Fraunhofer

ENAS

FRAUNHOFER INSTITUTE FOR ELECTRONIC NANO SYSTEMS ENAS

RESEARCH AND DEVELOPMENT SERVICES

YOUR SYSTEM AND TECHNOLOGY PARTNER IN THE FIELD OF
SMART SYSTEMS INTEGRATION BY USING MICRO AND NANO TECHNOLOGIES

YOUR IDEA – OUR CHALLENGE

Smart Systems Campus Chemnitz
photo: Dirk Hanus

YOUR PRODUCT IDEA BECOMES REALITY

The particular strength of the Fraunhofer Institute for Electronic Nano Systems ENAS lies in the development of smart integrated systems for different applications. These systems combine electronic components with nano and micro sensors as well as actuators, communication units and self-sufficient power supply. Fraunhofer ENAS develops single components, processes and technologies for their manufacturing as well as system concepts and system integration technologies and helps to transfer them into production.

STEP BY STEP PROJECT SUCCESS

The institute offers a complete research and development service portfolio, starting from the idea, via design and technology development or realization based on established technologies to tested prototypes. If standard components do not meet the requirements, Fraunhofer ENAS provides prompt help in the realization of innovative and marketable solutions. Moreover, Fraunhofer ENAS observes technological trends and markets. Based on our knowledge and technologies, feasibility studies can be carried out.

RESEARCH AND DEVELOPMENT SERVICE PORTFOLIO

Fraunhofer ENAS provides services in the development of single processes, complete technologies, components as well as systems depending on the needs of each customer:

- Design, technology, simulation, modeling and test of MEMS/NEMS
- Integration of nano functionalities, e. g. CNTs, quantum dots, spintronics, memristors
- Methods and technologies for wafer-to-wafer and chip-to-wafer bonding
- Packaging and integration for MEMS and electronic components
- Metallization: interconnect systems for micro and nanoelectronics and 3D integration
- Beyond CMOS technologies
- Simulation and modeling of devices, processes and equipment for micro and nano systems
- Material and reliability research
- Analytics for materials, processes, components and systems
- High-performance / high-precision sensors and actuators
- Development of printed functionalities for electronic applications
- Application-specific wireless data and energy systems
- Development of microfluidic systems and biosensor integration
- Sensor and actuator systems with control units, integrated electronics, embedded software and user interface
- Reliability of components and systems

YOUR IDEA – OUR CHALLENGE

Chemnitz Inkjet Technikum

Within this service brochure, all processes, technologies and technology services, which are currently available, are listed. Any other materials than the ones listed within this brochure are available on customer request. The listed components are examples of developed demonstrators and prototypes and can be further developed on customer demand.
Benefit from our wide-ranging research and development network as well as our cooperation arrangements with renowned international research institutes and universities.

SMART SYSTEMS CAMPUS

The Fraunhofer Institute for Electronic Nano Systems is located on the Smart Systems Campus Chemnitz, an innovative network with expertise in micro and nano technologies as well as in smart systems integration. This technology park provides renowned scientific and technical centers with entrepreneurial spirit and business acumen and an economic boost at a location where everything is on the spot. A close cooperation of science, applied research and industry is an everyday reality and reflects a strategy that is being fulfilled.

The partners of the Smart Systems Campus Chemnitz are:

- Chemnitz University of Technology with the Institute of Physics, the Center for Microtechnologies (ZfM) and the Center for Integrated Lightweight Construction (ZIL)
- Fraunhofer Institute for Electronic Nano Systems ENAS
- Young companies within the start-up building
- Companies within the business park

INFRASTRUCTURE

Fraunhofer ENAS maintains a close cooperation with the Chemnitz University of Technology especially with the Center for Microtechnologies (ZfM) of the Faculty of Electrical Engineering and Information Technology and with the Faculty of Mechanical Engineering. Both facilities share their infrastructure including laboratories, clean rooms and equipment.

Clean rooms

The building of Fraunhofer ENAS possesses 1400 m² of laboratories including 380 m² of improved cleanness.

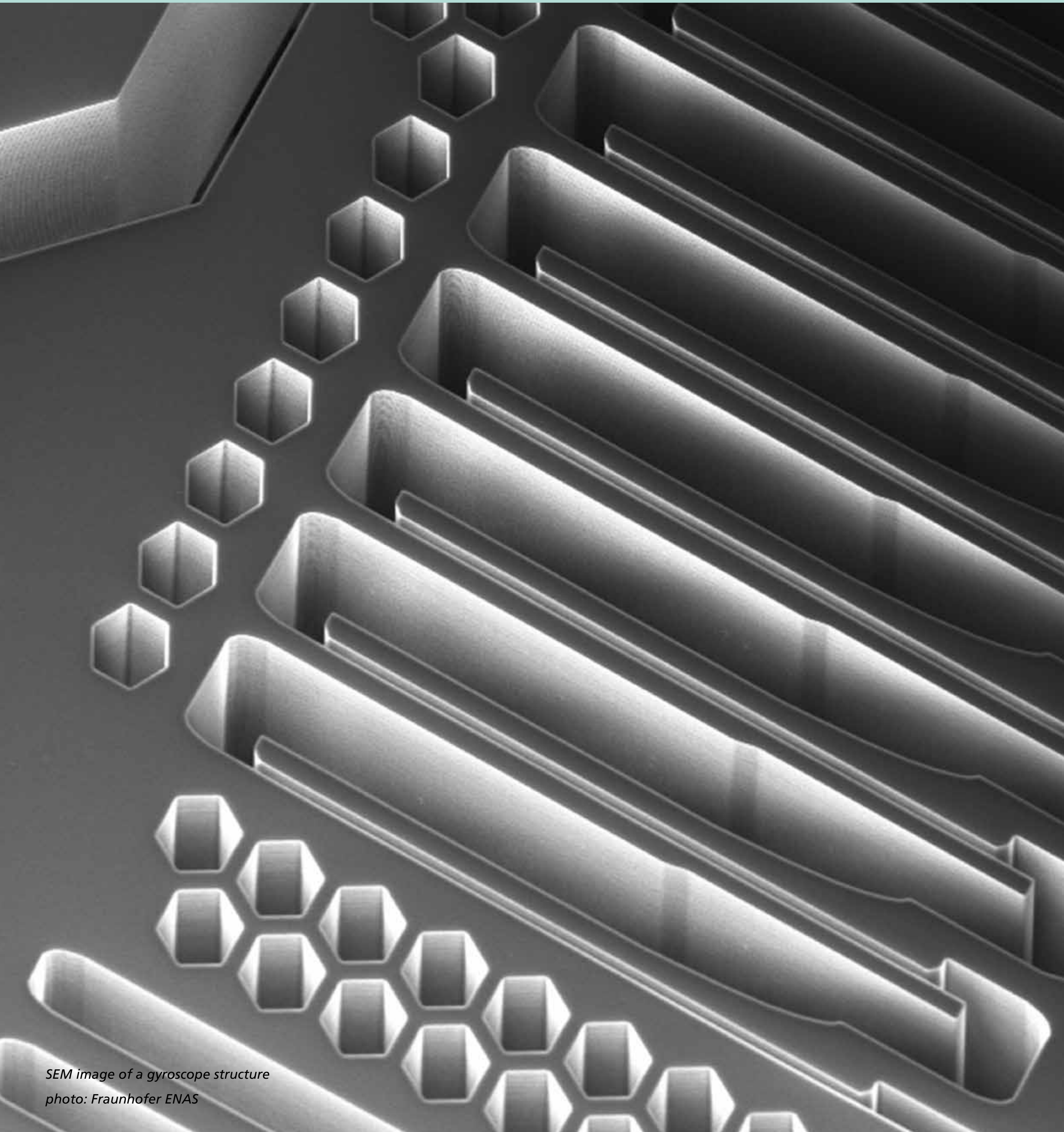
The ZfM facilities include a 1000 m² cluster of clean rooms (300 m² of them are class ISO 4). Modern equipment is installed for processing wafers as well as design and testing laboratories.

- Substrates
  - » Size: 150 mm, 200 mm
  - » Material: silicon, glass (on request: ceramics, lithium niobate, lithium tantalate, sapphire, silicon carbide and germanium)

Chemnitz Inkjet Technikum

Fraunhofer ENAS and the Department of Digital Printing and Imaging Technology of Chemnitz University of Technology jointly operate the Chemnitz Inkjet Technikum to offer a wide range of research and development services in the field of digital inkjet printing of functional inks. With its extensive research experience in the field of printed functionalities, such as RFID antennas, batteries and hierarchically structured membranes, the Inkjet Technikum is the ideal partner for beginners and for parties seeking support in basic research, new applications and lab-to-fab transfer.

TECHNOLOGIES



SEM image of a gyroscope structure
photo: Fraunhofer ENAS

MEMS and MOEMS technologies

- High aspect ratio (HAR) technologies for high-precision capacitive MEMS: Airgap Insulation of Microstructures (AIM), Single Crystal Reactive Etching and Metallization (SCREAM), Bonding and Deep Reactive Ion Etching (BDRIE)
- Bulk technologies
- Piezo-MEMS technologies
- Thin film encapsulation
- MEMS packaging (0 and 1st level) and 3D integration

Back-end of line technologies for micro and nano electronics

- Copper metallization (barrier, seed, fill)
- Low-k and ULK dielectrics (processes, integration)
- New materials and thin film processes
- Development and conceptual design of integration schemes
- Modeling and simulation of processes and equipment
- CNT-based interconnects

Fluidic integration technologies

- Prototyping and assembling of (micro)fluidic systems
- Peripheral systems (instruments, electronics, software)
- Microfluidic systems based on silicon, glass, polymers, metals
- Liquid-based microfluidics
  - (Bio)sensor integration
  - Assay integration
  - Integration of actuators (micro pumps, valves, heater)
- Gas-based microfluidics
  - Gas-fluidic actuators (SJA/PJA) and transducers
  - Prototyping and assembling of gas-based microfluidics for wind tunnel tests

Nano integration technologies

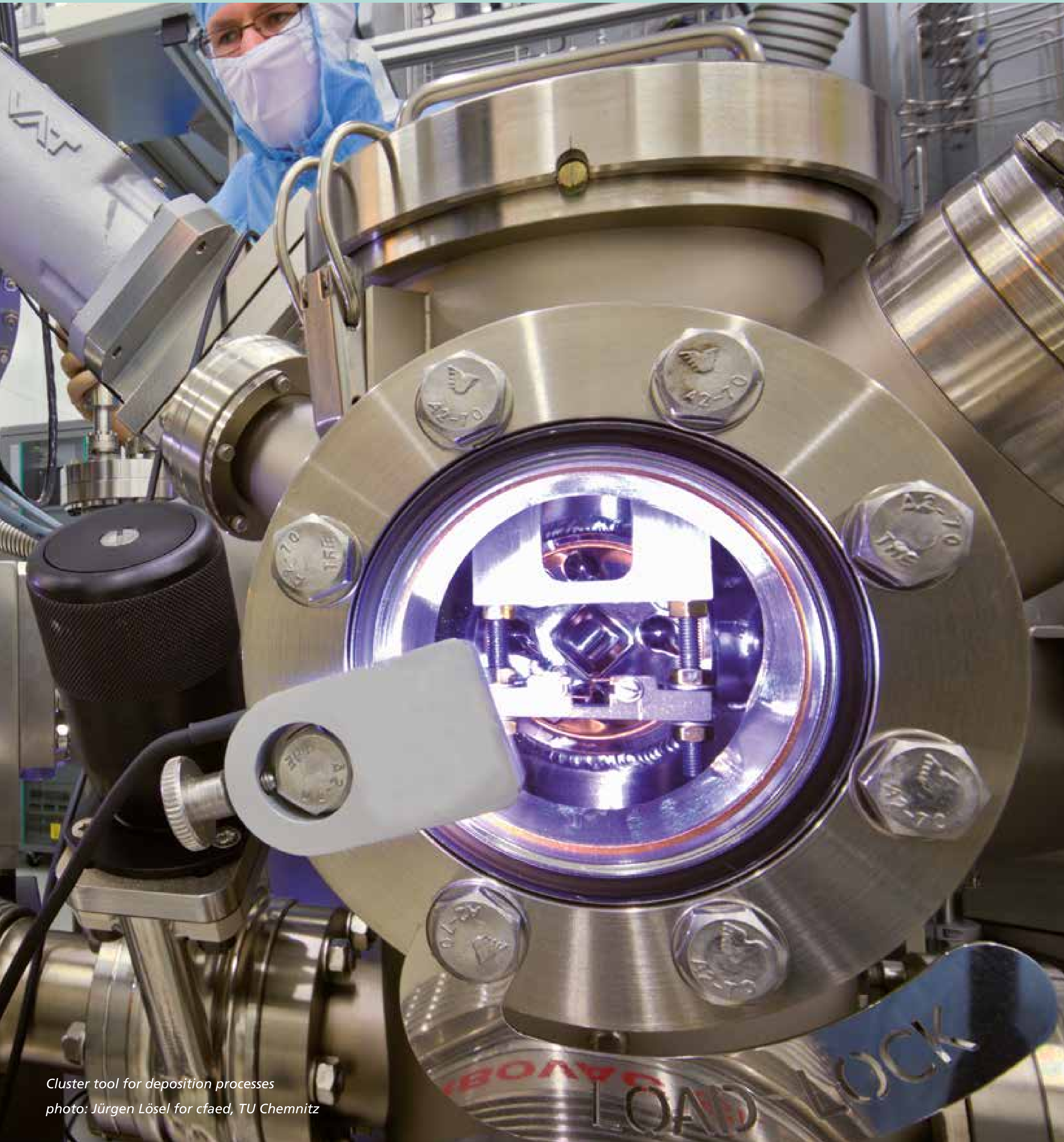
- Nano lithography
  - Electron beam lithography
  - Nano imprint lithography
- Layer-based technologies
  - Nanocomposites (semiconducting metal oxides, quantum dot-based layers)
  - Magnetic field sensors (multi-dimensional GMR sensors, microstructuring, laser annealing)
  - Memristive components (functional multilayers, circuit technologies)
  - Packaging with thin, exothermic metal layers
- 1D technologies
  - CNT functionality on wafer-level (coating, patterns, heterogenous integration)
  - CNT material: type-selective CVD, material purification, assembly
  - CNT-based piezoresistive sensor
  - CNT-based FETs for sensors
  - CNT-FETs for high-frequency applications

Printing technologies

- Sheet- and web-based printing processes up to pilot scale (aerosol jet, inkjet, screen printing, gravure, dispensing)
- Printing of functional inks on flexible and rigid substrates with 2D and 3D surfaces
- Functionality formation by sintering of printed patterns
- Integration of printing technologies in manufacturing environments
- Design and printing-based manufacturing of tailor-made flexible thin film batteries
- Design, simulation, printing and characterization of customized antennas (RFID, WLAN, Bluetooth, LTE, UMTS,...)

PROCESSES

PROCESSES



Cluster tool for deposition processes
photo: Jürgen Lösel for cfaed, TU Chemnitz

Cleaning

- RCA clean
- Piranha clean
- DI-water flushing

High-temperature processes

Thermal oxidation	dry, wet, HCl
Annealing	inert, reducing, oxidizing, ambient and forming gas
Diffusion	$POCl_3$

Deposition

Physical vapor deposition	
Sputtering	Ag, Al, Al-alloys, AlN, Au, Co, Cr, Cu, CuMn, CuTi, CuZr, Hf, Mo, Ni, NiMo, Pd, Si, Ta, TaN, Ti, TiN, TiO_2, TiW, W, metallic glass, pyrex
Ion beam sputter deposition	Al, Co, Cr, Cu, Mo, Ni, Ru, Ta
Electron beam evaporation	Al, Co, Cu, Ni, Pd, Pt

Chemical vapor deposition	
Plasma enhanced CVD	PETEOS-SiO_2, SATEOS-SiO_2, Si_3N_4, $Si_xO_yN_z$, SiCH, SiCOH, black diamond, diamond-like carbon, CNTs
Low-pressure CVD	SiO_2, Si_3N_4, polysilicon, amorphous silicon, SWCNT/MWCNT
Metal-organic CVD	Cu, TiN
CVD	Parylene N, C, D, F, AF4

Atomic layer deposition	
Metals	Ni, Co, Cu
Metal oxides and nitrides	Al_2O_3, Co_xO_y, Cu_xO, NiO_x, TiO_2, TaN, TiN

Electrochemical processes	
Electrochemical deposition (ECD)	Au, Cu, Ni, Pd, Sn, Al (ionic liquids), In, Ga, AgSn, AuSn (ionic liquids)
Electroless deposition (ELD)	Au, Ni

Others	
Dielectrophoresis (DEP)	selective placement of nanomaterials (e. g. CNTs, nanowires)
Spin-on	dielectrics, porous ULK

PROCESSES

E-beam lithography VSB-254, photo: Fraunhofer ENAS

Lithography

▪ Electron beam lithography	resolution: < 50 nm
▪ Projection lithography	400 nm
▪ Contact lithography	2 µm
▪ Nano imprint lithography	resolution: 50 nm
▪ Double side lithography	
▪ Spray coating	
▪ Spin coating	
▪ Plasma strip	oxidizing, reducing

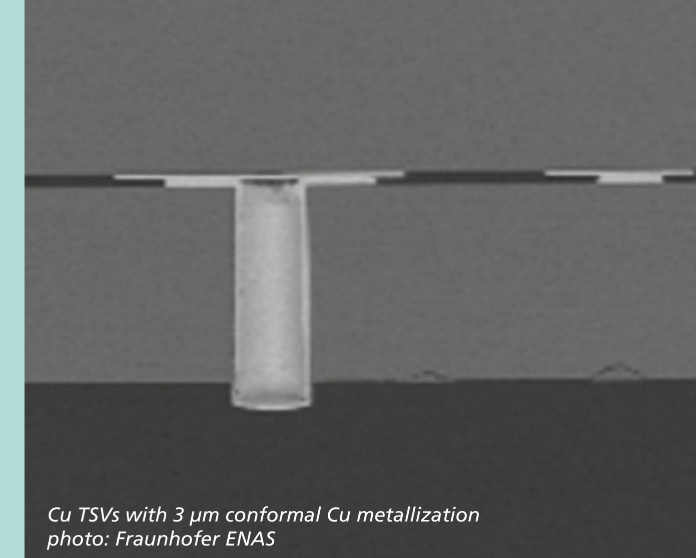
Patterning

▪ Wet processes	
» Metals	Al, Au, Cr, Cu, Pt, Ti, W, Pd/Al
» Non-metals	AlN, Cu_xO, Si_3N_4, SiO_2, Si, polysilicon, glass
▪ Dry processes	
» Metals	Al, Cr, Cu, Ti, Ta, TiW, W
» Non-metals	Si, polysilicon, SiC, SiO_2, Si_3N_4, silicides, TiN, resists, glass, low-k dielectrics
» Deep reactive ion etching	Si
▪ Lift-off	
▪ Gas phase etching of SiO_2	
▪ Assembly of CNTs	

Special processes for quantum dots (not within the standard clean room)

▪ Thermal evaporation	Al, Ag, Ca, MoO_x, HMTPD, CBP, TPD, mCP, ZnPc, C_{60}, LiF, spiroMeOTAD

Applied Materials Mirra, photo: Fraunhofer ENAS


Cu TSVs with 3 µm conformal Cu metallization photo: Fraunhofer ENAS

Chemical mechanical polishing and wafer thinning

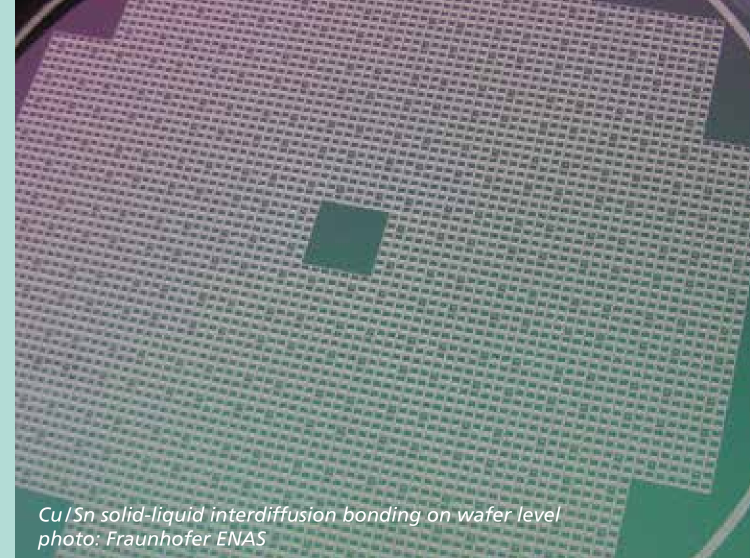
▪ CMP for patterning	Al, Cu, Ge, Si, SiO_2, W, barriers (TiN/Ti, TaN/Ta), ceramics ($LiNbO_3$, $LiTaO_3$), glass, isolators, stainless steel
▪ Planarization and surface finishing	
▪ Grinding	Si, glass, ceramics
▪ Spin etch	Si, glass

3D integration focused on MEMS

▪ Through silicon vias	
» Integration concepts	via last, via middle, vias for glass and silicon substrates
» Processes	deep etching, isolation, metallization, lithography in holes
» Metallization	metal-CVD, RDL, UBM, bumping (PVD, ECD, screen printing, aerosol jet printing)
▪ Wafer thinning and handling	Si, glass, ceramics

- Temporary wafer bonding and debonding for thin wafer handling
- Hybrid and vertical integration of MEMS/NEMS
- Aerosol jet printing

PROCESSES


Cu/Sn solid-liquid interdiffusion bonding on wafer level photo: Fraunhofer ENAS

Laser micromachined valves for pulsed jet actuators, photo: Fraunhofer ENAS

Roll-to-roll printed copper patterns, photo: Fraunhofer ENAS

0 and 1st level packaging

Thin film encapsulation

- Biocompatible packaging (parylene (C, D, F)) incl. pre-treatment (silanization)
- High aspect ratio microstructures

Wafer bonding (with or without interlayer)

- Conventional, permanent wafer bonding
  - » Silicon fusion bonding — RT ... 100 °C, 100 °C ... 200 °C, 200 °C ... 400 °C, > 400 °C
    Si, borosilicate glass, foturan glass, quartz glass, $LiTaO_3$, LTCC, stainless steel
  - » Anodic bonding — RT ... 550 °C, 0.... 500 kPa, 0 ... 2000 V
    Si, SiO_2, Si_3N_4, borofloat, pyrex, SD2
  - » Glass frit bonding — Si, glass
  - » Eutectic bonding — Au-Si, Au-Sn, Al-Ge
  - » Thermo compression bonding — Al-Al, Cu-Cu, Au-Au (nanoporous gold), plasma enhanced Cu-Cu bonding
  - » SLID bonding — Au-In, Au-Sn, Cu-In, Cu-Sn
- Low-temperature, permanent wafer bonding
  - » Reactive bonding — Si, Al_2O_3, Al, Cu, borosilicate glass, foturan glass, quartz glass, $LiTaO_3$, covar, stainless steel
  - » Plasma-activated bonding
  - » Laser-assisted bonding — glass-frit, glass-silicon
  - » Sintering — Ag, Cu
- Temporary wafer bonding
  - » Bonding and debonding — thin wafer processing

Packaging of integrated circuits

- Wire bonding
  - » Al-Si — 18, 32 µm
  - » Al — 125, 250, 300 µm
  - » Au — 25, 30, 50, 125 µm
  - » Cu — 32 µm
- Chip bonding — flip-chip, chip-to-chip (C2C), chip-to-wafer (C2W), multi-chip-module (MCM), chip-to-board (C2B), surface-mounting technology (SMT), printed contacts
- Encasings and Caps — metal, glass, ceramics, plastics, thin film encapsulation (Parylene)
- Dicing

Laser micromachining – laser work station

- Picosecond laser (10 W) — 266 nm, 355 nm, 532 nm, 1064 nm, pulsed energy
- Thulium fiber laser (20 W) — 1908 nm, continuous wave
- Materials:
  - » Polymers — PC, PMMA, PET, COC, acrylic resin, adhesive tapes (incl. cover sheets)
  - » Ceramics — $LiTaO_3$, Al_2O_3, $LiNbO_3$, PZT
  - » Metals — Al, Mo, Au, Pd, stainless steel
  - » Glass — borofloat, quartz, BK7, microscope slides
  - » Semiconductors — Si (mono and polycrystalline), ITO
  - » Others — solder, reactive foils, films with nanoparticles

Patterning based on printing

- Inkjet — sheet-fed, web-fed
- Aerosol jet — sheet-fed
- Gravure — web-fed
- Screen — sheet-fed, web-fed
- Functionality formation by sintering — thermal, IR, UV, laser, IPL, electrical, chemical, plasma
- Materials:
  - » Inks — conductive inks: Ag, Cu, Au, C, Zn, ...
    semiconductive inks (organic and oxide-based)
    dielectric inks (organic)
  - » Substrates — polymer films (PET, PEN, PI, PC, PVC, PP, ...)
    paper (uncoated and coated), congurated cardboard
    glass, ceramics, textiles, sheet metal, rubber

For your support, we operate the »Chemnitz Inkjet Technikum« offering the following research and development services:

- Customer-tailored R&D projects
- Ink printability verification
- Initial printing tests (inkjet, gravure, screen)
- Surface energy optimization of substrates
- Ink and layer characterization
- Consulting, workshops, lectures and hands on training

ANALYTICS / CHARACTERIZATION

ANALYTICS / CHARACTERIZATION

Scanning electron microscope
photo: Jürgen Lösel, TU Chemnitz

Preparation techniques for analytics

- Focused ion beam (FIB)
- Preparation for micrograph sections
- Sputtering: carbon, metals

Process-accompanying analytical methods

- Profilometry: tactile, optical (Datac, AFM, reflectometer, white light)
- XPS: surface, depth profile
- Wafer thickness
- Sheet resistance
- Wafer bow measurement
- Adhesion tests: 4 point bending
- Life time scanner
- Thermogavimetric analysis and differential scanning calorimetry
- (in situ) XPS spectroscopy
- (in situ) Raman spectroscopy

In situ plasma diagnostics for process optimization

- Optical emission spectroscopy
- Quadrupol mass spectrometry
- Quantum cascade laser absorption spectroscopy
- Langmuir probe

Optical inspection

- Spectroscopy: EDX, IR, FTIR, NIR, UV/Vis, fluorescence, Raman, spectral ellipsometry
- Microscopy: light, SEM, SEM/FIB, AFM, TEM, SAM, laser scanning, thermographic, fluorescence
- X-ray computer tomography
- White light interferometry
- Thermography
- High speed imaging (up to 150.000 fps)

Bond quality evaluation

- Shear test
- Micro Chevron test (MCT)
- Bending test
- Tensile test
- Hermeticity
  - » MEMS structures and pressure gauge
  - » Helium leakage test
  - » FTIR spectroscopy

ANALYTICS / CHARACTERIZATION

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Material and deformation analysis

- Material composition: EDX, laser scanning, LSAW, IR
- Material characterization: Young's modulus, Poisson's ratio, thermal expansion coefficient (CTE)
- Elastic-plastic and creep characterization of bulk materials and thin films (-70 °C … 500 °C)
- Visco-elastic characterization – DMA, TMA, TGA: Master curve, shift functions (time, temperature, humidity)
- Determination of fracture mechanics parameters for critical and sub-critical crack growth (-40 °C … 200 °C)
- 3D in situ warpage, deformation and strain measurements of 1 x 1 mm² … 300 x 300 mm² objects by chromatic sensor, white light interferometry, confocal microscopy or gray scale image correlation (microDAC) in air, N_2 or Ar between -80 °C and 400 °C with sub-micron resolution
- Micro and nano hardness and strength testing on films, MEMS structures and membranes
- fibDAC determination of the mechanical stresses in BEOL film stacks and MEMS structures with highest spatial resolution (down to 250 nm in-plane and 50 nm in depth)
- Electromagnetic material assessment

Electrical characterization

- Antenna measurement and characterization
- RF network and spectrum analysis
- EM near field characterization
- Wafer probe
  - Current-voltage
  - Capacity-voltage
  - Biased temperature stress
  - TVS measurements
  - Mercury probe

Fluidic characterization

- Hot Wire Anemometry (up to 300 m/s)
- 2D / 3D scan and visualization of pressure and velocity profiles (3D travers system, 200 mm x 200 mm x 400 mm)
- Automated measurement software for multi parameter data acquisition
  - Individual measurement workflows (parameter sweep, performance map, ...)
  - Parallel monitoring of environmental and system parameters (flow velocity, pressure, ...)
  - Signal analysis of digital sensors
  - Signal analysis of analog sensors (+/-10 V, up to 250 kHz)
- Combined characterization of transducer movement, cavity pressure and flow velocity in gas-fluidic actuators
- Amplifier and control system for piezoelectric actuators (up to 350 V, 220 mA)

Absorber chamber for antenna measurement
photo: Jürgen Lösel

DESIGN, SIMULATION AND MODELING

DESIGN, SIMULATION AND MODELING

Simulation lab at Fraunhofer ENAS
photo: Jürgen Lösel

We offer application-oriented design starting from the concept via component to device and system, while taking design for reliability into account.

MEMS/NEMS

- Inertial sensors
- RF MEMS
- MOEMS

Materials, processes and equipment for micro and nano-electronics

- Multi-scale simulation of thin film deposition (PVD, CVD, ALD, ECD) for process and reactor optimization
- Simulation of surface chemistry and film growth
- Structural, thermal, mechanical and electronical properties of thin films and nano materials

Electronics and communication

- Analog and digital circuits and mixed signal
- PCB layout
- Basic software programming
- RF circuit design
- Antenna design for data and energy transmission

Electrical and multi-physical systems

- Electro-mechanical coupling
- Modeling, simulation and measurement of parasitic electromagnetic effects
- Structural analyses
- Thermo-mechanical induced packaging stress
- Chip, packages, modules, PCB

Micro and nano devices and systems

- Thermal and electrical simulation of ULSI interconnect systems
- TCAD simulation of strained ULSI transistors
- Multi scale modeling and simulation of emerging nano-devices (CNT FETs, nanowire FETs, memristors)
- Ab initio simulation of electron transport in nanostructures
- Modeling of sensors based on nanomaterials
- Mask design, layout, technology support
- Electromagnetic simulations of antennas and systems
- Methodologies for multi-scale modeling of NEMS
- Electromagnetic simulations of RF MEMS components

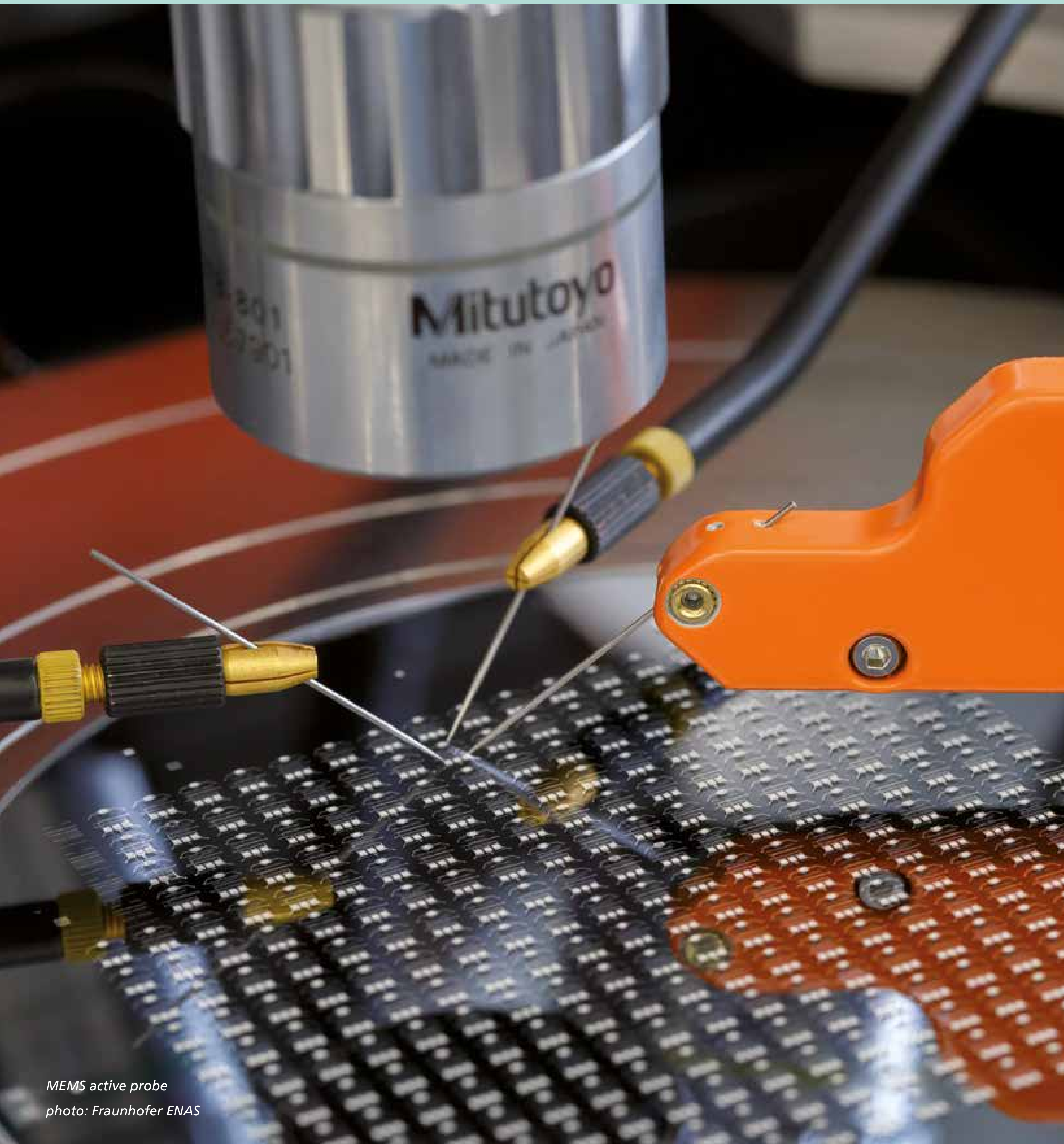
Fluidic systems

- Liquid-based microfluidic systems
- Gas-based microfluidic actuators and systems

Reliability

- Analysis, assessment and prediction of reliability
  - Mechanical and thermoelectromechanical
  - Crack and fracture modeling
  - Multi-field effects
  - Validation via coupling of simulation and experiments
- Fracture and damage mechanics (mm ... sub-nm)
  - Cohesive zone modeling (CZM)
  - Extended FEM (X-FEM)
- Life-time prognosis
- Virtual prototyping, robustness analysis and optimization
- Electromagnetic reliability analysis
- Near field localization of hot spots
- Near field/far field transformation

TEST



MEMS active probe
photo: Fraunhofer ENAS

Wafer and chip test

- Electrical parameters
- RF S parameters
- Nonlinearity
- Dielectric material parameters
- Transmission and reflection
- Surface parameters
- Vibrational analysis
- Combination of numerical simulation and characterization methods for parameter identification
- Electromagnetic compatibility
- Specific probe card development

Test programs for component and system tests

- Controllable optical filters
- Acceleration sensors
- Gyroscopes
- RF MEMS switches
- Wireless sensor nodes

Reliability

- Mechanical strain: pulling, pressure, shearing, bending, scratch, vibration, shock
- Structural reliability of composites (fatigue master curve)
- Compact tension (CT) fracture mechanical tests: single and multi-mode, critical and sub-critical, bulk and inter-faces
- Nanofatigue, membrane tests
- Thermoelectromechanical endurance: HT, (H)TC, APC
  - Thermal cycle test: -80 °C ... 500 °C,
  - Power cycle tests: up to 500 A, 80 V (air, oil)
- Accelerated lifetime tests with mixed loads:
  - Temperature cycle: -60 °C ... 180 °C
  - Humidity range: 10 % ... 90 %
  - Mechanical vibration: 0.1 Hz … 3 kHz
  - Electrical loads: bias voltage, electrical power
- Environmental testing: humidity, degradation, corrosion
  - Climate storage and shock testing: -60 °C ... 180 °C, humidity 10 %.... 90 %, salt dust
- Field-like long-term climatic and stress tests: 2 …10 years in the underground reliability lab (old silver mine)
- RF and microwave performance: functionality, electromechanical compatibility
- Near field measurement for EMC tests and debugging

DEMONSTRATORS AND PROTOTYPES

DEMONSTRATORS AND PROTOTYPES

ASTROSE sensor node in field test
photo: Fraunhofer ENAS

Smart systems consist of different components. The following demonstrators and prototypes have been developed and may be further developed on customer demand.

High-precision silicon-based inertial sensors

- Gyroscopes
- Acceleration sensors
- Inclination sensors
- Vibration sensors

RF MEMS

- Switches
- Varactors

Ultra-low power MEMS

- Wake-up MEMS

Optical sensors / MOEMS

- Fabry-Pérot filters
- Optical grating
- Controllable detectors
- Optical sensors
- Quantum dot-based systems

Pressure and force transducers

- Ultrasonic transducer
- MEMS loudspeaker
- Pressure sensitive resonators

CNT-based systems

- CNT-FETs for nanoelectronics and sensors
- MEMS with integrated CNTs (e. g. test platform for reliability analysis)
- Pressure sensor
- High-frequency FETs for analog wireless applications

Magnetic field sensors (GMR- and TMR-based)

- 2D compass sensor
- Magnetic marker detection in fluids

Printed components

- Printed batteries
- Printed antennas (smart labels)

Material and structural sensors

- Nanocomposite-based systems
- Acceleration sensors
- Acoustic emission sensors
- Humidity sensor
- Sensors for mechanical and thermomechanical load

Fluidics

- Microfluidic systems for liquid samples
- Gas fluidic actuators (SJA/PJA)

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Cover page:
Clean room of the Center for Microtechnologies of Chemnitz University of Technology; photo: Jürgen Lösel for TU Chemnitz

Fraunhofer ENAS is participant of the

Forschungsfabrik
Mikroelektronik
Deutschland