Application of Smart Systems for a Better Life

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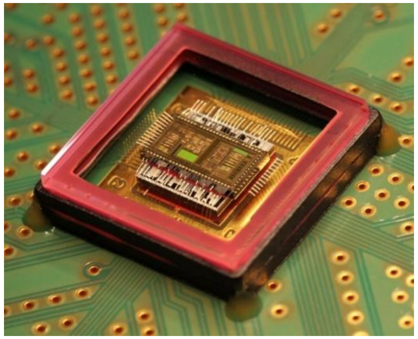


TECHNISCHE UNIVERSITÄT CHEMNITZ

ZfM Zentrum für Mikrotechnologien

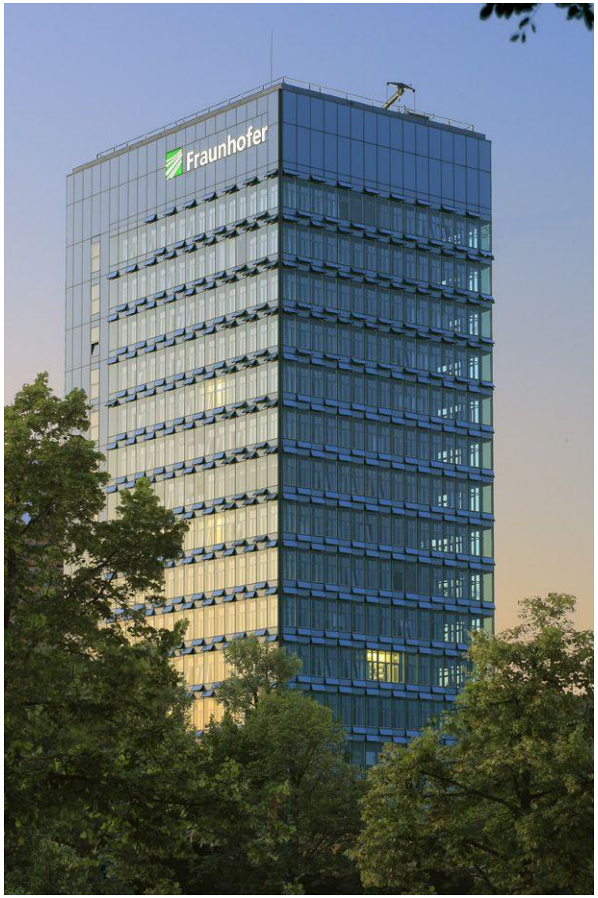
Fraunhofer ENAS

Outline

1. Introduction Fraunhofer ENAS
2. Smart Integrated Systems
3. Examples from Fraunhofer ENAS
   - High performance MEMS increase safety and security
   - High performance MEMS for smart grid applications
   - Smart medical systems
     - Based on polymer technologies
     - Based on printing technologies
4. Conclusion

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

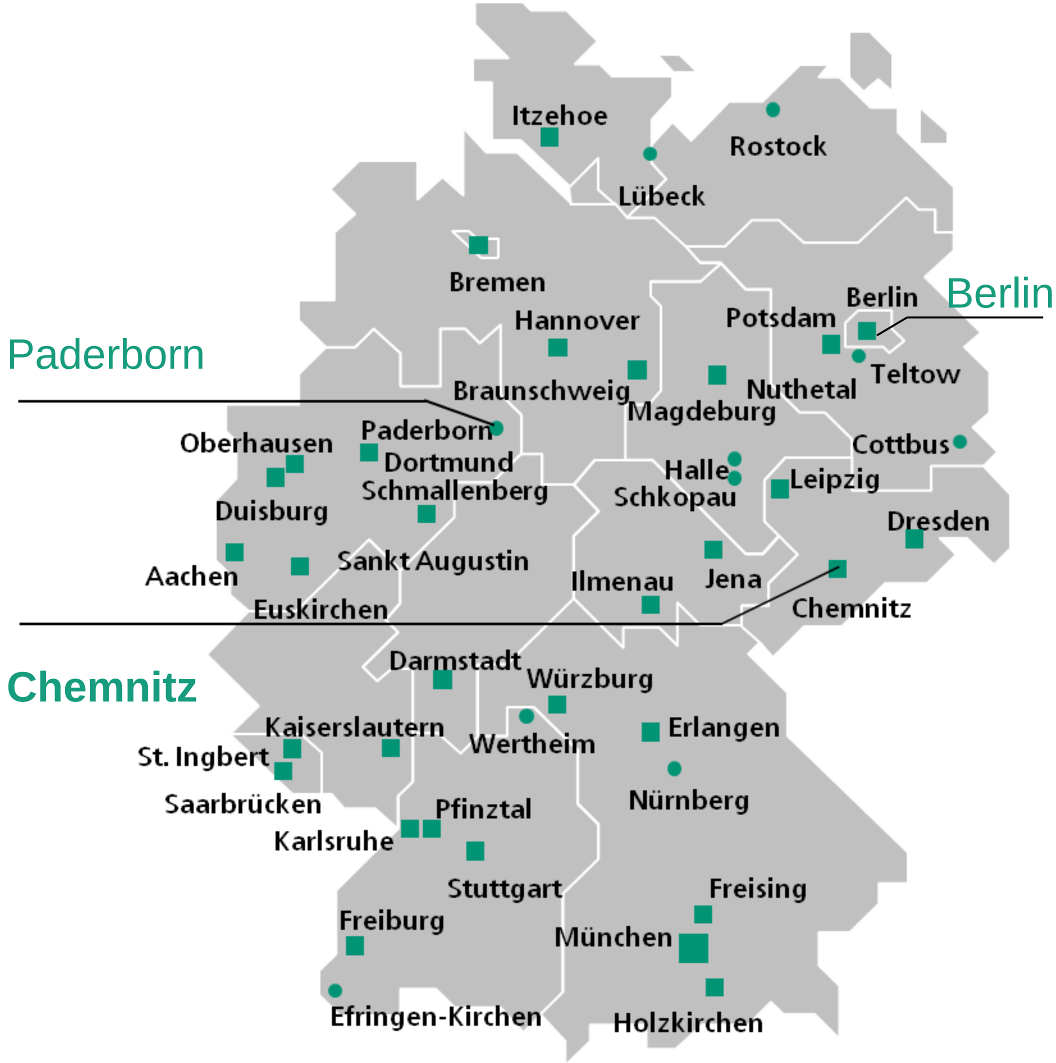


Our Customers:

- Industry
- Service sector
- Public administration

Fraunhofer is the largest organization for applied research in Europe

- 67 institutes and independent research units
- The majority of the more than 23,000 staff are qualified scientists and engineers
- More than 70 percent of this research revenue derives from contracts with industry and from publicly financed research projects.
- Almost 30 percent is contributed by the German federal government and the Laender governments in the form of institutional financing.
- International collaboration through representative offices in Europe, the US, Asia and the Middle East



Main working fields

International Offices of Fraunhofer ENAS:

Since 2001/2005	Tokyo/Sendai, Japan
→ Since 2012	Project-Center in Sendai
Since 2002	Shanghai, China
Since 2007	Manaus, Brazil

Systems integration by using of micro and nano technologies

- MEMS/NEMS design
- Development of MEMS/NEMS
- MEMS/NEMS test
- System packaging/waferbonding
- Back-end of Line technologies for micro and nano electronics
- Process and equipment simulation
- Micro and nano reliability
- Printed functionalities
- Advanced system engineering

Technology Campus

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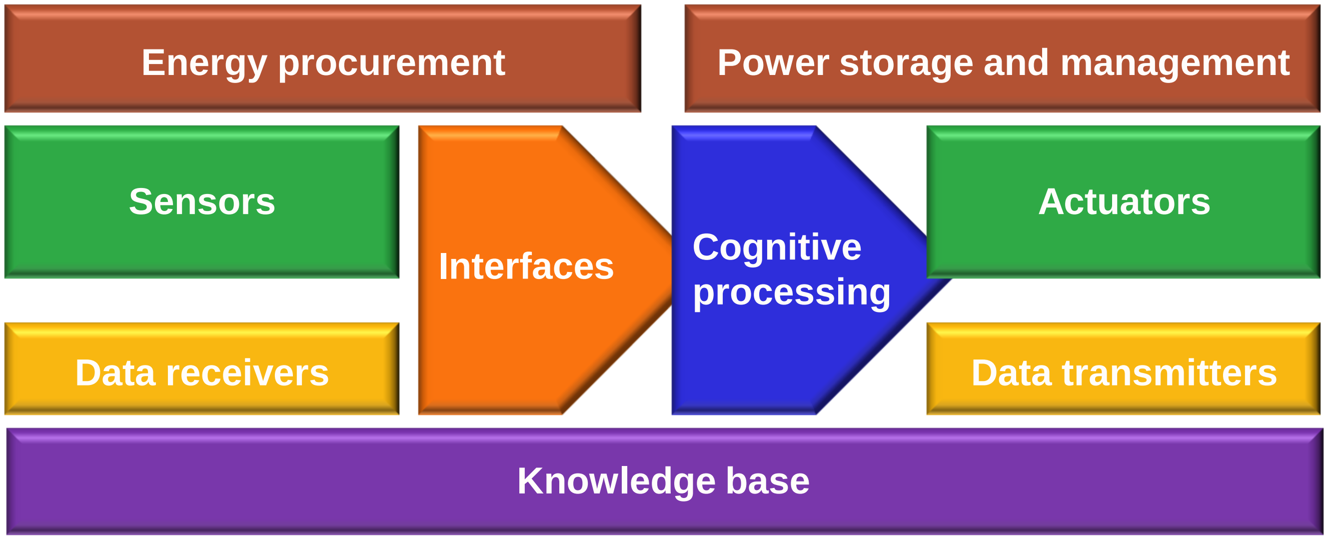
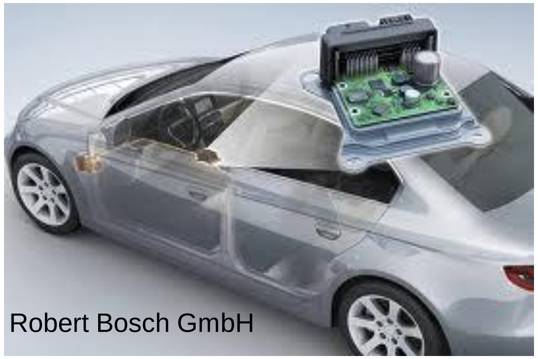
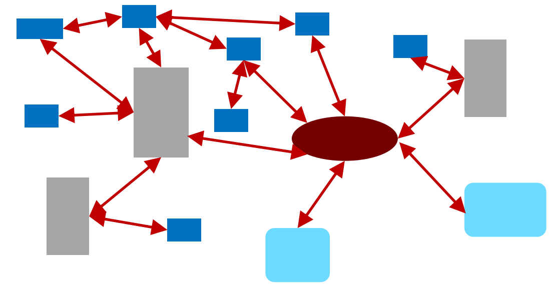
Definition Smart Systems



Definition based on SRA 2013 of EPoSS

- self-sufficient intelligent technical systems or subsystems with advanced functionality, enabled by underlying micro- nano- and bio-systems and other components
- able to sense, diagnose, describe, qualify and manage a given situation
- bring together sensing, actuation and informatics / communications
- their operation being further enhanced by their ability to mutually address, identify and work in consort with each other
- highly reliable, often miniaturised, networked, predictive and energy autonomous
- autonomous or collaborative systems





First Generation

- sensing and actuation
- signal conditioning and processing
- wireless/wired communication
- hybrid and monolithic integration, system on board, chip on board

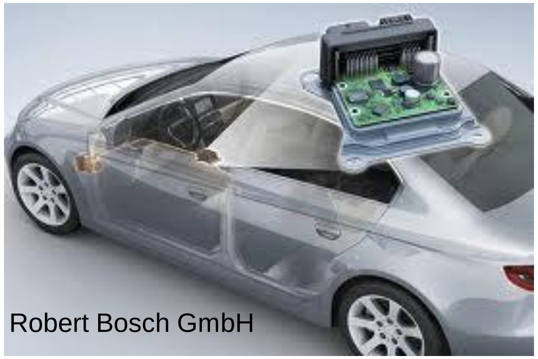
Second Generation

- multifunctional sensing, actuation and inference
- predictive and adaptive
- networking function
- partially autonomous
- partially 3D-integration

Third Generation

- self-calibrating and self healing sensors and actuators
- artifical intelligence
- self-oranized networks
- energy autonomous
- complete 3D-integration

1990 …. 2005 …. 2020


Robert Bosch GmbH

MPD


Source: journal Internet of things

First Generation

application

- medical engineering
- automotive
- …

Second Generation

application

- medical engineering
- automotive
- consumer
- monitoring …

Third Generation

application - internet of things

- smart home
- smart infrastructure
- smart production
- smart grid, ...

macro … micro … nano

Smart Systems in Everyday Life

Smart Me

Smart Mobility

Smart Home

Healthcare

Building Automation

Industrial Automation

Smart Grid

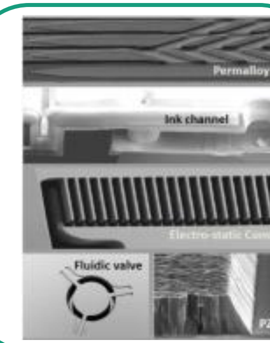
Smart Cities

The Enabling Factors of Smart Systems

Silicon Technologies

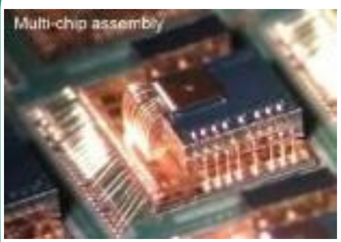
- Moore's Law: Miniaturization
- More than Moore: Functionalities
- 3D Structure : i.e. MEMS
- Through-Silicon Vias

New Materials



- Getters
- Polymers
- Shape Memory Alloy
- Piezoelectric (PZT)
- SiC & GaN
- Graphene

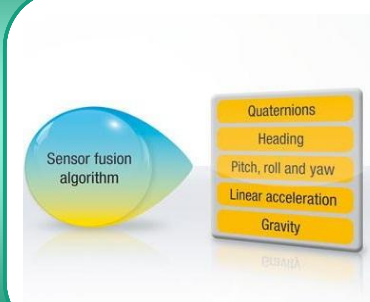
Heterogeneous Integration



- Wafer Level Packaging (Staked Multi Dice)
- New interconnections (Bondless. Sintering, Cu on Cu)
- Smart System In Package (SiP)

Package

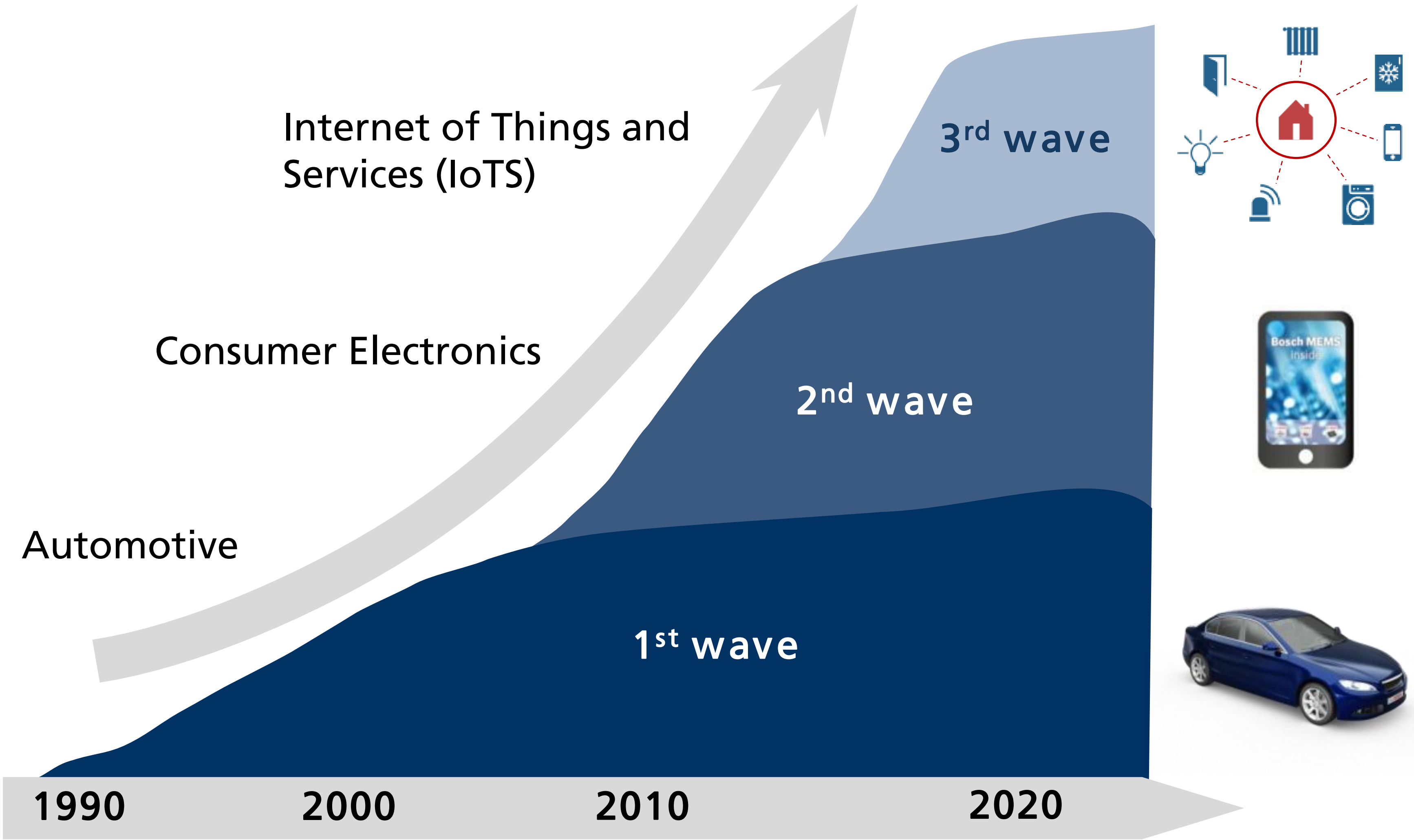
- Orientation & Localization Algorithms
- Embedded Predictive & Reactive Capabilities



IPs & Software

What does this mean for MEMS?

Waves of MEMS sensor proliferation - BOSCH SSI2014



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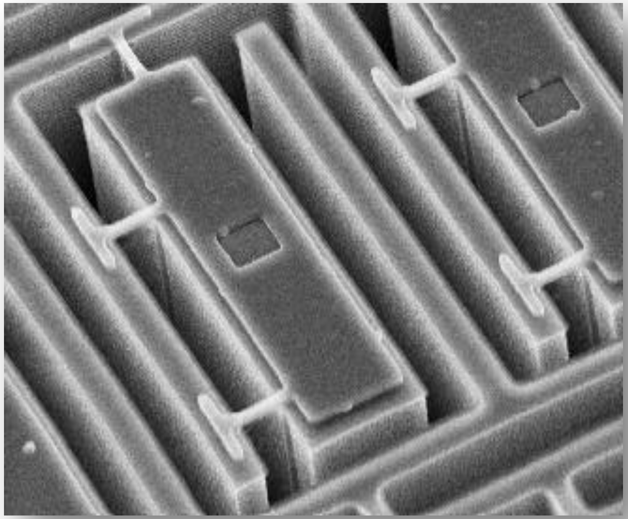
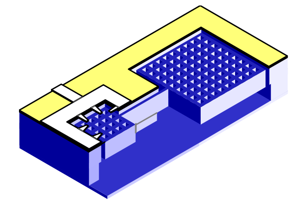
Technologies for Si-based high performance MEMS

- AIM technology: inclination and vibration sensors, RF switch
- BDRIE technology: gyroscopes
- Bulk technology: tunable infrared filters, micro mirrors
- System integration – thin film encapsulation, wafer bonding

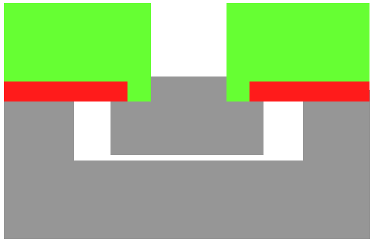


Core technology: AIM (Air gap Insulated Microstructure)



2a. Conducting metal

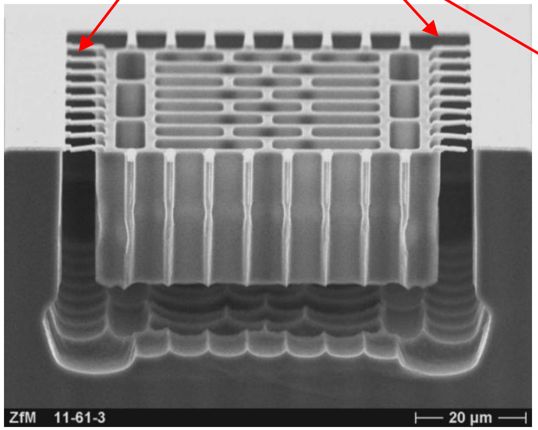
3.Silicon etching

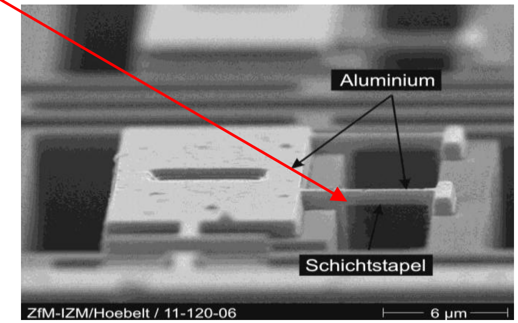


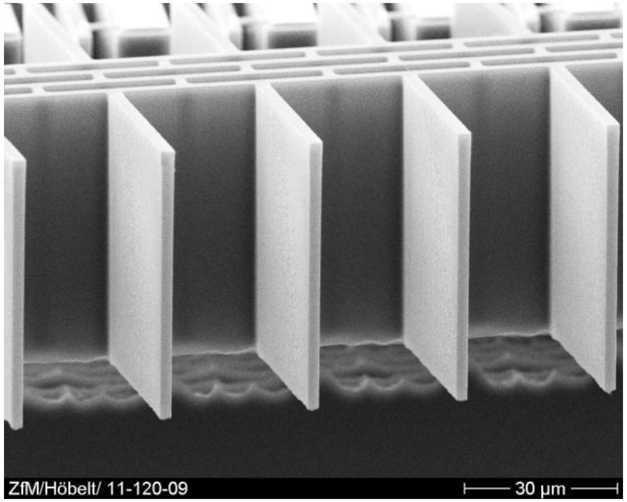
2b. Patterning of isolator (self alignment)

Silicon Isolator Metal

Seismic mass is fixed by interconnection beams consisting of an insulator and metal

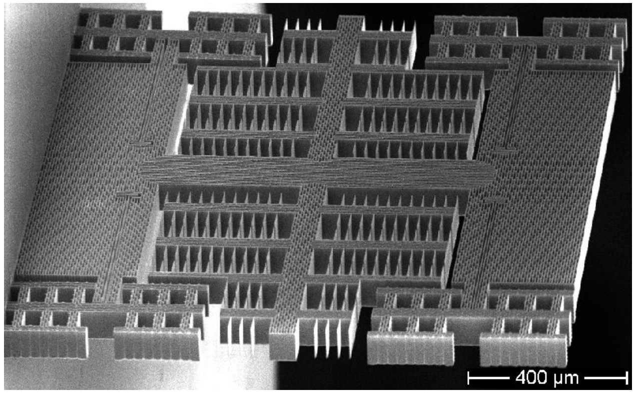




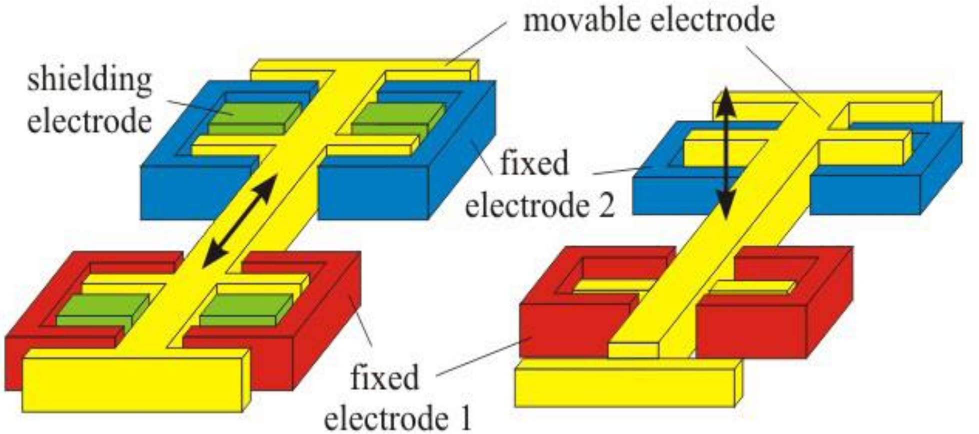


High Aspect Ratio MEMS for 3D sensing

- Two-step etch process, can be integrated in existing HAR technologies (e.g. AIM)
- 3D Sensor system with ASIC CVC1.1EE from Gemac for measurement range ± 50 g
- high sensitivity, low transverse sensitivity and outstanding temperature stability regarding sensitivity and offset temperature coefficients.

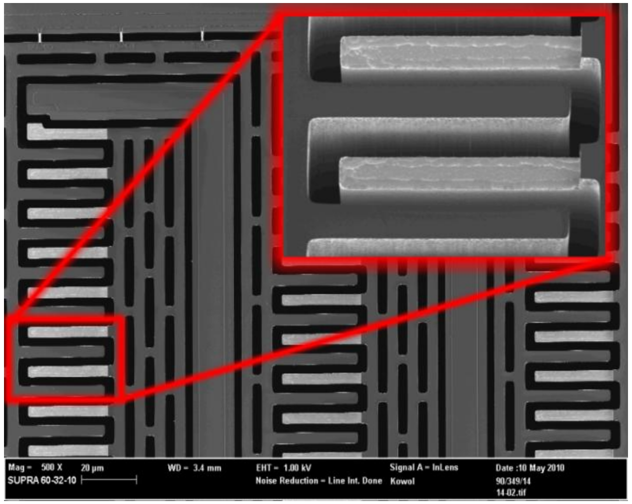


Details of seismic mass and vertical detection electrodes



a) in-plane sensing scheme

b) out-of-plane sensing scheme



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Application of robust acceleration sensors - for integration in wheel bearing of trains

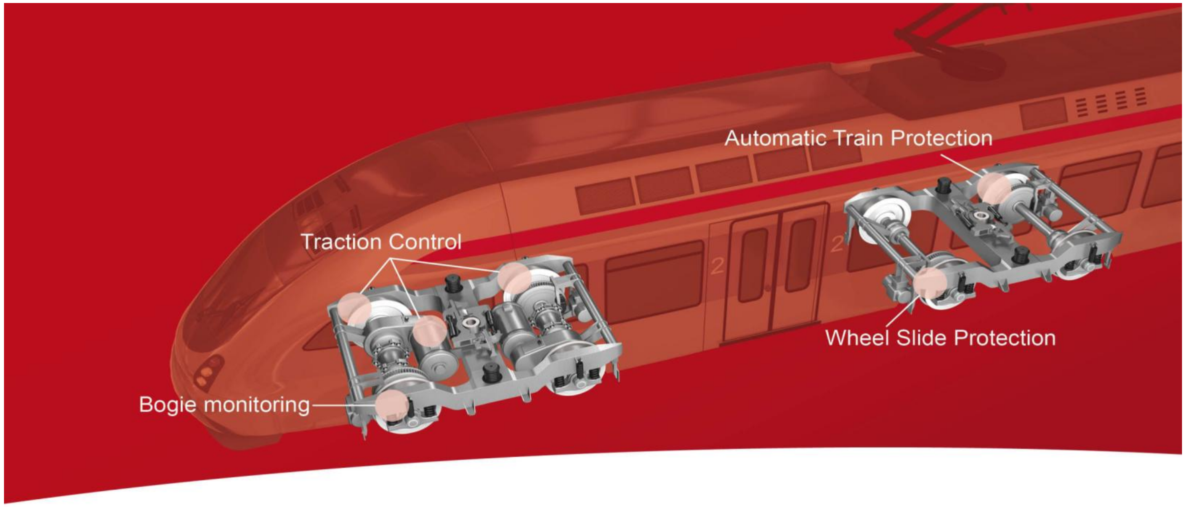
Requirements for monitoring system

- High precision and robust MEMS acceleration sensors
- Intelligent data processing
- Integration in the wheel bearing of trains

Challenges:

- Temperature stability
- Accuracy

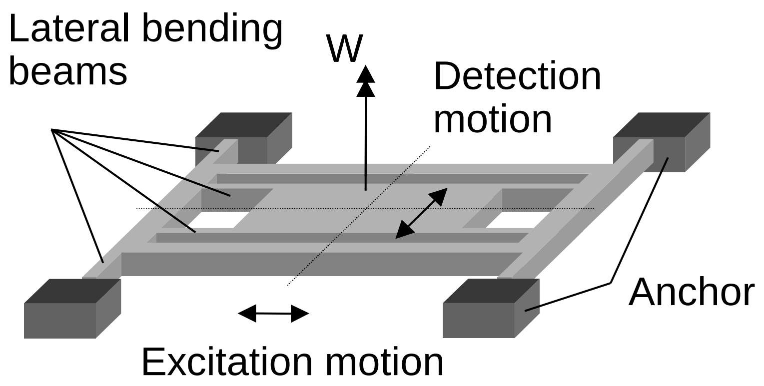
Not met by conventional systems

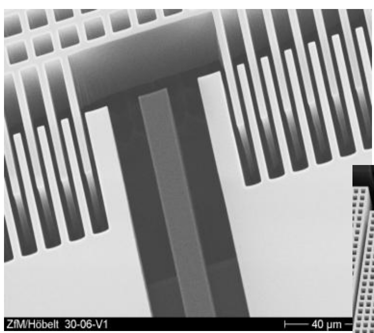


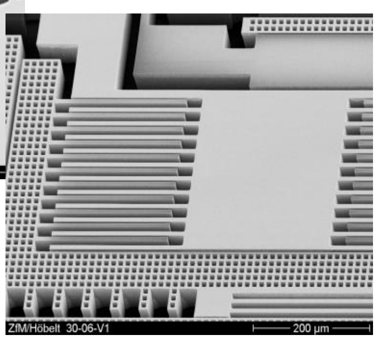
Angular rate sensors based on BDRIE technology

Prototypes of microgyroscopes (single axis, x,y,z)

- High aspect ratio, decoupled structures for high performance
- Vacuum package for high Q resonators (Q > 100,000)
- Co-operation with Northroup Grumman LITEF GmbH, Gyrooptics, GEMAC, EDC
- Application: navigation, motion capturing

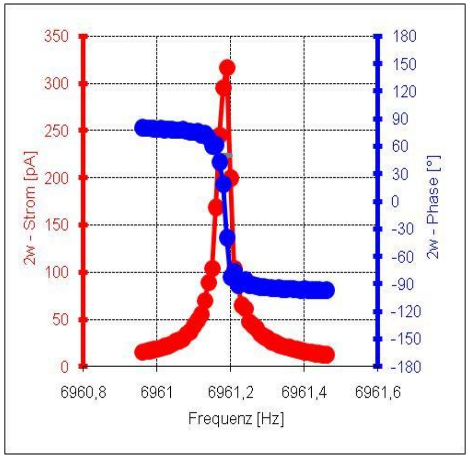


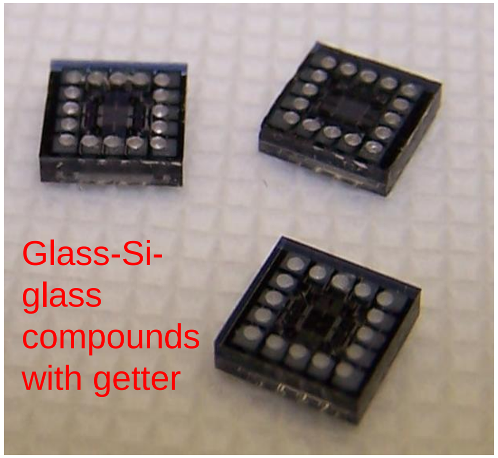




Details of comb drive and sense elements (2 µm gaps, 50 µm height)

Q factor measurement of vacuum packaged gyroscopes





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MEMS NIR/IR-Spectrometer irSys® E

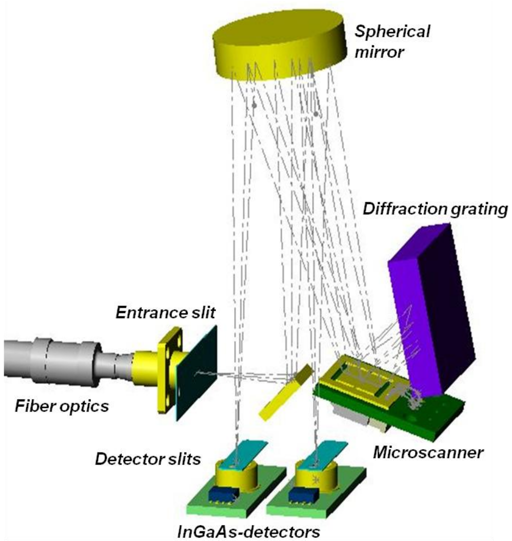
MEMS spectrometers

enable realizing smart systems to supplement or replace traditional technology for particular demands

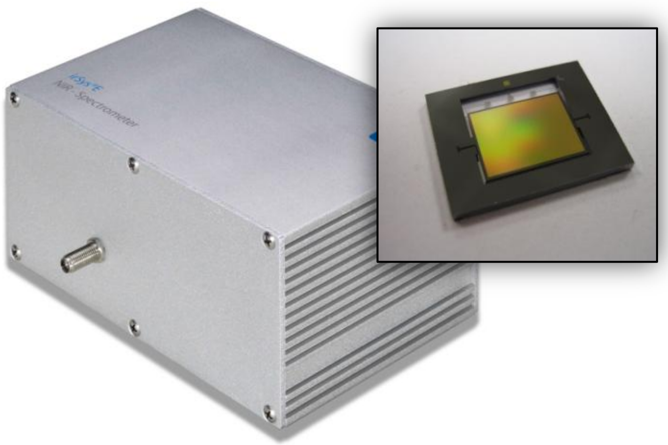
- Advantages:
  - enable miniaturization and portability
  - flexibility
  - cost efficiency

Properties - irSys® E

- High wavelength repeatability (< 0.1 nm)
- Low stray light (<30dB)
- Measurement throughput: 80 spectra /minute
- Suitable for relatively harsh environments



Functional principle irSys® E

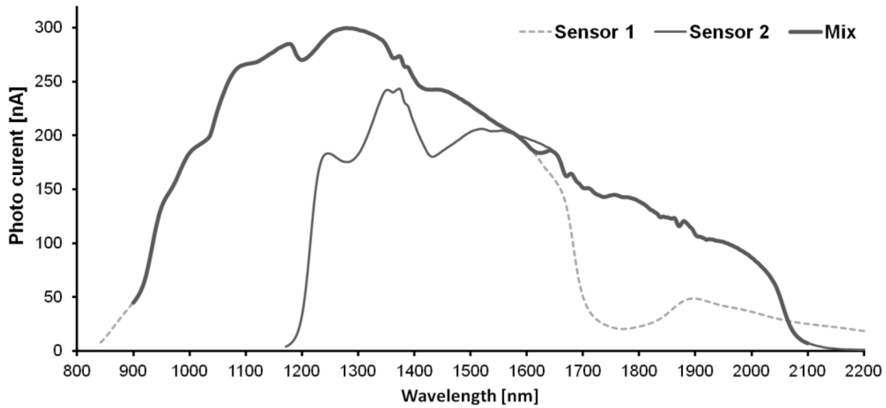


irSys® E Mechanical Set-up; micro mirror

MEMS NIR/IR-Spectrometer irSys® E

Configurable Optics and Sensors

- Spectral range (grating, detector)
- Spectral resolution (input slit width)
- Sensitivity: (detectors (uncooled; 1TE-; 2TE -cooled))
- Flexible sample presentation (direct/diffuse reflection, transmission)



Spectral efficiency of an irSys E 2.1 spectrometer

Spectrometer configurations

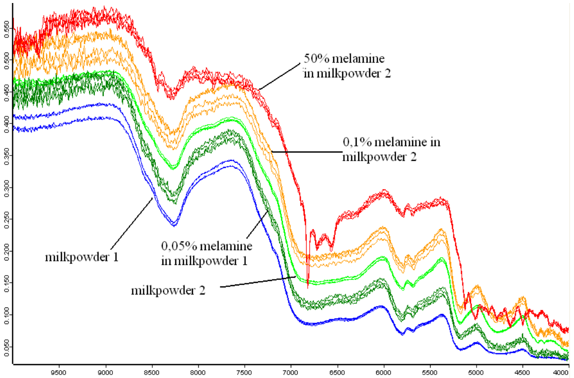
	irSys®E 1.7	irSys®E 2.1	irSys®E 2.4	irSys®E 4.9
Spectral range	660..1730 nm	910..2100 nm	910..2390 nm	2400..4900nm
Detectors	Si + InGAs	2x InGAs	2x InGAs	1 x MCZT
Spectral resolution	8 nm FWHM	11 nm FWHM	11 nm FWHM	12nmFHWM
SNR (single shot)	typically 7.000:1	typically 2.500:1	typically 1000:1	typically 1000:1

MEMS NIR/IR spectrometer – Realized applications
Food safety

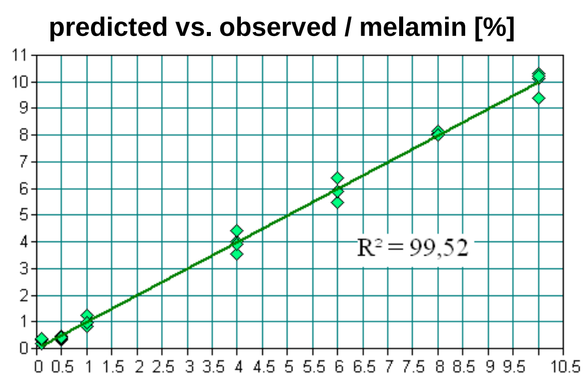
Example: detection of melamine in milk powder

- many food scandals every year worldwide (EU: every 3 month on average)
- melamine contaminated milk powder is a serious issue
  - causes toxic problems, kidney failures
  - thousands babies became ill, 6 die after being fed with contaminated milk powder

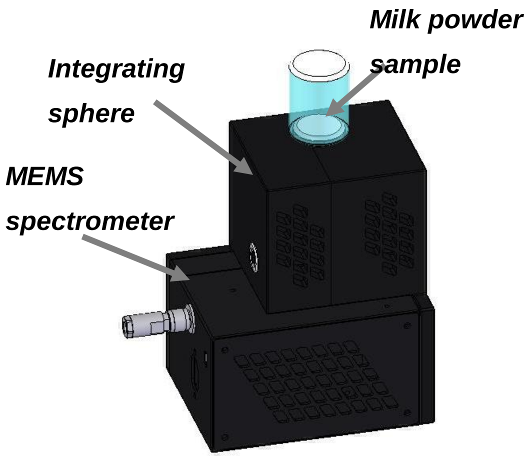
→ frequent control (using compact, cost efficient analytical devices) can avoid such accidents and ensure product safety



NIR-spectra of milk powder/melamin



PLS-calibration of melamine



Principle measurement set-up

→ Qualitative detection of melamine-concentrations until 0,0001% at least are possible using NIR MEMS spectrometer

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MEMS NIR/IR spectrometer – Realized applications

Determination of drugs (heroine, amphetamine, etc.)

Object of investigation:

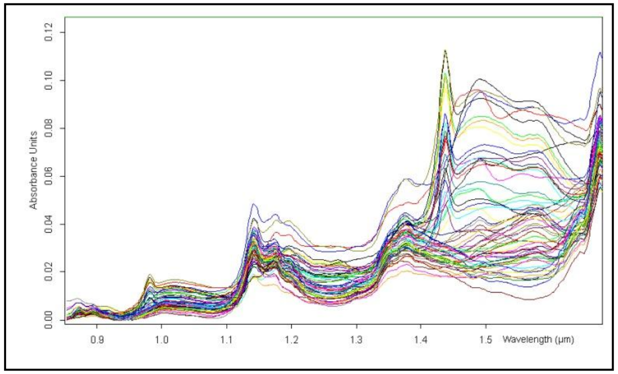
- Samples of heroine and methamphetamine

Wavelength range:

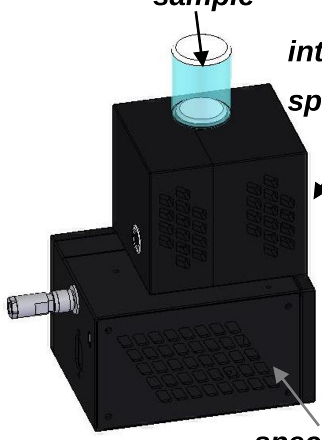
- 660...1730nm

Measuring technique:

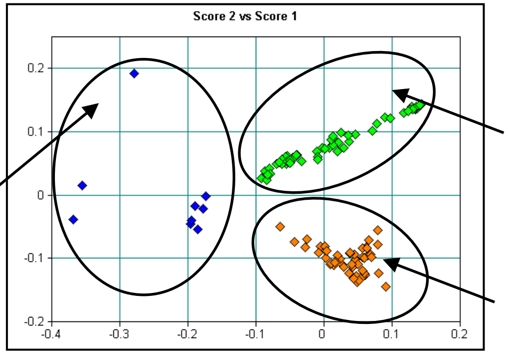
- diffuse reflection



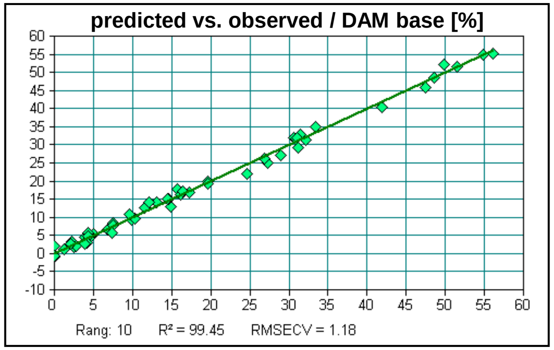
heroine spectra



Qualitative differentiation by principle component analysis



Quantitative analysis by PLS- calibration



heroine (cross-validation)

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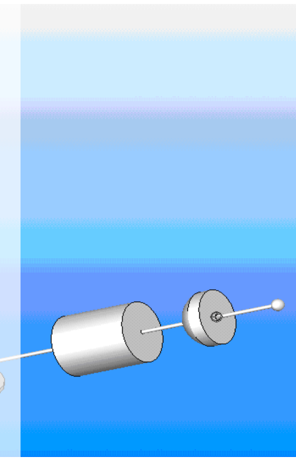
MEMS NIR/IR spectrometer - Realized applications (examples)

Forensic

Identification of heroin and methamphetamine

➜ Qualitative and quantitative determination of active components and supplements using diffuse reflectance



Spectroscopic Ellipsometry

Determination of optical constants of layer and layer stacks by measuring polarization change

➜ Replacement of traditional used FTIR- spectrometer

Medicine

Determination of fecal fat

➜ Important to get evidence for malassimilation and for estimating the efficacy of treat-ment with enzymatic enzymes (e.g. at mucoviscidosis)

Fuel Gas Analysis

Direct identification of natural gas constituents to determine fuel value

➜ Improvement of the process and product quality (e.g. operation of industrial firing process)

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Challenges for power supply

- Reliable power supply
- Economic efficiency
- Ressource efficiency
- Climate protection

Why power line monitoring

<ins>Problem</ins>: increasing supply of renewable energies (e.g. solar and wind) and its high fluctuations

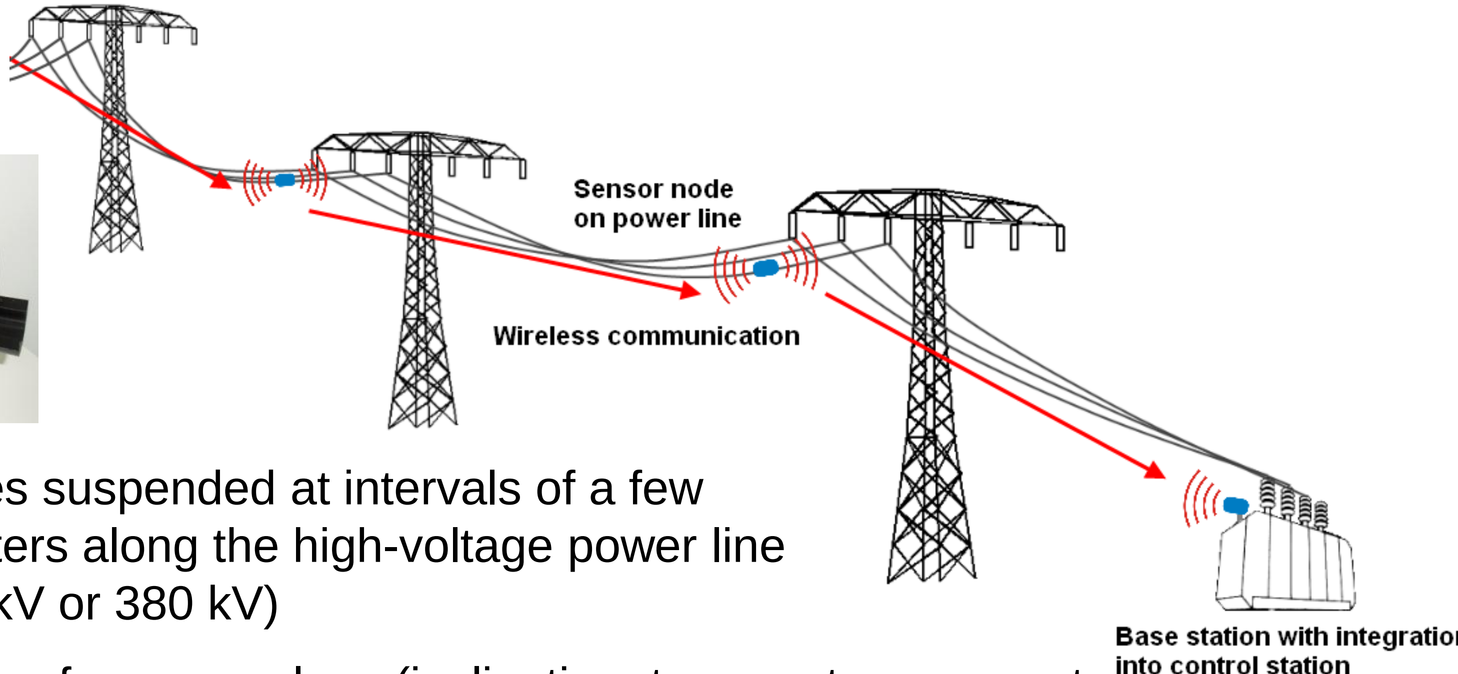
- Distribution of power from renewable sources is difficult **(transport bottleneck**)
- Safety margin (distance between power line and ground) reduce capacity utilization

<ins>Goal</ins>: online monitoring of the power lines (temperature of the conductor, magnitude of the current, conductor sag)

- Monitoring system allows **evaluation and optimization of the capacity utilization**

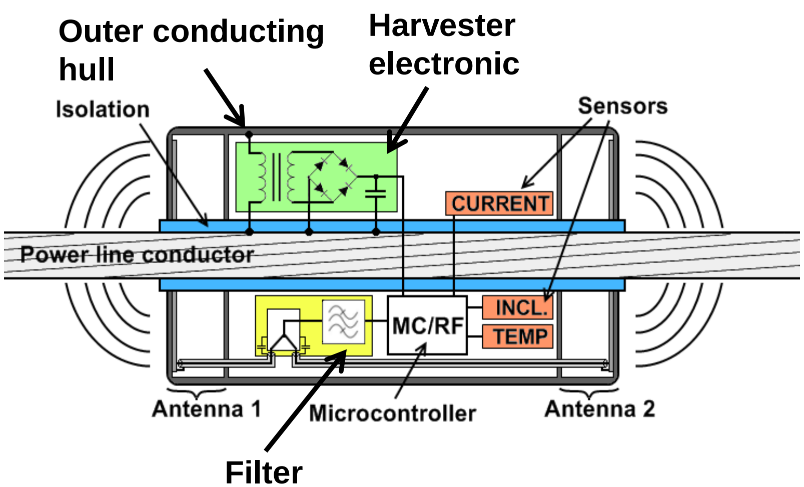
ASTROSE
Autarkic sensor network for monitoring of power lines

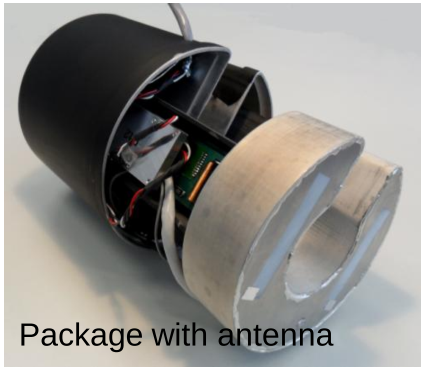
Power line monitoring

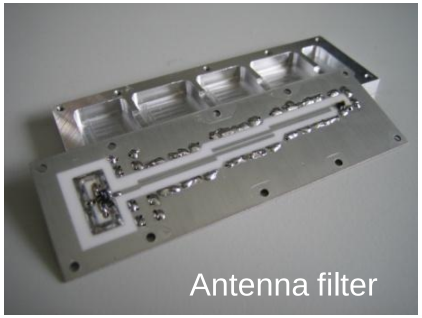


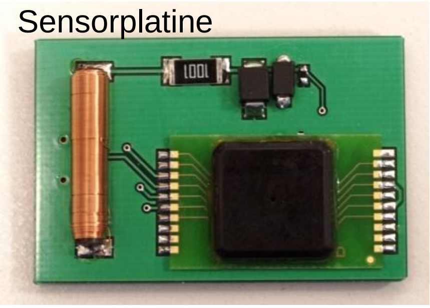
- Sensor nodes suspended at intervals of a few hundred meters along the high-voltage power line (e.g. at 110 kV or 380 kV)
- Transmission of sensor values (inclination, temperature, current along the chain to a base station
- Self-organization of the network
- Wireless communication in 2.4 GHz frequency band
- Energy required to operate the system is harvested from the electrostatic fringing field of the power line

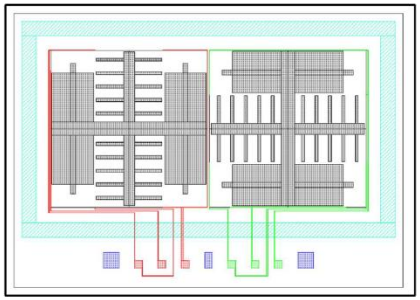
Sensor node



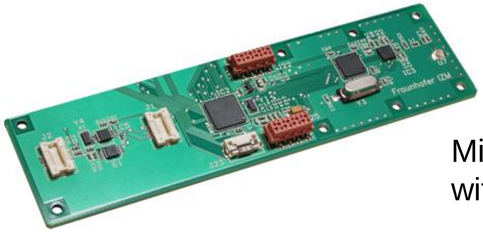

Package with antenna


Antenna filter


Sensorplatine


X-Sensor (±10° deflection) Y-Sensor (±50° deflection)

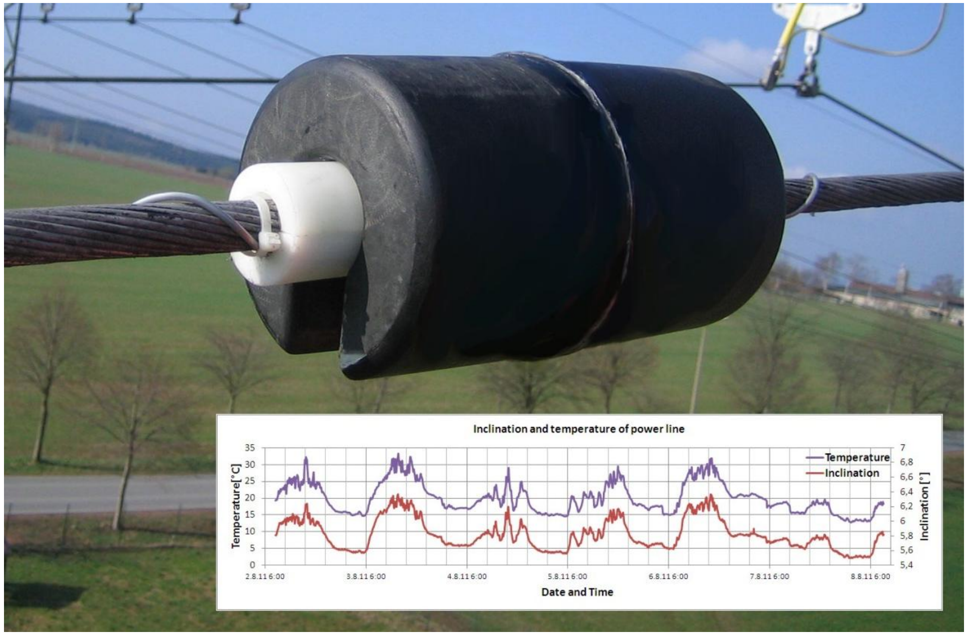
Smart system contains sensors for measuring inclination, current and temperature.


Microcontroller board with wireless transceiver

Characterization

Field test at a 110 kV power line

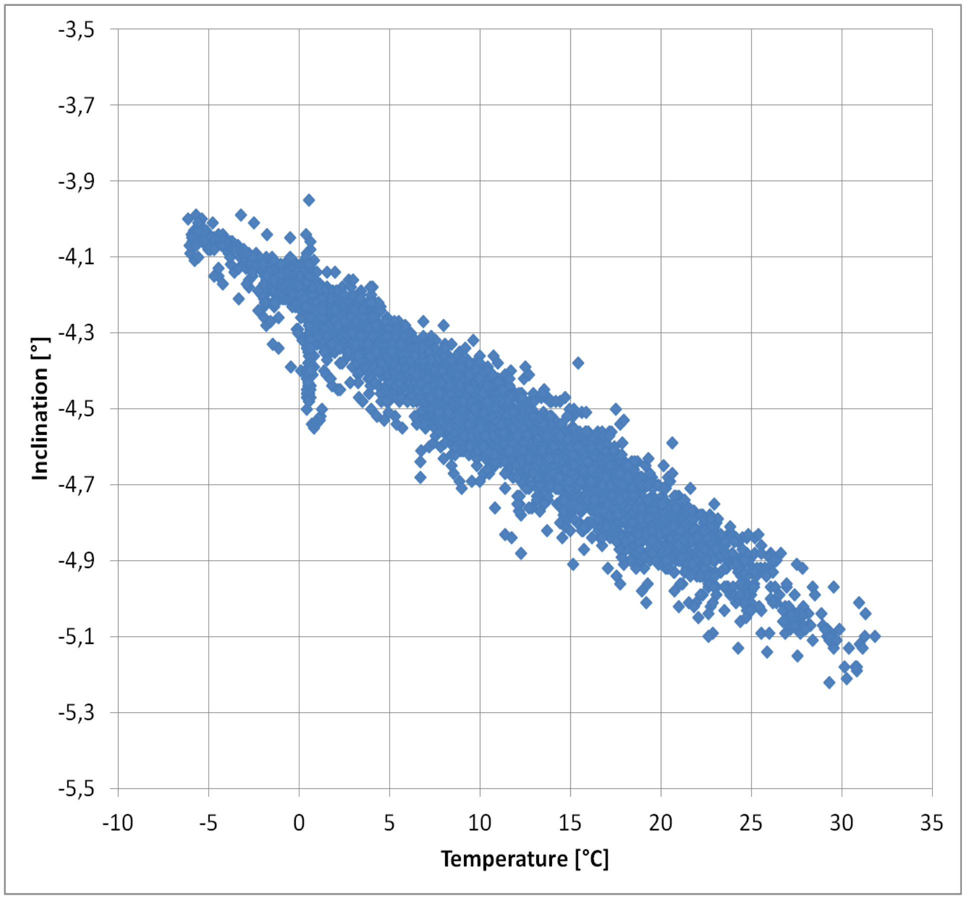
Measurement of temperature and inclination



- Approval of the concept: power transmission can be monitored by measurement of inclination
- Wireless communication in 2.4 GHz frequency band
- Energy needed is harvested

Correlation between temperature and inclination

ASTROSE
autarkes sensornetzwerk zum
monitoring in der energietechnik



- Temperature and inclination correlate
- Sensor concept is ok: sag can be obtained by measurement of inclination
- Project will be continued: next field test will take place in Harz

→ From public funded project to real industry project

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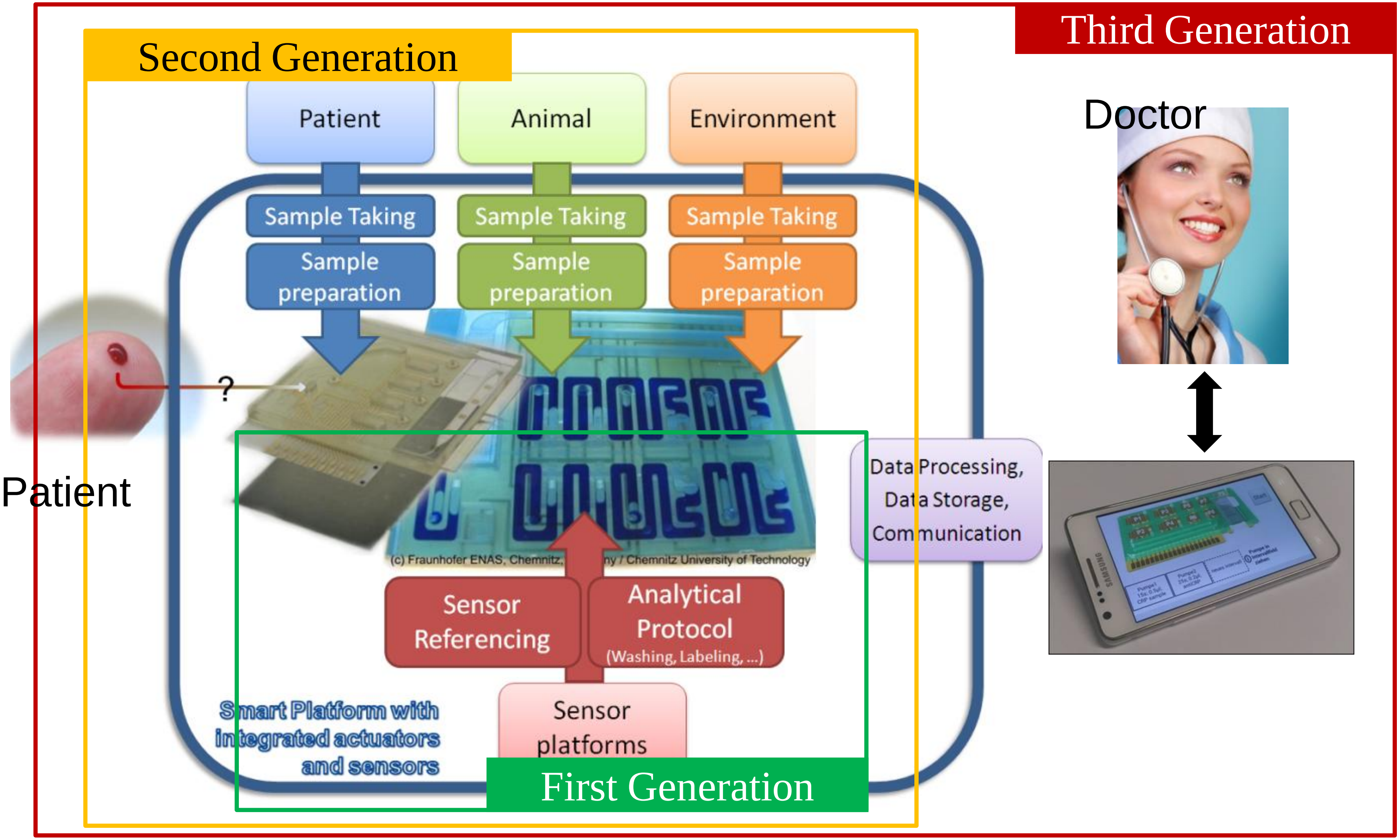
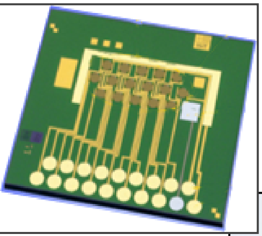
   - High performance MEMS for smart grid applications
   - Smart medical systems
     - Based on polymer technologies
     - Based on printing technologies
4. Conclusion

Smart Microfluidic Systems – 3 Generations

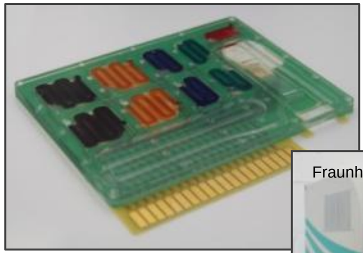


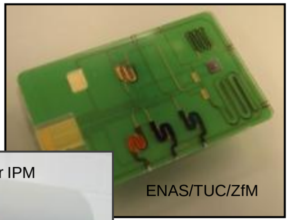
Smart Microfluidic Systems – 3 Generations



AJ eBiochip

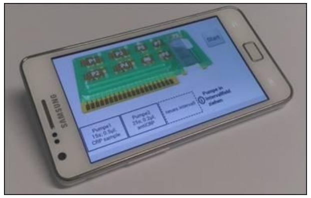
Abbott iStat

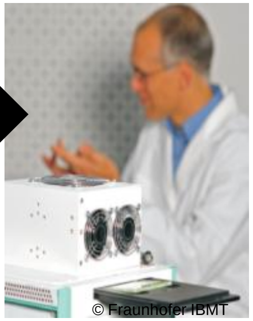




ENAS/TUC/ZfM

Fraunhofer IPM





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Our Research Activities

First Generation

- Hybrid devices
- Sensing, external actuation
- signal conditioning and processing
- wireless/wired communication

Second Generation

- Full integration of sensing and actuation
- Integrated Sample Preparation
- Integrated Electronics / Standard interfaces and Technologies (e.g. I²C communication on ChipCard)

Third Generation

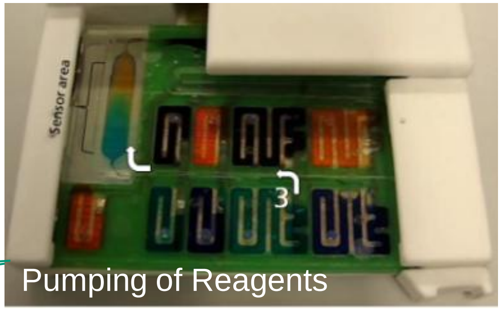
- TeleMedicine / „Dr. Phone“
- Remote Diagnostics
- Self-powered, smart disposables (including biosensor, actuators, power source, electronics, communication)

2000 .... 2015 2025

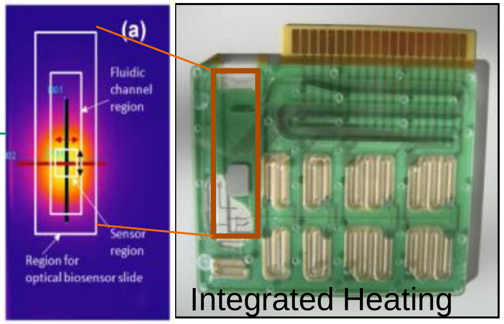
Smart Microfluidic Systems: Functions to be integrated

Fraunhofer ENAS works on full integration of the following components:

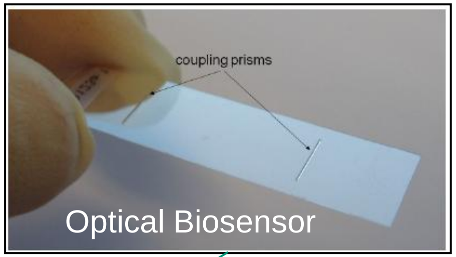
- Reagents
- Pumping
- Heating
- Control Electronics
- Communication
- Power supply
- Sensing



Pumping of Reagents



Integrated Heating



Optical Biosensor

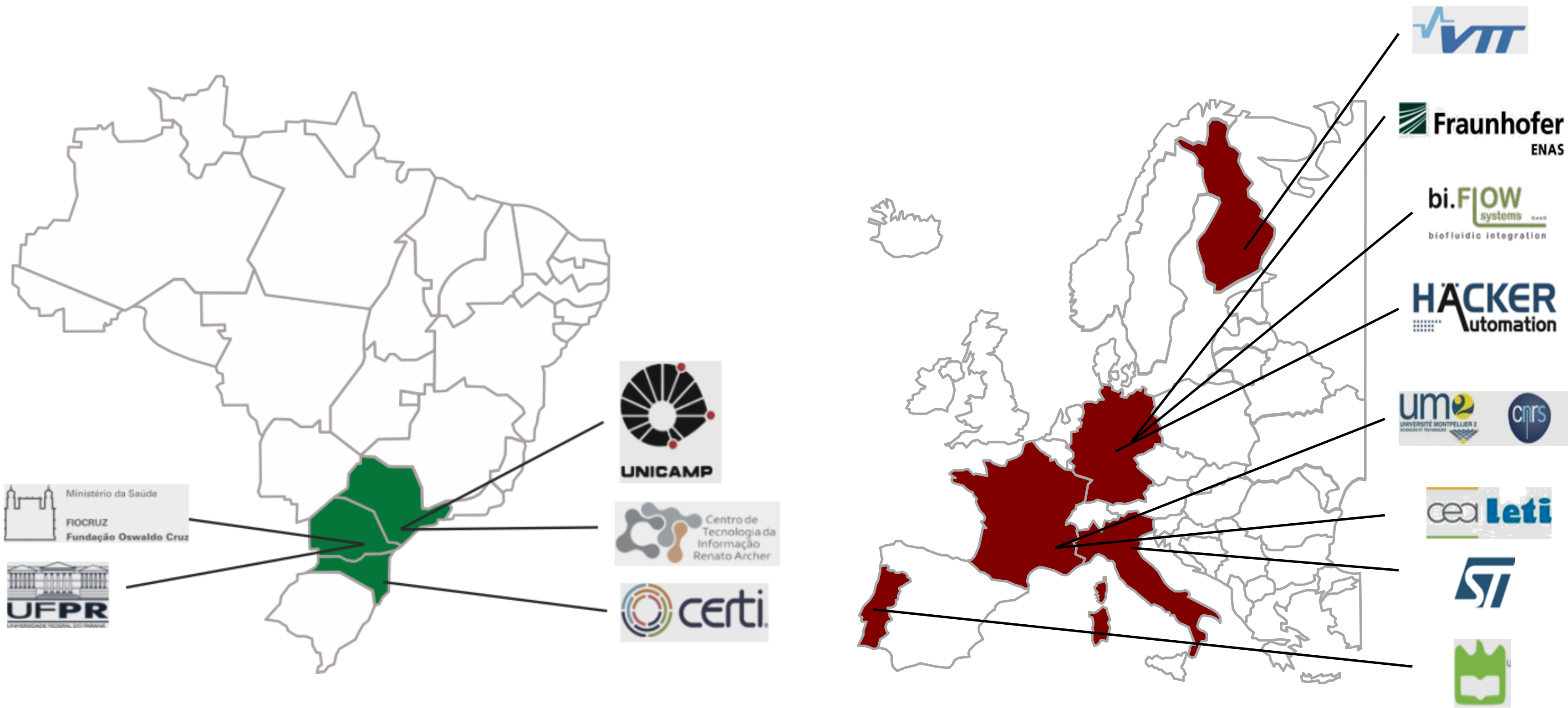
Application fields

- Detection of tropical deseases like Chagas
- Detection of cancer
- Influenca diagnostics

Application: PodiTrodi – Detection of Chagas

PodiTrodi
Point-of-care diagnostics for tropical diseases

8 European and 5 Brazilian partners from research and industry



Background of project

What is Chagas disease?

- Caused by protozoan parasite *Trypanosoma cruzi*
- Transmitted by *Triatoma infestans („Kissing bug“) or through blood*
- One of the “top neglected diseases” (WHO 2010) with about 15-17 Mio people infected worldwide
- Ranked at the 4th cause of death within tropical diseases

Goal:

- Detection of disease in the **acute and chronic phase**
- Combined protein and nucleic acid testing in **pocket size cartridge**

Microfluidic cartridge

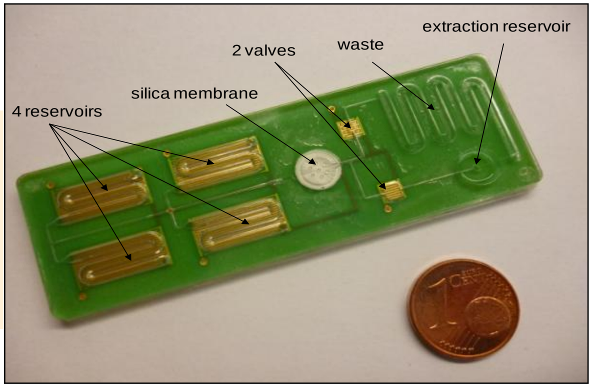
PodiTrodi
Point-of-care diagnostics for tropical diseases

Goal of microfluidic cartridge development

- Integration of complete sample preparation:
  - Sample take up
  - Lysis of cells
  - DNA isolation (binding, washing and elution)
- Integration of RT-PCR chip
  - Distribution to RT-PCR chambers
- Integration of lateral flow based immuno assay
- Reagent storage

DNA extraction chip

→ purification lysed sample

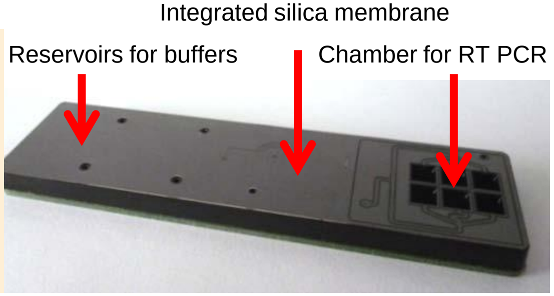


Real time PCR-Chip (ST Italy)

→ highly sensitive detection

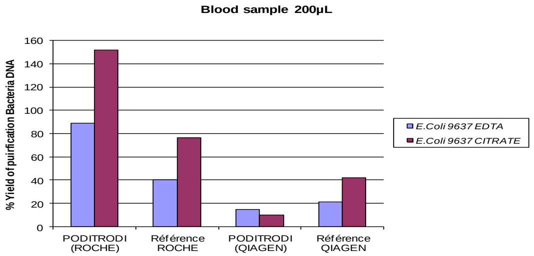
Extraction and PCR Chip

→ DNA purification and real time PCR on one chip



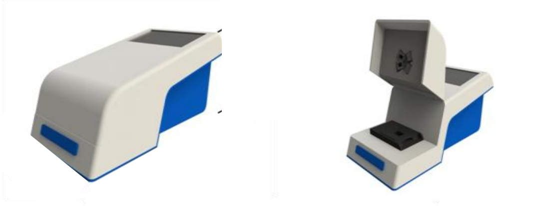
PodiTrodi – Detection of Chagas

Bio Assay and sample preparation

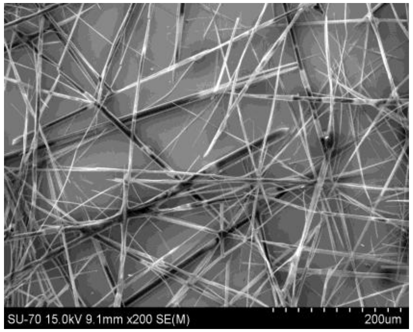


Microfluidic cartridge

Instrumentation



Bio sensor



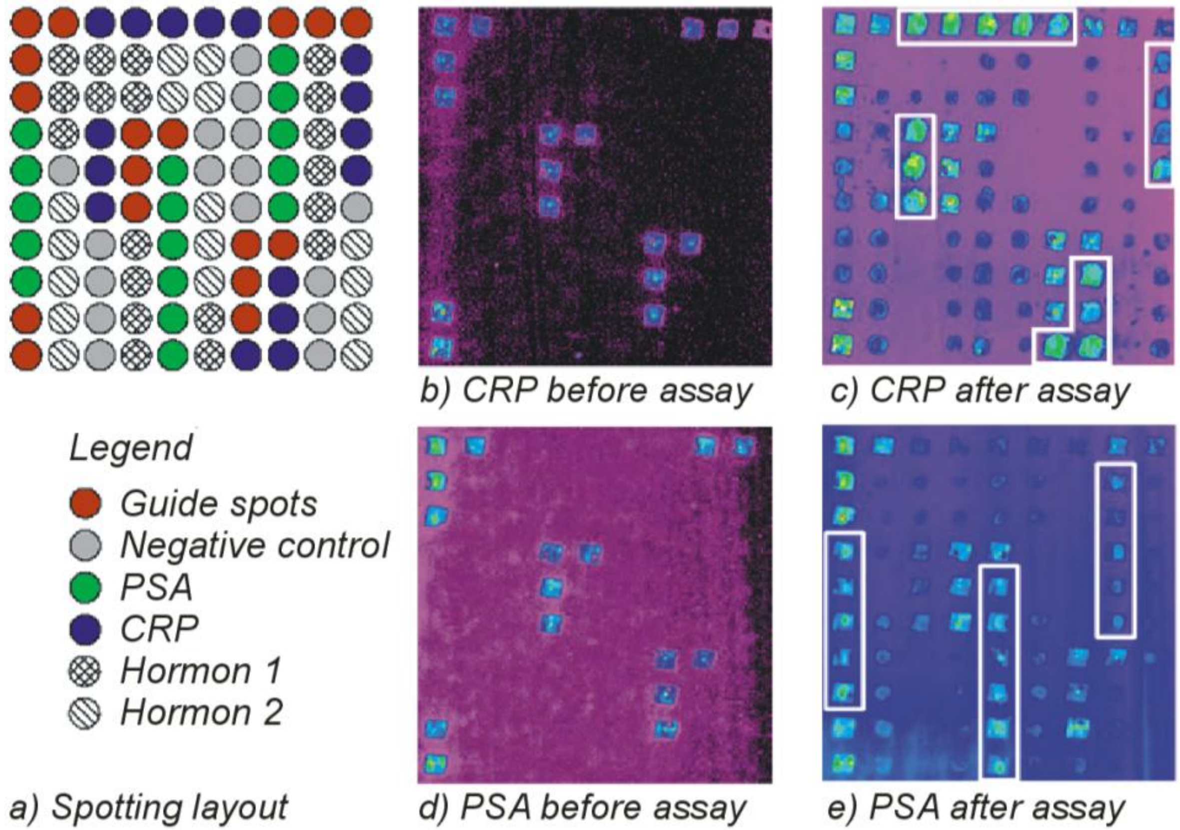
TECHNISCHE UNIVERSITÄT CHEMNITZ

ZfM Zentrum für Mikrotechnologien

Fraunhofer ENAS

Sample BioAssay: CRP- and PSA Immunoassay (ELISA)

Readout Instrument (Fraunhofer IPM) and CRP assay (Fraunhofer IBMT)



Sequence:

1. Washing
2. Sample
3. Washing
4. Antibody 1
5. Washing
6. Antibody 2 (labled)
7. Washing

Fraunhofer IPM

Fraunhofer IBMT

Chipcard for Influenza Diagnostics

Contact Module with ASIC

Reagent reservoirs with pumps

Detection Area

PCR (up to 95°C)

Reverse Transcription (up to 95°C)

Lysis Chamber (95°C)

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Cholesterol detection in the blood – European SIMS project

Develop a smart, miniaturised sensing system through the integration of

- a nanosensor
- a printed low cost display
- a mobile phone interface
- a printed battery
- organic circuitry

Current demonstrator

- printed battery
- EC display
- sensor

Awarded by OE-A "Best publicly funded project demonstrator" at LOPE-C 2013

vision 2010

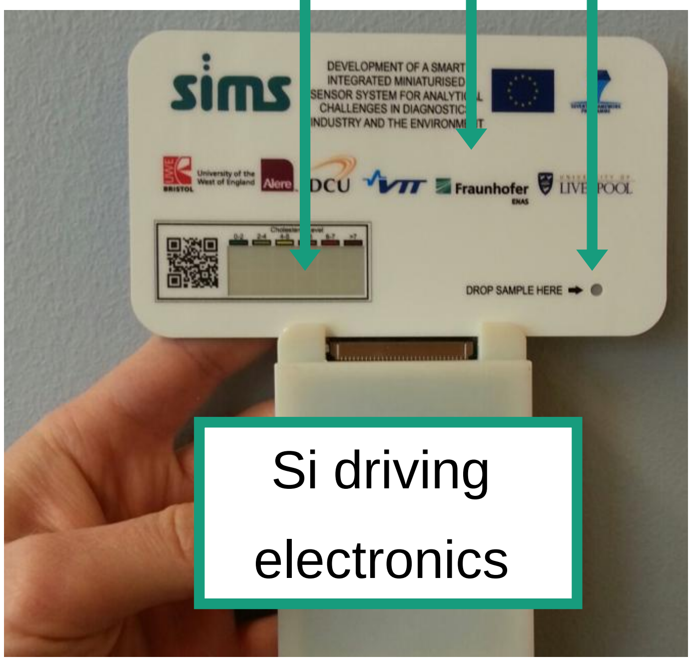
Aim: standalone application

Current development status

printed battery (backside)

printed EC display

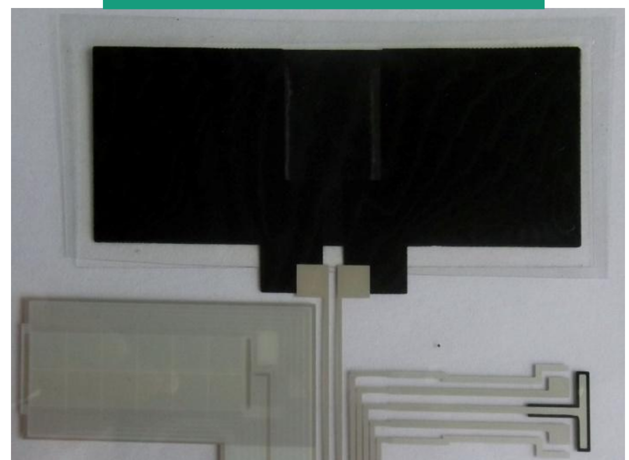
printed sensor



Si driving electronics

Without cover:

printed battery



printed EC display

printed sensor

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Conclusion

- Smart Systems will provide solutions to address grand challenges and risks for mankind in social, economic and environmental terms
- Progressive development of Smart Systems characterized by their increased autonomy
- Smart System Integration as a cross-cutting technology is the technology of the future

International Conference & Exhibition on integration issues of miniaturized systems – MEMS, MOEMS, ICs and electronic components

smartsystems integration

9. Conference: 11-12 March 2015, Copenhagen, Denmark

Organizer: Mesago Messe Frankfurt, Fraunhofer ENAS, Fraunhofer IZM

Part of the Activities of: EPoSS European Technology Platform on Smart Systems Integration

Chair: Prof. Dr. T.Gessner, Fraunhofer ENAS

Co-Chair: Dr. Guenter Lugert, Siemens AG and EPoSS