Geneva, 11th of February 2004

Electronic Noses: Potential for Mine Detection?

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Outline

- Introduction
- Chemical Sensing
  - Sensitivity
  - Stability
  - Selectivity
- Application Examples
  - Good Case
  - Bad Case
  - Why?
- Situation for Mine Detection
- “Offer” of the Sensor Community
- Summary

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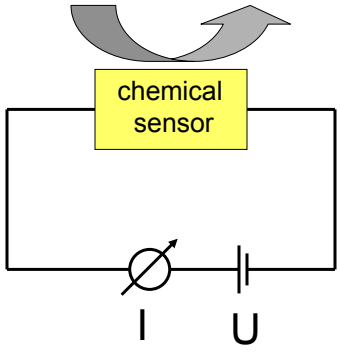
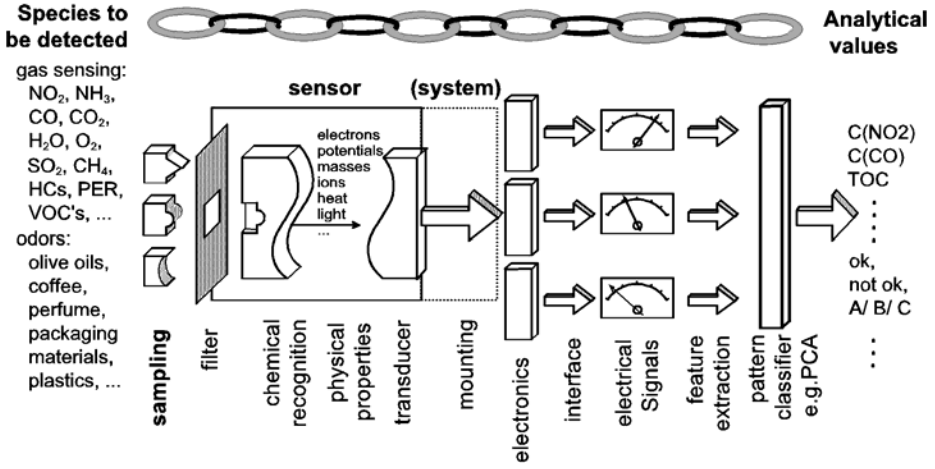
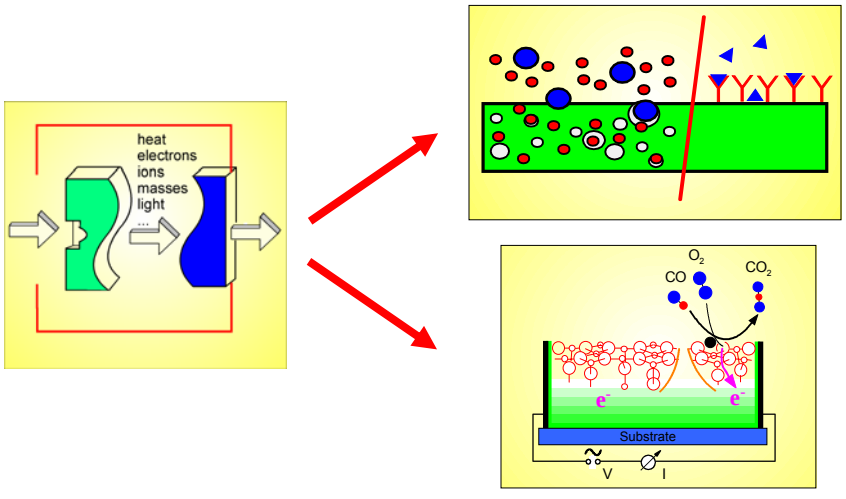
Motivation



Sensor system



Interaction Mechanisms



Issues / Problems / Goals

- Sensitivity
  - to detect also very low concentrations
- Stability
  - To get the same result over time (one day, one week, one year)
- Selectivity
  - To get the right information even if other compounds are around

(3S Problem of Chemical Sensing)

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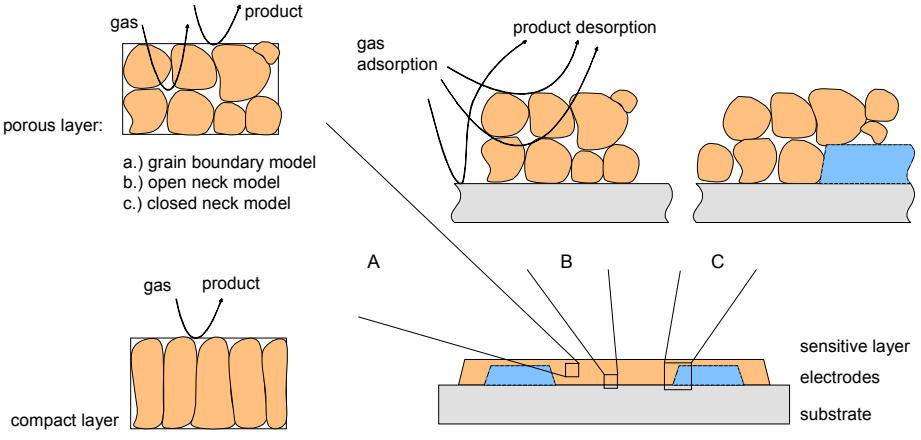
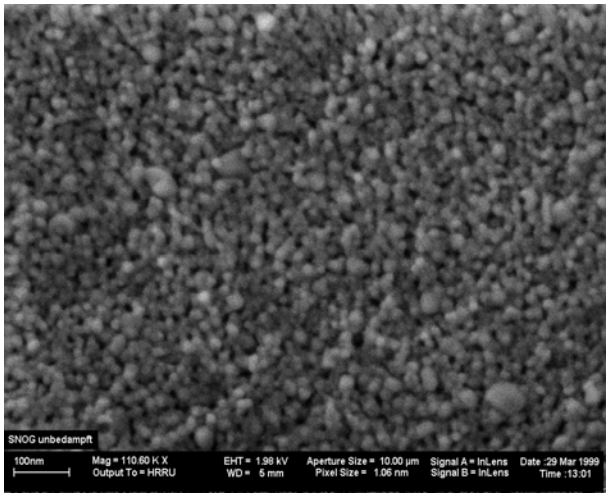
Actual Sensor Structures

Overview “sensor”

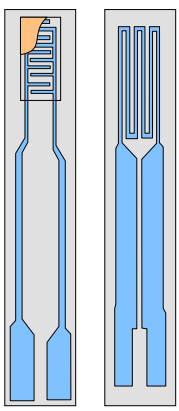


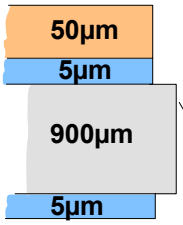
Actual sensor structures

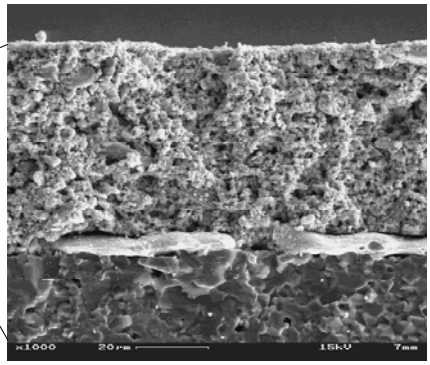
Powder based (450°C, undoped)



Planare Sensor Struktur



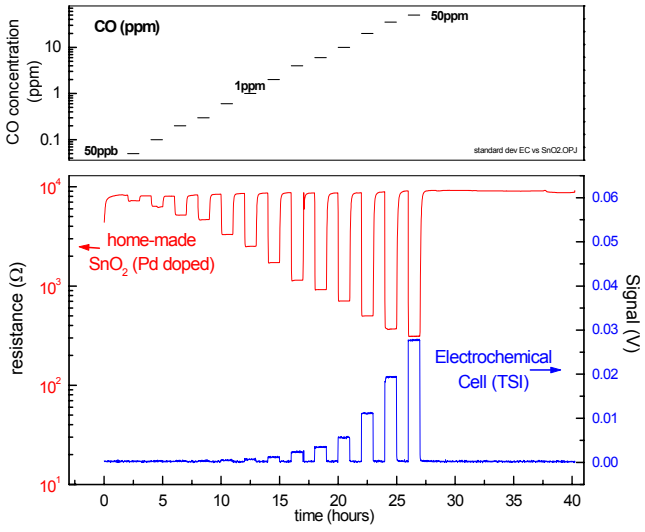




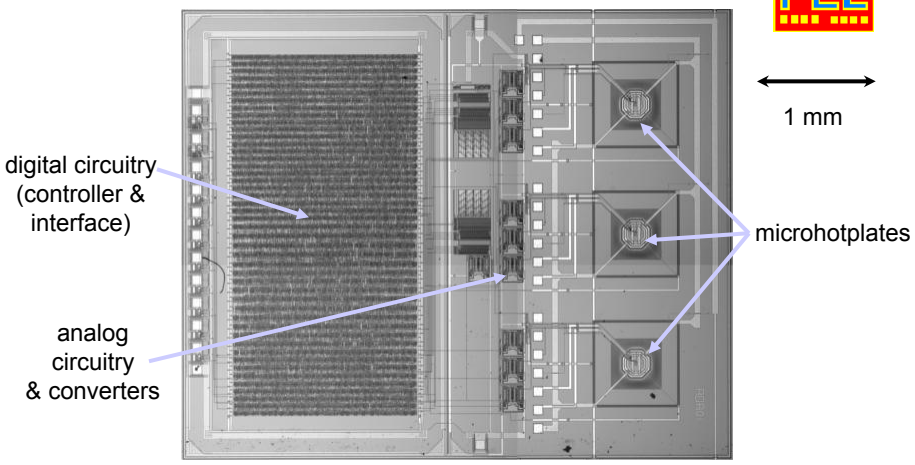
25.4mm x 4.2mm

High Sensitivity

DC Results



Smart Chemical Gas Sensor



M. Graf et al., Proc. IMCS 2002, 141
D. Barrettino et al., Eurosensors XVI

F. Udrea et al.,Proc. Transducers 2001, 1688 (SOI)

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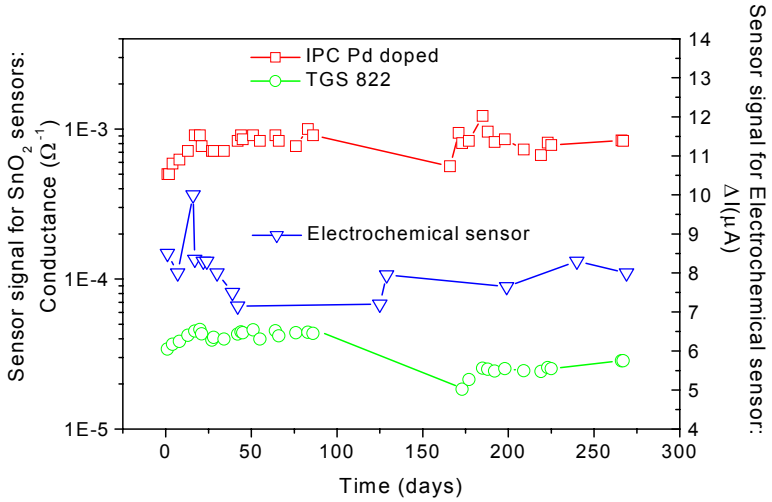
High Stability

Long Term Results



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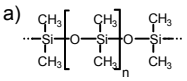
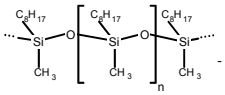
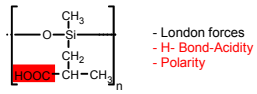
Pattern Generation

a) 

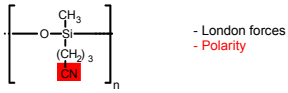
Polydimethylsiloxane (PDMS)

d) 

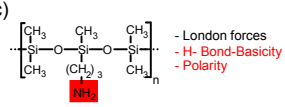
Polyoctylmethylsiloxane (POMS)

b) 

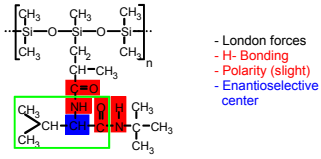
Poly(isopropylcarboxylic acid) methylsiloxane (PiPCAMS)

e) 

Poly(cyanopropyl)methylsiloxane (PCPMS)

c) 

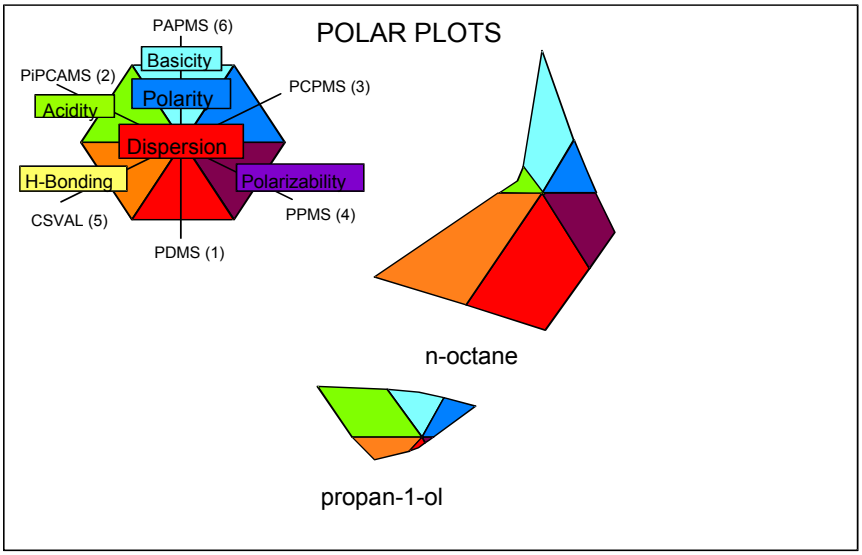
Poly(aminopropyl)methylsiloxane (PAPMS, 10% amino-groups)

f) 

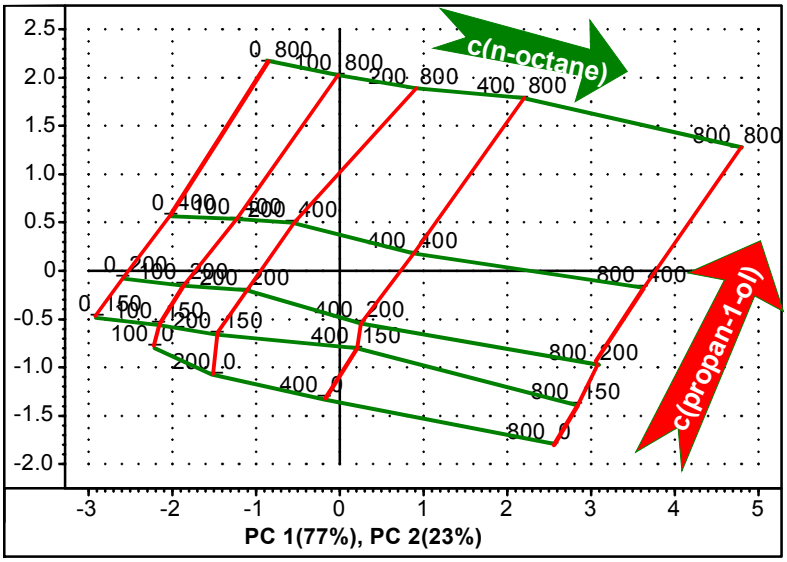
Poly[2-carboxy(D-valin-t-butylamide)propyl] -methylsiloxane (Chirasil-Val, 10% valin-groups)

synthesized Bayer/Koppenhöfer, Organic Chemistry, Tübingen

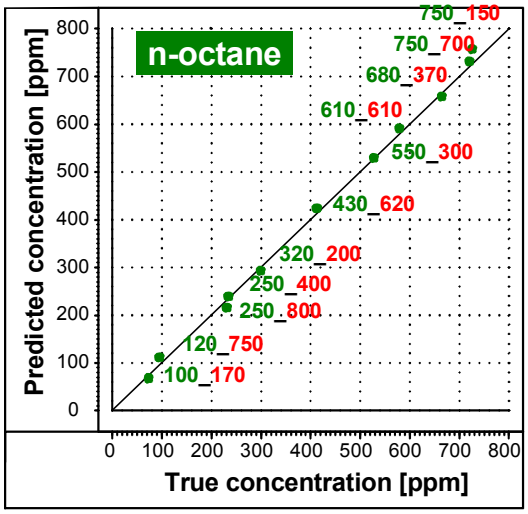
Polarplots



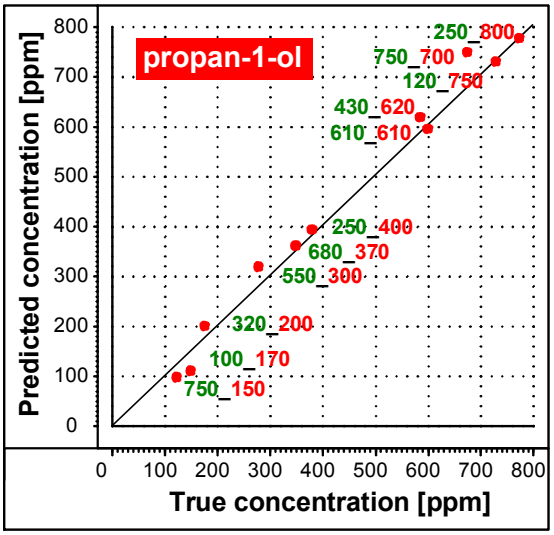
mixture of n-octane/propan-1-ol



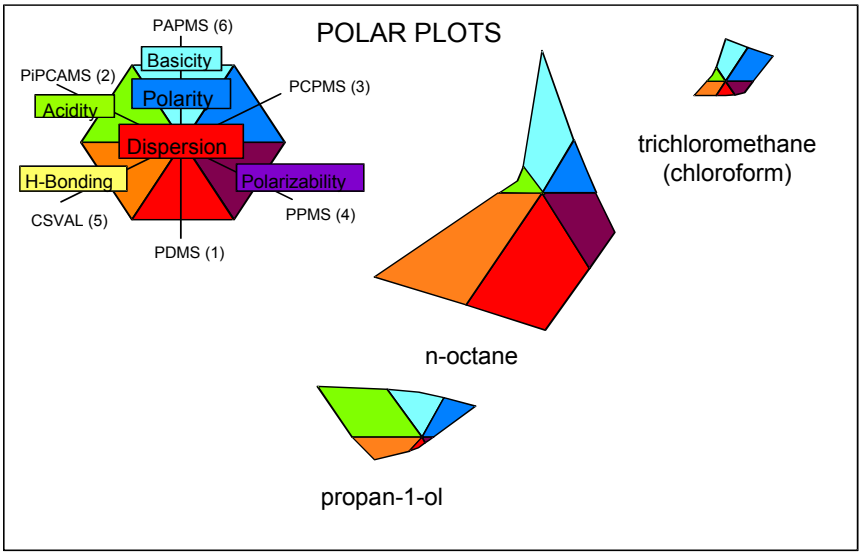
PLS - n-octane



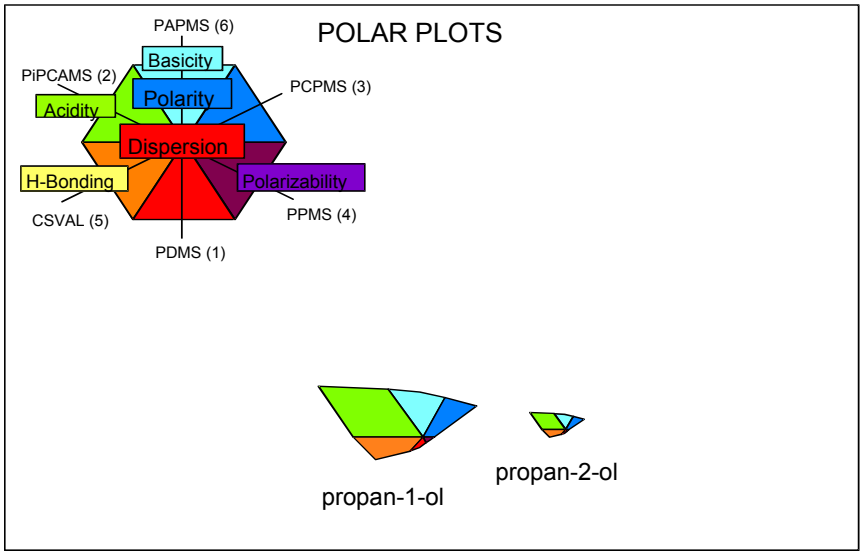
PLS - propan-1-ol



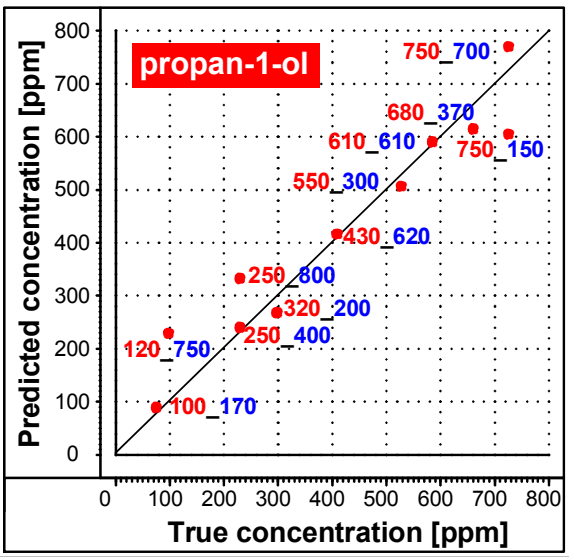
Polarplots



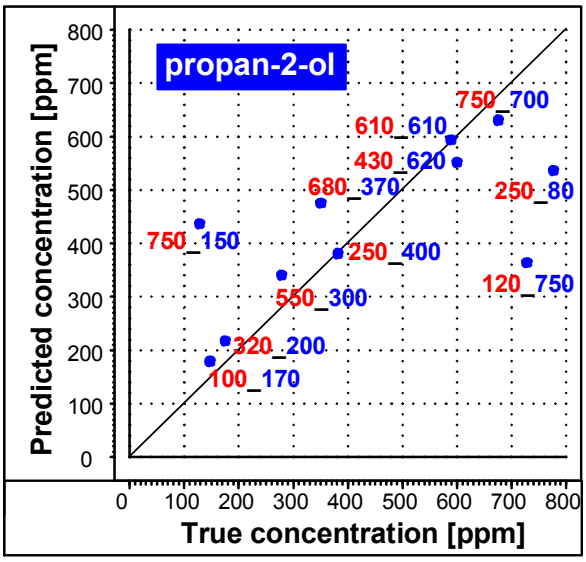
Polarplots



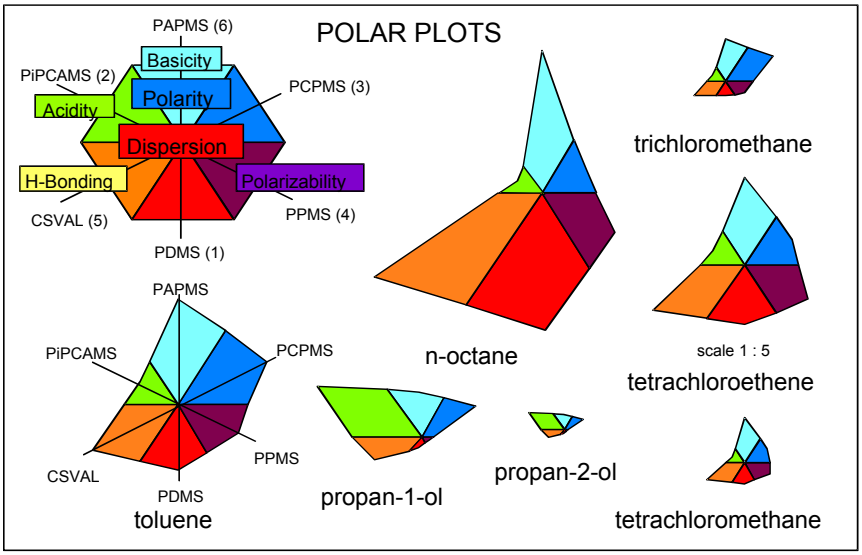
PLS - propan-1-ol



PLS - propan-2-ol



Polarplots



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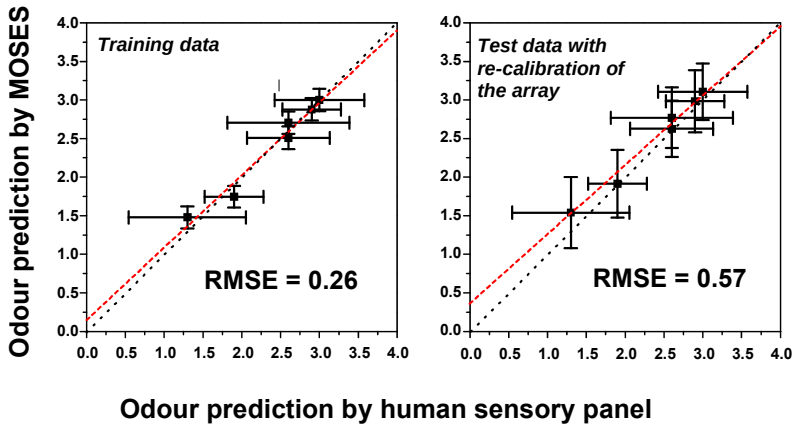
Quality control of packaging material

State of the Art:
Human Odour Panel

Development

Automated investigation
with "Electronic Nose"
Better called application specific
sensor system (a triple s)

Application: Quality control of packaging material



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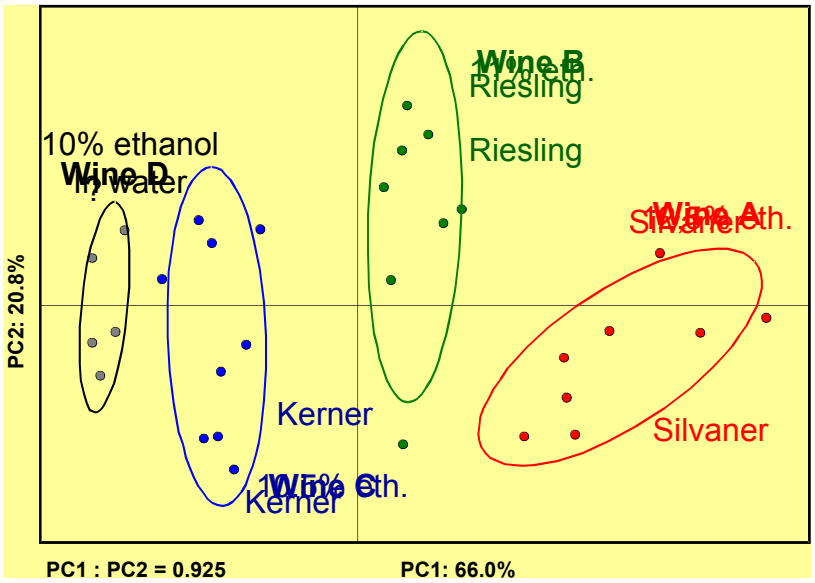
Wine Differentiation



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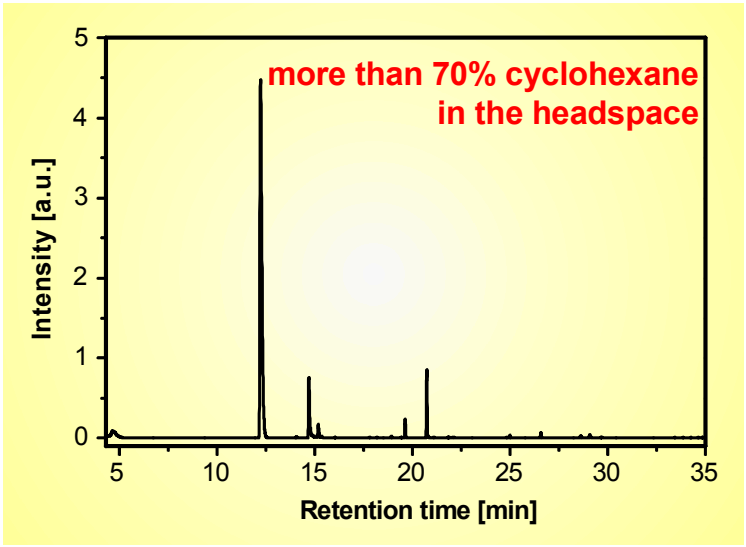
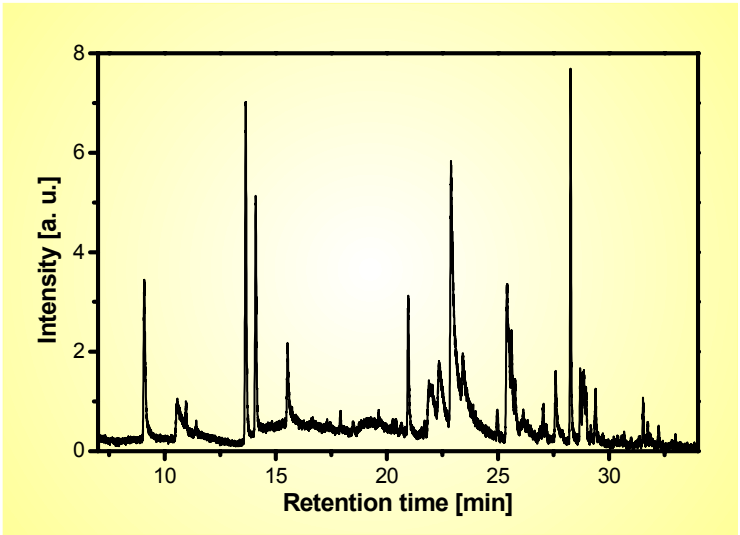
GC/MS of Packaging Material “Good Case”



GC/MS of instant coffee “Bad Case”



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Situation for Demining:

- Sensitivity
  - Considerable improvement during the last decade!
  - We are at the medium ppb level and have to go to the ppt level (4 to 5 orders of magnitude improvement required!) → 10.000.000%
- Selectivity
  - Even more a challenge!
  - Concepts are developed (during the last two to three years) for other purposes, but have to be tested after/while solving the sensitivity issue
- Stability
  - Nobody has experience in this concentration domain!

Further issues: (next transparency)

Further issues:

- Speed
  - How long takes an analysis (→ online)!
- Power
  - Power consumption of the overall system (battery operated)
- Costs
- Field applicability

A lot of work to be done!

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NOSE II

The **Second Network on Artificial Olfactory Sensing**

Topics: sensors, sensor systems, and electronic noses

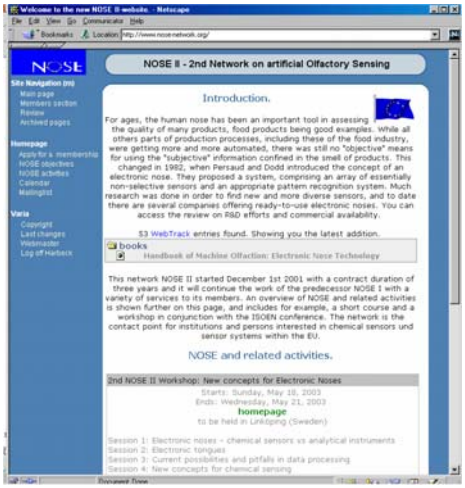
IST Project 2001-32494

NOSE II members

100 Members from
18 European countries

NOSE II website

www.nose-network.org



NOSE II office

University of Tübingen, ipc

Udo Weimar, Mika Harbeck

Auf der Morgenstelle 8, 72076 Tübingen, Germany

Website: http://www.nose-network.org

Email: nose@ipc.uni-tuebingen.de

University of Tübingen Institute of Physical Chemistry

GOSPEL

General Olfaction and Sensing Projects on a European Level

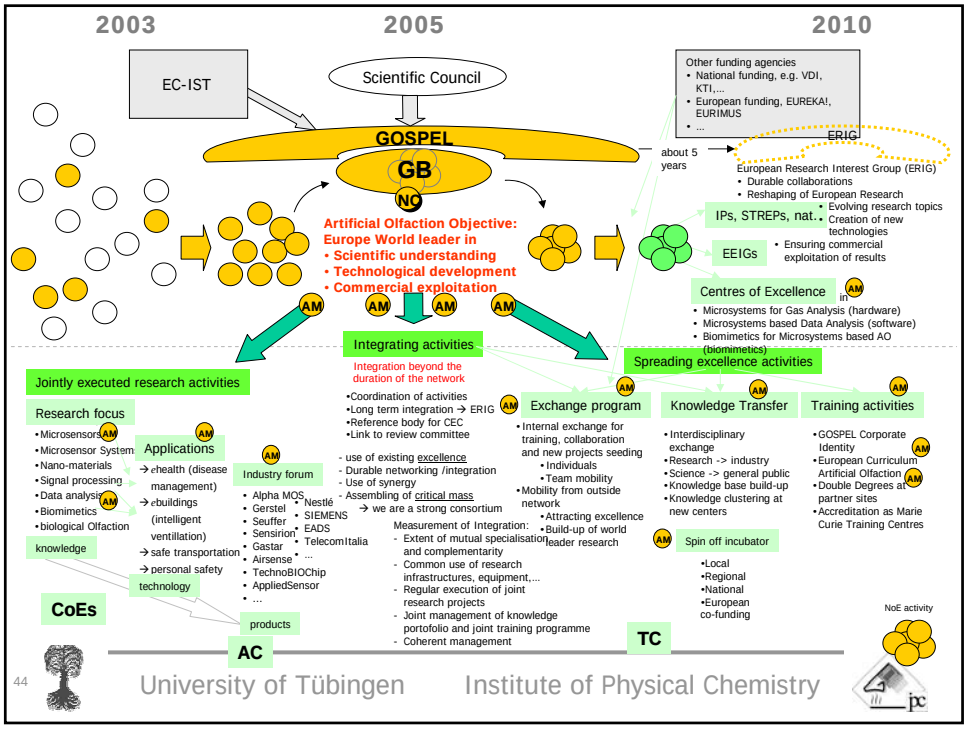
Information Society Technologies

IST 507610

Coordination: ipc, Tübingen

Project Officer: Thomas Sommer

2004-2007



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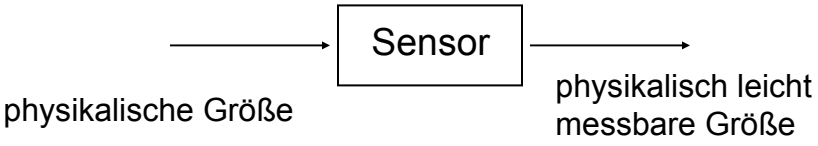
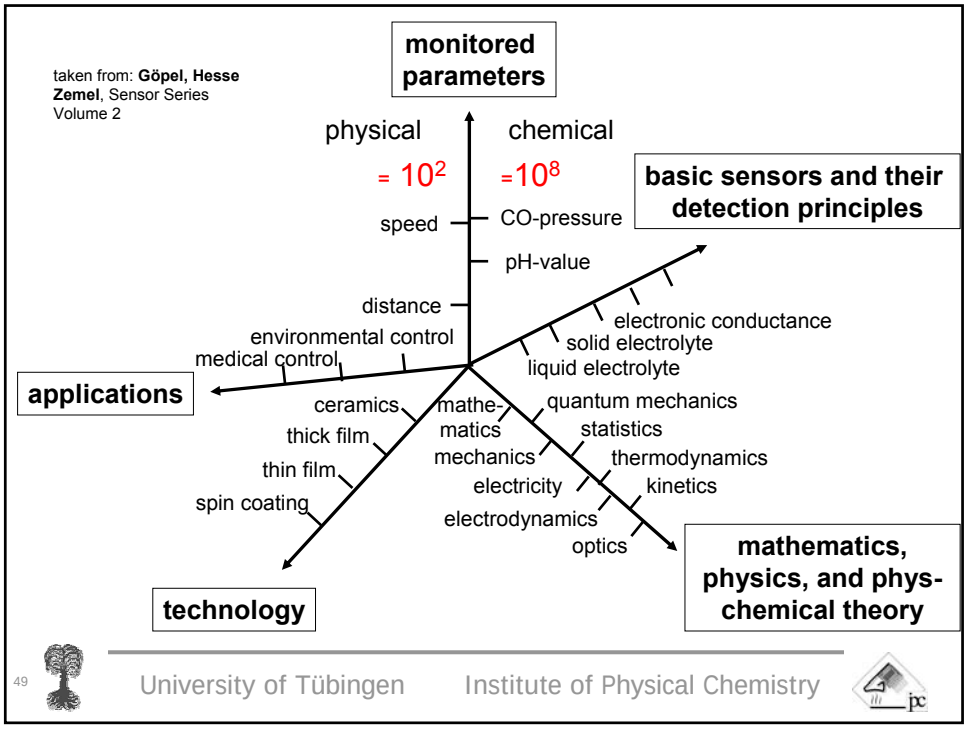
Summary (take home message)

- Mine detection with currently available chemical sensors not feasible
- Boundary conditions for the development (partially) understood
- Big challenges for research and development
- Need for a coordinated approach with all stake holders (very interdisciplinary!)
- Potential frame for discussion with sensor partners in Europe is NOSE and GOSPEL

Einführung


Sensor
physikalische Größe
physikalisch leicht
messbare Größe


taken from: Göpel, Hesse Zemel, Sensor Series Volume 2
monitored parameters
physical
chemical
= 10^2
=10^8
basic sensors and their detection principles
speed
CO-pressure
pH-value
distance
environmental control
medical control
electronic conductance
solid electrolyte
liquid electrolyte
applications
ceramics
thick film
thin film
spin coating
mathe-matics
mechanics
quantum mechanics
statistics
thermodynamics
kinetics
electricity
electrodynamics
optics
mathematics, physics, and phys-chemical theory
technology
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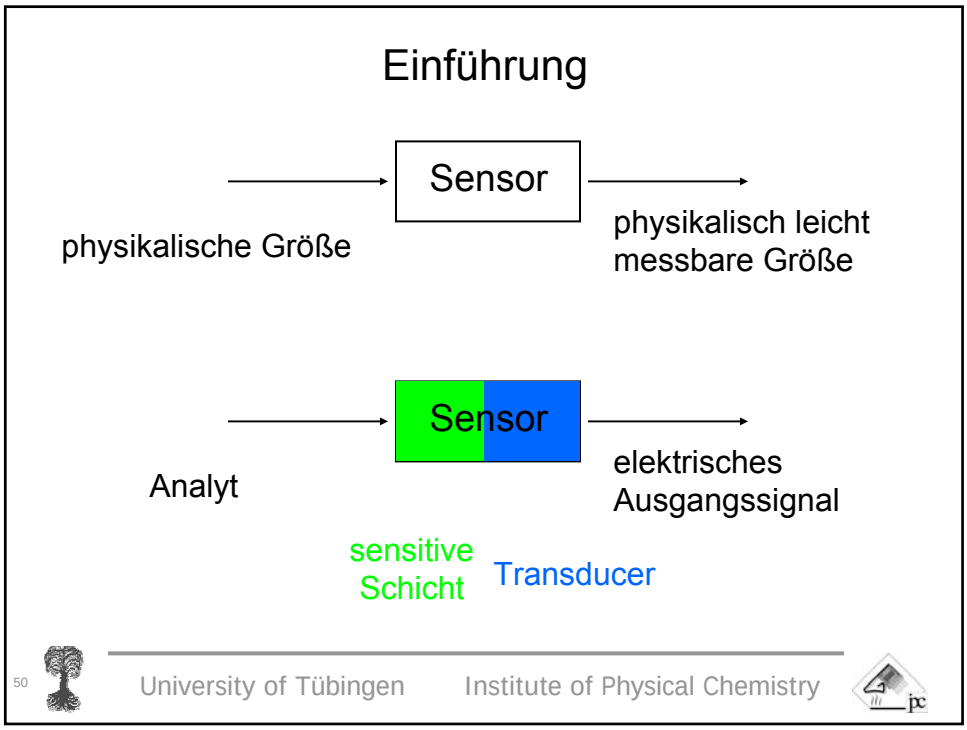
Einführung
Sensor
physikalische Größe
physikalisch leicht messbare Größe
Sensor
Analyt
elektrisches Ausgangssignal
sensitive Schicht
Transducer
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physikalisch leicht messbare Größen

- Potential (Potentialdifferenz, Spannung)
- Strom
- Masse (Massenänderung)
- Temperatur (Temperaturdifferenz)
- Kapazität (Kapazitätsänderung)

physikalisch leicht messbare Größen

- Potential (Potentialdifferenz, Spannung)
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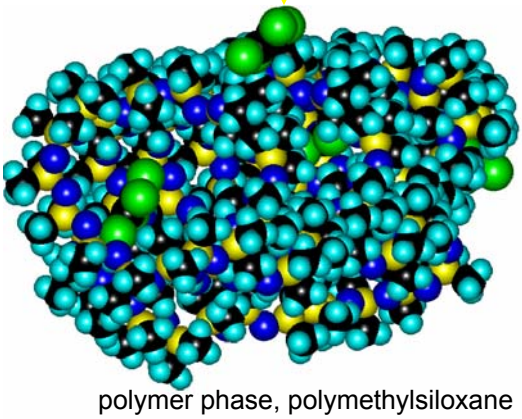
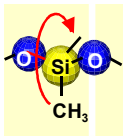
Analytabsorption

C_2Cl_4 gaseous phase



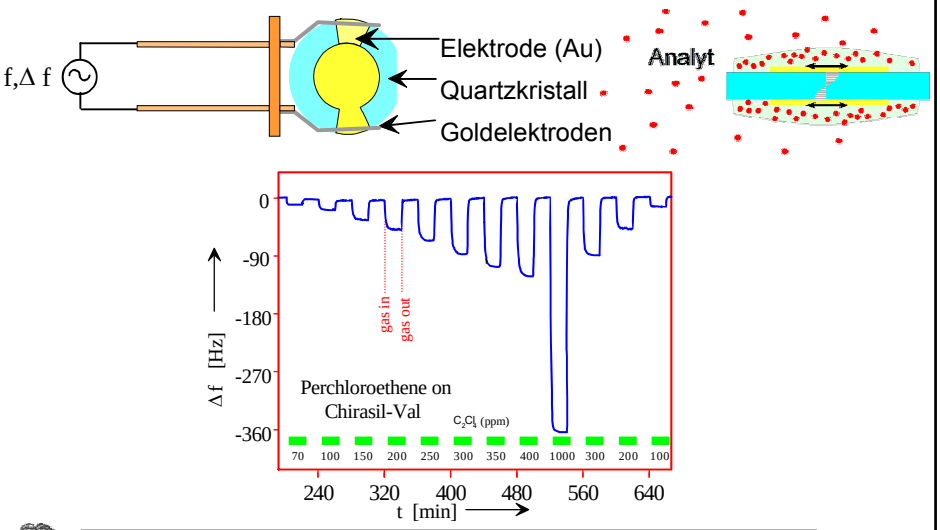
polymer phase, polymethylsiloxane

fast volume adsorption

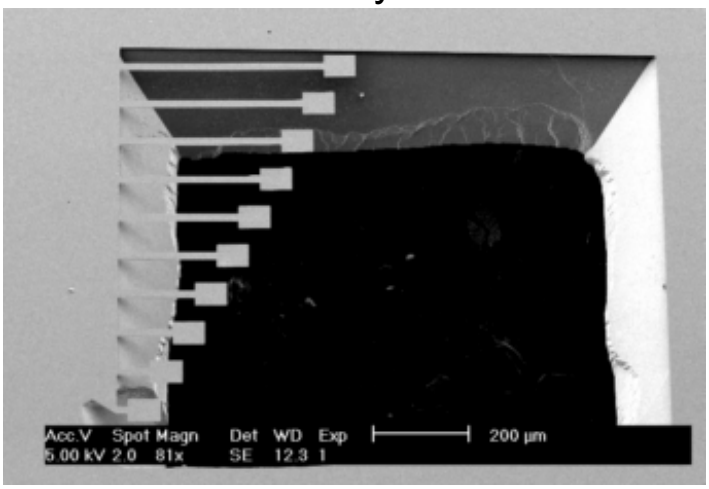


small E_A for adsorption
High mobility of the chain
(low glass temperature)

Schwingquartz (QMB, QCM)
Dickenscherschwinger (TSMR)

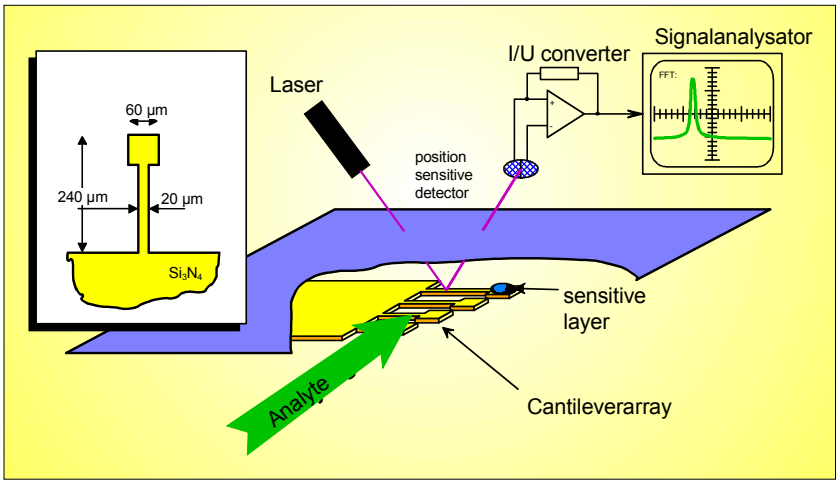


Mikrosystem

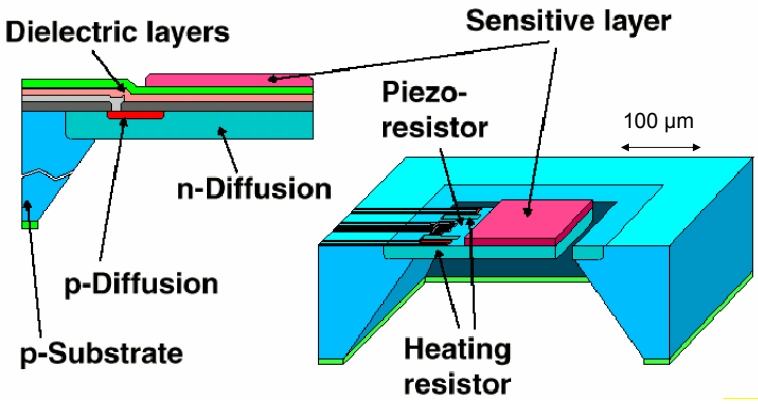


Quelle: Byong Hak Kim, Arbeitsgruppe Prof. Kern, Angewandte Physik, Universität Tübingen

Cantilever array signal reading

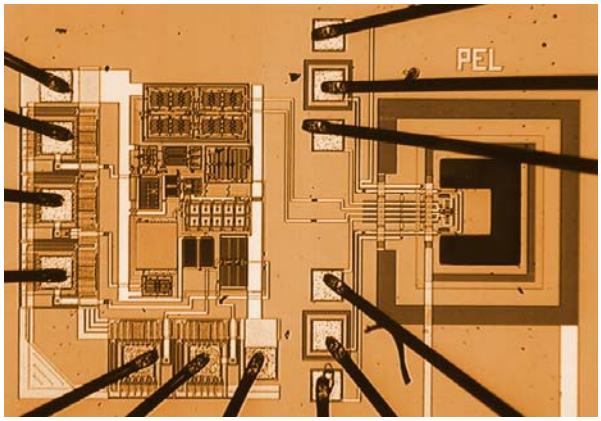


Entsprechendes µ-System: Cantilever



Quelle: PEL, Physical Electronics Lab, ETH Zürich

Realisierung: Cantilever, 100x120 µm, 380 kHz, incl. Amplifier

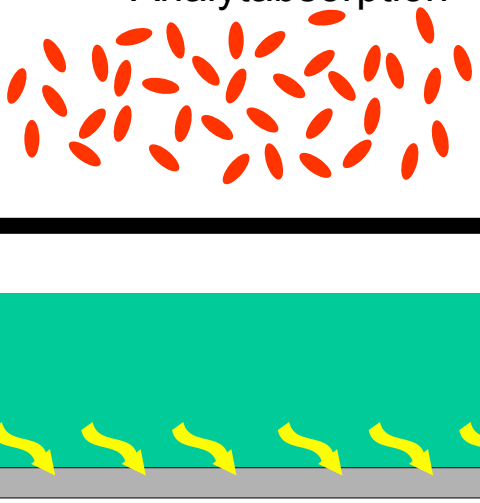


Quelle: PEL, Physical Elecetronics Lab, ETH Zürich

physikalisch leicht messbare Größen

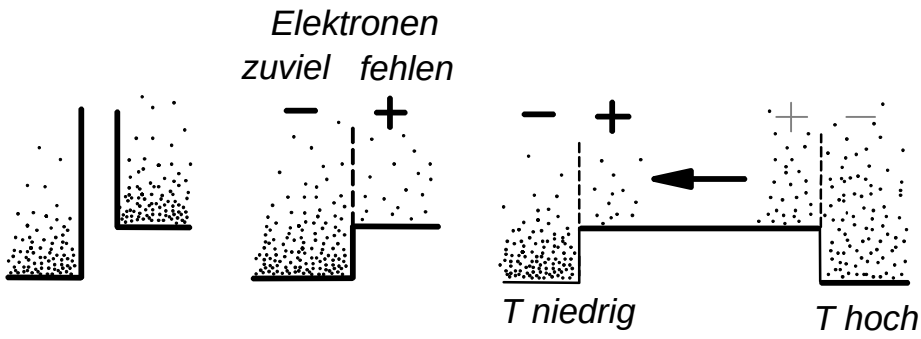
- Potential (Potentialdifferenz, Spannung)
- Strom
- Masse (Massenänderung)
- Temperatur (Temperaturdifferenz)
- Kapazität (Kapazitätsänderung)

Analytabsorption



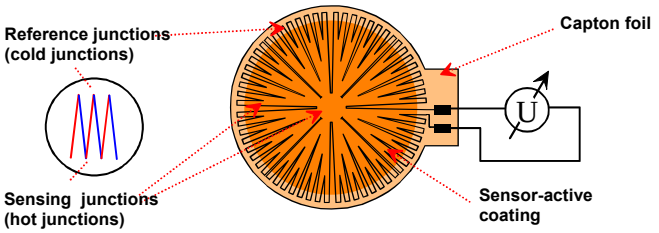
→ ΔT

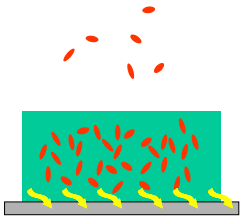
Seebeck Effekt



Nach: Gerthsen; Kneser, Vogel, Physik, 14. Auflage, Springer Berlin, Heidelberg, New-York, Seite 293

Aufbau: Kalorimetrischer Sensor (Thermopile)

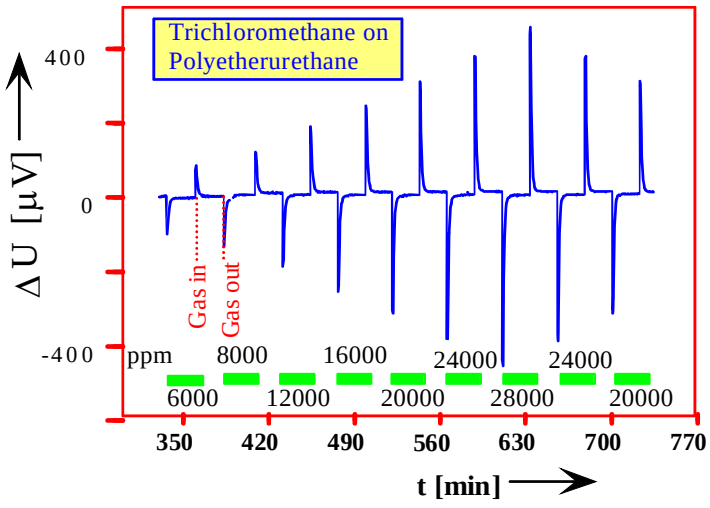




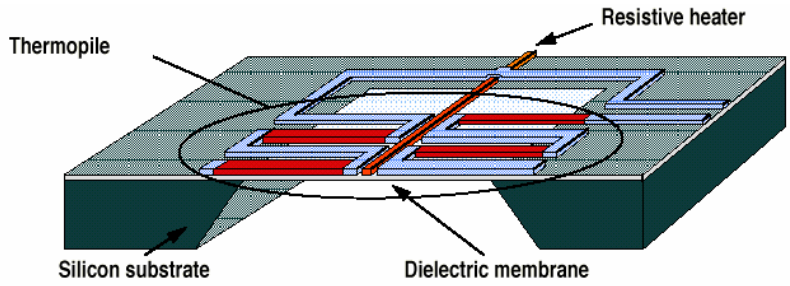
Heat of sorption leads to a pulse of thermovoltage between inner and outer junctions:

$$Q \rightarrow \Delta T \rightarrow \Delta U$$

Kalorimetrischer Sensor - Messkurve



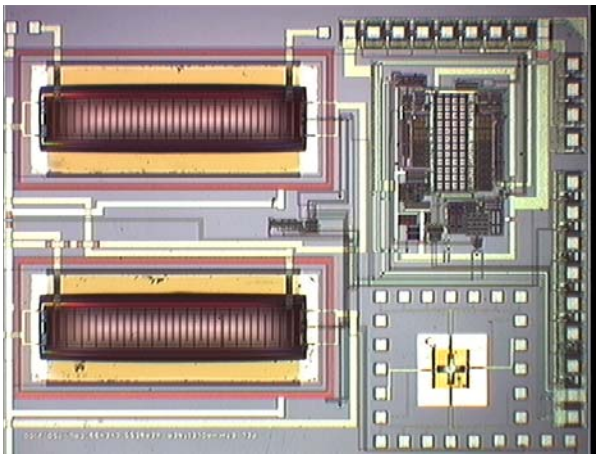
Calorimetric Sensor



- **Thermopile**
  - 44 thermocouples
  - n^+- polysilicon / aluminum
- **Membrane**
  - 700 x 1500 μm ^{2}, dielectric
- **Fabrication**
  - 1 μm CMOS process
  - Post-process KOH etching of wafer

Quelle: PEL, Physical Elecetronics Lab, ETH Zürich

Micro calorimeter, 300 TC poly-Si/Al, incl. amplifier

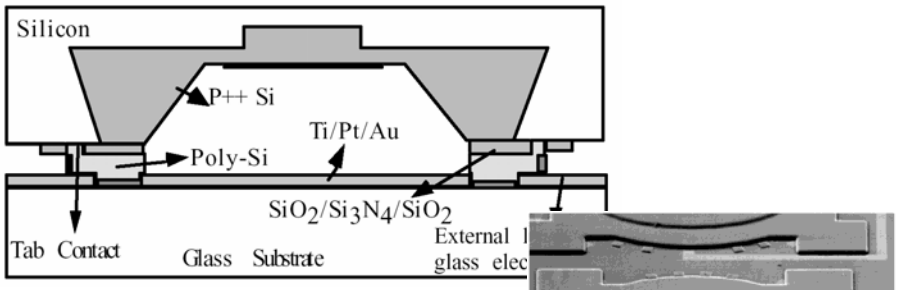


Quelle: PEL, Physical Electronics Lab, ETH Zürich

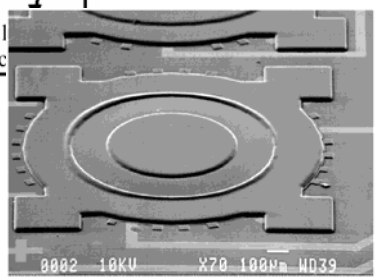
physikalisch leicht messbare Größen

- Potential (Potentialdifferenz, Spannung)
- Strom
- Masse (Massenänderung)
- Temperatur (Temperaturdifferenz)
- Kapazität (Kapazitätsänderung)

Drucksensor

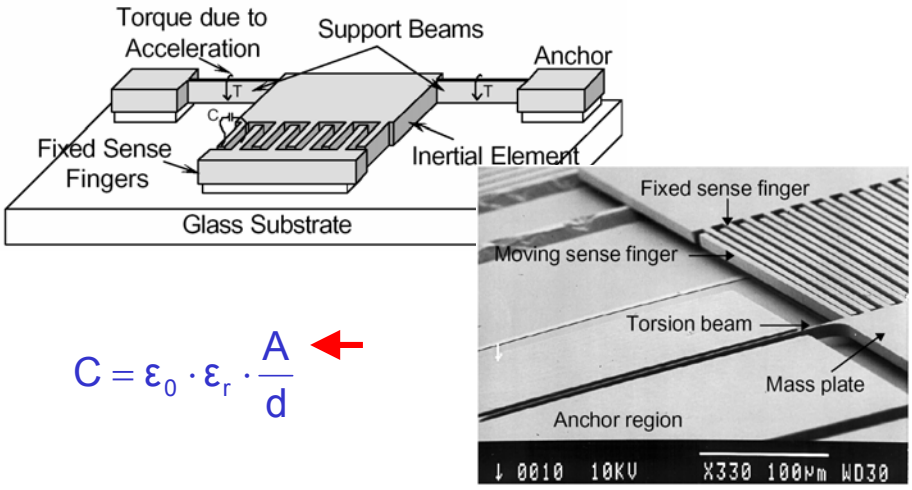


$$C = \varepsilon_0 \cdot \varepsilon_r \cdot \frac{A}{d}$$



A. V. Chavan, K. D. Wise, "A Batch-Processed Vacuum-Sealed Capacitive Pressure Sensor," Digest, Int. Conf. on Solid-State Sensors and Actuators (Transducers '97), Chicago, pp. 1449-1452, June 1997.

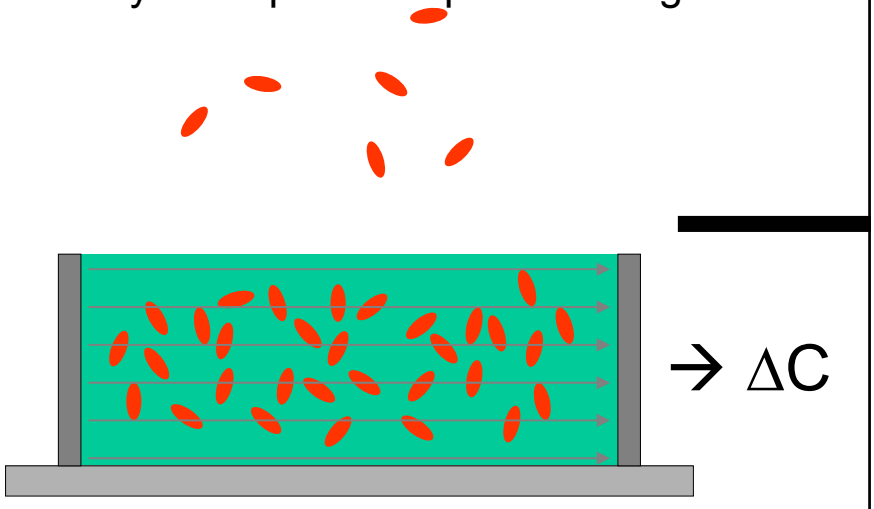
Beschleunigungssensor



$$C = \varepsilon_0 \cdot \varepsilon_r \cdot \frac{A}{d}$$

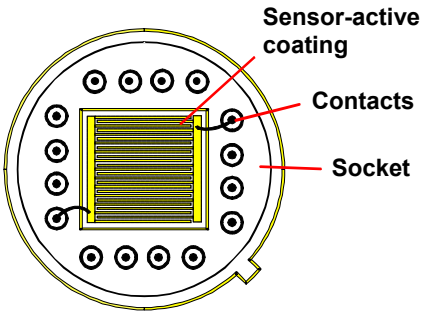
A. Selvakumar, F. Ayazi and K. Najafi, "A High Sensitivity Z-Axis Torsional Silicon Accelerometer," Digest, IEEE Int. Electron Device Meeting, San Francisco CA, pp. 765-768, December 1996.

Analytabsorption - kapazitives Signal

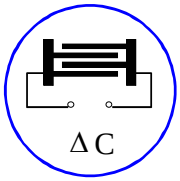


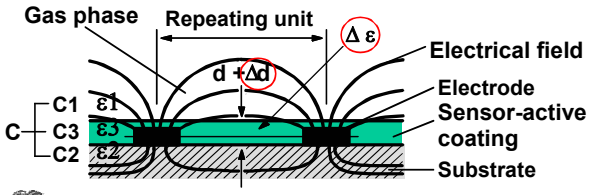
→ ΔC

Kapazitiver Sensor



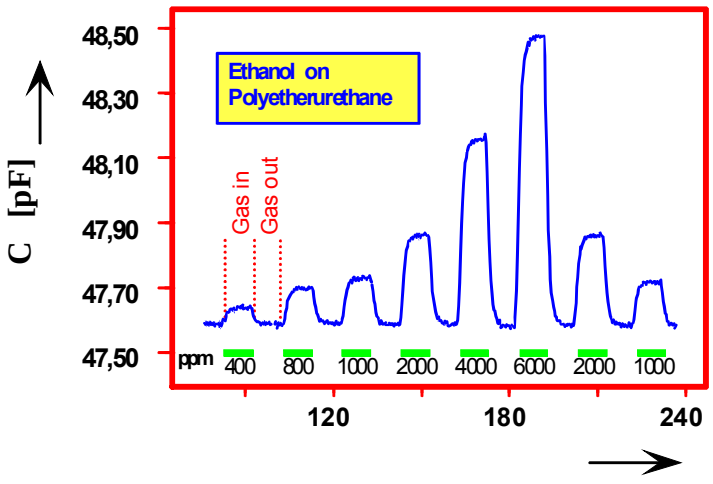
Interdigitated structure (schematically)





$$C = \varepsilon_0 \cdot \varepsilon_r \cdot \frac{A}{d}$$

Kapazitiver Sensor - Messkurve



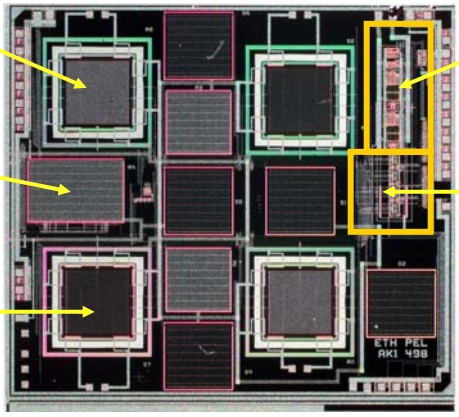
Capacitive Multi-Sensor Chip

5 Reference capacitors

Tunable reference (6 bits)

7 Sensing capacitors

6 mm



Read-out circuitry (∑Δ) (digital output) Δf ~ ΔC

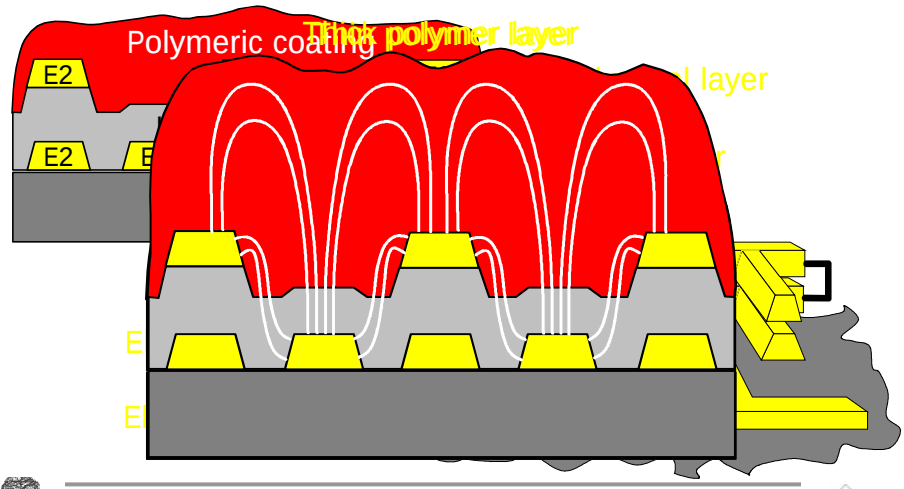
Multiplexer

Fabrication:

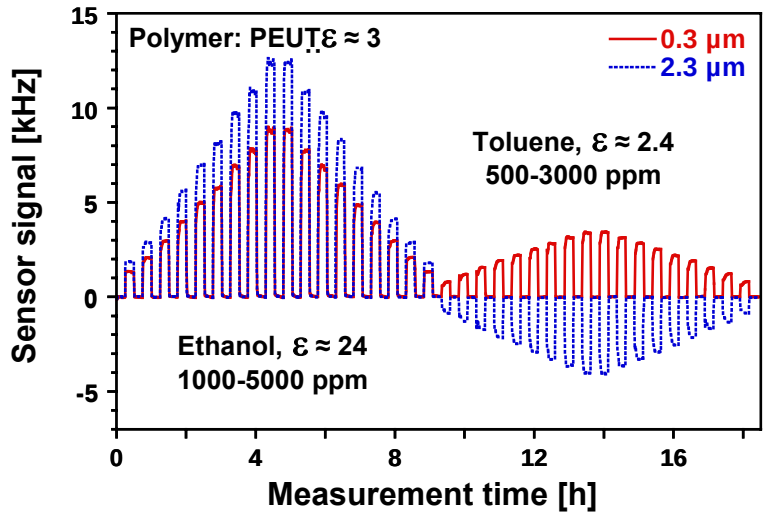
1. **Standard CMOS**
2. **Post processing: Polymer coating**

A. Kummer, A. Hierlemann, H. Baltes, Tuning the Sensitivity of Capacitive Chemical Microsensors, Eurosensors 2002, Prague, Czech Republic

Capacitance sensor



Thick and Thin Sensitive Layer



A. Kummer, A. Hierlemann, H. Baltes, Tuning the Sensitivity of Capacitive Chemical Microsensors, Eurosensors 2002, Prague, Czech Republic

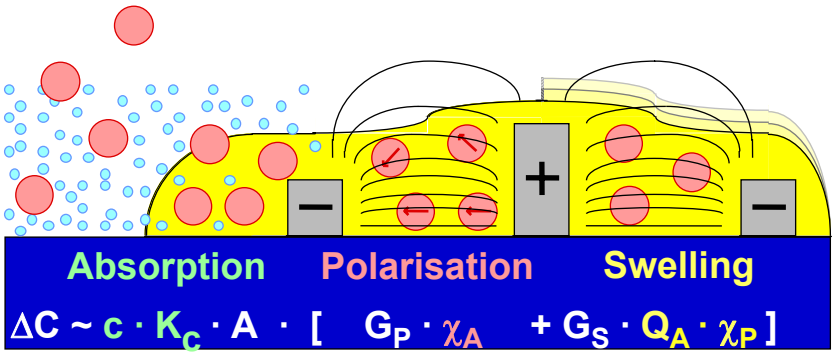
Zusammenfassung

- Chemische Parameter sind wichtige Kenngrößen
- Wandlung chemischer Information in elektronische Signale ist möglich
- Mikrosysteme helfen uns, machen manche Messungen erst möglich

Ende

Danke für Ihre Aufmerksamkeit!

Sensing Principle

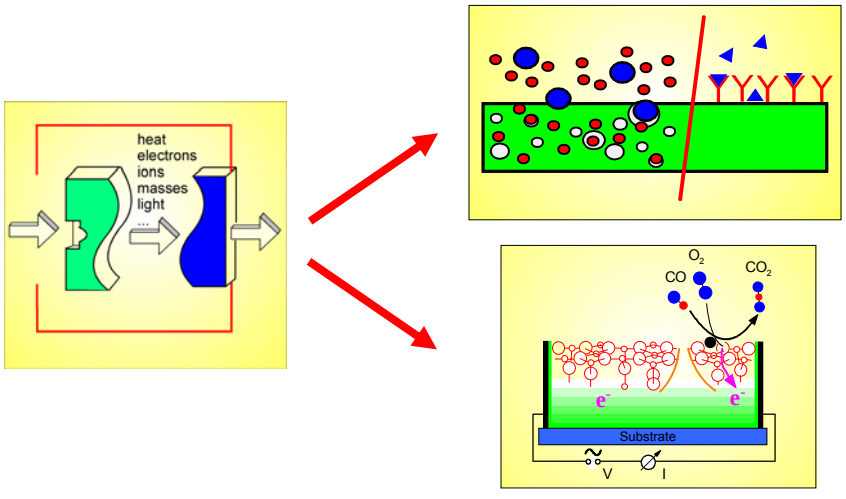


A. Kummer, A. Hierlemann, H. Baltes, Tuning the Sensitivity of Capacitive Chemical Microsensors, Eurosensors 2002, Prague, Czech Republic

Outline

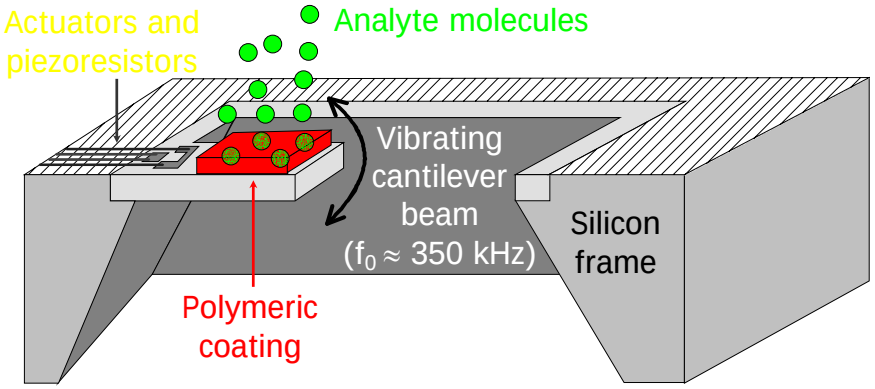
- Einleitung und Motivation
- Messprinzipien
  - Massenänderung
  - Temperaturänderung
  - Kapazitätsänderung
  - Leitfähigkeitsänderung
- Anwendung Teil 1
- Mustererkennung
- Anwendungen Teil 2
- Möglichkeiten und Grenzen
- Ausblick

Wechselwirkungsmechanismen

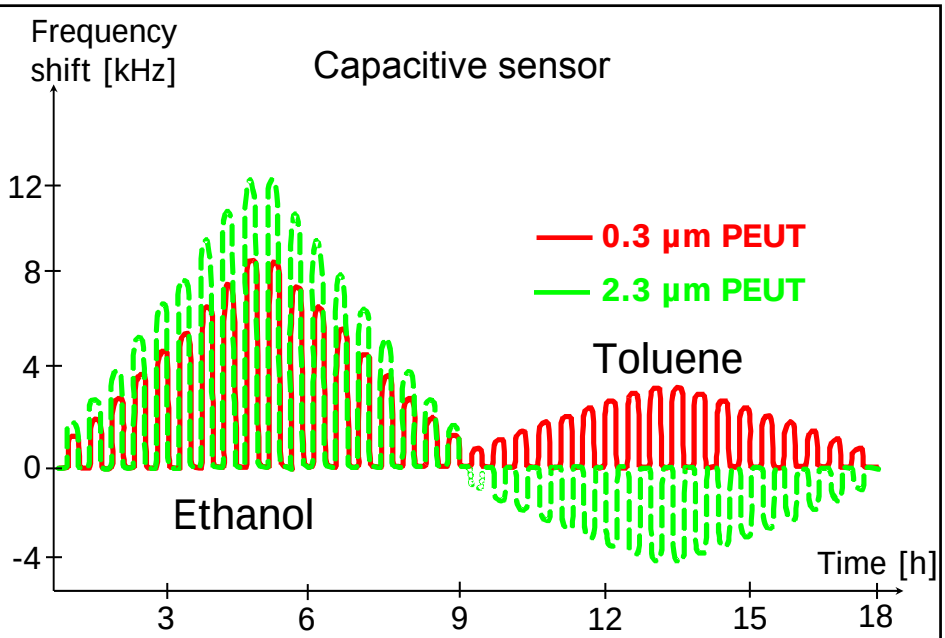


Micromechanical cantilevers (active)

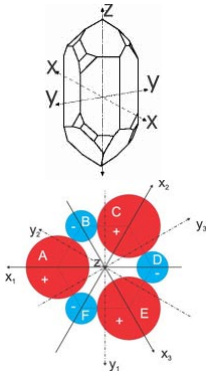
ETH Zurich



Capacitive sensor



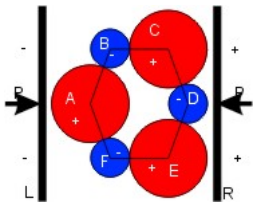
Piezoelektrischer Effekt

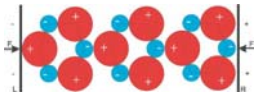


Quarz: SiO_2

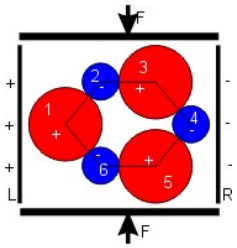
blau: Sauerstoff
rot: Silizium

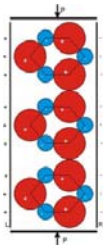
longitudinaler Effekt



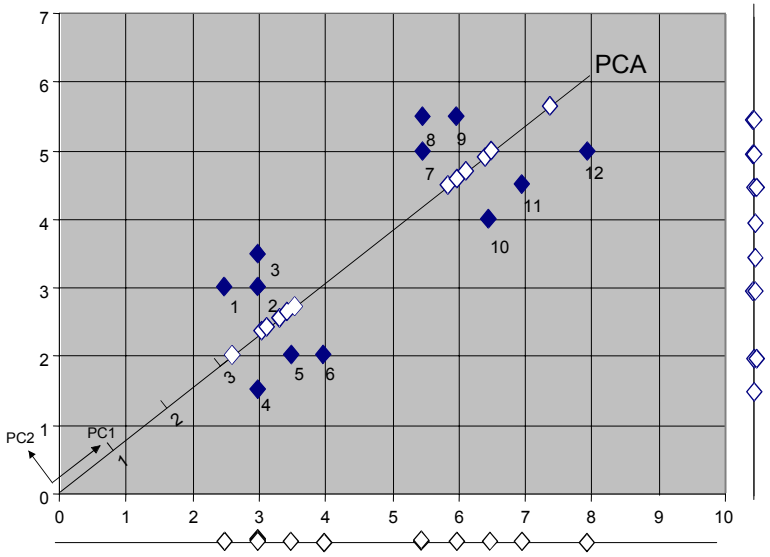


transversaler Effekt

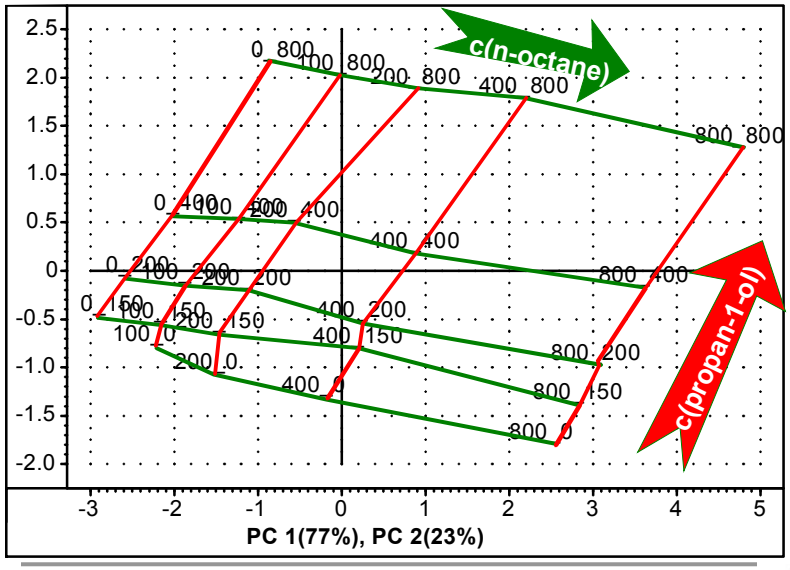




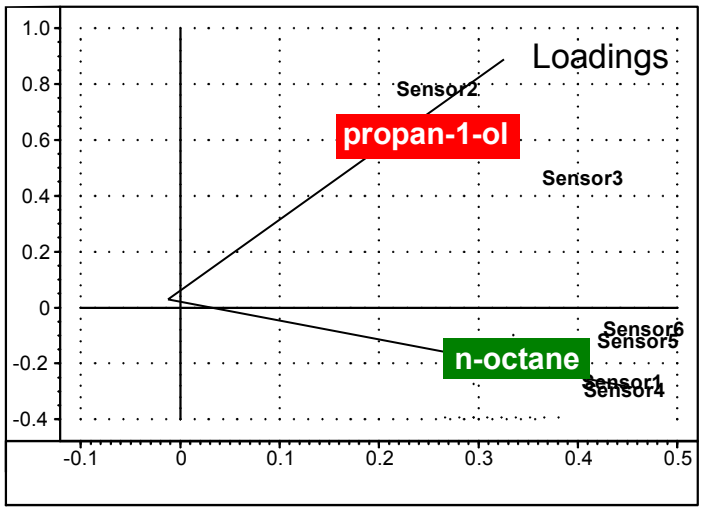
Principal Component Analysis (PCA)



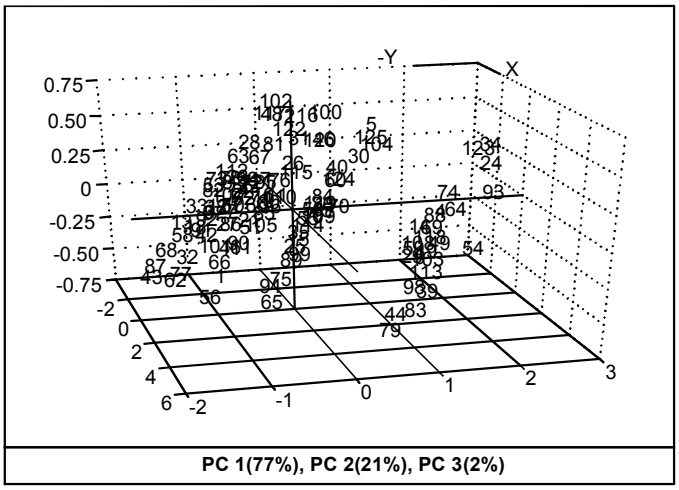
mixture of n-octane/propan-1-ol



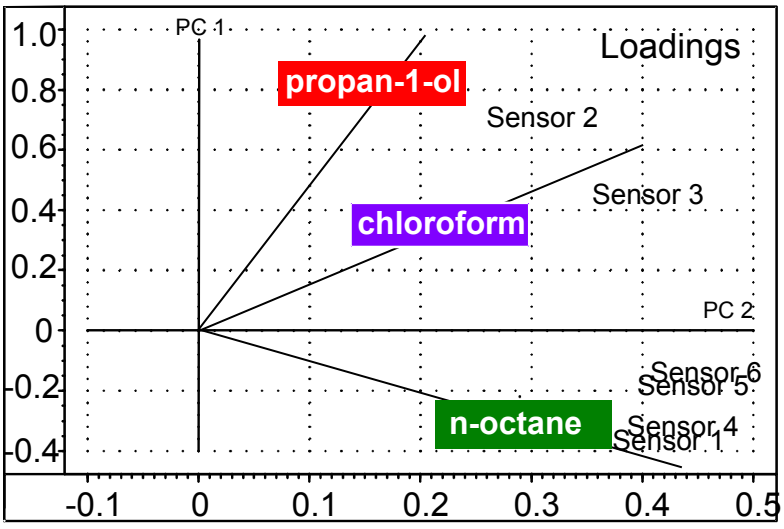
Loadings



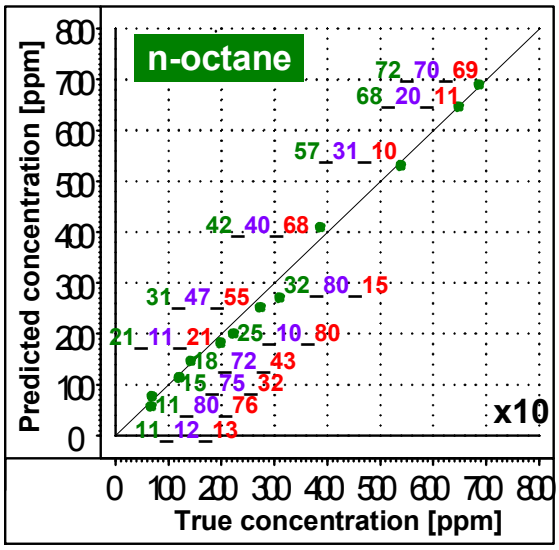
Mixtures of n-octane, propan-1-ol and chloroform



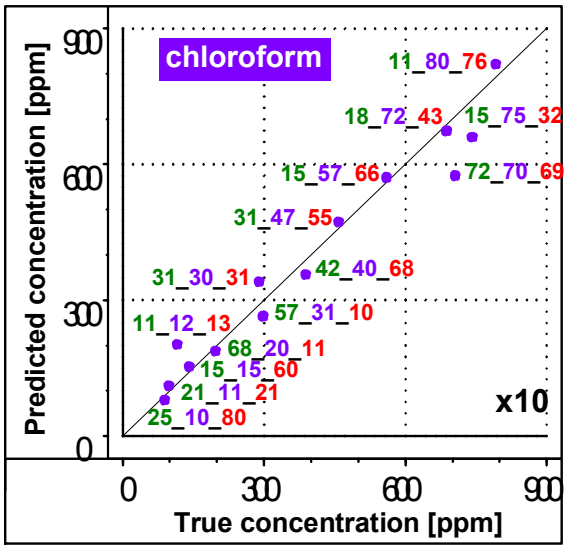
Loadings



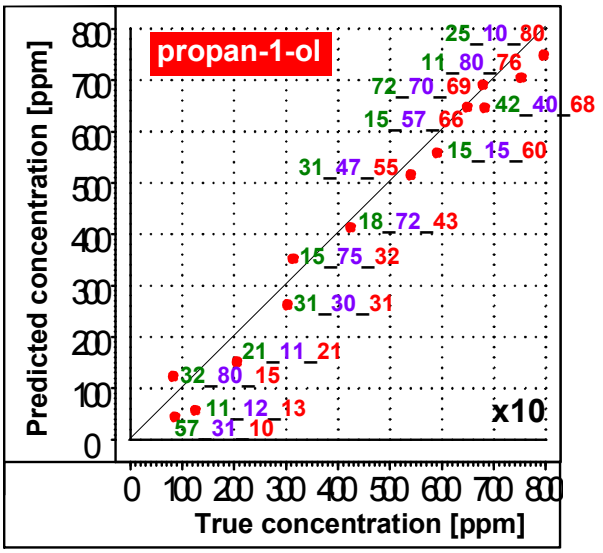
PLS - n-octane



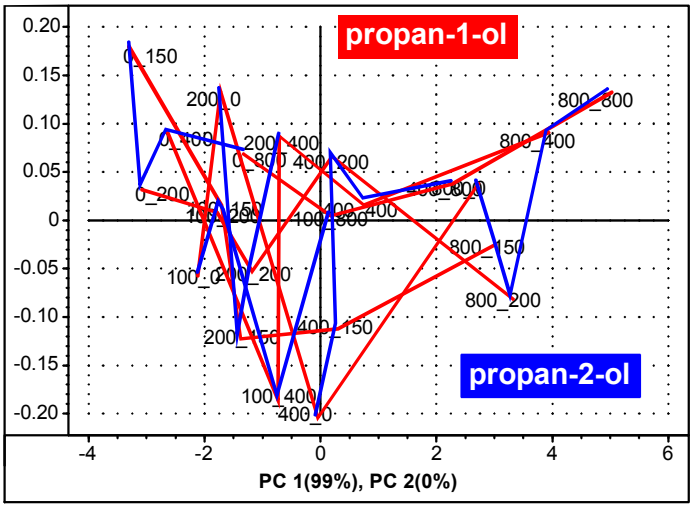
PLS - chloroform



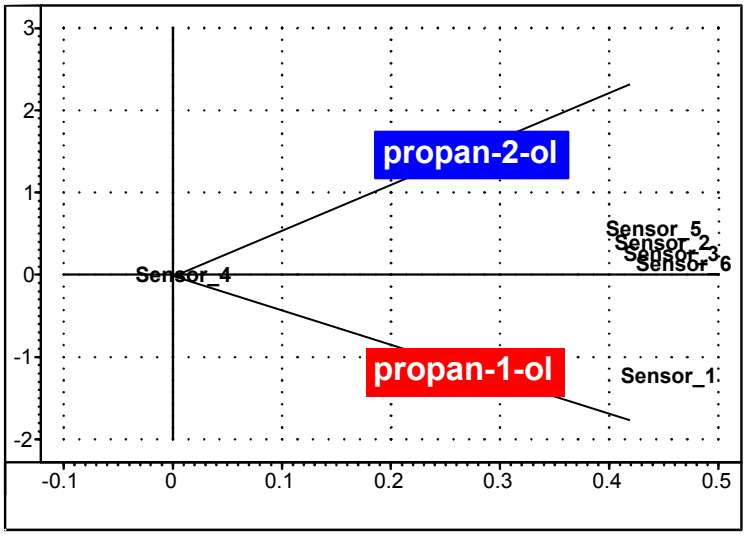
PLS - chloroform



mixture of propan-1-ol/propan-2-ol



Loadings



PCA of Packaging Materials