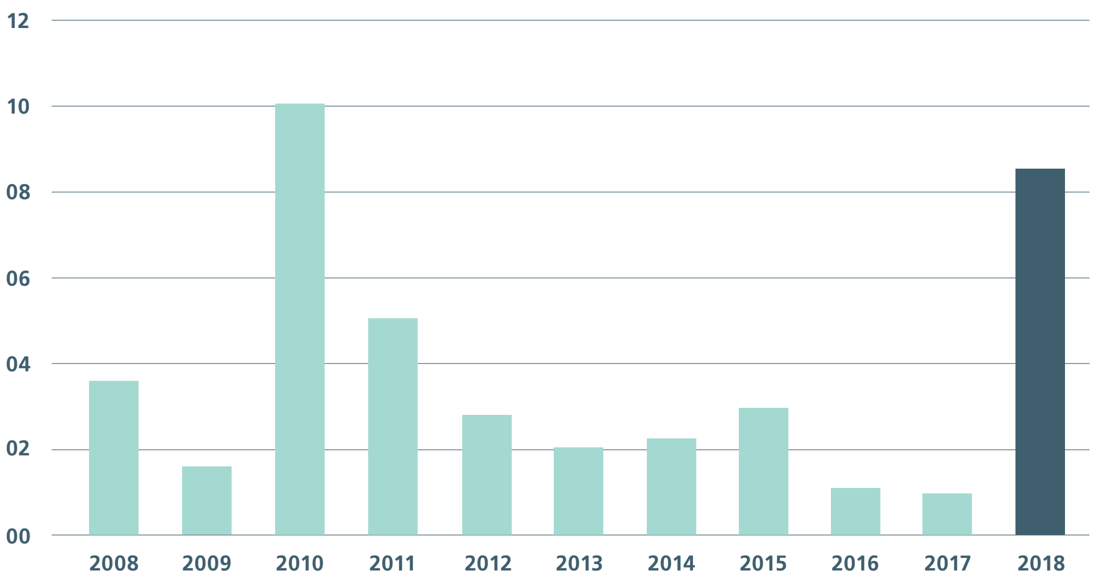
Laboratories	
Biohybrid sensors	45 m²
inHaus-Center	3500 m²
Laboratory space	800 m²
High-frequency measurement chamber	24 m²



STAFF MEMBERS

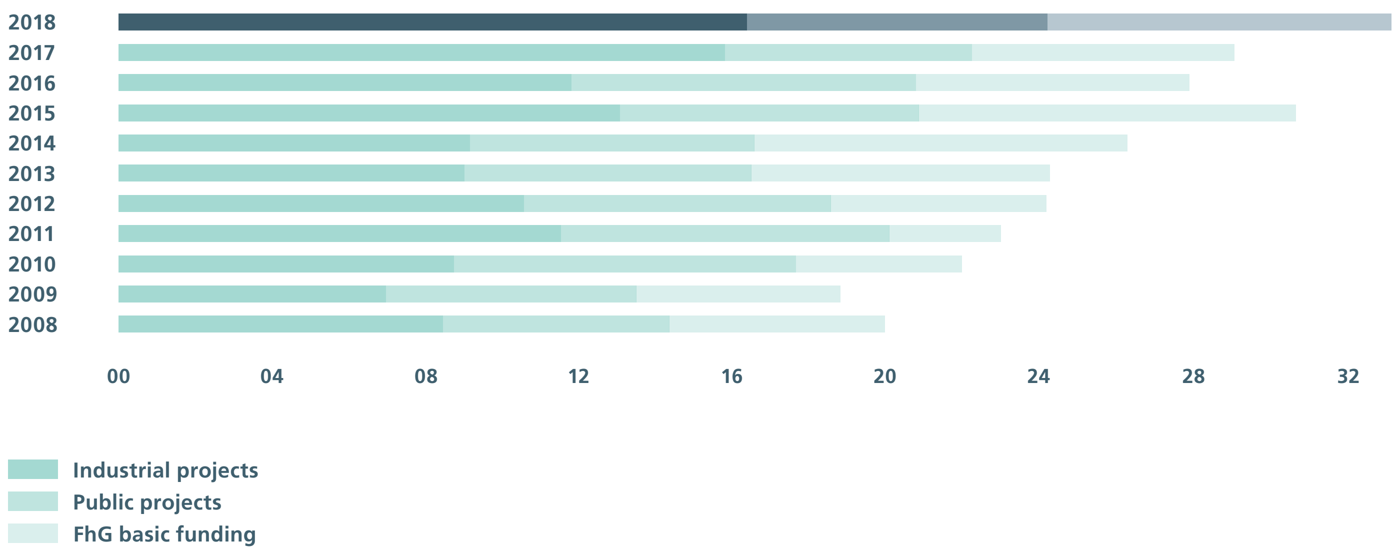


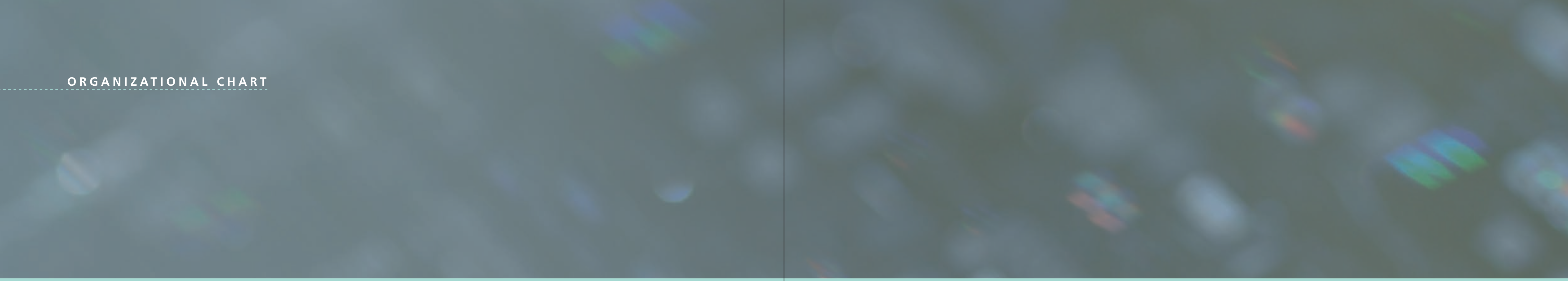
CAPITAL INVESTMENTS (in million euros)



“Together with our partners we will keep on developing technology that is applicable and successful at the market, strengthen the local economy and through that we will create future.” *Prof. Anton Grabmaier*

BUDGET (in million euros)





ORGANIZATIONAL CHART

DIRECTOR
Prof. Anton Grabmaier

DEPUTY DIRECTOR
Prof. Holger Vogt

PRESSURE SENSOR SYSTEMS
Görtz

CMOS IMAGE SENSORS
Brockherde

WIRELESS AND TRANSPONDER SYSTEMS
Dr. vom Bögel

ASICS
Prof. Kokozinski/
Dr. Vogt

ELECTRONIC ASSISTANCE SYSTEMS
Kemmerling

DEVICES AND TECHNOLOGIES
Kappert

IR IMAGERS
Dr. Weiler

BIOHYBRID SYSTEMS
Görtz

INHAUS-CENTER
Gröting

ADMINISTRATION SERVICES
Benninghoff

MARKETING, SALES
Bollerott

QUALITY ASSURANCE
Kelter

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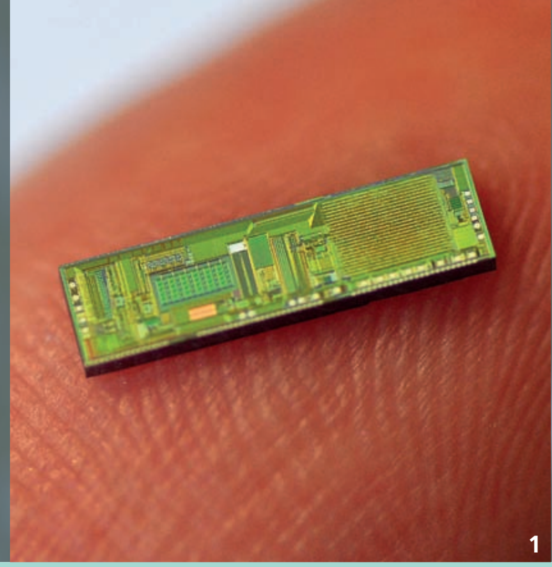
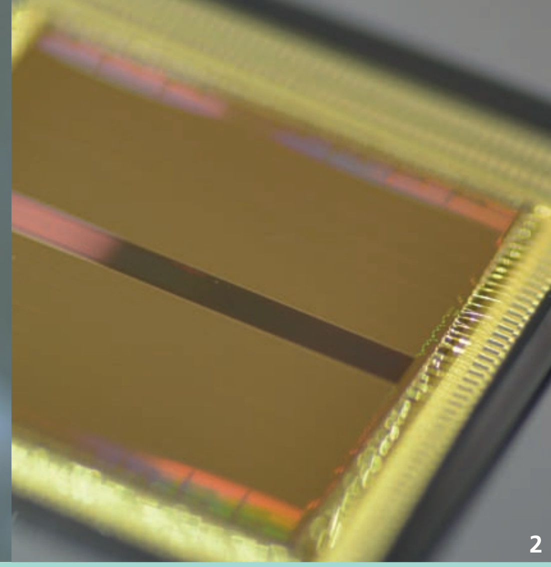
Niederrheinische Industrie- und Handelskammer

Prof. Frank-Hendrik Wurm
Universität Rostock

8 Business units

1 Innovation center





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*

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.

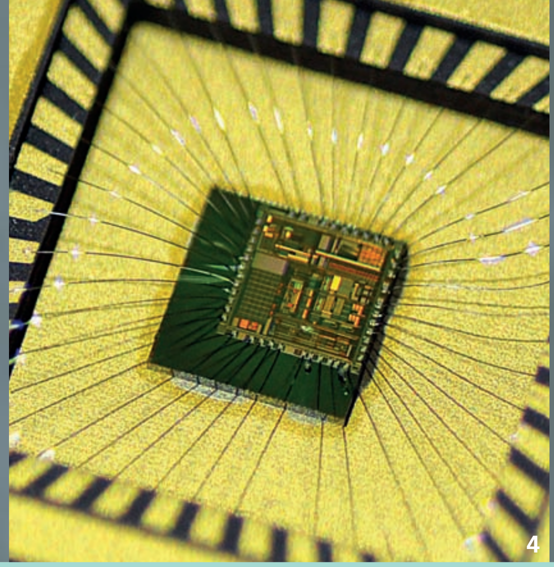
Our customers benefit from a 0.35 µm "Opto" CMOS process optimized for imaging applications. "Pinned" photodiodes with low dark current and little signal noise and with color filters, micro lenses as well as stitching can be integrated. Our developments cover a broad spectrum from x-rays to EUV, UV and 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 surface sensors*
- *UV- and XUV sensitive sensors*
- *Color filters and micro lenses*
- *Customized packaging and testing*
- *Pilot manufacturing in 0.35 µm "Opto" CMOS process*

1 *Pressure sensor for medical implants*

2 *xposure CMOS line scan sensor*



WIRELESS AND TRANS-PONDER 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 durable. 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*

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.

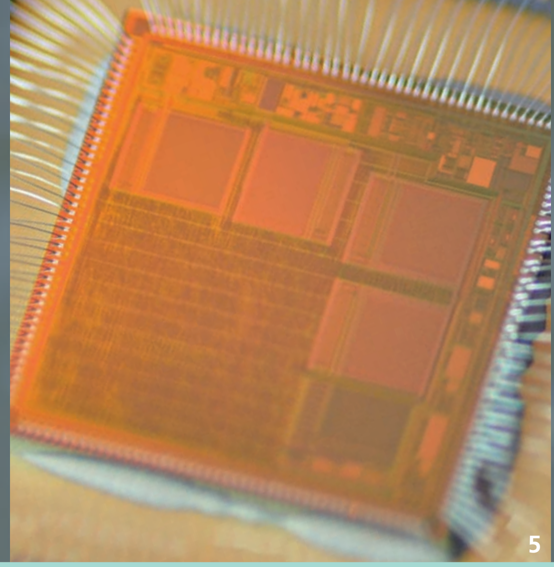
Special circuit parts or sensor system components are individually and custom-designed and integrated with standard components like sensor readout, signal processing, interface components or embedded micro controllers on an IC.

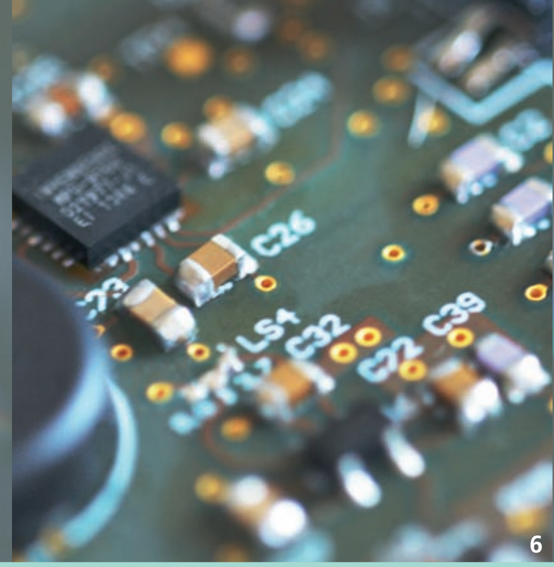
Supply and services/technologies:

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

3 HF transponder

4 MEMS accelerometer readout IC





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*

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.

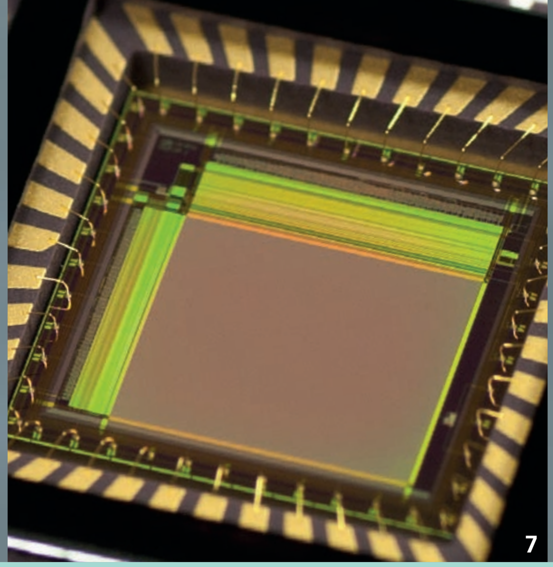
We provide our service and know-how across all industries. Our circuits and systems are used especially where it's all about the creation of unique selling points and competitive advantages for our customers. Then, our customer is able to best serve the target market.

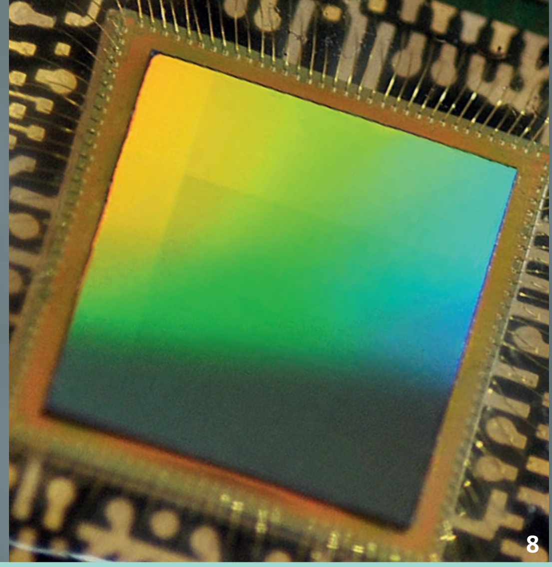
Supply and services/technologies:

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

5 HT micro controller

6 Bicycle fall detection PCB





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*

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.

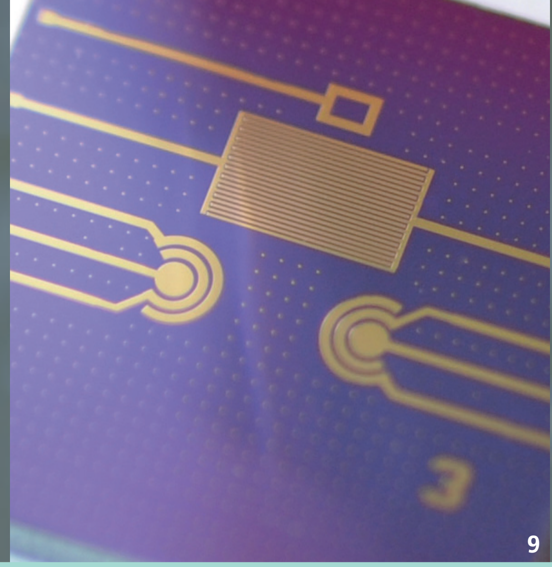
Similar safety aspects, e.g. personal security or measurement technology in process monitoring, are also important to the industrial sector. In the sensor system, the gas analysis is of increasing interest. Further applications include thermography in buildings or in medicine, but also border and building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

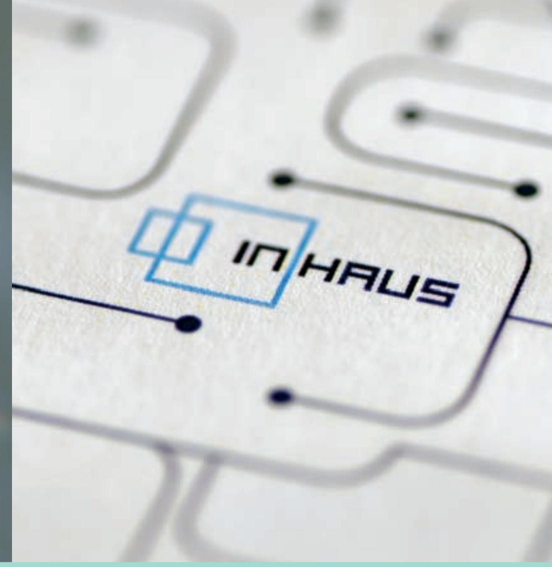
Supply and services/technologies:

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

7 High frame rate eye sensor for lasik surgery

8 Uncooled IR detector for thermal imaging





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*

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 100 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:

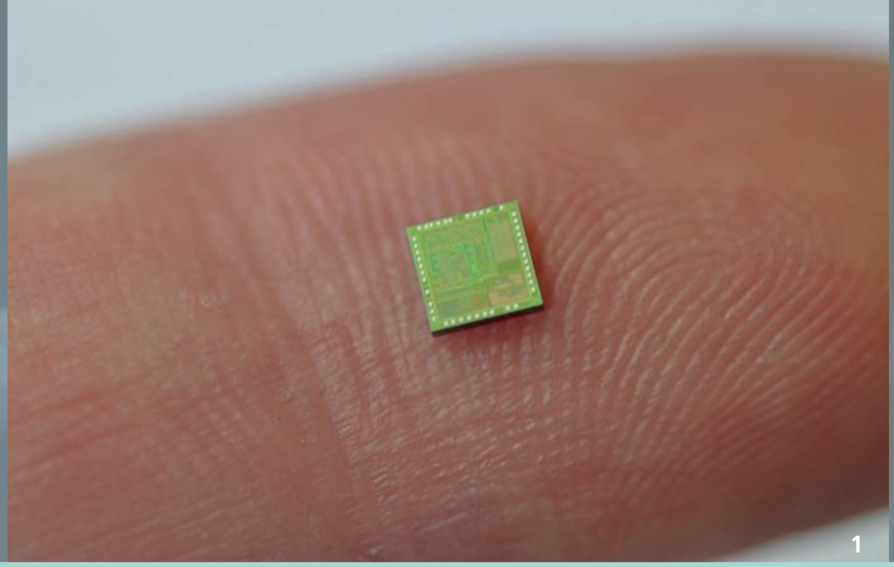
- *Building/planning with IT support*
- *Energy transparency/ -energy efficiency*
- *Logistics and operational processes*
- *Interaction between people and technology*
- *Multifunctional component building systems*
- *Sustainable construction*
- *Performance-oriented rooms*
- *Security and safety*
-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

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

5 Selected projects

1 Main theme “industrial sensors”

In this chapter:



EARLY DETECTION OF CRITICAL EVENTS BY HIGH-PRECISION ACCELEROMETERS

Mahatma Gandhi once said "the future depends on what you do today." It might not be the first thing to come into one's mind when reading the quote, but it fits taking precautions in an industrial context as well as it fits a social reformist. Fraunhofer IMS, in cooperation with the Universities of Duisburg-Essen and Liege as well as with the British company Mir Enterprises Ltd. developed a new device to care for today as well as possible.

This MEMS based accelerometer can be installed and used for the means of different tasks. It is a sensor for seismic activity like it can be seen when earthquakes take place or while drilling for oil and gas exploration. Installed in bridges or in the fundament of buildings it can furthermore detect any suspicious movements or vibrations that are abnormal and thus signs of possible future damage or even collapse. It can also be installed in machinery or rotating parts to detect imbalances or unforeseen additional stresses.

In all these cases it helps to repair today what tomorrow might mean a major failure. To be able to do so, the sensor must be the most sensitive for it is normally just the smallest deviation of what is to be expected of a machine or building that can be a messenger of upcoming failure. In addition, certain obstacles in the design and manufacturing process of the accelerometer that are common for these devices need to be overcome. For example, a significantly increased noise level and thus reduced measurement performance is often seen in micro-electro-mechanical systems but is also symptomatic of the read-out-integrated-circuit (ROIC). The accelerometer that is to be presented here combines both of these components. It follows that during the design process the researchers focused on achieving low noise, while at the same time manufacturability was an important feature as well.

The MEMS sensing element is a so called capacitive device with in-plane, single axis sensitivity. It consists of a mass that is spring-loaded and has comb fingers attached to the top and bottom. These fingers can move in between another comb stationary with respect to the accelerometer. Any movement of the mass will therefore influence the distance between the comb fingers of the proof mass and the fingers attached to the housing. Due to the capacitive habits installed in between the combs, these changes in distance can be detected as this causes a difference in the electric voltage which will be evaluated later on. The sensing elements are produced by etching the desired shape into a silicon wafer using hydrofluoric acid in a dicing-free process. The yield of this fabrication process is extremely high, as there is no dicing that imposes any unnecessary mechanical stress onto the wafer. Thus, the risk of damaging the already finished element is reduced greatly. An unusually large proof mass leads to a high sensitivity in conjunction with a very low noise.

The ROIC that is responsible for processing the before mentioned electrical signals is a root of additional noise for every system. However, it was possible to design a circuit that accomplishes an unprecedentedly low noise level. To do so, the researchers designed a number of noise filters as well as found characteristic frequencies and waveforms that allow for the best and least fault-prone transfer of signals inside of the device. In detail, the ROIC is made up from a two-stage amplifier, a demodulator and an output filter. In all of these stages, different kinds of noise are either generated or distributed. By identifying which component induces which noise (this is possible because each noise is of a specific frequency) certain modifications of the parameters in the respective parts of the circuit were able to be undertaken. So, for example, having noticed that the most noise comes from the first stage of the two-staged amplifier a mathematical model describing the formation of the noise was developed. Because this model is able to describe the noise's power in dependency of the system's frequency, this frequency was able to be chosen very specifically and, finally, such that the noise is now minimized to the greatest possible extent.

To finally prove that the measuring devices developed work sufficiently, an automated test and characterization environment for acceleration measurement systems was developed at Fraunhofer IMS. The measured voltages at the output showed a very linear relation to the specific accelerations and even relatively high or low temperatures didn't cause a considerable deviation from this desired determinant relation. Noise measurements on the system's outputs showed that the achieved performance is much better than that of similar systems created and examined during the last years and at least equal in capacity to systems which are much more complex and costly to produce than the presented one. Thus the newly developed system now offers a cost efficient manufacturing process to produce highly sensitive and capable accelerometers.

1 *The IMS-CAP51 on a fingertip*

2

WIRELESS SENSORS FOR INDUSTRY 4.0

Industry 4.0 with all its related attributes is said to bring more productivity and reliability and lower the costs of production, while at the same time becoming more flexible. This can only be done by implementing advanced computing systems into the production process. Only, computers alone do not provide the solution as long as their "hands, ears and eyes" are missing. There are plenty of solutions already available that are able to read in or measure data and act according to what they are told using the built machinery. However, in the future the customers will demand ever more flexibility. It is clear that this 'batch size of one' production cannot be successfully implemented having only the immobile machines and infrastructure of today at hand for they restrict the freedom in alternative workflows and are constrained by cables and wires. Instead, in order for these sensors and actuators to be working efficiently in an ever more mobile and adaptable environment, it is urgent to have wireless systems at hand.

In the past, the market penetration of wireless systems has been delayed by the tough requirements the market is used to employ on wired systems. These requirements include minimal delay, high reliability and sufficient data rates. Yet, the emerging standard "IO-link Wireless System Extensions", which is currently in the final specification phase, adopts the market demand as an extension of the IO-Link standard. IO-Link Wireless equipment operates in the unlicensed 2.4 GHz ISM band and uses frequency hopping to reduce the impact of interference. IO-Link Wireless realizes a communication between the air interface of a Wireless Master (W-Master) and the air interface of one or more Wireless Devices (W-Devices). Being an extension of an already existing standard, IO-Link Wireless can provide the same functionality as its wired version. This includes the processing and storing of data, but also provides mobility to the system that is not only equal to but exceeds the wired form's mobility.

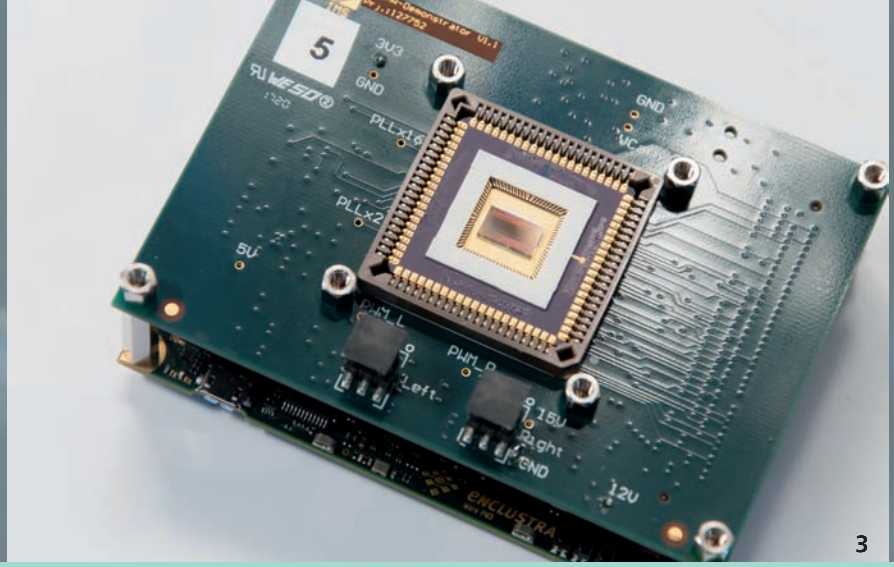
To do so the designated area in which the system is meant to be applied and mobile is divided into multiple W-Master cells ranging from 20 to 40 meters in diameter. Well-defined handover procedures allow the Wireless Devices to switch between base station cells (W-Master cells). The cell concept bases upon the use of orthogonal frequency hopping sequences by the W-Masters and their associated W-Devices in order to allow operational coexistence of overlapping W-Master cells. It is necessary to mention at this point, that besides the IO-Link Wireless System Extensions, there is currently no established wireless standard known that can fulfil both, the requirements for real-time operation and intercell-roaming.

However, wireless solutions remain insufficient as long as contactless power transfer for mobile devices is not available. In this regard Fraunhofer IMS has developed a solution for the contactless power supply of mobile cyber-physical systems for a variety of factory automation applications. The concept is based on the assumption that cyber-physical systems move on deterministic trajectories in production environments and remain on at least one position for a sufficient time to transfer an adequate amount of energy electrical to an electrical storage. This transmission of energy is done by a conversion from electrical to magnetic energy and vice versa by the help of inductive coupling. During this process the transmitter and receiver remain at a distance of several millimeters. This system therefore can allow a hermetic protection against dirt and fluids.

The system architecture we found to bring the best results incorporates both wireless real-time communication and contactless energy transmission. This system is made up of two main components: a cyber physical system and a base station. The cyber physical system incorporates a smart sensor/actuator unit capable of acquiring and processing data as well as an IO-Link Wireless component for communication and a power receiver, storage and manager unit that is contactless charged by the base station and then supply the smart sensor/actuator with energy.

Generally, cyber-physical systems are essential components of the industrial environment of tomorrow. They combine the capability of being able to interact on the physical layer (as in drilling modules, workpiece carriers, etc.) but also are equipped with embedded systems and their related computing power that can store and analyze data, can perform sensor fusion, for example using artificial intelligence (AI) algorithms such as neural networks. By this they can directly acquire physical data that can immediately affect the physical processes the system is acting out at that moment. In this sense, cyber-physical systems enable decentralized control systems and networks, real time synchronization of the physical world with the models of the digital world and effectively a more self-contained, error-stable and easier to manage workshop.
The base station on the other side comprises the correspondent components (wireless interface, transmitter) and an interface for the integration into fieldbus systems to receive general orders or even to interact and communicate with other machines.
To conclude, independent, wireless systems are a necessity for any industry willing to develop further. Although wireless standards capable of both real-time operation and intercell-roaming are rare still, advances have been made. Wireless systems that can act according to the data they process at the same time are the basis of decentralized hierarchies and more flexibility in the industry. The presented architecture and the connected system components are ready and able to fulfil these needs.

2 *Boost & Fly Trade Show Exhibit*



3 *SPADeye2 dual line LiDAR sensor with evaluation board*

3D VISION FOR THE FUTURE OF INDUSTRIAL AUTOMATION

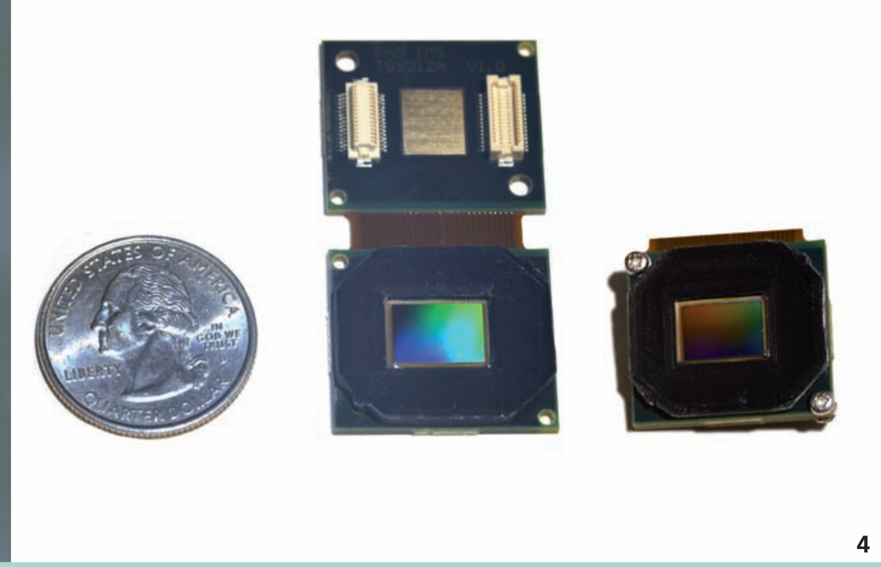
Teaching machines to see and act like humans – this is what engineers and scientists have been dreaming of since the early ages of the industrial revolution. Today, many sensors and actuators are involved in industrial production plants and help to identify objects, detect irregularities in the production process and assist or even replace human staff in many everyday industrial tasks.

LiDAR (light detection and ranging) is a technique which allows a three dimensional perception of objects or the environment. It works similar to radar, but uses light waves instead of radio waves for distance measurement. To determine the distance, a short light pulse is emitted towards the scene of interest and the time until the reception of the reflected signal is measured by a sensor-integrated electronical stopwatch. By knowing the speed of light, the distance between the camera and the target object is calculated. To achieve distance resolutions in the range of centimeters or smaller, high precision stopwatches are required. If this time measurement is performed in many single pixels, similar to conventional image sensors, a three dimensional image of the whole scene is acquired.

The business unit "CMOS Image Sensors" at Fraunhofer IMS develops custom flash LiDAR sensors for many different applications. In industrial environments possible applications include object detection and counting, speed measurements of moving products, security barriers at machines or plants to keep harm from humans, fill level monitoring, and many more. The IMS CMOS process allows the integration of high performance photodetectors along with dedicated auxiliary and signal processing electronics in a single solid-state chip. This co-integration increases the reliability of the sensor and reduces the cost at the same time. For low power and low light applications sensors based on SPADs (single-photon avalanche diodes) are part of the Fraunhofer IMS portfolio. These highly sensitive photodetectors are able to detect even single photons with a very high timing resolution, making them the first choice for many applications.

The full-parallel time acquisition implemented in the sensors allows a simultaneous distance measurement in all pixels of the sensor and therefore the use of flash illumination. Compared to scanning approaches in this technique the whole target scene is illuminated and measured in a single light shot. A faster acquisition and a simpler illumination source, since moving parts can be avoided completely, are just two advantages. Additionally, solid-state systems are much more shock resistant and therefore qualified to be used in rough environments.

For sensor characterization and demonstration purposes, IMS has developed the LiDAR camera "Owl", which integrates all components required to operate the LiDAR sensors including power supply, FPGA-board for sensor control, PCB for FPGA and sensor interconnection, flash light source, and optics. Together with the latest LiDAR sensor "SPADeye2" – a 2 x 192 pixel flash sensor dedicated to high ambient light applications – a fully functional LiDAR system with a range of more than 50 m, a nominal resolution of 5 cm, and a field-of-view of 1° x 36° for each of the two pixel lines is available at the institute, ready for customer demonstration. The existing LiDAR system also allows consumers to investigate the applicability of the LiDAR technology in any possible application. The Fraunhofer IMS roadmap includes sensors with higher spatial and temporal resolution, improved SPADs, and additional features. Additionally, with its own CMOS fab, microsystems lab, and latest wafer bonding technology, IMS is the perfect partner for custom LiDAR sensor and system R&D projects.



4 *Digital 17 µm QVGA-IRFPAs mounted on a detector board including protective cap.*

HIGH-PERFORMANCE UNCOOLED DIGITAL 17 µm QVGA-IRFPA-USING MICROBOLOMETER

Given the wide range of possible applications for infrared detectors and cameras that include the pedestrian detection for automotive driving-assistance systems, aid in firefighting or the usage in military contexts like target recognition, broad research in that field sounds justifiable at least.

New results of this kind of research performed at the Fraunhofer IMS will be presented here. To be more specific the new setup of microbolometers, the vacuum-packaging, the architecture of the readout electronics, and the electro-optical performance of high-performance digital Infrared Focal Plane Array Imagers (IRFPA) with a resolution of 320 × 240 pixels (QVGA-standard) are to be introduced. This infrared detector provides a broad usability in different scenarios being designed to work best at Long Wavelength Infrared bands (LWIR, 8 µm .. 14 µm) and at Medium Wavelength Infrared (MWIR, 3 µm .. 5 µm) due to a broad-band antireflection coating. Another advantage of the developed system is that it does not need a cooling system. Thus, setting it apart from other existing devices it allows for better mobility, smaller size and a lower price.

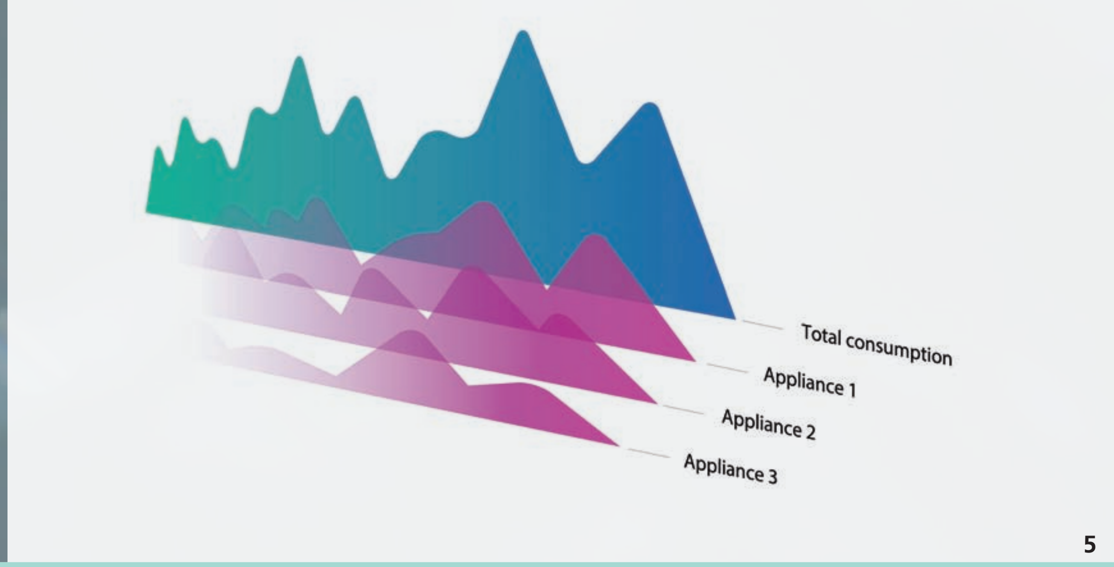
This infrared detector works by detecting incidental radiation of the designated frequencies in little cells called microbolometers acting as pixels in the later produced picture. In order to digitize the incoming infrared radiation and its intensity in each pixel a thermal resistor is installed over a Readout Integrated Circuit (ROIC) with a small gap between the two. This gap is needed because the thermal resistor, in order to detect the intensity, will be heated by infrared radiation, changing its resistance and thus alienating the current, which is a measurable and processable parameter for a circuit and computer. At the same time thermal losses to the environment limit the performance capacity of the sensor unit.

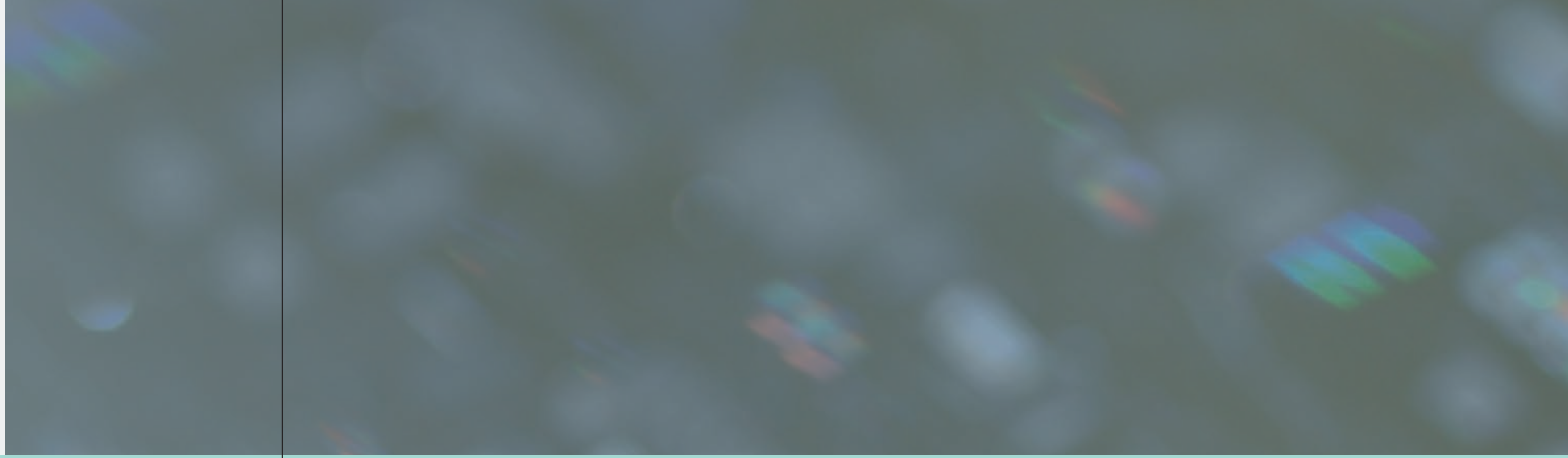
In order to achieve the goals, formulated by these issues, which are little thermal fluctuation inside the sensor and only small thermal losses to the outside of it, known techniques have been updated and improved and new methods have been developed. In this context it can also be pointed out that during the thermal insulation process that is now done by a chip scale vacuum packaging followed by a more efficient and easier soldering of lid wafers to the chips and by a more efficient use of antireflection coating the production costs of the sensor system were able to be significantly reduced.

The before mentioned ROIC's basic structure was able to be taken from previous models, nevertheless, through optimization of components inside the ROIC, noise was significantly reduced. Its overall structure with 16 bit output signal allows for a high sensitivity and a high dynamic range at the same time.

The chip itself requires an area of approx. 94 mm2 and contains approx. 1.5 million transistors. The elements are mounted on two rigid plates, connected by a flexible data link. This enables a very slim or a very compact installation and build.

The digital 17 µm QVGA-IRFPA was tested in terms of the correctness of measured temperatures, after that physical and thermal stress was imposed on the structure and chip. The devices have passed each of these tests with no failures.





WITH NILM INTO THE FUTURE OF ENERGY MANAGEMENT

Anyone who wants to measure device-specific consumer data within an equipment fleet in a commercial or industrial context needs to pay a lot of money for the installation of expensive subcounters – that is how it was so far. Fraunhofer IMS managed the task of minimizing the expenditure for energy management of affected companies and simultaneously maintaining added values, provided through single device detection. Therefore, an intelligent algorithm for device-specific consumption detection with only one measurement point has been developed. In October 2015 a research project for the development of a cost-effective alternative was launched. This alternative is called NILM (Nonintrusive Load Monitoring) and is enabled by using latest hardware and software components. The success of the NILM-project is ensured by close cooperation of well-known specialists of the energy industry. Besides Fraunhofer IMS, smart-metering-specialist GreenPocket as well as Innogy SE, EasyMeter and Discovergy are participating in the project. The NILM-project is funded by the federal ministry for economic affairs and energy and is close to completion.
Both core components of the NILM-technology are namely the NILM-algorithm, developed by Fraunhofer IMS, as well as a counter, developed by measuring system producer EasyMeter. The NILM-counter records consumption data in an especially high resolution, which are transferred via a powerful gateway of the mains connection provider Discovergy to the algorithm for processing. To make these resulting enormous amounts of data legible for the user and to even make the resulting added values usable, the high-performance visualization and energy management software by GreenPocket is used.

The development of the NILM-algorithm is up to Fraunhofer IMS. Here, in a first step, the so-called feature extraction, it is evaluated which electrical characteristics are particularly suitable for device detection. On this basis, methods of the "machine learning" area analyze the summed load profiles and break these down on causing devices. In doing so, special unsupervised processes like e.g. hierarchical clustering are used. But also supervised algorithms like neural networks were evaluated.

The added values, which can be generated with the help of the NILM-technology, can signify an important lead in efficiency for companies. That way, for example due to device-specific consumption detection without circumstantial searching for reasons, it can be traced if all devices have been switched off at the end of operations. If a device is switched on, non-scheduled alarms make sure that countermeasures can take action on time. Moreover, through the non-appearance of these high investment costs for the rebuild of the equipment fleet the application of this technology pays off right from the beginning.

But with this the possibilities of the NILM-technology are not yet exhausted. In future, this technology can recognize, if the consumption of the devices is within their normal parameters. Malfunctions and damages of the devices therefore can be detected prematurely and countermeasures can be initiated. Furthermore, due to the device-specific consumption detection even the process optimization in operation can be supported – because of that not only the efficiency of single devices become visualizable, but also the processes and applications of more involved devices. In the future it can be shown which processes cause the highest costs.

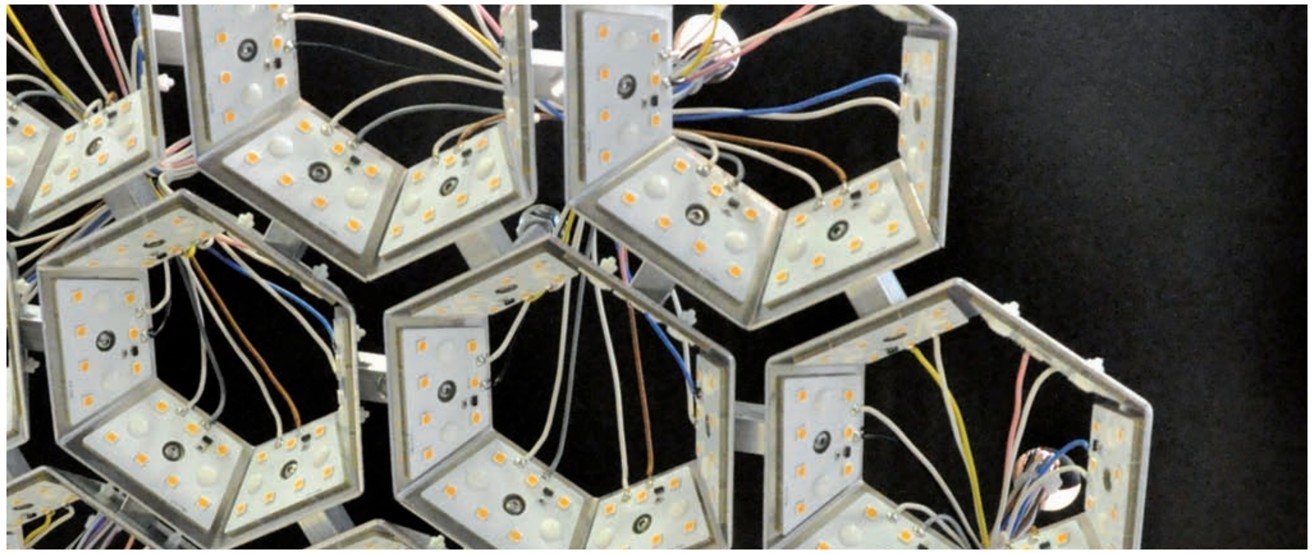
For the development of the NILM-algorithm and the NILM-counter in the first project phase a measurement campaign has been realized. For this, an especially great and high-resolution measuring data amount was needed. These were provided by a measuring hardware with a high resolution of 100 kS/s or rather 1MS/s, so that the load curve could be recorded especially detailed. Special focus was set on the development of unsupervised machine learning – which means the algorithm needs only a short training period and provides an optimal solution for each application context. The results of the measurement campaign are promising: In equipment fleets without variable load a very high detection rate of over 80% is achieved.

With the measurement campaign the development of the NILM-algorithm has also been successfully completed and even the NILM-Smart-Meter, developed by EasyMeter, is now available for testing in practice. The resolution of the counter amounts to 8,000 measured values per second – this is the ideal value to guarantee high measurement accuracy in manageable data volume. In the final test phase the detection accuracy of the NILM-technology is checked in four real application contexts: in a bakery, an industry of metal processing and a mushroom cultivation industry as well as in a company for metal recycling. In case of satisfactory test results the market launch of the hardware is planned in approximately one year after completion of the NILM-project.

5 *Disaggregation of electricity consumption*

NEW HEAD FOR THE INHAUS-CENTER

“The inHaus-Center is supposed to become an open forum for ideas and promote practical innovations”, Wolfgang Gröting hopes. Since October 2017 he is the new manager of the Fraunhofer-inHaus-Center. He will focus on areas like health, healthy aging and care in the future. Also, areas regarding Smart Home will be of great importance, according to his estimaton.



FINAL SEMINAR “INTELLIGENT LIGHTING”

In July 2017, the Federal Ministry of Education and Research and the project’s sponsor VDI invited to the final seminar "Intelligent Lighting" at the Fraunhofer-inHaus-Center. The agenda was focused on discussing the so far achieved results in measurement, perception and effect of semiconductor light as well as the results of all industry-led projects.

BAU 2017 IN MUNICH

At the world’s leading trade fair for architecture, materials and systems, the NILM research project –led by the Fraunhofer IMS – was met with great interest by the professional audience. NILM is the new generation of intelligent electricity meters that enables assessment of device specific power consumption in industry, trade, commerce and services using a single sensor.

IHK MEETS FRAUNHOFER

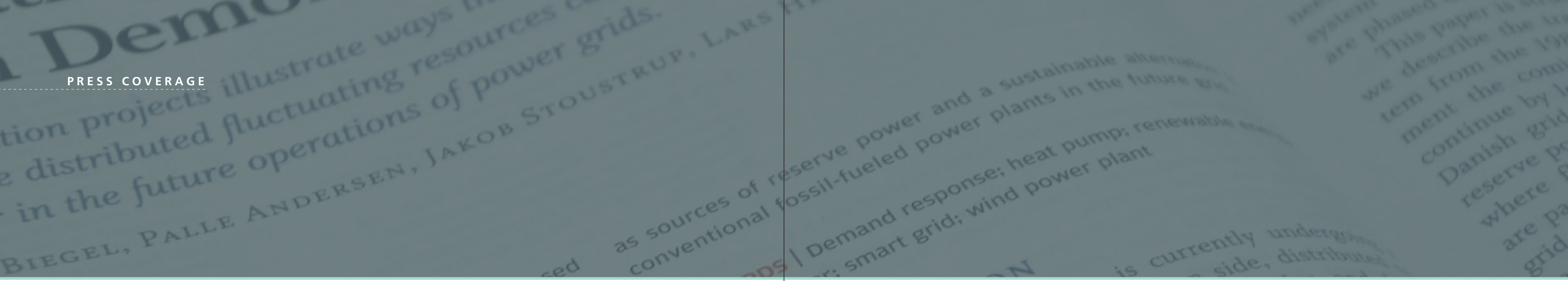
How can companies benefit from application-oriented research at Fraunhofer? In September 2017, the participants dealt with this question during the event "IHK Meets Fraunhofer" with the main topic "Sensor Technology and Automation" at the inHaus-Center. The annual IHK event aims at making it easier for entrepreneurs to become partners in research.

"GIRLS' DAY"

At the nationwide "Girls' Day" there was a lot to see and do for the scientists of the future who visited the Fraunhofer IMS. During their tour behind the scenes of the research institute, the 17 female students were always on the track of the wafers at a total of four stations.

FAB MICROELECTRONICS GERMANY (FMD)

Great honor for the Fraunhofer IMS: As part of the Research Fab Microelectronics Germany (FMD), a network consisting of a total of eleven institutes of the Fraunhofer-Gesellschaft and two Leibniz-Institutes, the Fraunhofer IMS was honored for its accomplishments and received 25.5 million Euros. This money is going to be invested in new machines and the structural development of the research lab.



"THE RESEARCHERS DEVELOPED A CAPACITATOR THAT WITHSTANDS TEMPERATURES OF UP TO 300 °C"

Produktion, September 2017

"THEIR IDEAS SAVE LIVES."

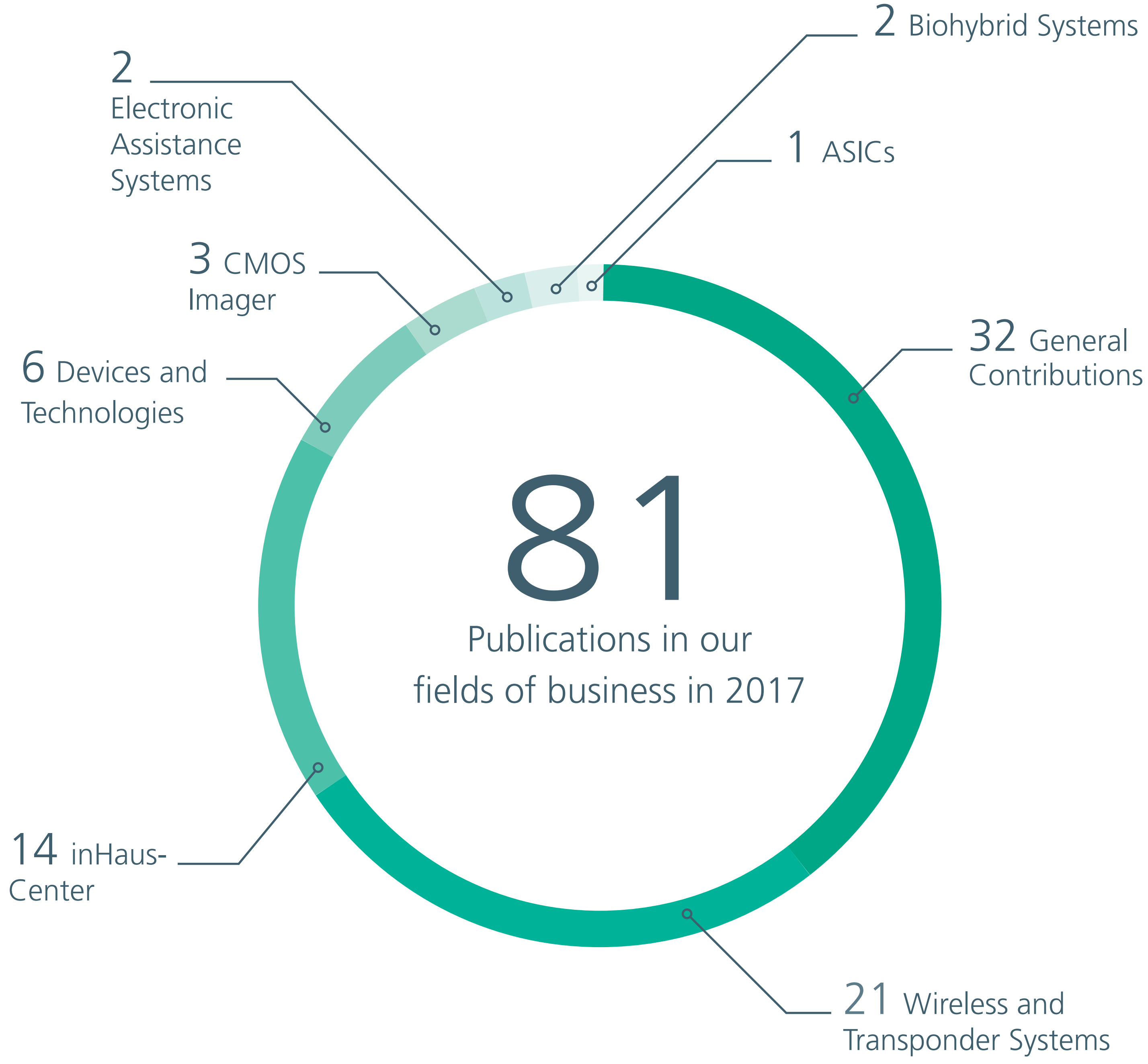
Kieler Nachrichten, May 2017

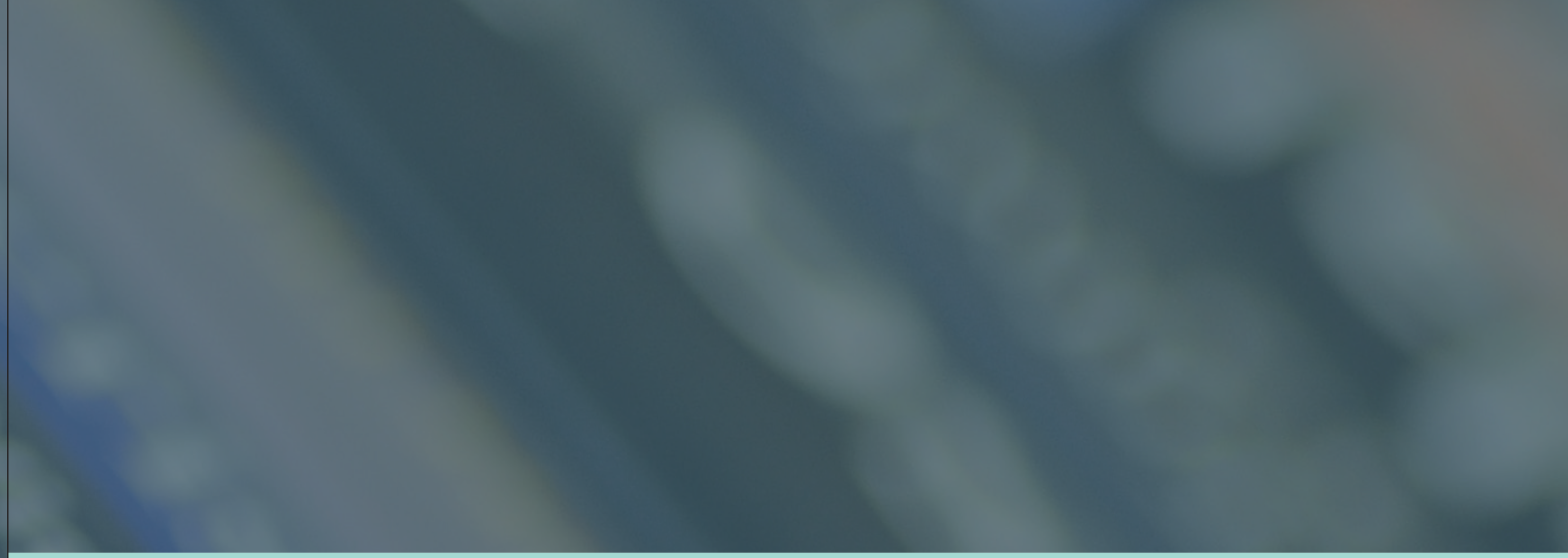
"INTELLIGENT, LONG-TERM STABLE CELLULAR IM-PLANTS THAT HAVE IMMEDIATE CONTACT WITH THE NERVOUS SYSTEM."

DeviceMed, August 2017

"THROUGH NILM, SAVINGS OF MORE THAN 12% ARE POSSIBLE"

elektronik information, January 2017





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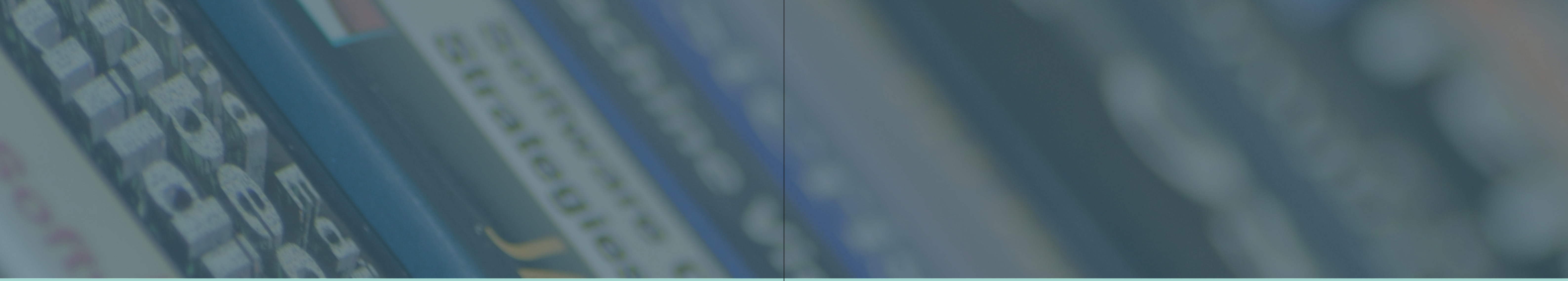

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4. Patents

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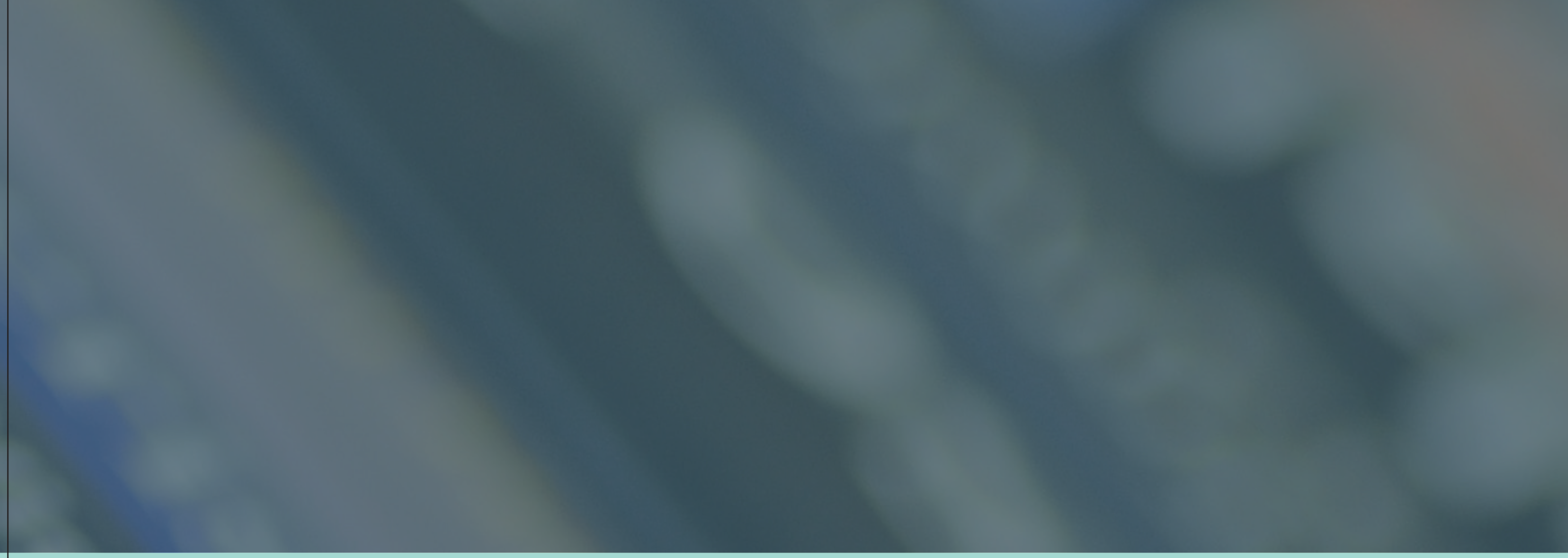

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5. Theses

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5.4 Project Theses

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