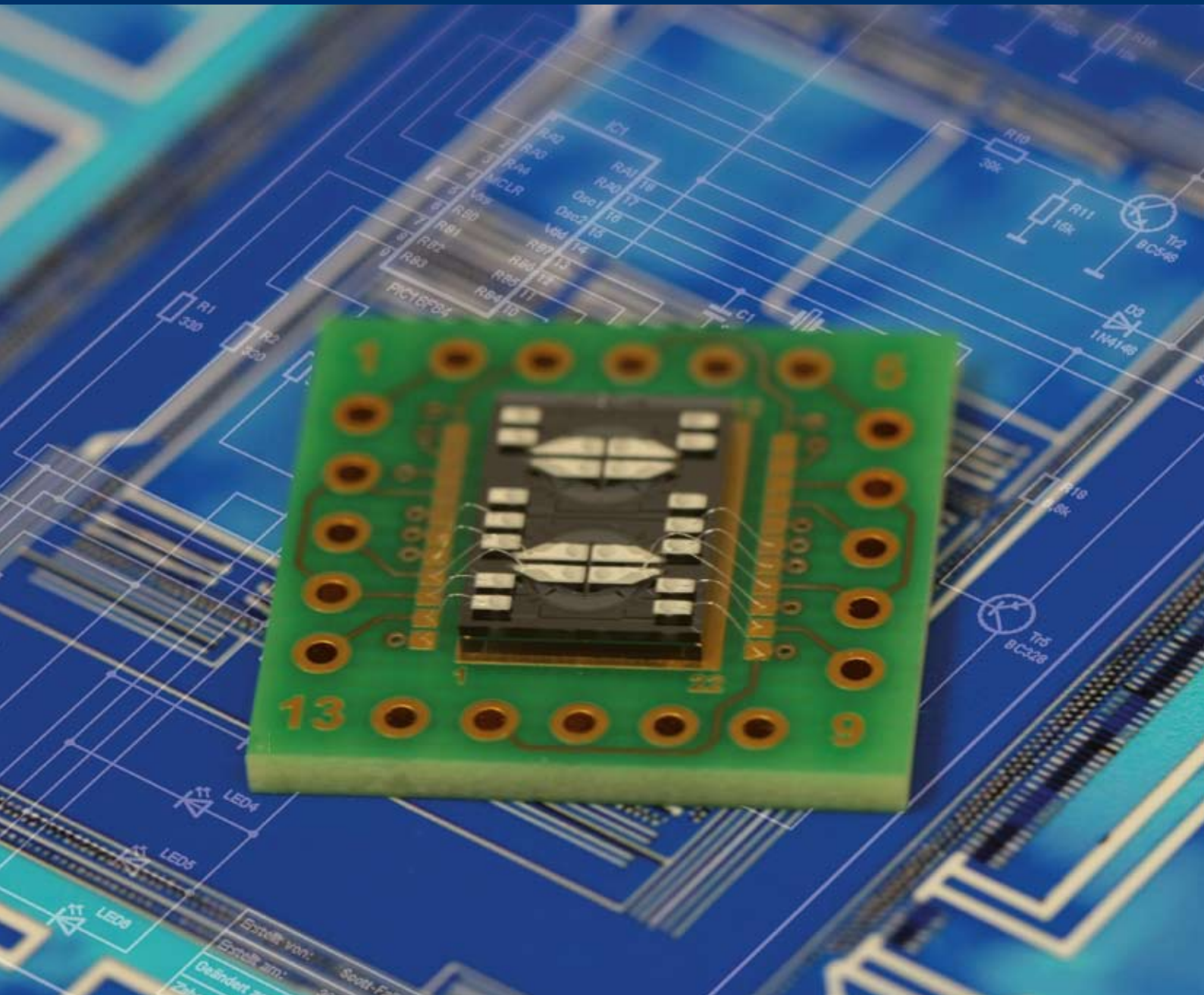
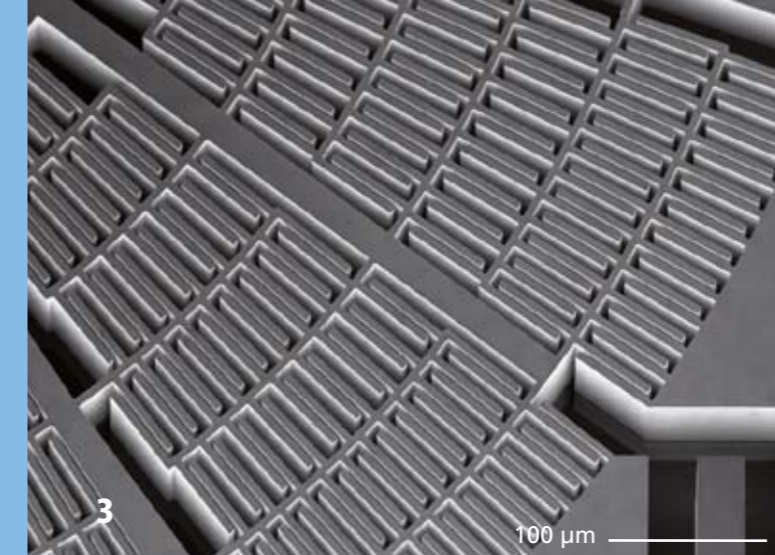
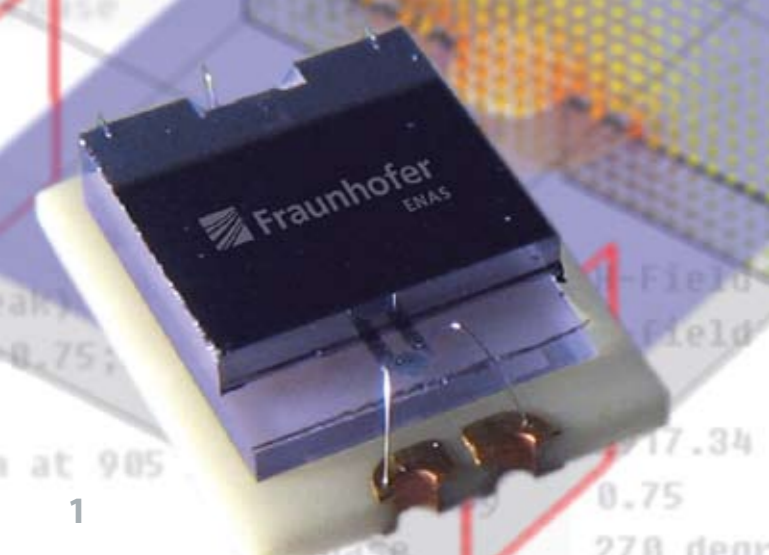


# MULTI DEVICE INTEGRATION





The actual developments of micro and nano technologies are fascinating. Undoubtedly they are playing a key role in today's product development and technical progress. With a big choice of different devices, different technologies and materials they enable the integration of mechanical, electrical, optical, chemical, biological and other functions into one system using very small space.

The Fraunhofer Institute for Electronic Nano Systems ENAS in Chemnitz focuses on research and development in the fields of smart systems integration by using micro and nano technologies with partners in Germany, Europe and worldwide. Based on prospective industrial needs, Fraunhofer ENAS provides services in:

- ▶ Development, design and test of MEMS and NEMS (micro and nano electro mechanical systems)
- ▶ Wafer level packaging of MEMS and NEMS
- ▶ Metallization and interconnection systems for micro and nano electronics as well as 3D integration
- ▶ New sensor and system concepts with innovative material systems
- ▶ Integration of printed functionalities into systems
- ▶ Reliability and security of micro and nano systems.

#### Department Multi Device Integration

The strategic direction of the Multi Device Integration department is focused on the integration of MEMS and NEMS into functional modules and the development of MEMS and NEMS using silicon based and non-silicon materials (nanocomposites, ceramics and polymers).

In terms of Smart Systems Integration, the department combines primarily the activities in the areas of:

- ▶ MEMS/NEMS design
- ▶ Electronics design
- ▶ Microoptics
- ▶ Fluidic integration
- ▶ Nanocomposites
- ▶ RF-MEMS
- ▶ Inertial measurement
- ▶ Measurement, test and characterization
- ▶ System integration.

The aim of the research is to develop and apply integration technologies taking into account of different materials and components to provide products which are able to fulfill the users' needs under different conditions by means of smart systems integration.

#### MEMS/NEMS Design

Novel modeling and simulation techniques are essential for designing innovative micro and nano electromechanical systems. Subsequent development processes require an understanding of the coupling of different physical domains at multiple levels. For this process, commercial and customized software tools are deployed for design, analysis and optimization of MEMS and NEMS. An effective linkage of these tools enhances the work of a design engineer to a great extent.

Coupled field analyses enable accurate predictions of MEMS and NEMS functional components and devices behavior. In consideration of process-induced geometric tolerances, the whole simulation chain is feasible. This includes the layout, process emulation, behavioral modeling of components with the help of the Finite Element Method and model order reduction up to system design. The model of the device can be used to optimize the layout for a mask fabrication and the final device is ready for the test within a virtual development environment and for measurement purpose. Extracted values from parameter identification are used to improve further models for the optimization of e. g. test structures, resonators or whole MEMS and NEMS devices.

We own the following core competences:

- ▶ Modeling, multiphysics simulation, design and optimization of conventional MEMS and future-oriented NEMS
- ▶ Application-oriented MEMS/NEMS conceptual, component, device and system design
- ▶ Combination of numerical simulation and characterization methods for parameter identification
- ▶ Development of simulation methodologies for multi-scale modeling of NEMS
- ▶ Design of RF-MEMS
- ▶ Design of MOEMS and optical design
- ▶ Mask design, layout and technology support.

The main simulation activities in the fields are:

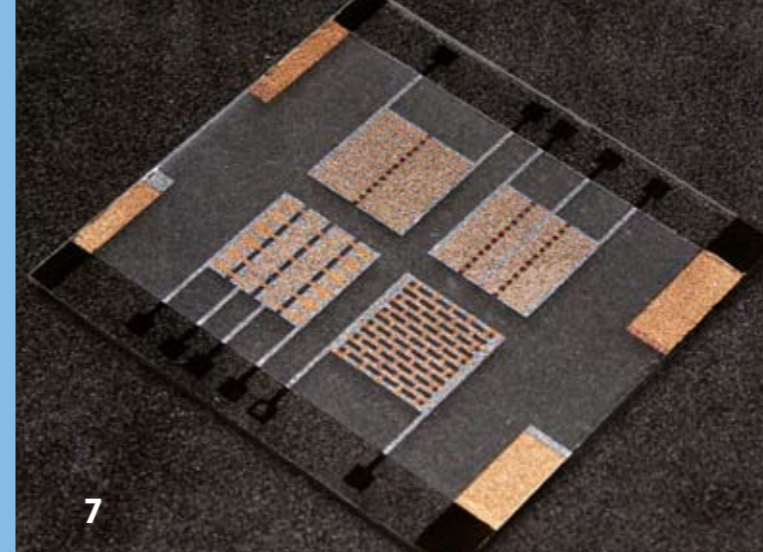
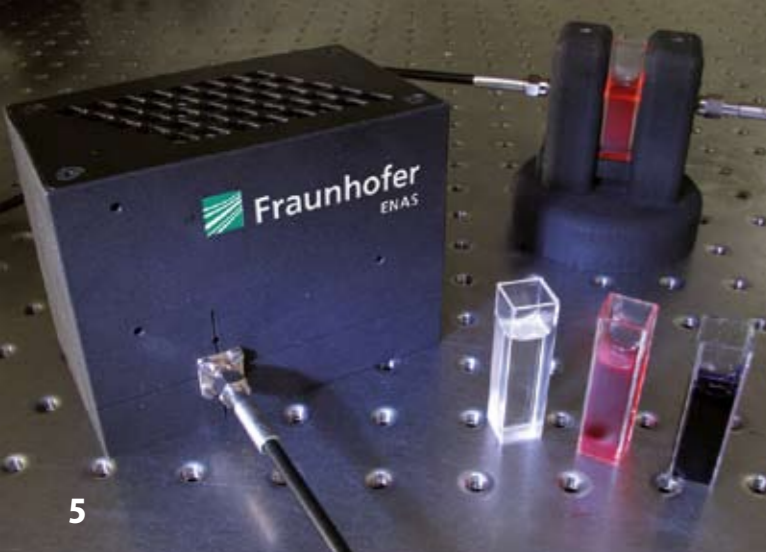
- ▶ Structural analyses
- ▶ Electromechanical coupling
- ▶ Fluid-structure coupling
- ▶ Microfluidics and acoustics
- ▶ Thermo-mechanical induced packaging stress
- ▶ Low frequency electromagnetic analyses
- ▶ Electromagnetic simulations of RF-MEMS components, antennas and systems.

Fig. 1: Packaged device of a varactor chip

Fig. 2: Microfluidic bio chip

Fig. 3: This MEMS accelerometer features 50 micron thick single-crystal comb structures

Fig. 4: Design and Simulation in the Fraunhofer ENAS MEMS/NEMS lab



### Electronics Design

Electronics plays a crucial role for the operation of sensors and actuators. Only the concentrated interplay can lead the individual elements to an overall optimal functioning system. The main points of the electronics development are in the following areas:

- ▶ Analog and digital circuits and mixed signal
- ▶ PCB layout
- ▶ Software programming.

### Microoptics

The Fraunhofer ENAS develops micro system-based opto-mechanical setups and packages using a parameterized design, including thermal and mechanical simulations. Furthermore, the development of low-noise signal processing electronics is subject to these researches. Other priorities include testing and qualification on the component level as well as on the system level.

### Near Infrared Spectroscopy (NIR/MIR)

The development and validation of infrared MEMS spectrometers is exemplary for the activities in the field of microoptics. Such systems can be configured for different wavelength bands and hence be used in various applications. Food studies, environmental monitoring, medical diagnostics, metrology or the physical forensic analysis belong to the fields of application.

### Temperature Scanner

A novel principle of an infrared line scanner for the accurate and fast detection of a temperature distribution within a temperature range of 350 °C to 2000 °C is based on silicon micromechanics. The core is a micromechanical deflection unit (micro mirror), reflecting the incident thermal radiation to a detector.

### Tunable Infrared Filter (Fabry-Perot Interferometer)

The Fabry-Perot Interferometer (FPI) is based on quarter wavelength stacks supported by ultra flat silicon carriers used as mirrors. A specially designed parallel spring suspension of the movable reflector allows parallel actuation, and thus a potentially high wavelength resolution and high transmission rate.

### Fluidic Integration and System Technologies

Microfluidics has become an important tool for many applications, e.g., in the fields of health care, chemical processing and consumer products. Microfluidic systems enable faster analyses, lower sample and reagent volumes, new methods of detection, advanced cooling mechanisms and the processing of macroscopically difficult to control chemical reactions. The integration of additional functionality into such microfluidic systems leads to smart, autonomous devices, reduces fluidic interfaces and requires less complex control and readout instrumentation.

The competencies include

- ▶ microfluidic modeling and system design
- ▶ fabrication of microfluidic devices in multiple materials such as polymers, glass and silicon
- ▶ integration of functionalities such as pumping, valving, temperature control and sensors into microfluidic systems
- ▶ sensors and actuators for active flow control
- ▶ microfluidic and thermal characterization.

### Fully Integrated Cartridges for In-Vitro Diagnostics

Using an integratable, low-cost, single-use pumping technology, Fraunhofer ENAS has developed disposable, micro-fluidic cartridges which incorporate both, liquid reagents and integrated micropumps. As they are completely self-contained, the cartridges are able to run bioassays in a fully automated way. The technology platform can easily be adopted to different biosensors, assays or even completely other applications.

### Nanocomposites

As modern hybrid materials, nanocomposites combine polymeric matrices with nanoscale inclusions such as particles, fibers or tubes. Different functions are realized by different nano-fillers, while the matrices ensuring mechanical stability and electrical connection to the environment. In current work we deal with the development of humidity sensors, piezoresistive composite sensors for the detection of forces and with the use of semiconductor nanocrystals for nano-sensors or in light-emitting systems.

### Polymer-based optical sensors

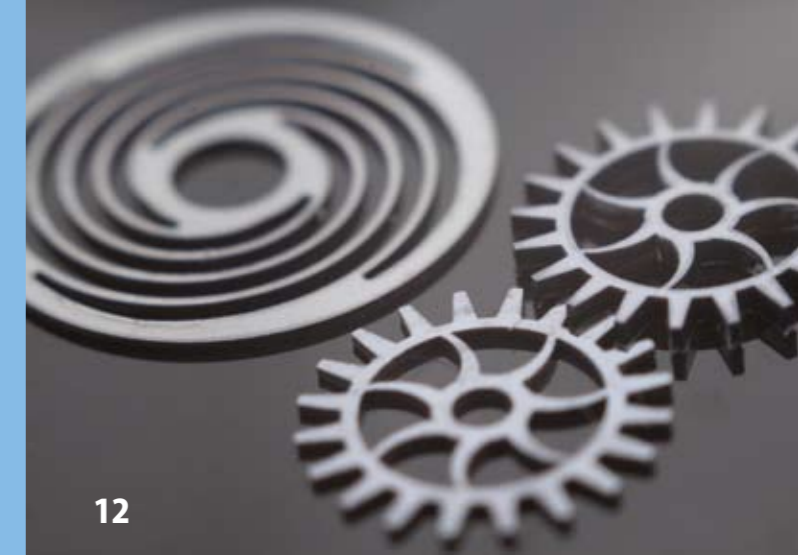
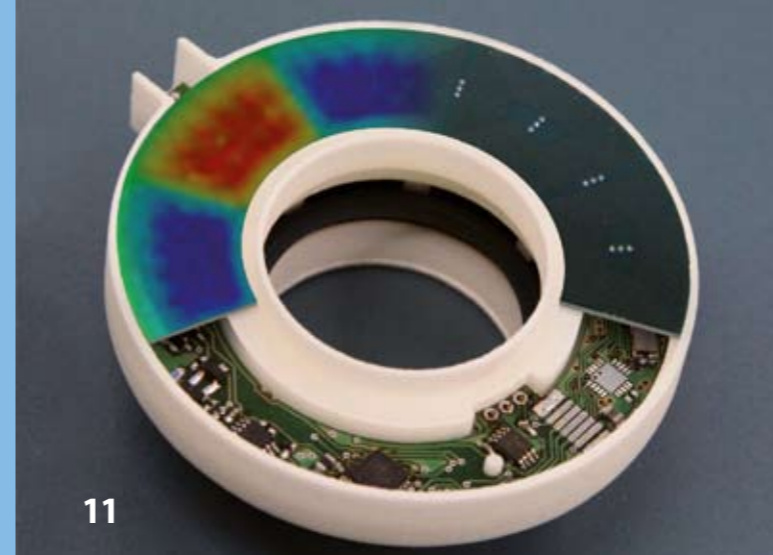
Polymer-based nanocomposite systems are particularly suitable for the material-integrated sensors such as in the field of condition monitoring. Currently we are developing layered systems in which semiconductor nanocrystals are embedded in various polymer matrices. The aim is to detect, for example, overloading of mechanical components, as changes in fluorescence of the nanocrystals. Due to the flexible mechanical properties of polymers, a development of sensors for curved or textured surface is desired.

Fig. 5: Overall system for transmission measurement: MEMS Spectrometer with cuvettes

Fig. 6: Microfluidic cartridge with integrated, gel based low cost pumps for in-vitro diagnostics

Fig. 7: Composite-based humidity sensor

Fig. 8: Optical characterization of quantum dots through embedding into different matrices for compositioning



#### RF-MEMS

The use of MEMS in microwave circuits as a replacement for conventional semiconductor devices can make a vital contribution to the optimization regarding DC-power consumption and signal attenuation. The proprietary Air Gap Insulated Microstructure (AIM) process is now optimized for the use of high resistivity substrates and low loss conductors. This leads to devices with very good RF performance. Due to their high temperature stability, hermetic packaging technologies can be applied. The high quality of a hermetic chip scale package for frequencies over 60 GHz has been demonstrated.

#### Inertial Measurement

Inertial sensors are used to measure acceleration, vibration, inclination, shock and angular velocity. An advantage of the micro mechanical inertial sensors is that the manufacturing costs are much cheaper than for other mechanical or optical alternatives. The areas of application are industrial electronics, automotive, aviation and aerospace and medical technology. The main end products are navigation systems, stabilized antennas, condition monitoring systems for machinery, equipment and vehicles as well as medical monitoring devices. Together with the Center for Microtechnologies, Fraunhofer ENAS uses different fabrication technologies for the development of high precision inertial sensors. In particular, these are the AIM- and the BDRIE (Bonding and Deep Reactive Ion Etching)-technology. Both allow a large aspect ratio for an excellent electromechanical transducer effect and minimal cross sensitivity. Our services range from the sensor concept phase to the prototype development and technology transfer.

#### Measurement, Test and Characterization

A method for the extremely fast determination of dimensional and material parameters based on a combination of the Finite Element Method (FEM) and the measurement of Eigenfrequencies has been developed in recent years and is now improved and adapted to different classes of MEMS devices. In fabrication sequence, the Eigenfrequencies are measured by optical vibration detection and electrostatic excitation of the sample by external optical transparent electrodes. A further step calculates the dimensions or material parameters by estimation algorithms, being performed in less than two seconds and at wafer level.

Amongst others, the following instrumentation is available:

- ▶ MEMS motion test stage including wafer probe station, in-plane and out-of-plane motion analyzer, miniaturized vacuum chamber, LCR-meter, signal generator
- ▶ Topography measurement instrumentation and white light interferometer including stroboscopic illumination to measure dynamic deformation
- ▶ RF-MEMS test bench including wafer probe station, vector network analyzers up to 110 GHz, signal generators and spectrum analyzer.

#### System Integration

The integration of functionalities plays a central role for the implementation of the smart systems vision. An intelligent system should not only be able to perform a function monotonously but also interact with its environment and respond to it. The application fields of sensor integration design are very diverse:

#### Condition Monitoring of Sealing Rings

The condition monitoring of maintenance-intensive components, such as sealing rings on rotating parts, uses the wear of an integrated thin film resistance. Permanent monitoring of components may:

- ▶ Prevent unnecessary downtime and personnel costs for maintenance measures,
- ▶ Prevent plant failures due to sudden failure of components or
- ▶ Prevent unnecessary expenses for preventive component change and thus reducing or avoiding maintenance costs and follow up costs at unexpected failures.

The monitoring of relevant data of specific sealing rings, called shaft seal, similar to the bearing condition monitoring, e. g. with the help of vibration sensors, is of great significance. Information of interest may vary depending on the application, for example tightness of the Simmerrings®, temperature at the sealing lip and approaching a wear limit. Developments in wireless transfer assemblies are taken place in cooperation with the Freudenberg Dichtungs- und Schwingungstechnik GmbH & Co. KG in Weinheim.

#### Microstructur Vario Laser

Laser micromachining is a powerful tool. New designs can be rapidly implemented through direct writing (no masks needed) and processing of computer-generated files. Especially picosecond pulse laser machining is capable of delivering high precision, short processing times and outstanding quality at the same time for nearly every material using a 10 W-Picosecond Laser machine with four different wavelengths (1064 nm, 532 nm, 355 nm and 266 nm) and additionally a continuous wave Thulium fiber laser (1908 nm). By manipulating a range of parameters, i. e. power, pulse frequency, mark speed, focal spot diameter etc., an optimal result can be achieved.

Fig. 9: Components of a micro coil

Fig. 10: On-wafer measurement with RF-probes

Fig. 11: Condition monitoring system of a sealing ring

Fig. 12: Silicon parts, fabricated by ultra short pulse laser micro machining

Contact:

Fraunhofer Institute for Electronic Nano Systems ENAS  
Department Multi Device Integration

Technologie-Campus 3  
09126 Chemnitz  
Germany

Head of the department Multi Device Integration

Prof. Dr. Thomas Otto

Phone: +49 371 45001-221

Fax: +49 371 45001-321

Email: [thomas.otto@enas.fraunhofer.de](mailto:thomas.otto@enas.fraunhofer.de)

Internet: <http://www.enas.fraunhofer.de/EN>

*Front page:*

*High performance MEMS for inertial measurement*

*Photos: Fraunhofer ENAS*

*Andreas Morschhauser, Hendrik Specht, Roman Forke, Mathias Lipowski*