European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

WGs and MC Meeting at ISTANBUL, 3-5 December 2014

Action Start date: 01/07/2012 - Action End date: 30/06/2016

Year 3: 1 July 2014 - 30 June 2015 (***Ongoing Action***)

Applications and trends in gas sensing for home and health

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Erhard Magori, Roland Pohle

Function in the Action: Invited Expert

Siemens AG / Germany

COST is supported by the EU Framework Programme

ESF provides the COST Office through a European Commission contract

Outline

- Siemens AG – Facts & Figures
- Metal-Oxide gas sensors
- Examples for gas sensor applications
- Early Fire Detection
- Activity Detection
- Room Air Monitoring
- Further sensing principles
- Summary

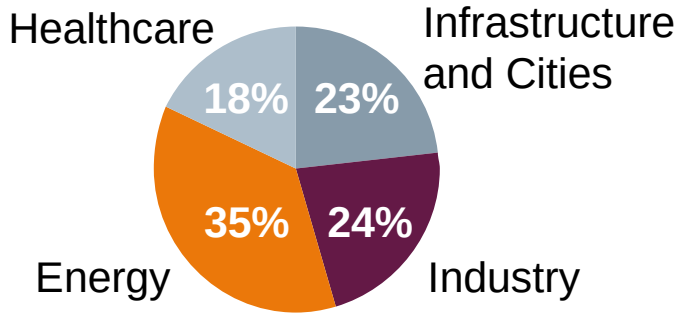
Siemens AG facts&figures

R&D employees and spending

General Numbers

In millions of €	FY 2012	FY 2013
New orders	75,939	82,351
Revenue	77,395	75,882
Income	4,642	4,212
Free cash flow	4,727	5,257
Employees	366,000	362,000

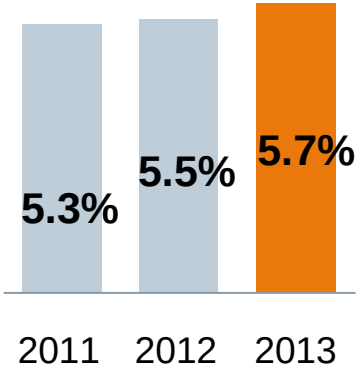
Revenue by Sector (2013)



Employees in R&D

- **13,300** employees in R&D in Germany
- **16,500** R&D employees in ~**30** other countries worldwide

R&D spending as % of revenue (€4.3 billion)



Patent applications (position)

Germany (2013) No. 4

Europe (2013) No. 2

USA (2012) No. 11

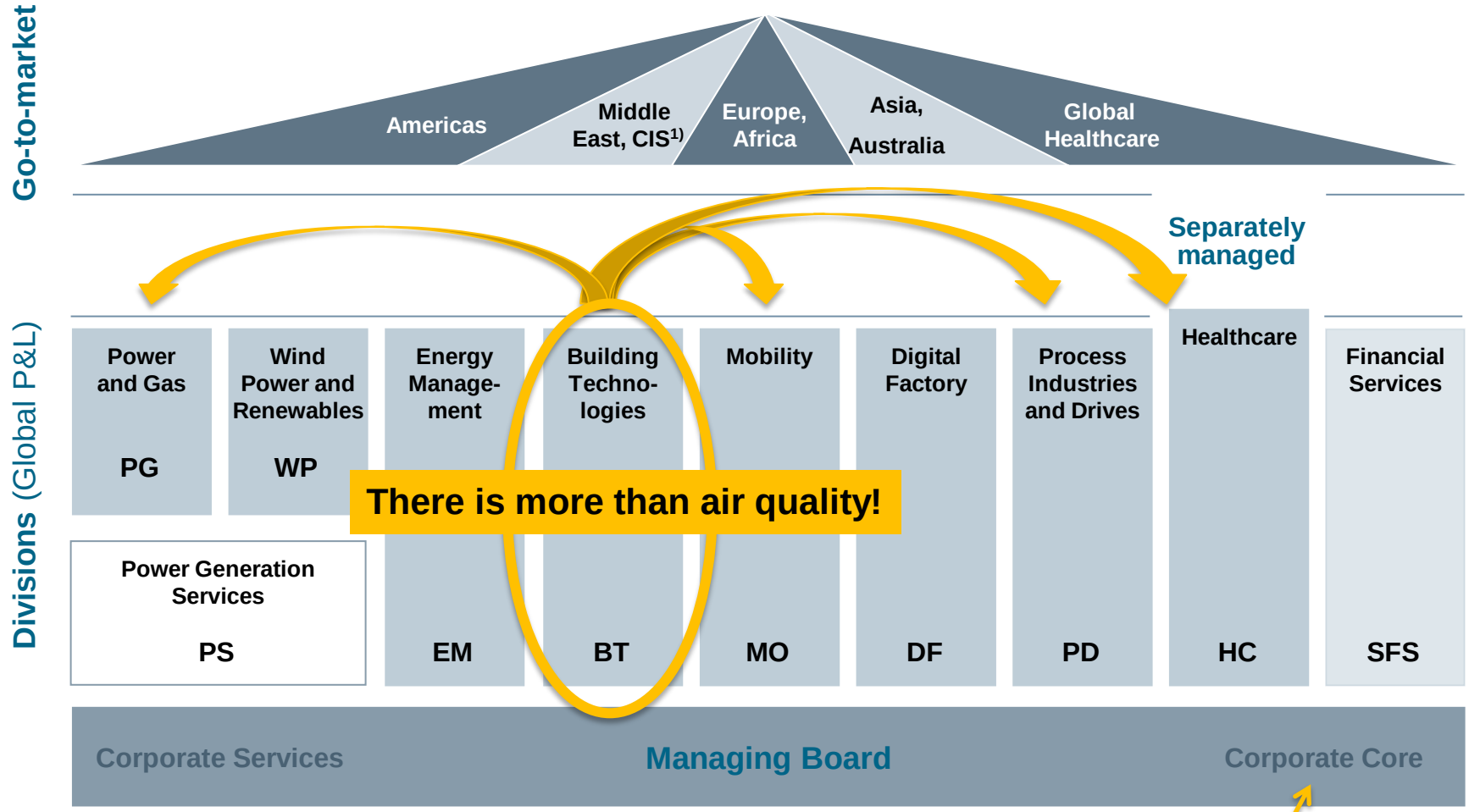
- Siemens currently holds approximately **60,000** patents granted worldwide
- **21,400** patents and intellectual property rights are related to our Environmental Portfolio

Partnerships

- Approximately **1,000** partnerships with universities and research institutions per year

Siemens AG Setup 2015

Application fields for innovative low cost gas sensors



1) Commonwealth of Independent States

Corporate Technology gas sensor group is here

Megatrends

Demographic change

World population

- 2012: 7.1 billion people
- 2050: 9.6 billion people

Worldwide life expectancy

- 2012: 70 years
- 2050: 76 years
- By 2050, the share of the population aged 60 or over will, for the first time, equal the share of the population younger than 15

Urbanization

Growth of cities

- 2009: more than 50% of the world's population lived in cities
- 2050: 70% of the world's population will live in cities

Megacities worldwide

- 1970: 2 megacities with more than 10 million inhabitants
- 2025: 37 megacities; more than 13% of the world's population will live in a megacity

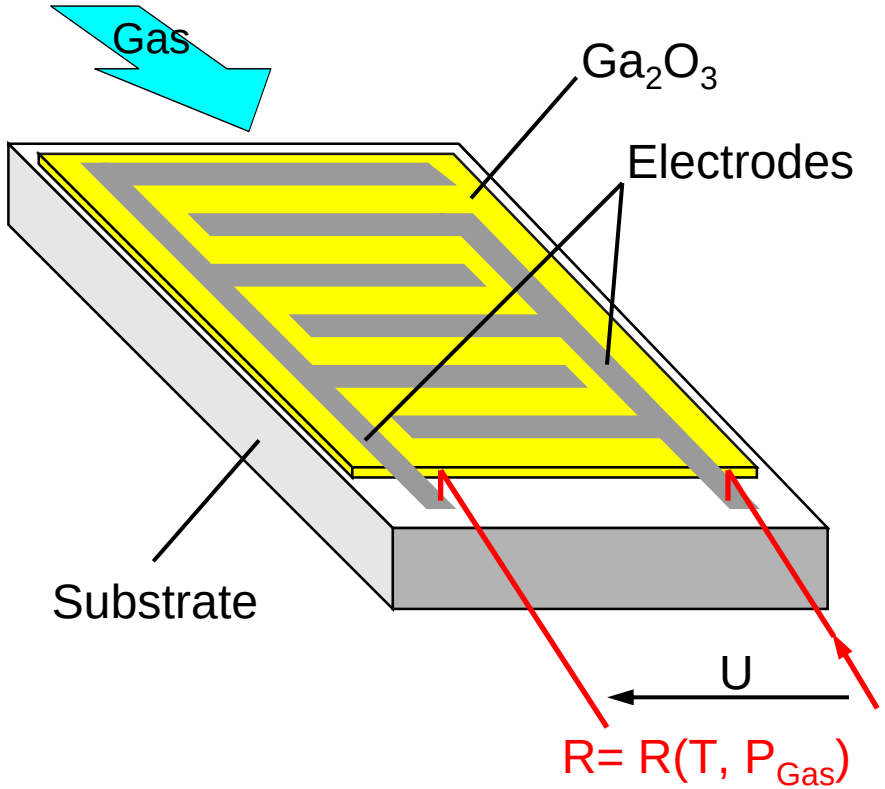
Climate change

Greenhouse effect

- 2013:
  Highest CO_2 concentration in the atmosphere in 800,000 years
- 2001 to 2010:
  Warmest decade on record

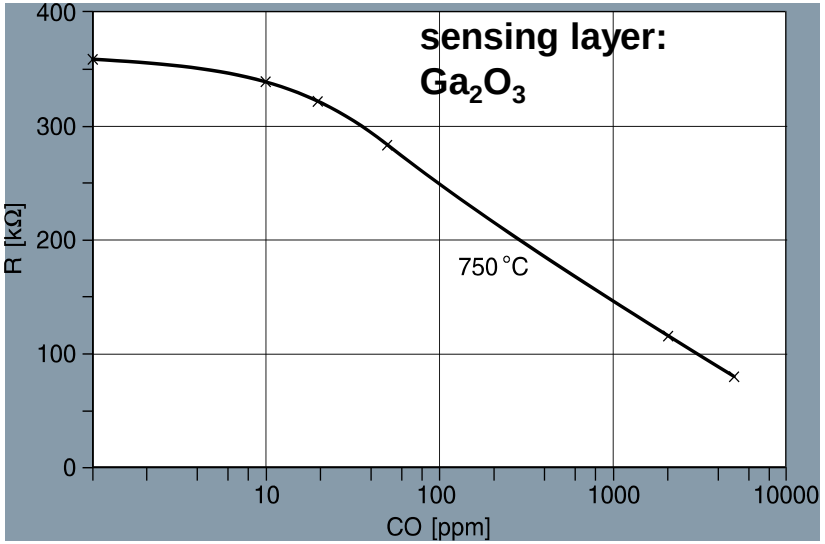
Metal Oxide Gas Sensors

low cost gas sensing: Sensing Principle



Principle

- Metal oxides show semi-conductivity at high temperatures (200-800°C)
- Reversible change of conductivity due to reaction with target gases



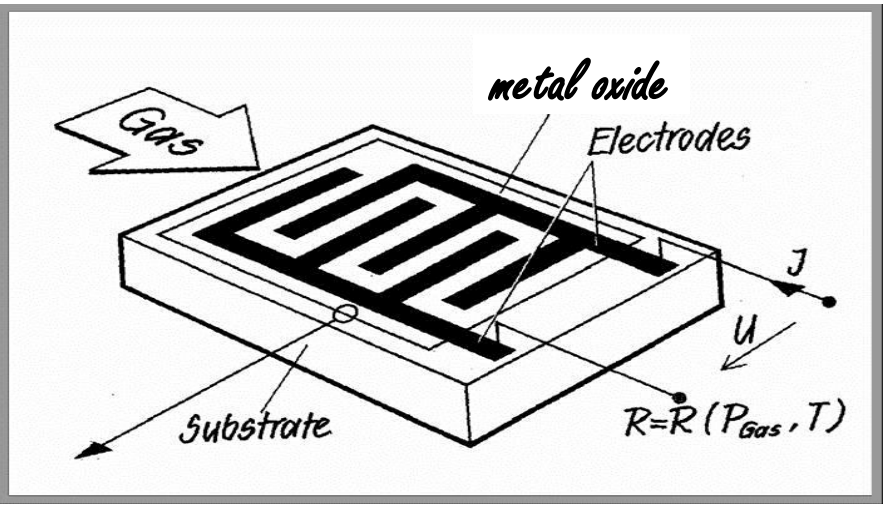
Manufacturers: AppliedSensor, UST, IST, Steinel Solutions,…..

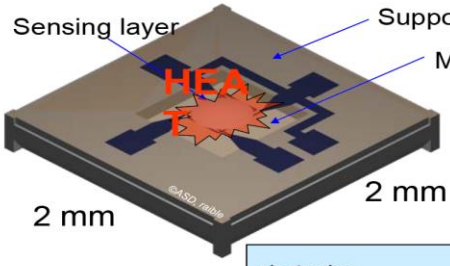
Metal Oxide Gas Sensors

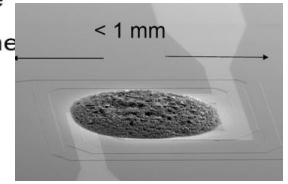
Classic Operation vs. Innovative Approaches

Metal Oxide Gas Sensors

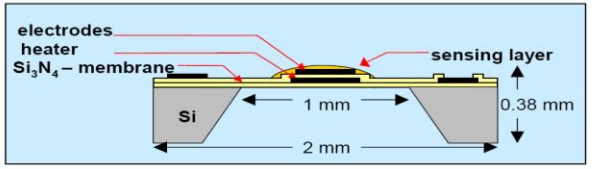
Temperature as key parameter for gas sensing characteristic

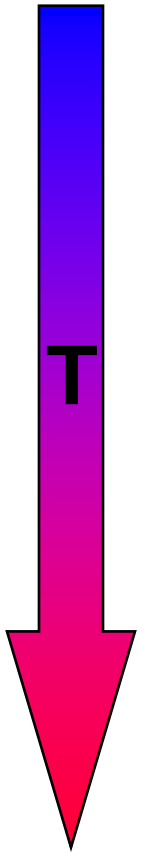


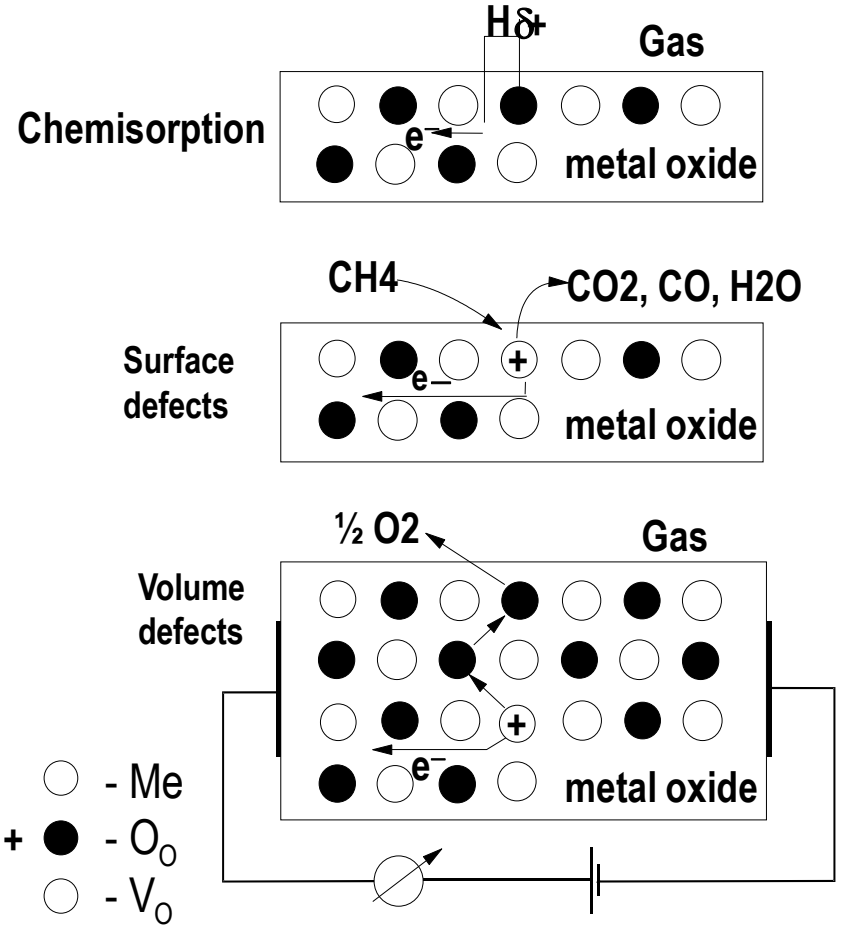




Power consumption ~30mW





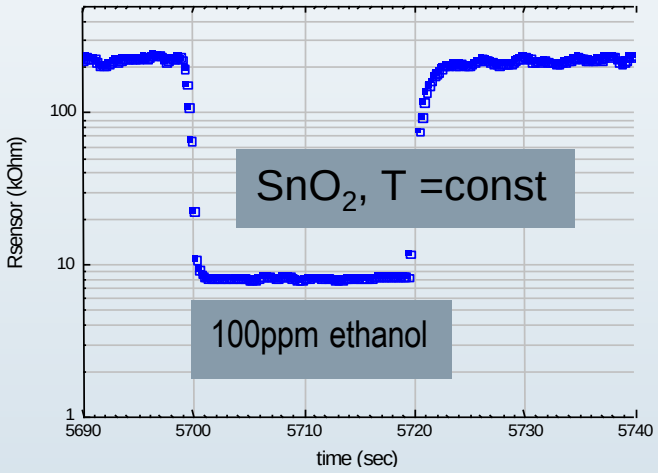


- Gas response strongly dependent on sensor temperature
- „Virtual Array“ created by temperature modulation

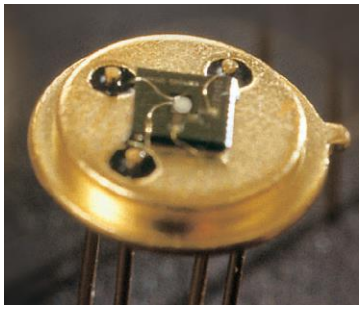
Metal Oxide Sensors for Multigas Recognition

Basic Idea: Transient Operation provides Multidimensional Signal

Continuous operation

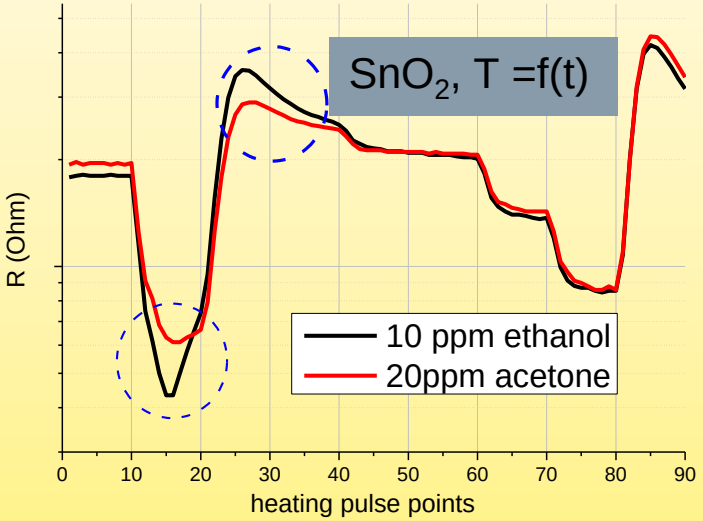


□ **one-dimensional signal**



µ-Machined Metal Oxide Sensor

Transient T modulation



□ **multi-dimensional signal**

Transient input parameters: Temperature, Voltage, Current, Light, …..

→Chemical/Physical Influence on Sensing Mechanism

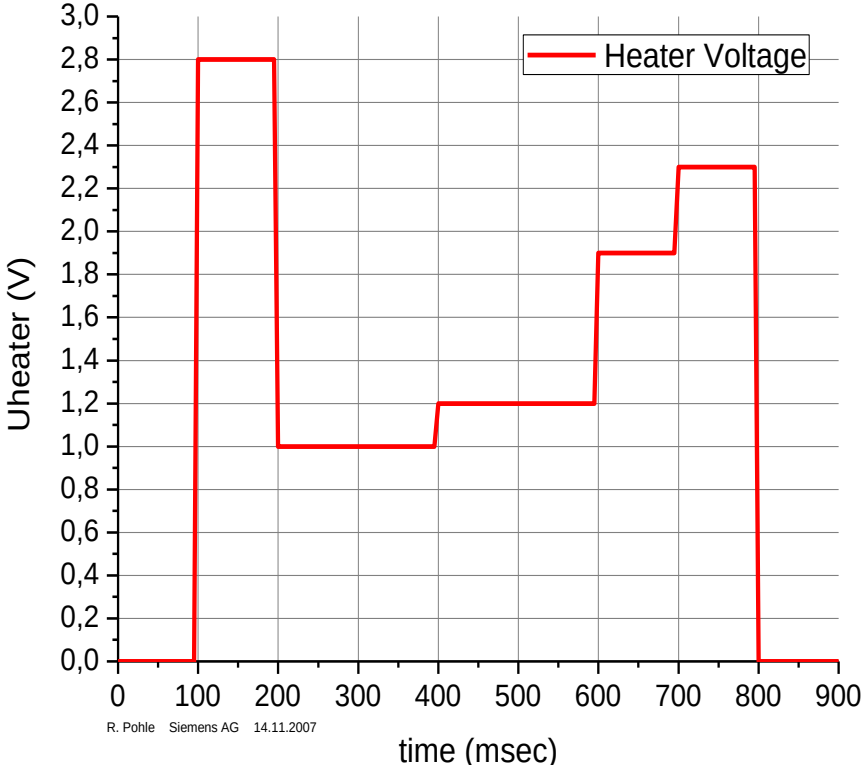
→Variation of Sensitivity/Selectivity

→Multidimensional Signal: scalar → vector

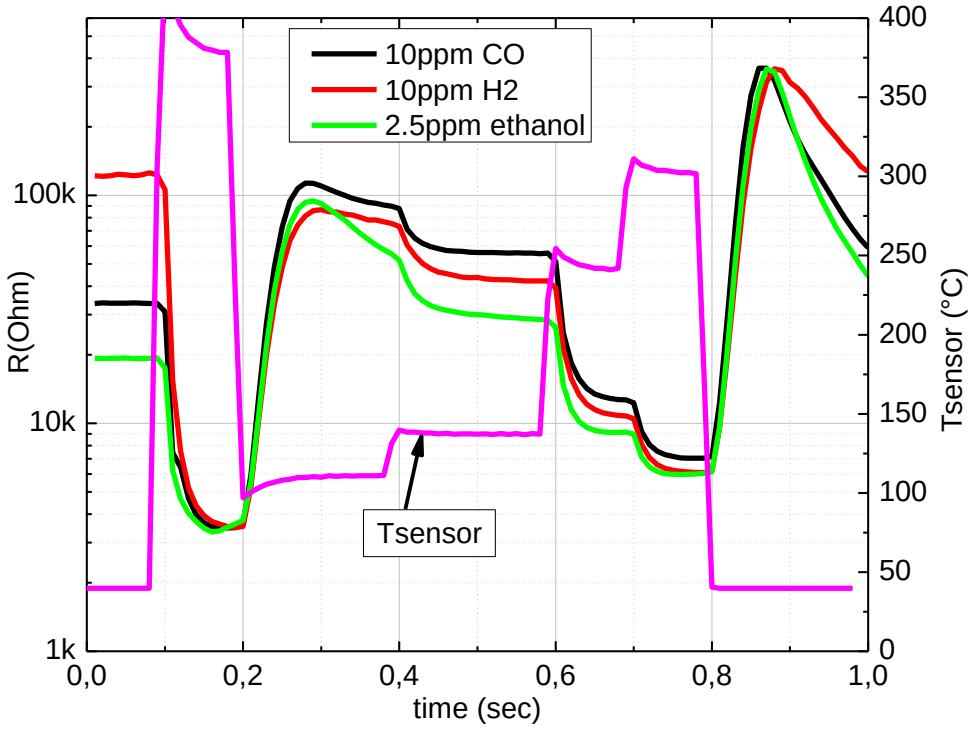
Metal Oxide Gas Sensors

Temperature Modulation as Key to Multigas Recognition

Temperature Modulation by
Heating voltage profile



Sensor response



- Application of heating pulse leads to change in resistance of sensor
- Shape of response curve depends on present gases

Gas sensors applications

Examples for Gases relevant for Comfort, Health and Safety

Fire Detection

gas	c (ppm)
CO2	400-5000 ppm
NO2	0,05-5 ppm
CO	10-70 ppm
H2	4-20 ppm
Methanol	<10 ppm
Formic acid	<5 ppm
Methane	<10 ppm
Formaldehyde	<10 ppm
Ethylene	<10 ppm
Acroleine	<10 ppm

Breath Analysis

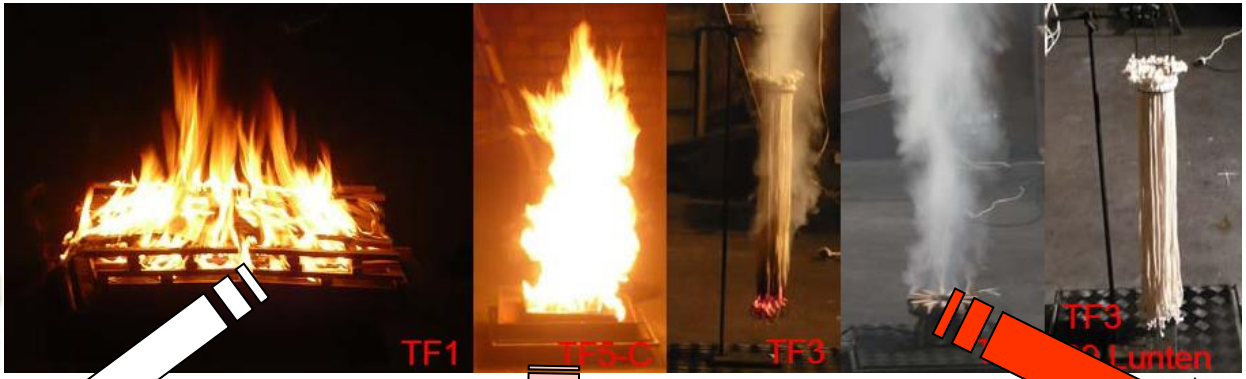
gas	c (ppm)
CO2	3-4%
Ethanol	25–200
Acetone	0.1 - 2
NO	30 – 40
CO	10 – 100
VOC	~ xx ppb
…	~ x ppb

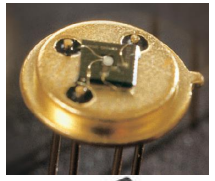
gas	c (ppm)
CO2	400-2000 ppm
Acetone	0,1-700 ppm
Pentanal	~ 5-10 ppb
HC-Mix	~ 500 ppm
Ethanol	0,2-5.000 ppm
CO	30 ppm
Ethylacetate	0,05-200 ppm
...	ppb - ppm

Analysis of complex gas mixtures required ↔ strong request for low cost solutions

Gas Sensors for Early Fire Detection

Why should we use gas sensors?





Particles/ Aerosols
false alarms

sensitivity

Simple inorganic gases
(CO, H2, NOx, CO2, H2O, NH3)
- Correlation to fire events established (literature+ own work)

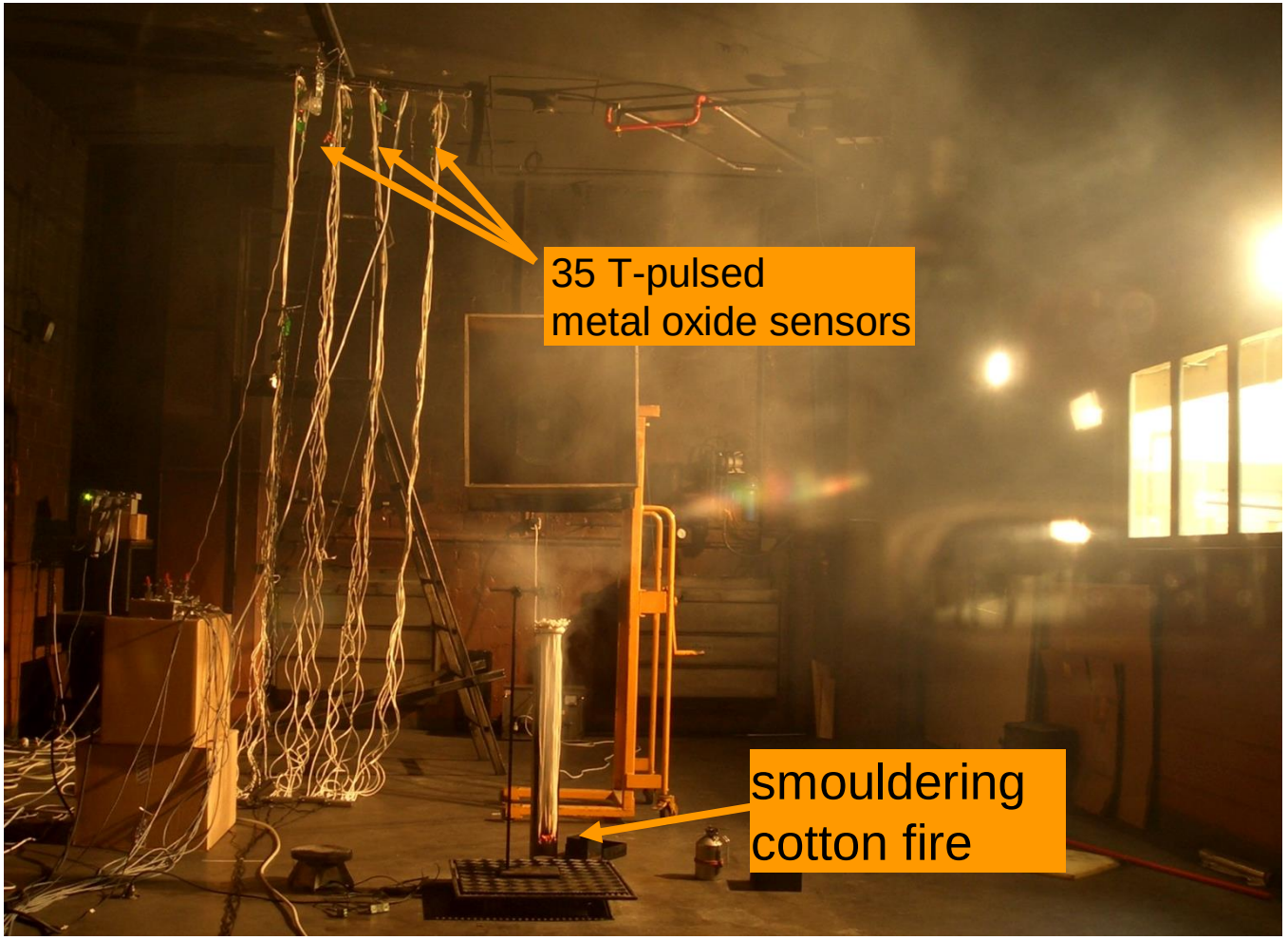
Complex gases
(Amines, Amides, Organic Acids, Ketones, Aromates…)

Reliability of fire detection

Miniaturisation

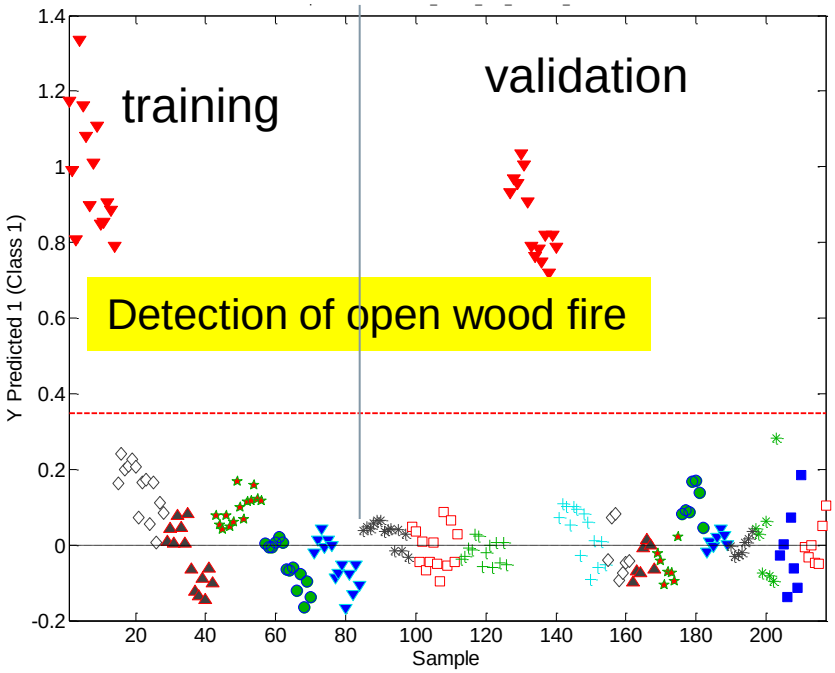
Gas Sensors for Early Fire Detection

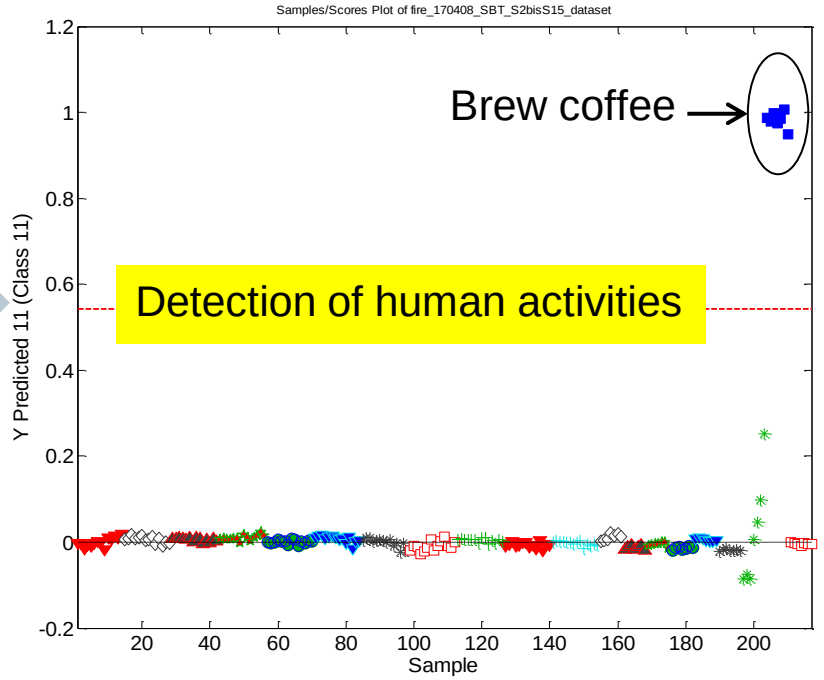
Fire Testing Regarding European Standard EN54



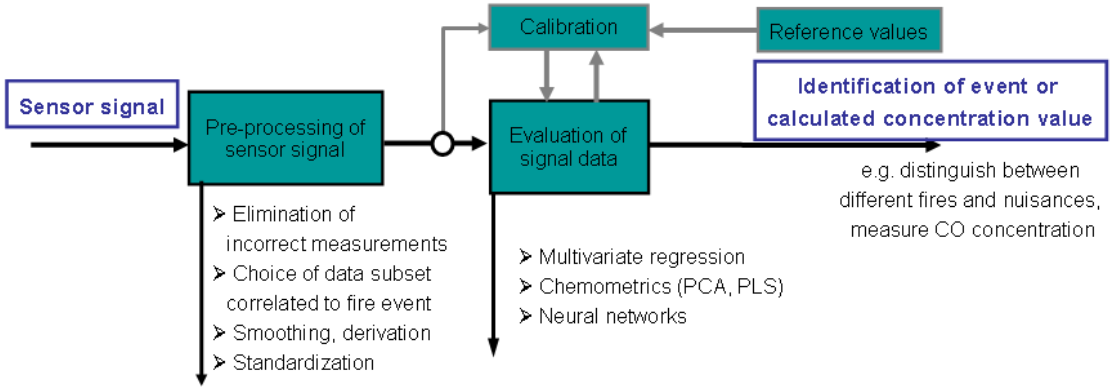
Event description	Class
TF 1 open wood fire	1
TF 2 smouldering wood fire	2
TF 3 cotton	3
TF 4 PU	4
TF 5 heptane fire	5
TF 6 EtOH fire	6
TF 7 decaline fire	7
Nuisance smokers	8
Ref 8S aerosol	9
Nuisance ethanol	10
Nuisance hairspray	11
Normal air	12

From Gas Detection to Event Detection





- reliable detection and classification of test fires demonstrated
- Classification of human activities?



SmartSenior

Intelligent services for senior citizens

Be safe on the go.

Get well and stay healthy.

Live independently at home for longer.

http://www1.smart-senior.de/

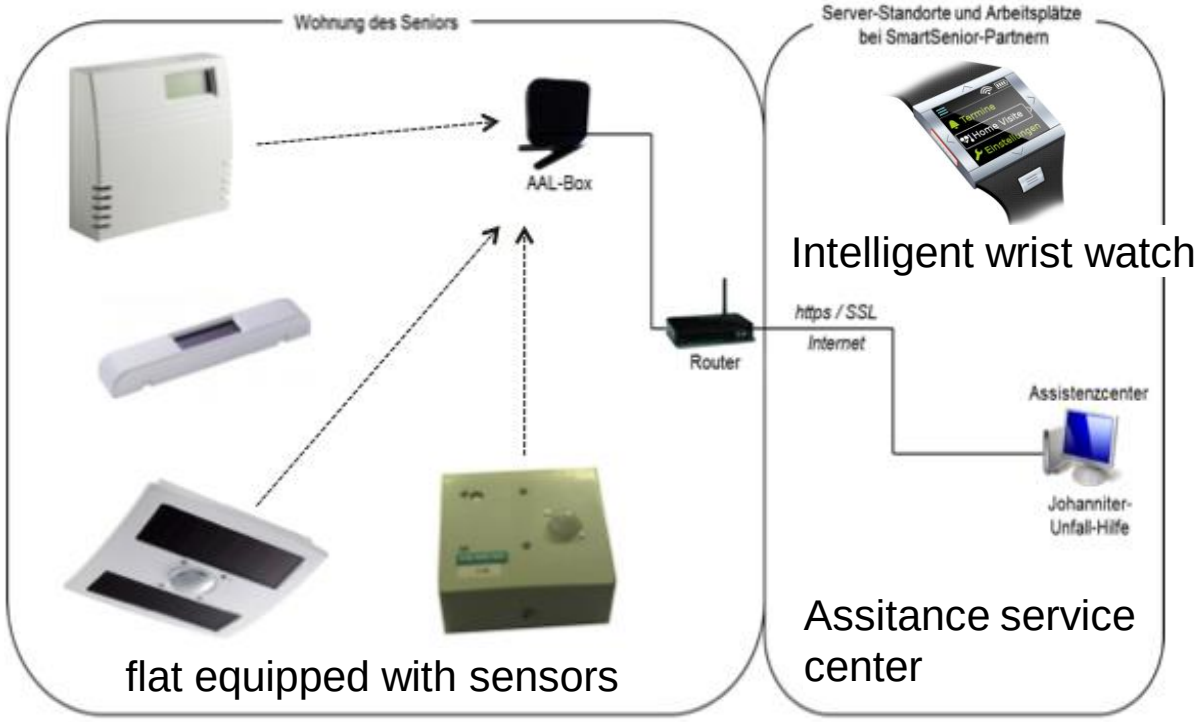
The various scenarios in SmartSenior are derived from known basic needs

SmartSenior

Intelligent services for senior citizens

Live independently at home for longer.

- Assistance with everyday domestic life, integration of social and other services
- **Safety in the home, prevention and identification of emergency situations**
- Integrated, easy-to-use communication facilities with social network and service providers.



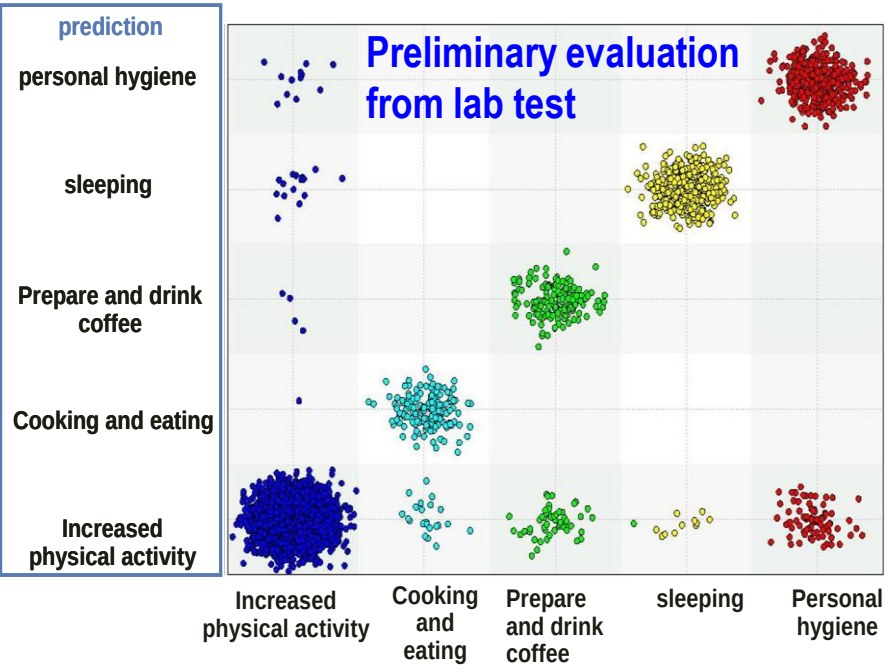
Activity monitor with T-pulsed gas sensor, PIR motion detector and Wi-Fi communication

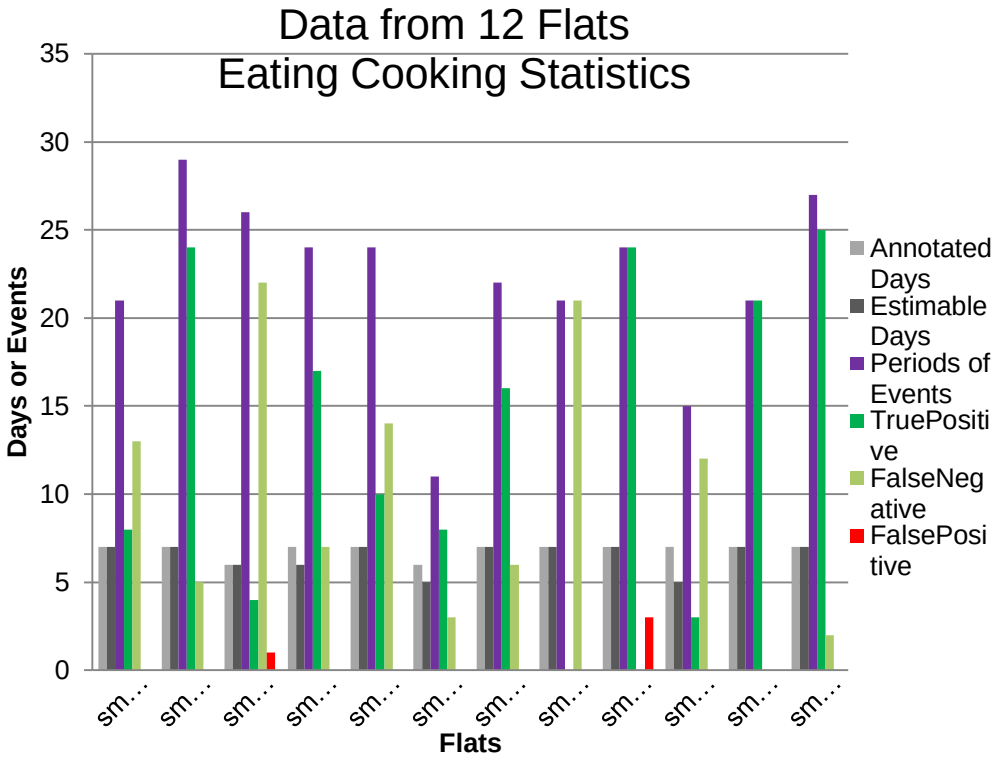
→100 systems installed in real homes (data evaluation ongoing)
→Early Fire Detection to safe people, not buildings
→Additional potential for Activity Monitoring (cooking, cleaning, open windows...)

SmartSenior

Monitoring of human presence and activities

Gas sensor supported prediction of activities of daily living





- promising results from testlab appartment
- Evaluation of real life data:

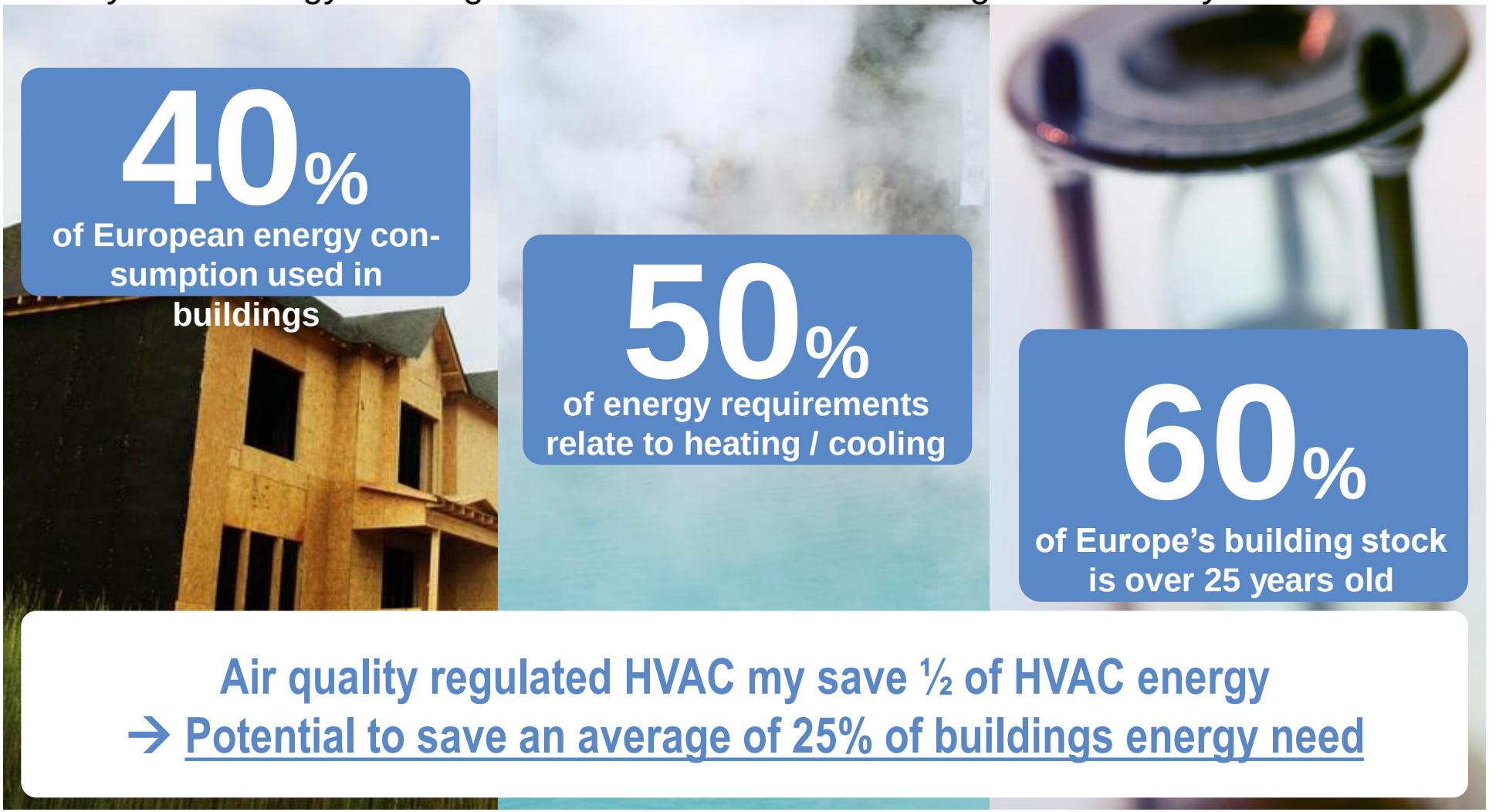
→ performance is highly fluctating from flat to flat (i.e. from user to user)

→ Algorithms has to be adapted to the specific user

Room air monitoring

Need to save energy AND provide comfort&health

EU: Reducing greenhouse gas emissions by 40% until 2030
Nearly Zero-Energy Buildings: Standard for all new buildings in the EU by 2020



40%
of European energy consumption used in buildings

50%
of energy requirements relate to heating / cooling

60%
of Europe's building stock is over 25 years old

Air quality regulated HVAC my save ½ of HVAC energy
→ Potential to save an average of 25% of buildings energy need

Room air monitoring

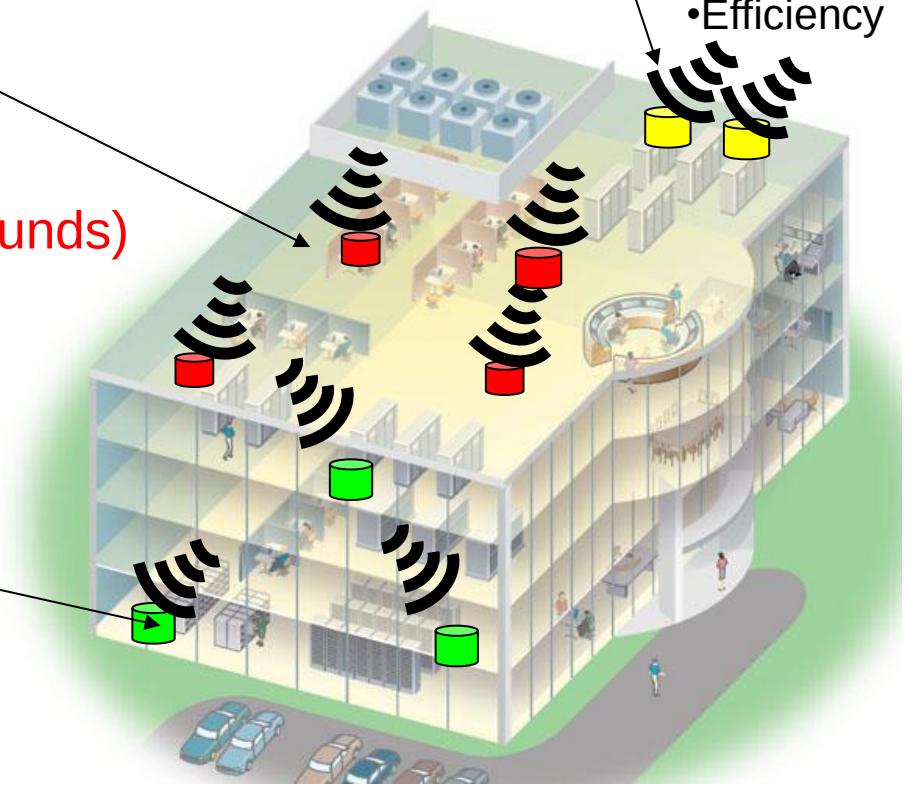
Micro-systems for Building Environment

Comfort Monitoring and control

- Temperature
- Humidity
- Air flow
- Light
- Occupancy
- TVOC (Total Volatile organic compounds)
- CO
- CO_2

Energy knowledge:

- Monitoring and control
  - Usage
  - Profile
  - Efficiency



Lighting/shade:

- Monitoring and control
  - Natural light
  - Artificial light
  - Blind control

- **Improved Indoor Environment Quality**
- **Energy conservation-demand based intelligent usage**
- **Operational efficiency- repair/change**

Room air monitoring

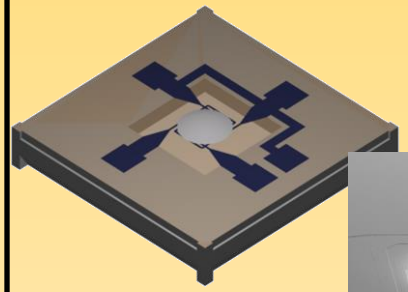
state of the art vs. MEMS based approach

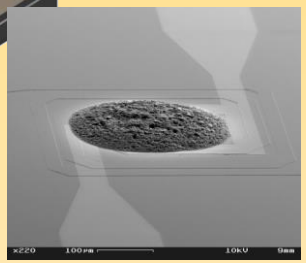
State of the Art industrial

Sensor package:
Semiautomatic mounting

Room air monitor: discrete electronics

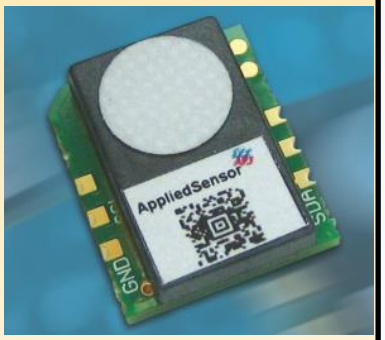
State of the Art consumer





MEMS platform
Special process for gas sensing layer

AppliedSensor 2014



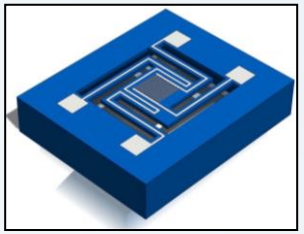
3.3V
70mW CW
10mW pulsed

Heterogenous integration

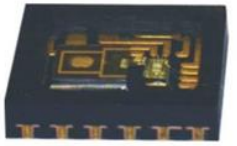
MEMS Approach

Si based sensor chips

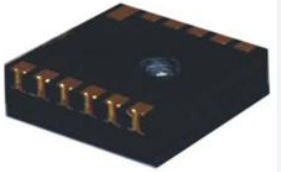
Micronas 2014



µ-hotplate



Low cost housing



MEMS mike

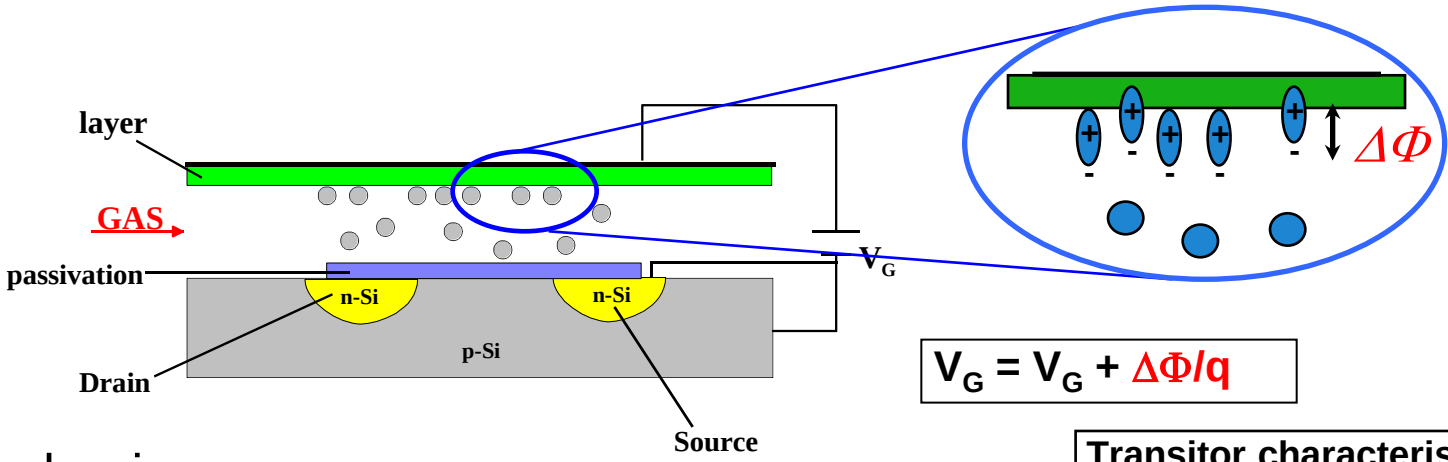
Low cost Microcontroller
- readout, interface

Target: <<1mW

2010 → 2014 → > 2014

Suspended Gate FET

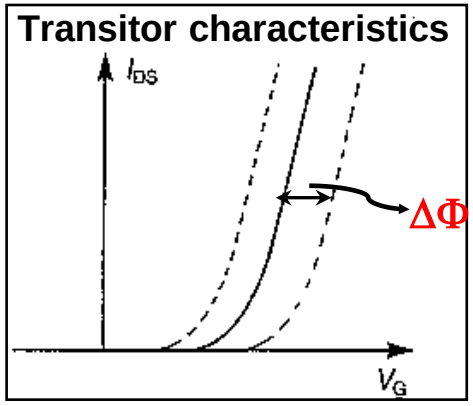
Low-Power Low-Cost Gas Sensors based on Workfunction Readout



$$V_G = V_G + \Delta\Phi/q$$

Mechanism:

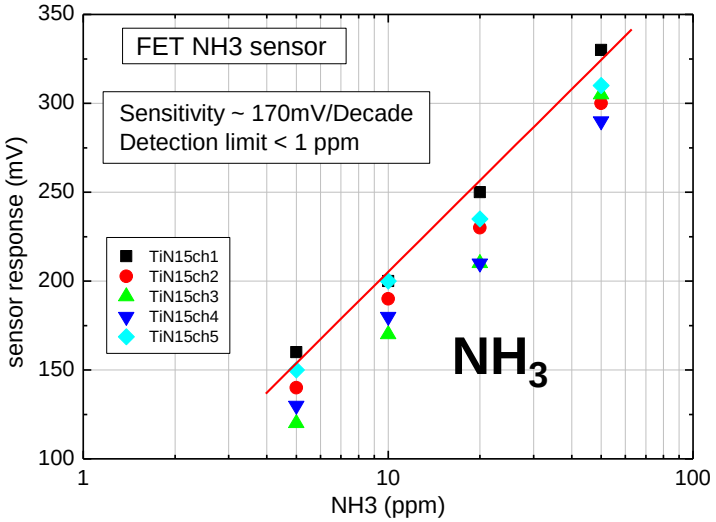
- Gas diffusion in air gap
- Interaction of gas at sensitive surface: surface potential acts as additional V_G
- Capacitive coupling to channel

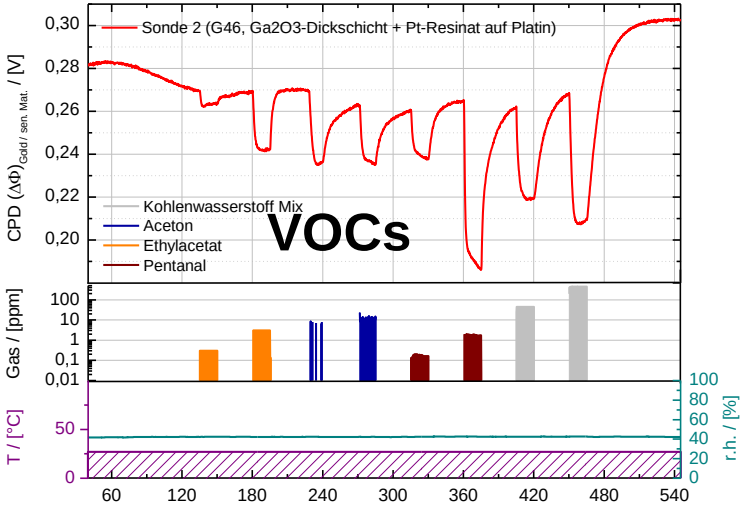


- low power consumption (µW -mW) possible
- Use of versatile sensor layers (e.g. metals, inorganic salts, organic compounds...) gives wide spectrum of detectable gases.

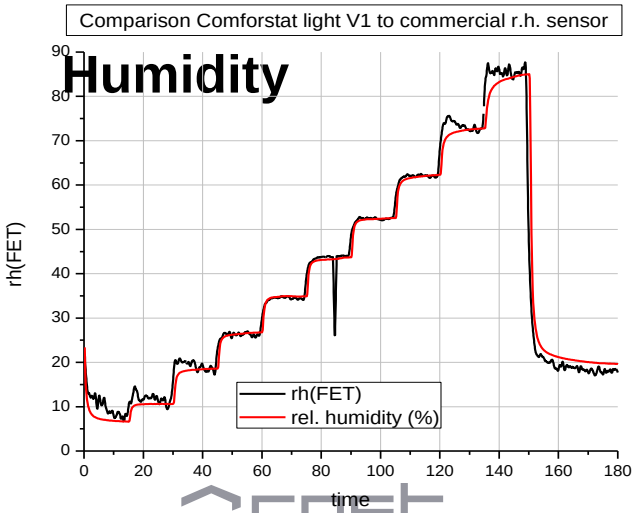
Suspended Gate FET

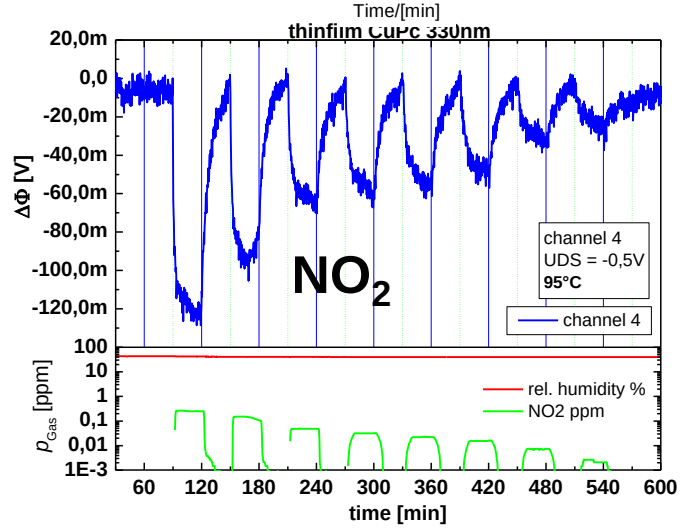
Ability for Multigas Detection





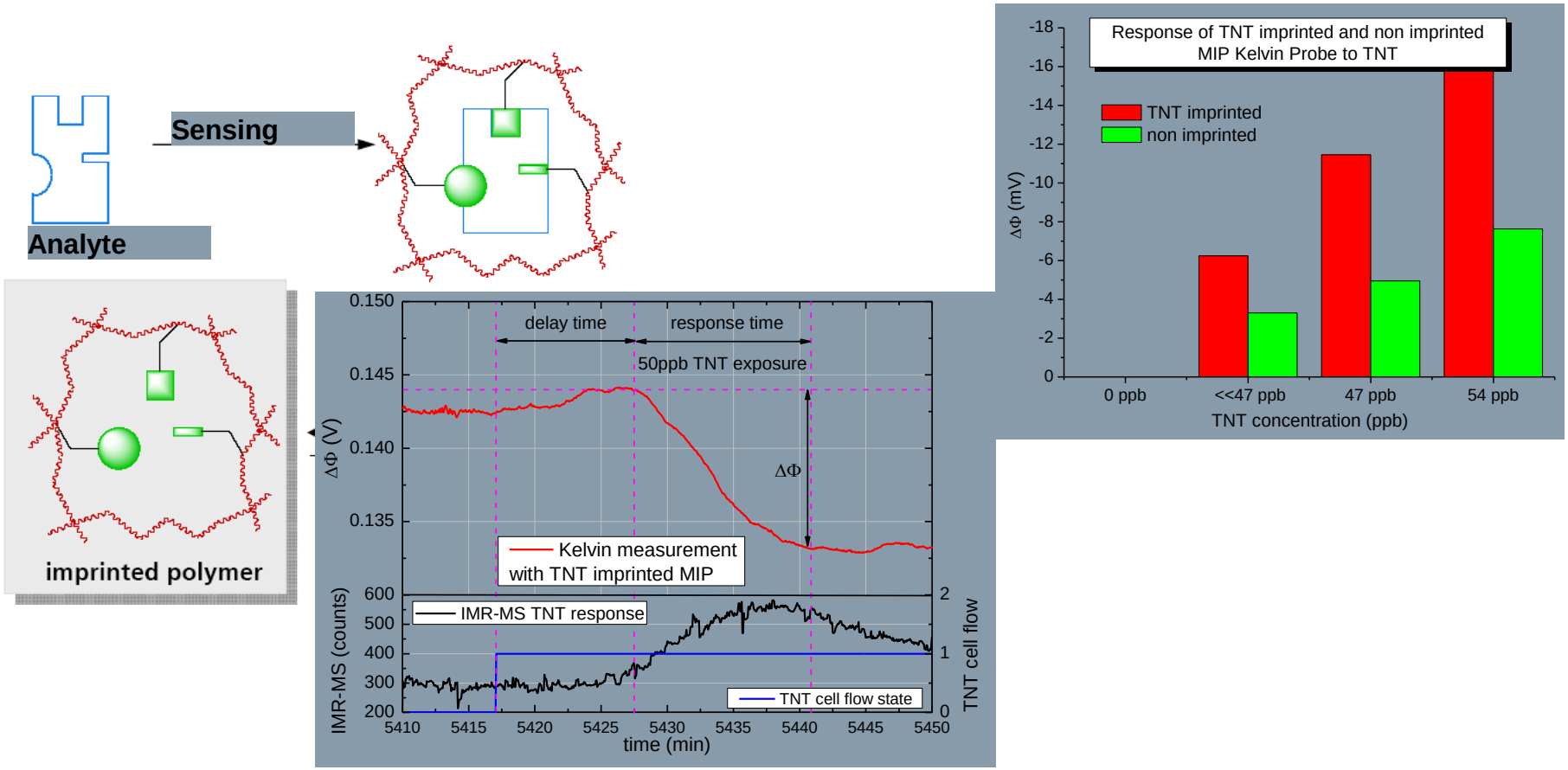
Micronas
MySENS





From ppm to ppb

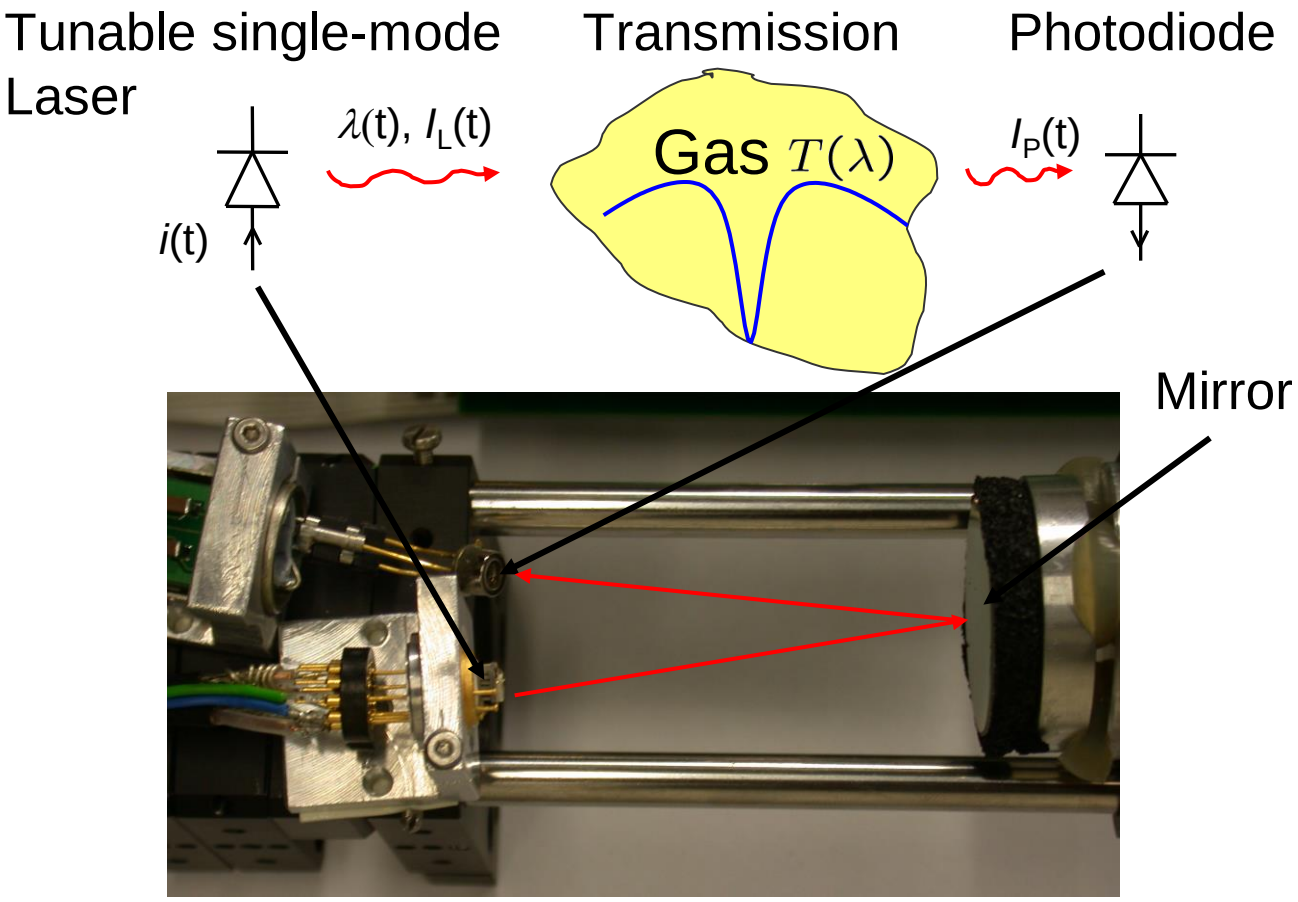
Detection of explosives (TNT) with Molecular Imprinted Polymers



- Significant, concentration-dependent response to TNT in ppb level
- Readout with GasFET feasible

Tunable Diode Laser Spectrometry (TDLS)

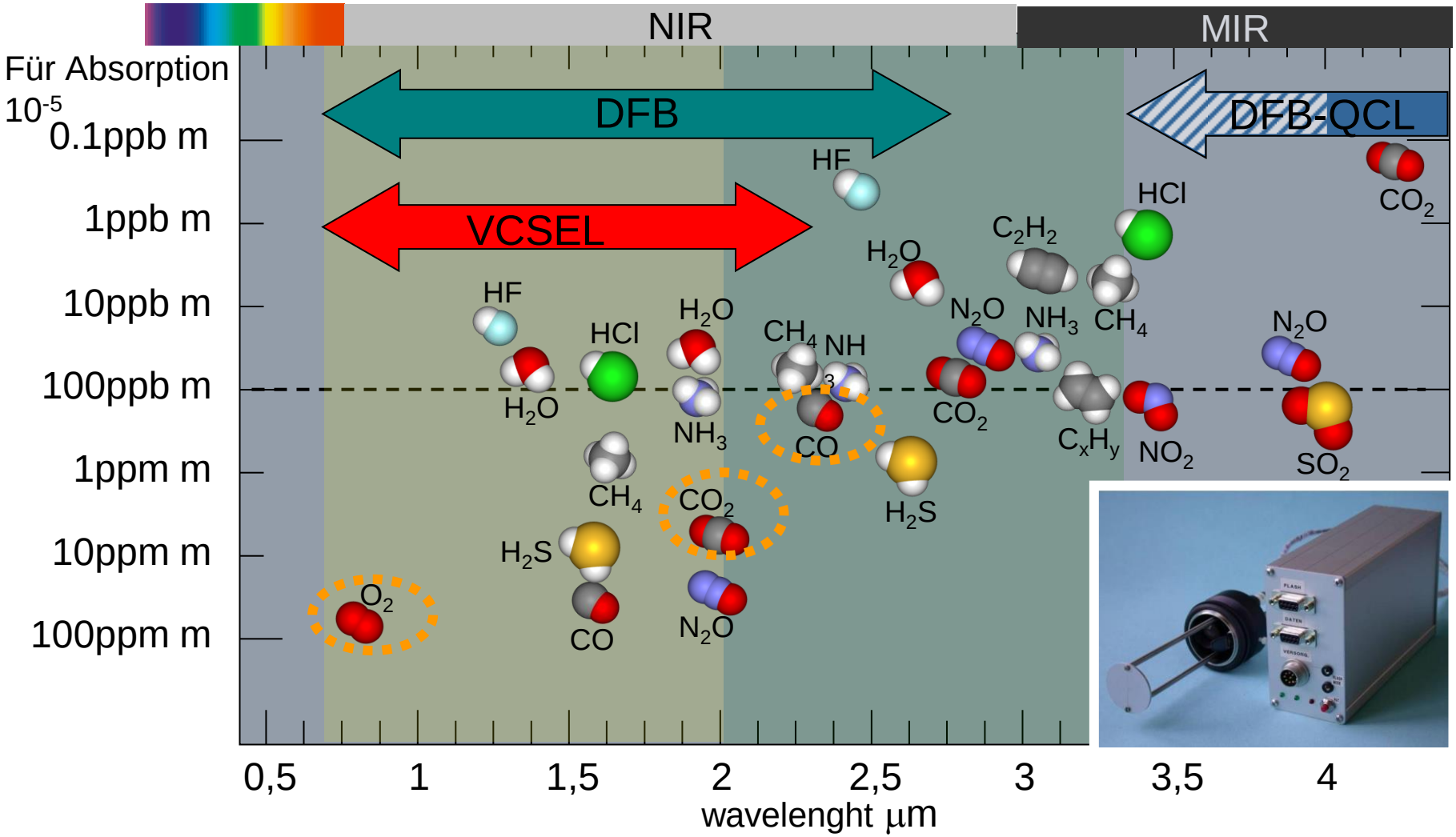
General Principle



Transmission measurement of gas allows for determination of *C*, *p*, *T*, etc…

Tunable Diode Laser Spectrometry

Detectable gases and achievable sensitivity



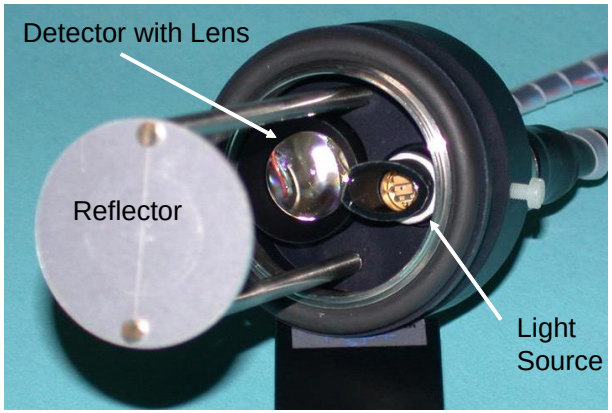
→Optical path limits miniaturization

Tunable Diode Laser Spectroscopy

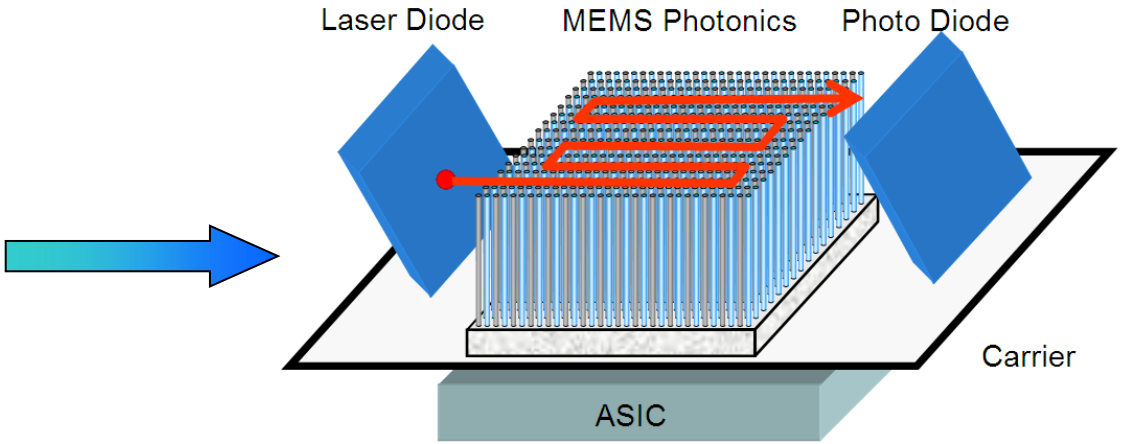
MEMS based Photonics designs and vertical Integration

Main Targets:

- Reduce the length of the light absorption path → <1 cm
- Integrating the light source, detector diode, ASIC with small form factor
- Targeted form factor for selective gas detection 1 cm^3



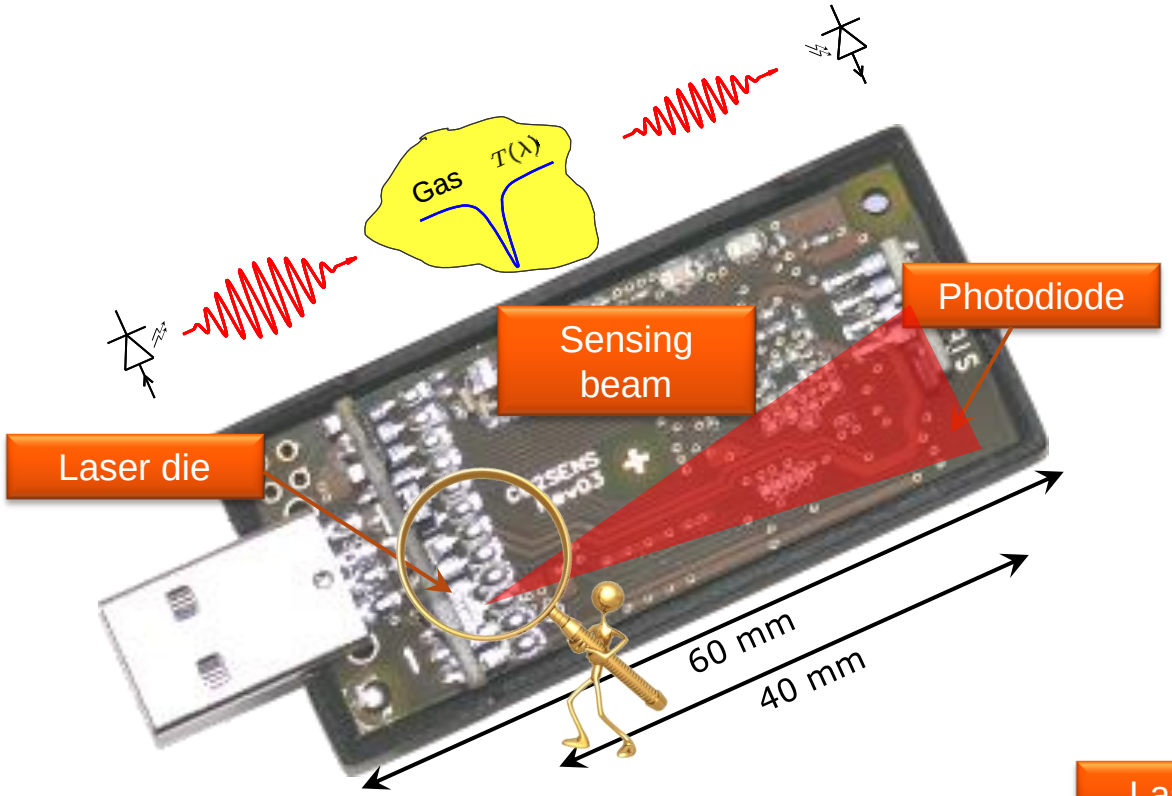
Conventional design

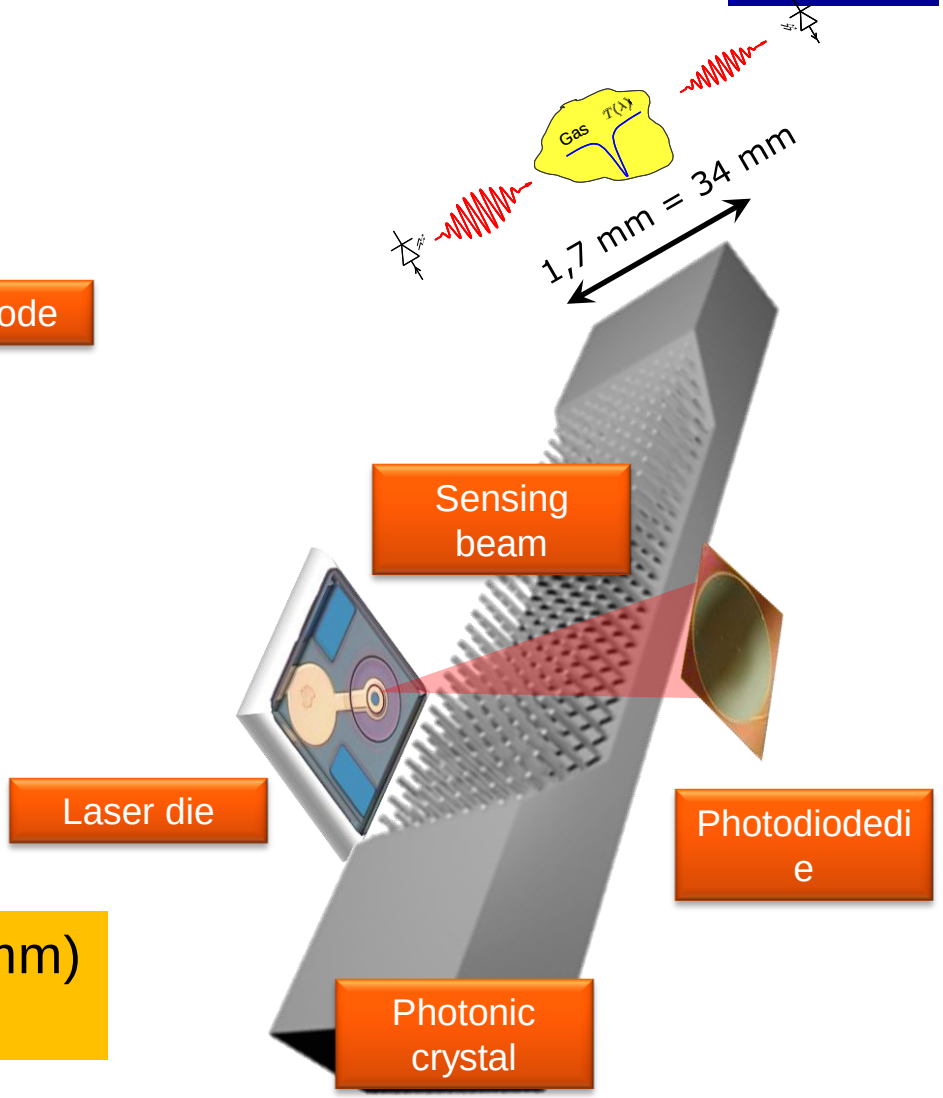


Photonic integrated design

Tunable Diode Laser Spectroscopy

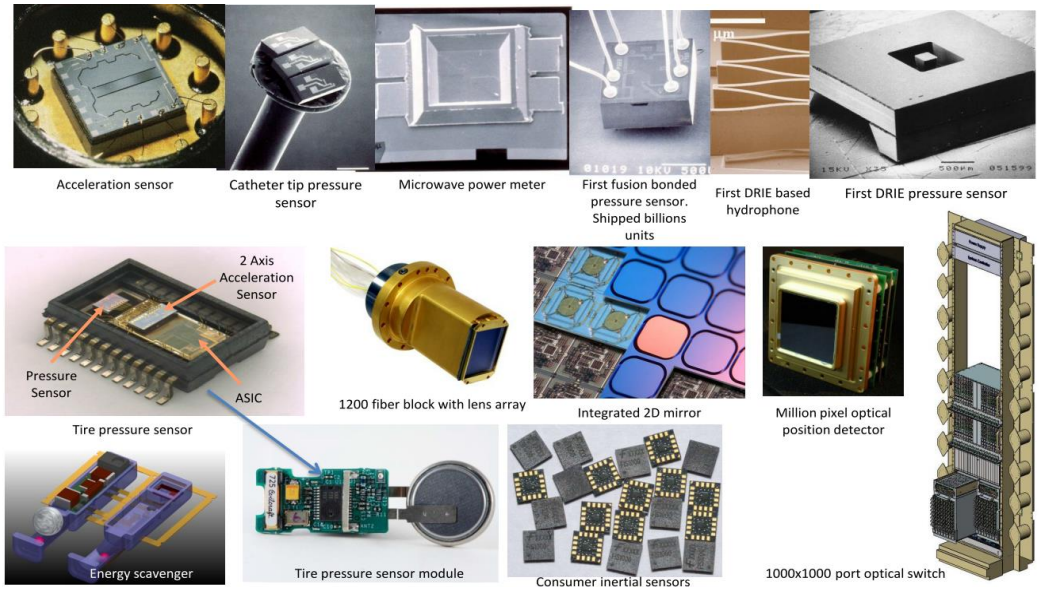
MEMS based Photonics designs and vertical Integration

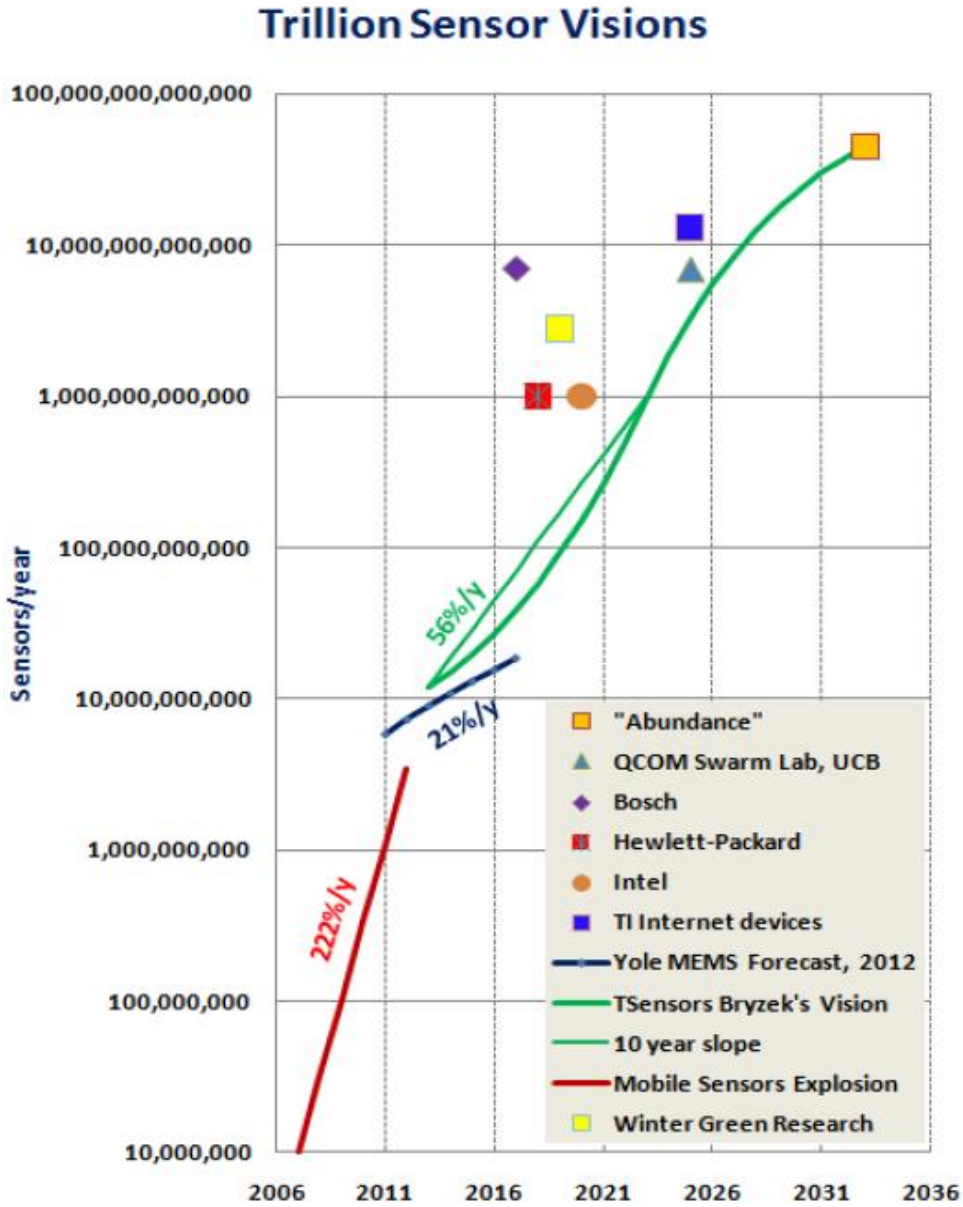




Enhancement-factor : 20 (1,7mm → 34mm)
No special coupling geometry required!

Trillion Sensors (TSensors) Visions





→ don‘t forget to add gas sensors !

Summary

Applications and trends in gas sensing for home and health

- Gas sensing is suitable to contribute significantly to
  - Reduce energy consumption in buildings
  - Reduce age and health associated problems

- Manifold upcoming MEMS/NEMS sensor technologies with high potential for low cost fabrication

- Main technical issues to be solved for industrialization
  - Reduce power consumption mW → µW
  - Lower detection limits ppm → ppb
  - Overcome stability problems

  → Identify and use options from system perspective

  Sensor + Operation Mode + Data Evaluation

Thank you for your attention!

Questions?