UNIVERSITÄT DES SAARLANDES

LAB FOR MEASUREMENT TECHNOLOGY
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EuNetAir 2nd Scientific Meeting

Gas Sensors and Sensor Systems for Air Quality Monitoring

Queens College, December 18-20, 2013, Cambridge, GB

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

mnt-era.net
VOC-IDS

SENSIndoor

Why worry about indoor air?

- Safety
  - Gas leak detection (combustible gases, e.g. CH_4)
  - Fire detection (various gases)
  - Hazardous gas detection (e.g. CO)
- Malodor detection (kitchen & bathroom ventilation)
- HVAC systems
  - Reduced air circulation for greatly reduced energy consumption
    - ➢ CO_2 monitoring for fresh air
  - Increased levels of VOCs lead to sick building syndrome
    - ➢ Selective (formaldehyde, benzene etc.) and sensitive (ppb level) detection
  - Systems have to be adapted to the specific room use scenario

> Background: Indoor Air Quality

Sensor requirements

- Low cost
- Networked systems (in major buildings, but also private homes)
- Long lifetime: >10 years without maintenance for private homes

Which sensors are used today?

- Safety
  - Gas leak detection: human nose, Japan: MOS; pellistors: only industr.
  - Fire detection: various sensors, mostly optical;
    gas sensor systems under development (EC, MOS, GasFET)
  - Hazardous gas detection: EC, MOS
- Malodor detection: MOS
- HVAC systems
  - CO_2 monitoring: NDIR (in major rooms/buildings), EC, GasFET
  - VOCs: MOS (total VOC), GasFET (emerging)

VOC-IDS: Volatile Organic Compound Indoor Discrimination Sensor

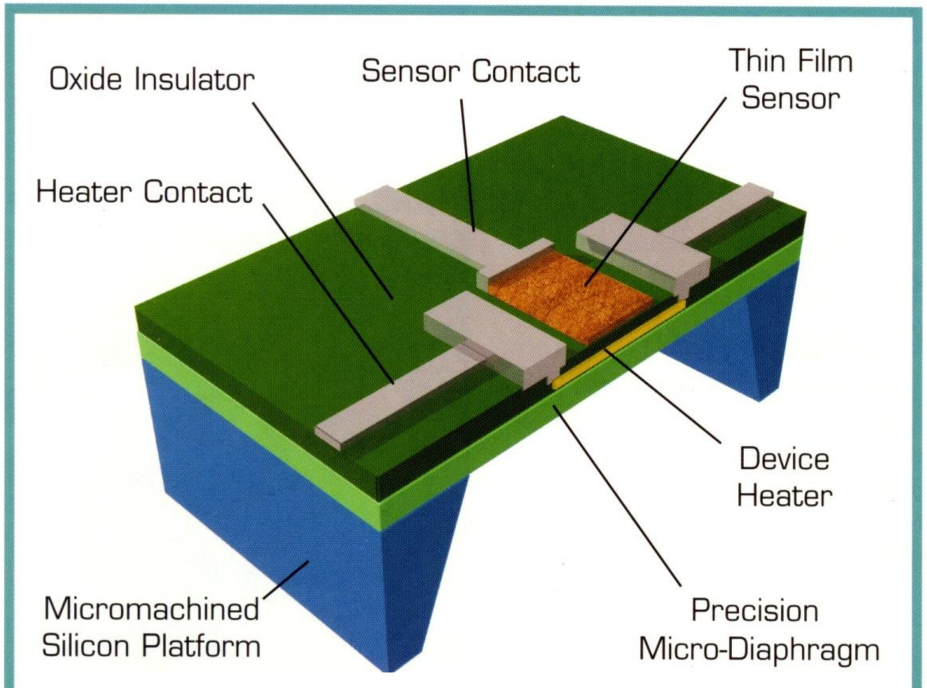
- Transnational project funded within MNT-ERA.net
- Selective VOC detection, primarily formaldehyde, benzene
- Novel ceramic nanomaterial metal-oxide semiconductor gas sensors
- Intelligent signal processing based on temperature cycling
- Networked systems connected to KNX bus

SENSIndoor: Nanotechnology based intelligent multi-SENsor System with selective pre-concentration for Indoor air quality control

- EU-FP7 project NMP.2013.1.2-1:
  Nanotechnology-based sensors for environmental monitoring
- Microtechnology based approach for MOS and SiC-GasFET sensors
- Pre-concentration to boost sensitivity and selectivity
- Integrated multi-sensor approach
- Application specific priorities and field tests

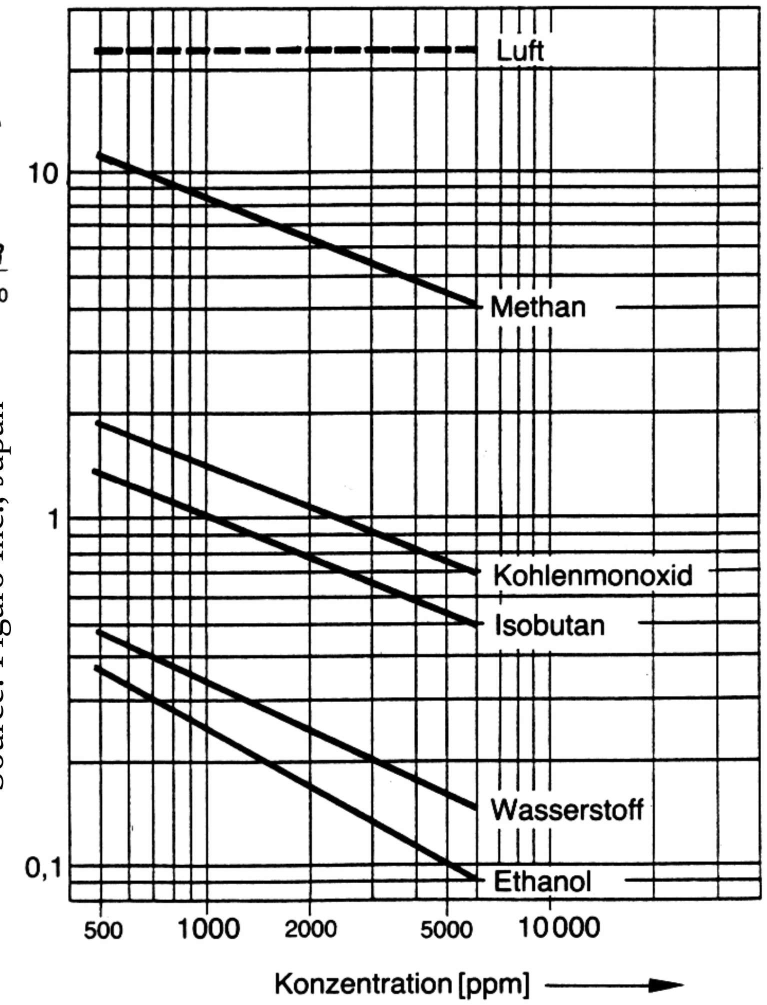
Gas sensors for air quality

- Metal Oxide Semiconductor (MOS), e.g. SnO_2, Ga_2O_3, WO_3
  - Oxygen adsorption leads to energy barrier at grain boundaries
  - Gas adsorption or reaction with O^- influences energy barrier
- Very high sensitivity (exponential effect of energy barrier on resistance)
- Very low cost: manufacturing based on MEMS and screen printing



Source: MicroChemical Systems S.A., Corcelles, CH

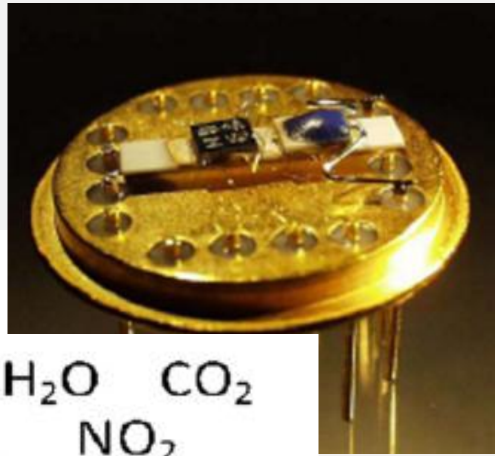
- Metal Oxide Semiconductor (MOS), e.g. SnO_2, Ga_2O_3, WO_3
- Great robustness (> 10 years lifetime in applications)
- Poor stability
  - Sensor drift due to poisoning etc.
  - Influence of background, esp. humidity
  - ➢ **quantitative meas. difficult**
- Poor selectivity
  - Response is mainly due to changing oxygen coverage
  - “Its surprising if the MOS sensor does not show a reaction!”
  - ➢ **greatest challenge for R&D**



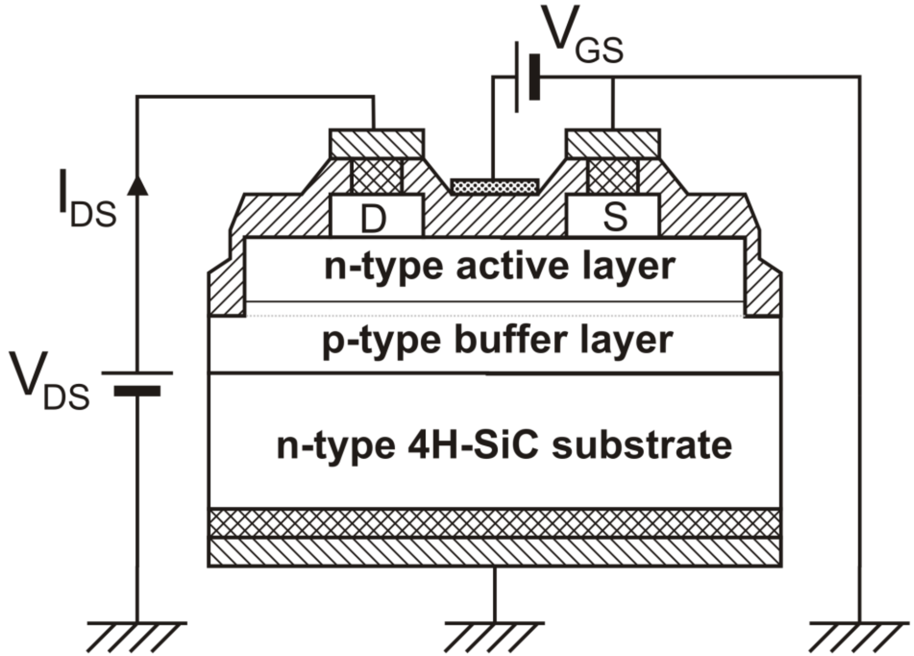
Source: Figaro Inc., Japan

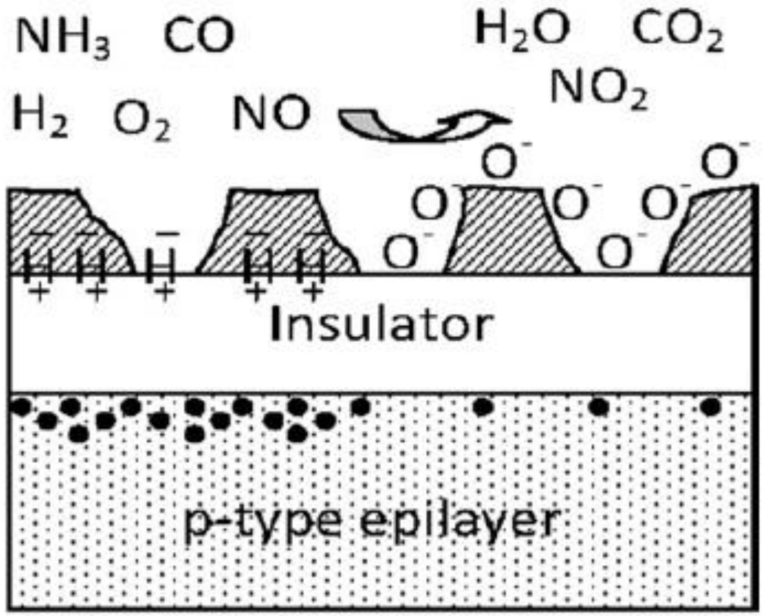
SiC Gas-sensitive Field Effect Sensors (Linköping U, SenSiC)

- high temperature operation
- allows temperature cycled operation as for MOS
- (nano-)porous platinum and iridium gate materials



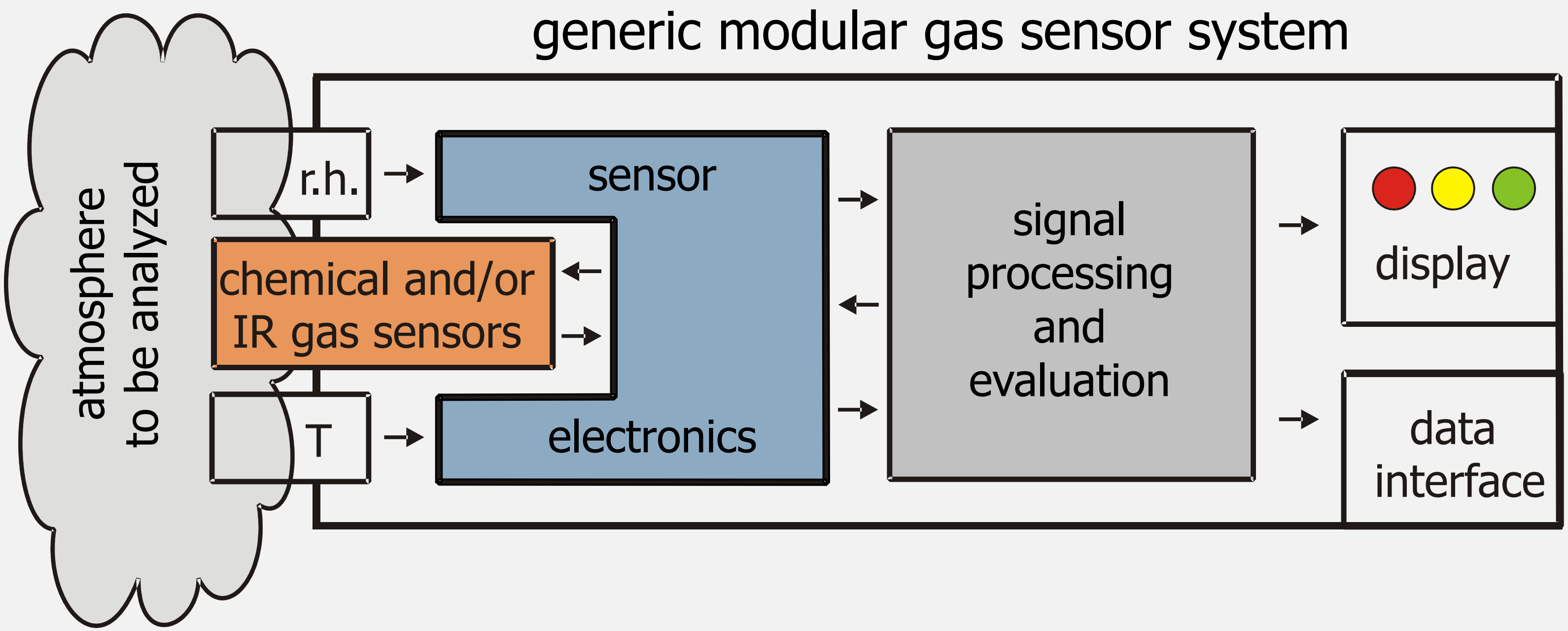
C. Bur et al.: Detecting Volatile Organic Compounds in the ppb Range with Pt-gate SiC-Field Effect Transistors, Proc. IEEE Sensors 2013; Baltimore, USA, Nov. 3-6, 2013



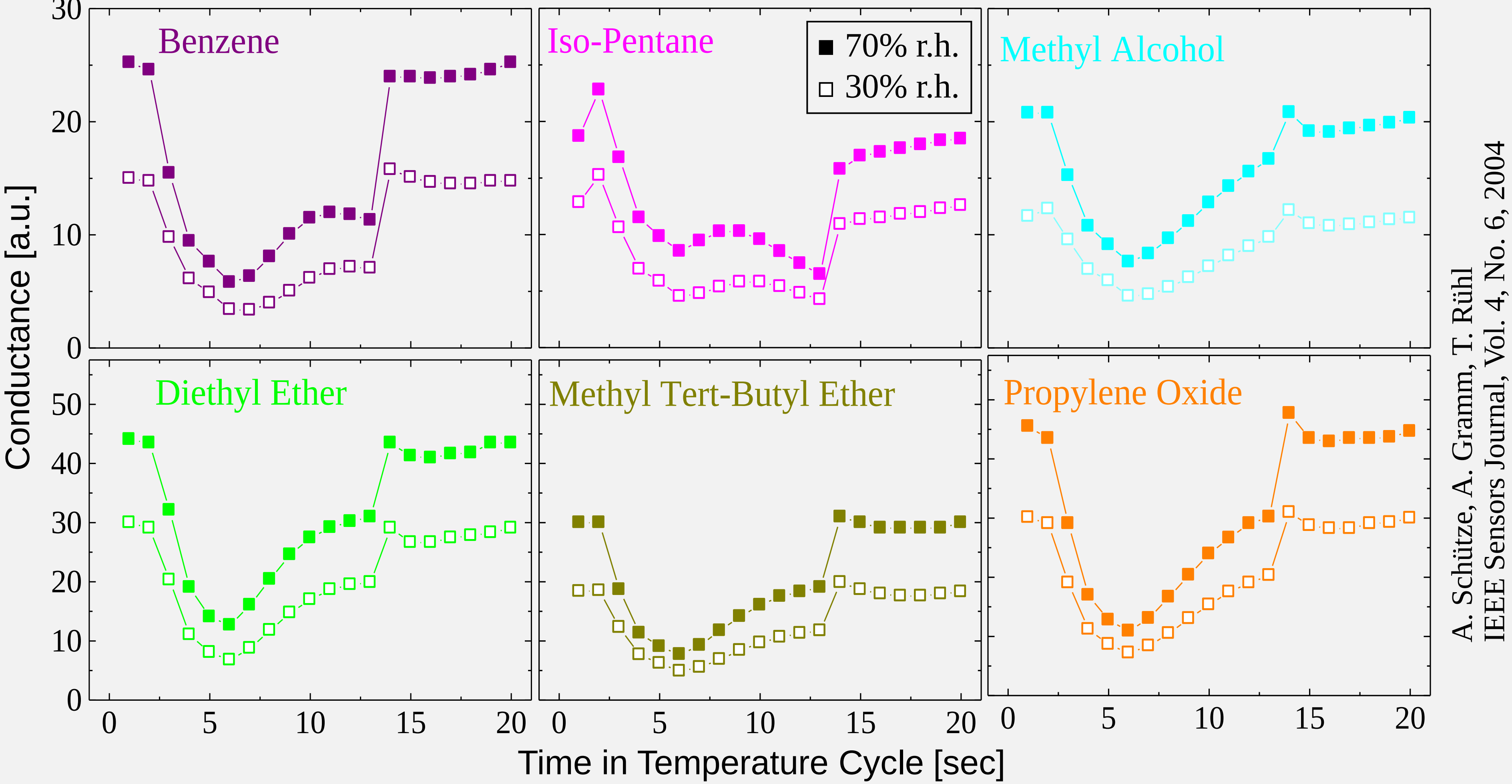


The three "S"

- Sensitivity
  - Broad spectrum
    from below ppb (for malodors, ozone, hazardous VOCs)
    up to 1000 ppm (gas leak, CO_2)
- Selectivity
  - False alarms are primary concern for fire detection (ratio 10:1)
  - VOC detection: hazardous (formaldehyde) vs. neutral (alcohol vapor, cleaning agents) vs. wanted (odorants)
- Stability
  - Industrial applications: maintenance interval < 6 months
  - Public buildings: annual or bi-annual tests (if that)
  - Private homes: 10 years lifetime w/o regular maintenance?


generic modular gas sensor system
atmosphere
to be analyzed
r.h.
chemical and/or
IR gas sensors
T
sensor
electronics
signal
processing
and
evaluation
display
data
interface

Temperature Cycled Operation (TCO)



Signal evaluation:

1. Normalization of the response curves ⇒ reduces sensor drift
2. Generation of secondary features, i.e. levels, slopes etc.
3. Suitable patterns are extracted for further evaluation

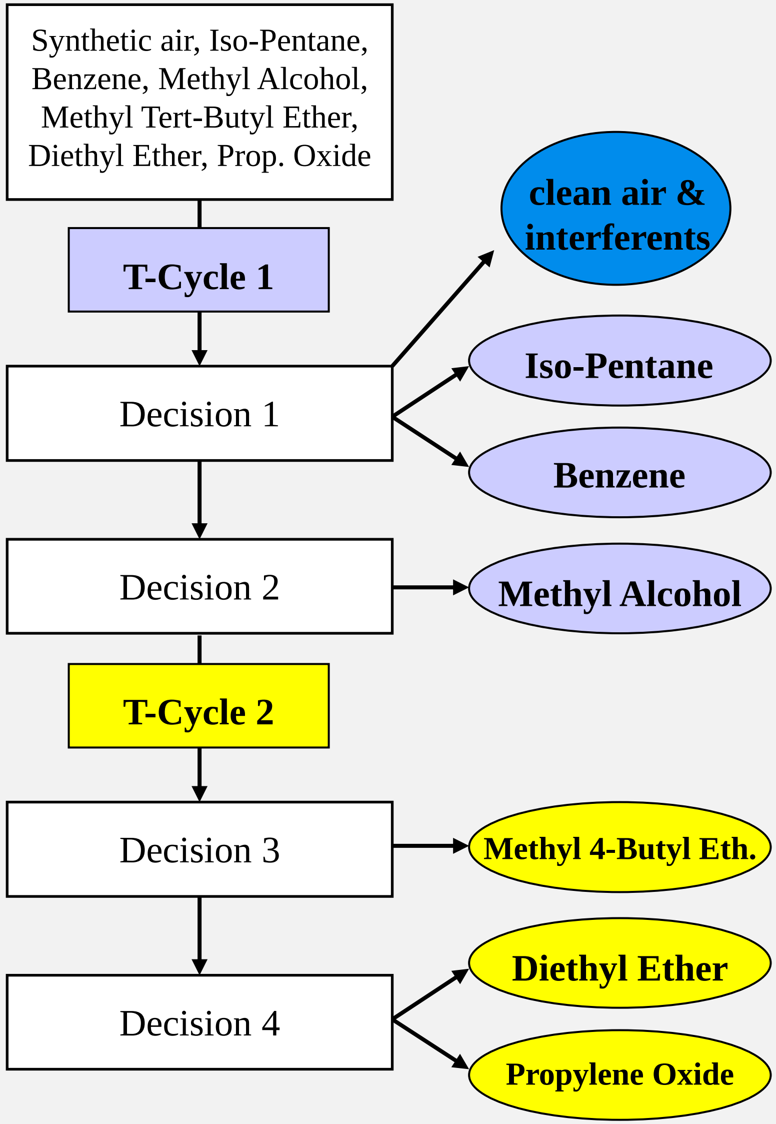
Temperature Cycled Operation (TCO)

Evaluation of sensor data based on temperature cycling (example)
→ **Virtual multisensor**

Characteristic features of the curve shapes (i.e. ***slope at the end of the high temperature phase*** and ***curvature during the low temperature phase***) are evaluated, to discriminate between different gases in several steps.

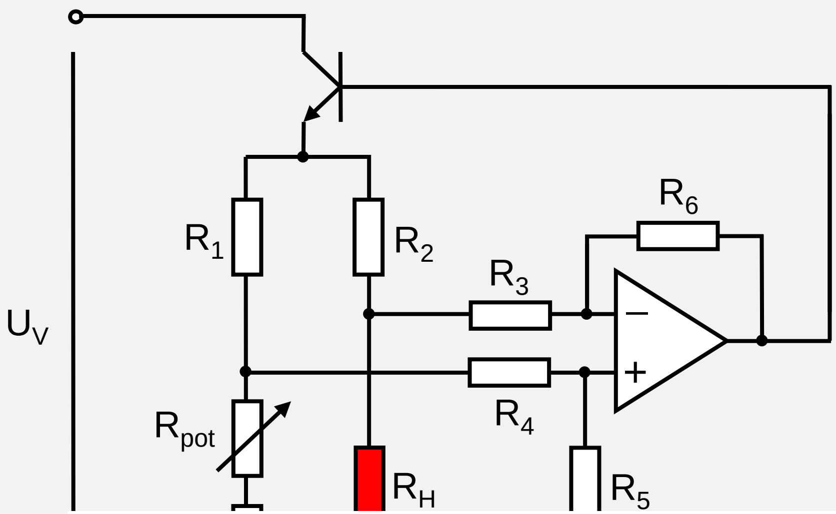
Note: the decision tree reflects the chemical composition of the solvents starting with the alkane pentane and the aromatic benzene (both pure CH-compounds), then the alcohol (R-COH) and finally the three ether compounds (R1-O-R2). This indicates that an expansion might be possible to classify many different molecules.

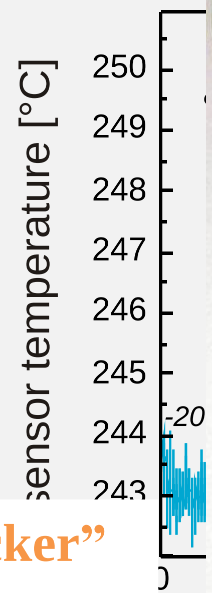
Source: A. Schütze, A. Gramm, T. Rühl
IEEE Sensors Journal, Vol. 4, No. 6, 2004

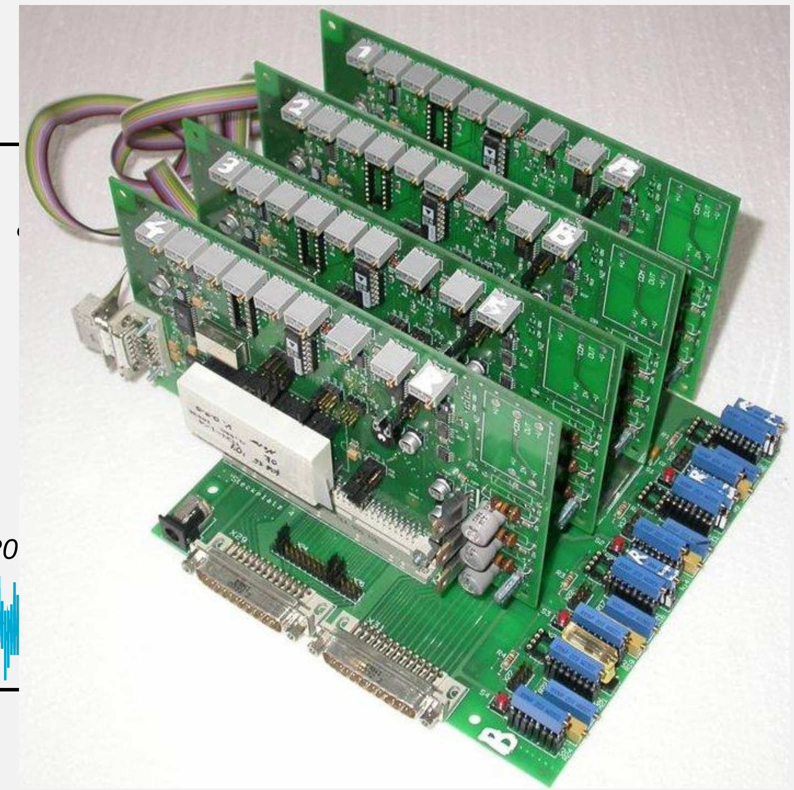


Hardware platform GasTON for exact temperature control and large dynamic range data acquisition – Gas sensor T-cycle Operating uNit

- Heater temperature control
  Heater resistor $R_H(T)$ controlled for exact temperature control of (micro-)hotplates
- Sensor read-out with large dynamic range
  for MOS, GasFET and pellistor type sensors



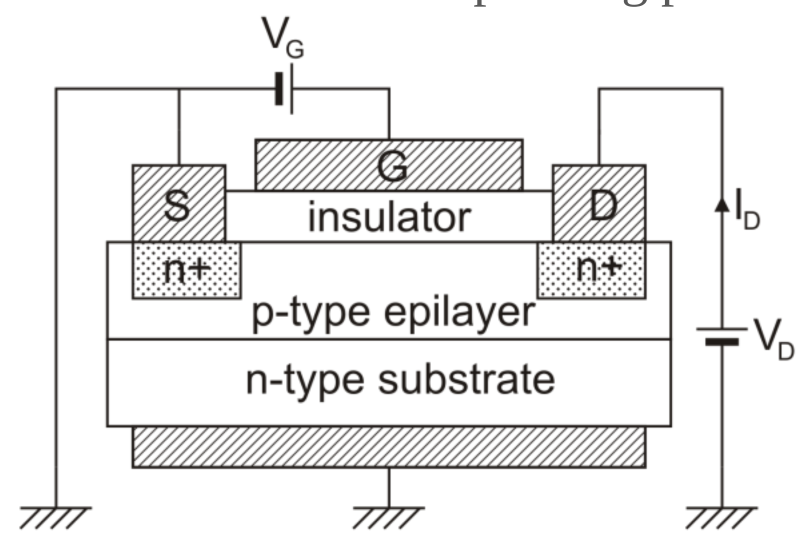


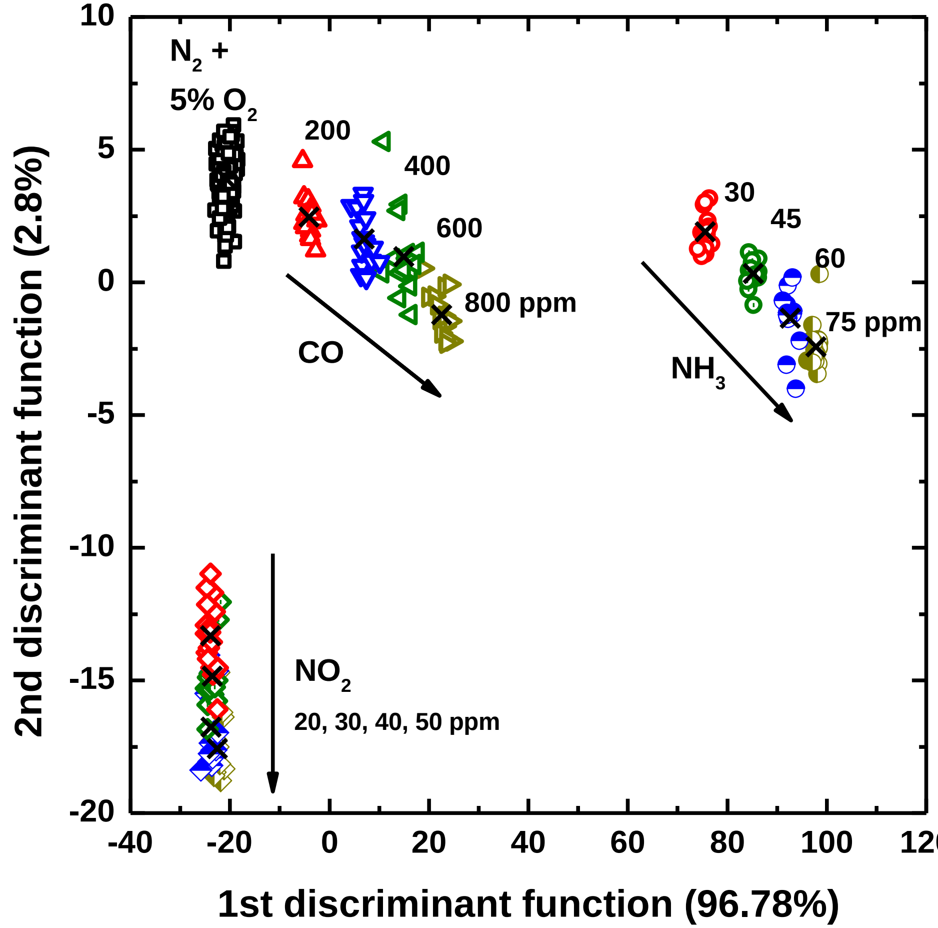


➢ **now commercialized "OdorChecker"**
by 3S GmbH (spin-off of LMT)

TCO hardware platform extended to allow Gate Bias Variation

- Heater resistor $R_H(T)$ controlled for exact temperature control
- Sensor read-out: voltage drop V_D measured at constant current I_D
- Gate voltage V_G varied to influence the operating point





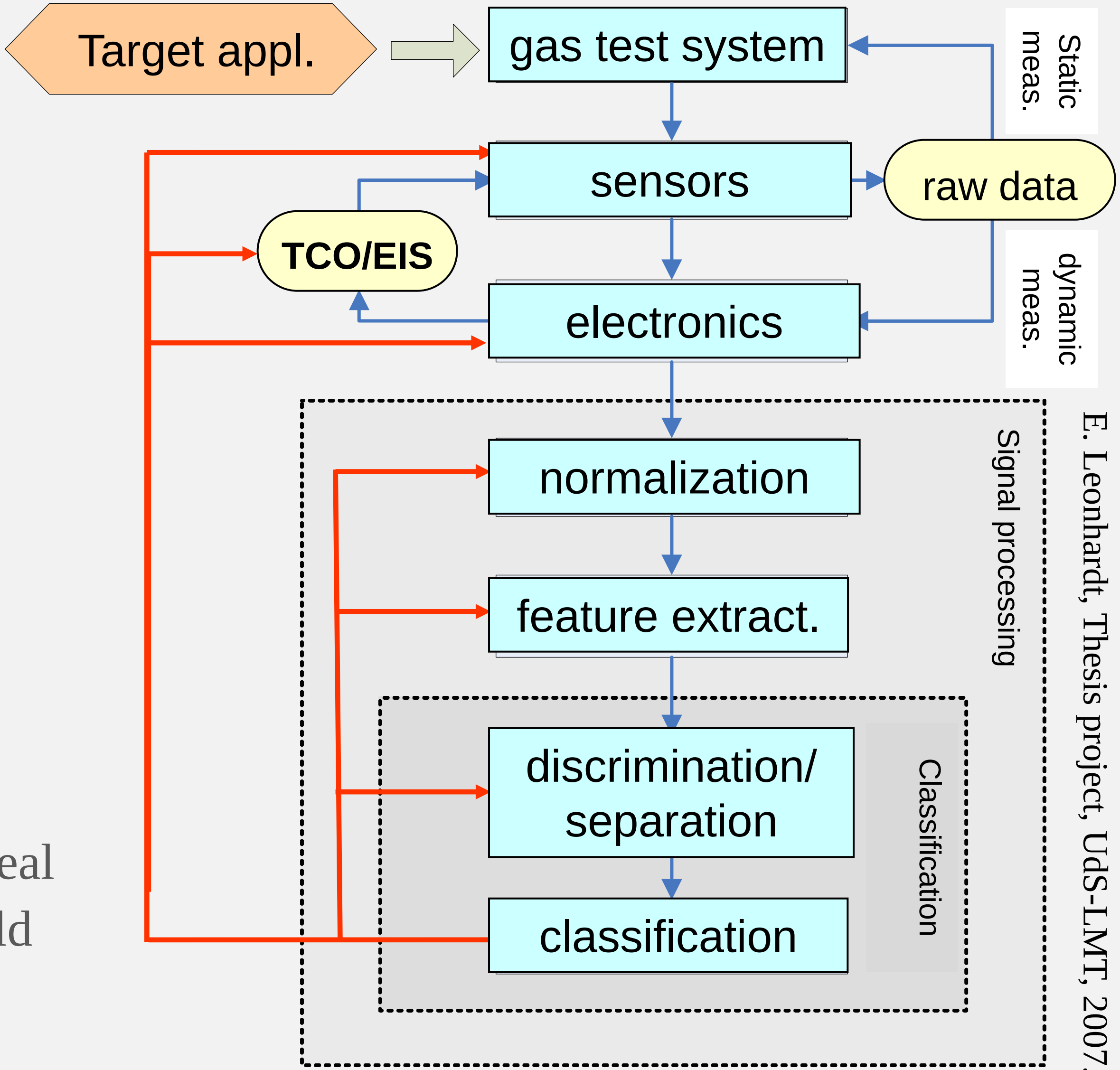
C. Bur et al.: Combination of Temperature Cycled and Gate Bias Cycled Operation to enhance the Selectivity of SiC-FET Gas Sensors, Proc. Transducers 2013 & Eurosensors XXVII; Barcelona, Spain, June 16 - 20, 2013

Temperature Cycled Operation – system design

Many possibilities for optimization:

- Sensor selection
- Operating mode
  - TCO
  - EIS
  - GBCO
- Data acquisition
- Signal preprocessing
- Feature extraction
- Separation
- Classification

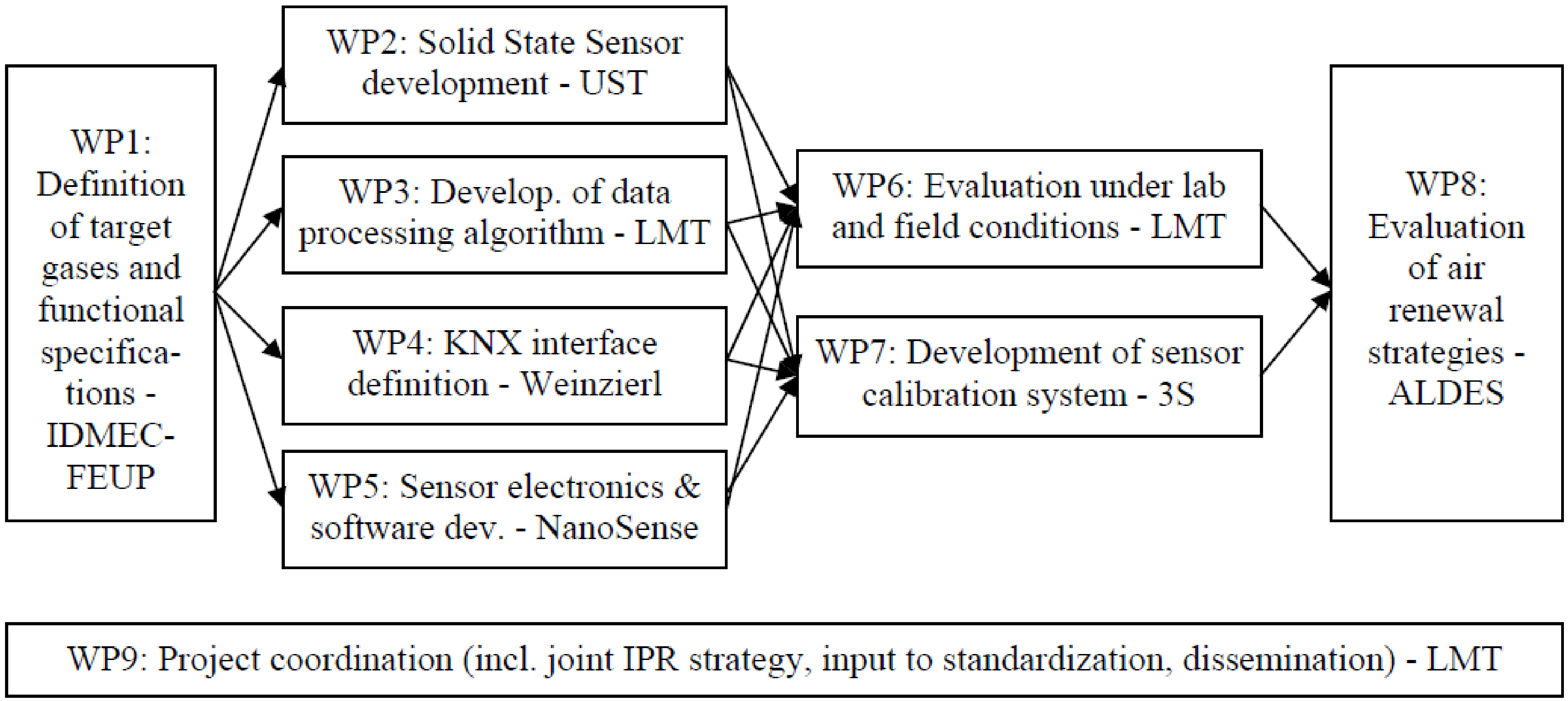
…and **always** testing under real application conditions (field testing)!



E. Leonhardt, Thesis project, UdS-LMT, 2007.

MNT-ERA.net project VOC-IDS

- Volatile Organic Compound Indoor Discrimination Sensor
- Scenario specific detection of hazardous VOC
- Integration of sensor system into KNX building automation networks



MNT-ERA.net project VOC-IDS

- Example for selective detection of VOCs in interfering background
- Classification of Formaldehydye, Benzene, Naphthalene in presence of ethanol

target gas	Concentration (ppb)	humidity	Interferents (EtOH ppm)
Air	NA	40%, 60%	none, 0.4, 2
Formaldehyde	10, 100	40%, 60%	none, 0.4, 2
Benzene	0.5, 4.7	40%, 60%	none, 0.4, 2
Naphthalene	2, 20	40%, 60%	none, 0.4, 2

interferent concentrat.	relative humidity	number of LDA steps for charac.	Estimated number of LDAs	
0, 0.4, 2	40%, 60%	1	1	generalized classification
None	40%, 60%	2	1+10(?)*1	classification w known EtOH
0, 0.4, 2	None	1 (2)	(1+) 5*1	classification w known r.h.

MNT-ERA.net project VOC-IDS

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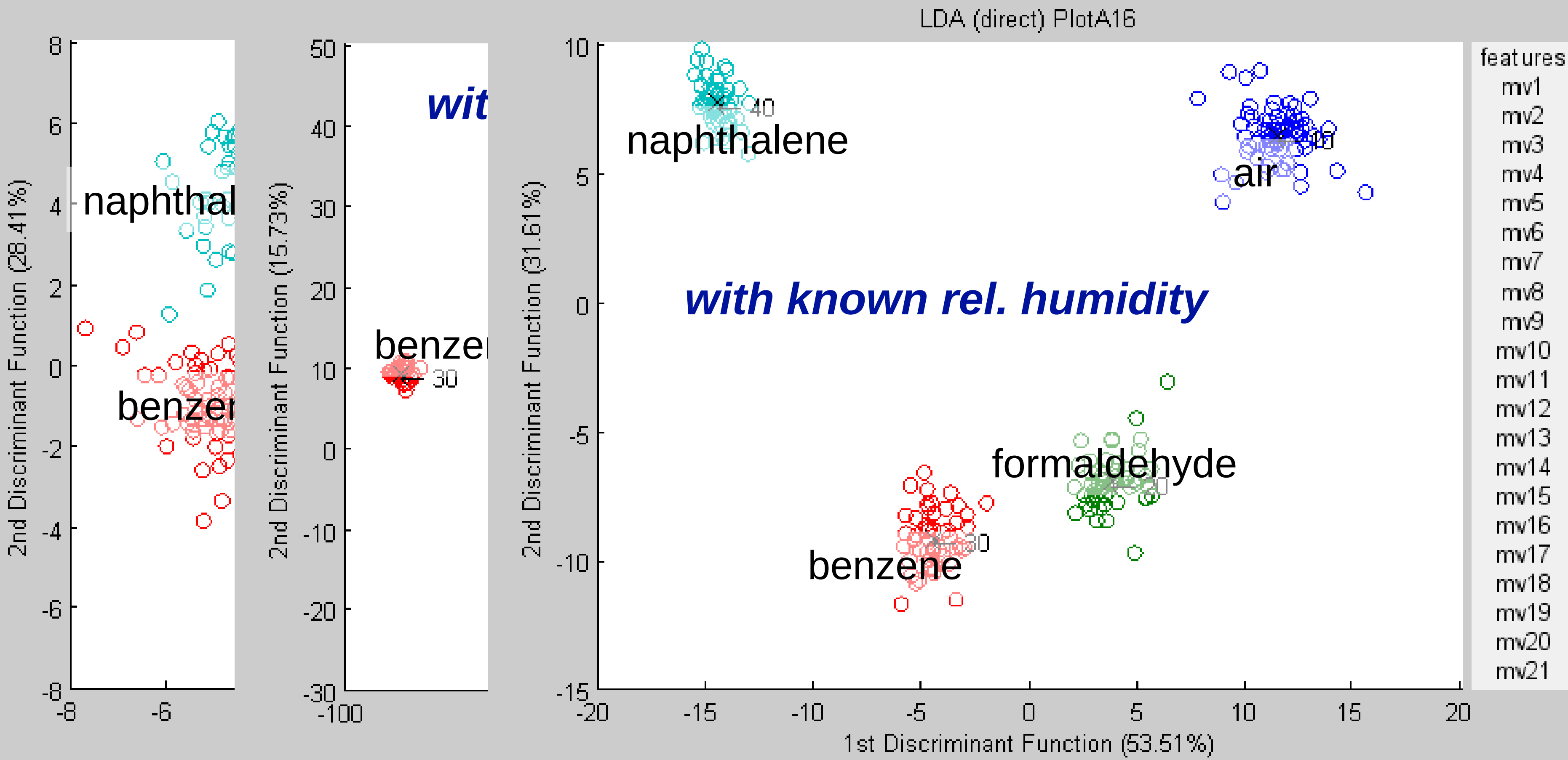
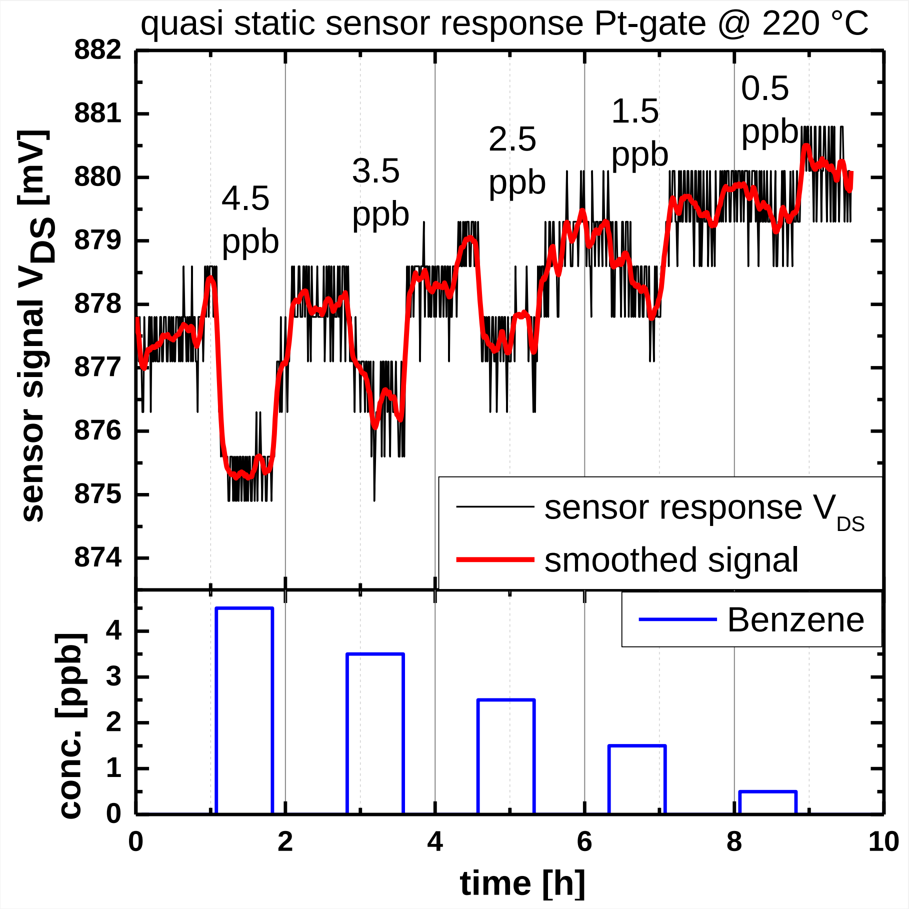
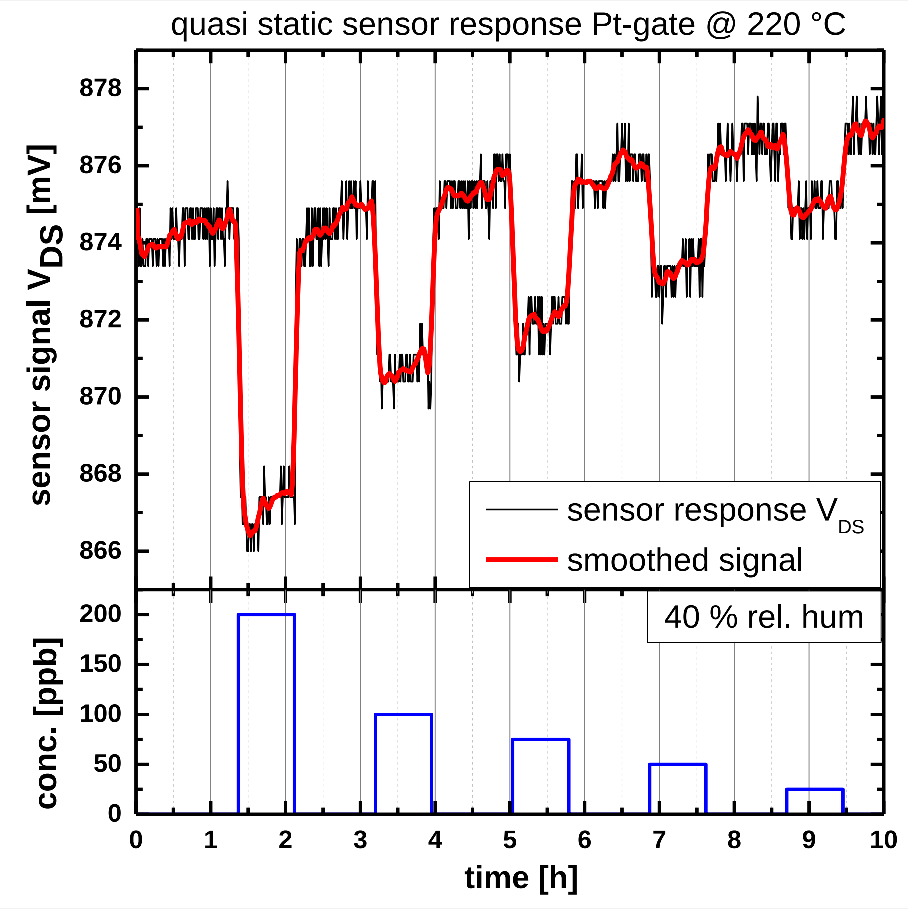


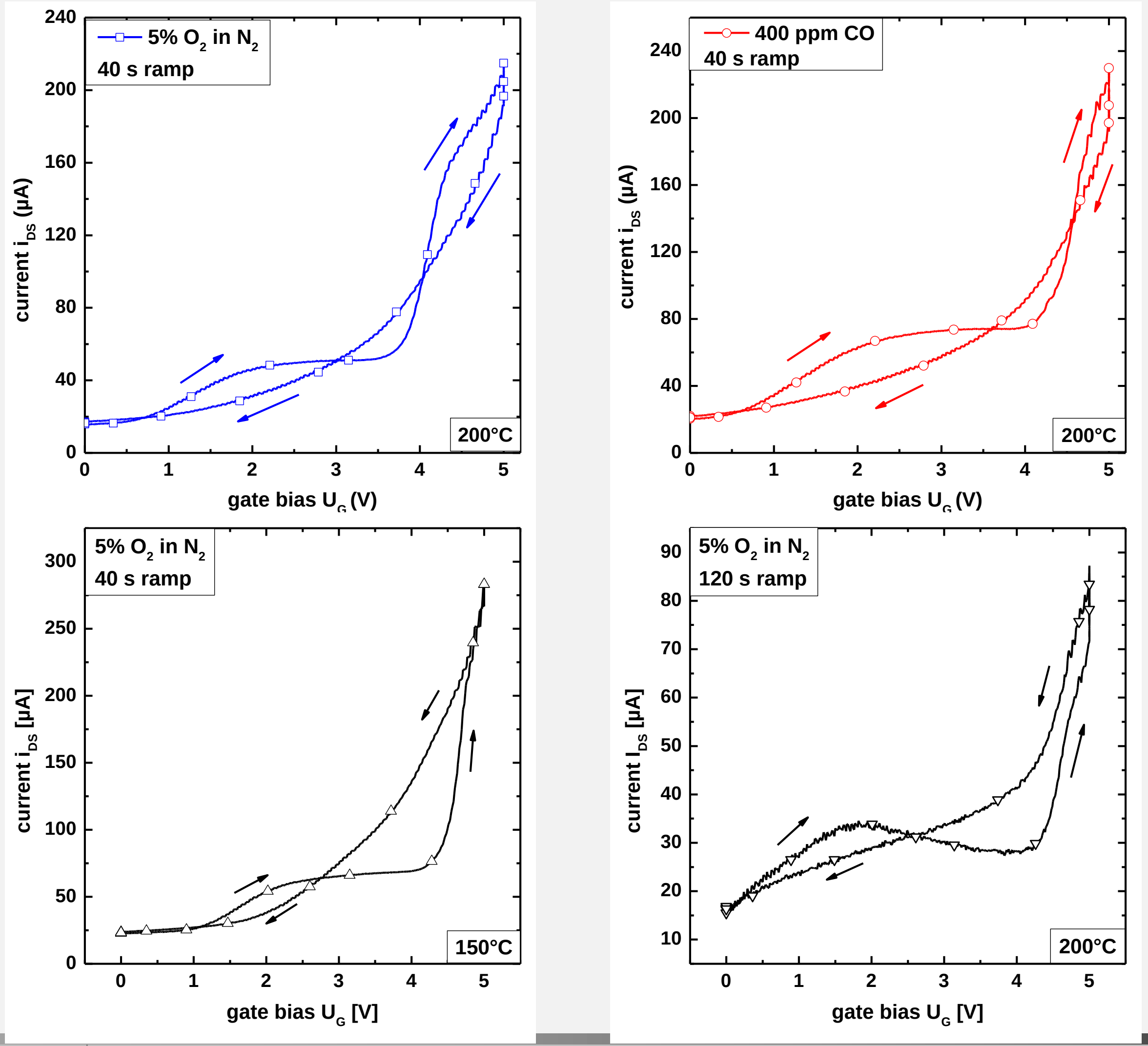
Highly sensitive VOC detection with SiC GasFETs (SenSiC AB)

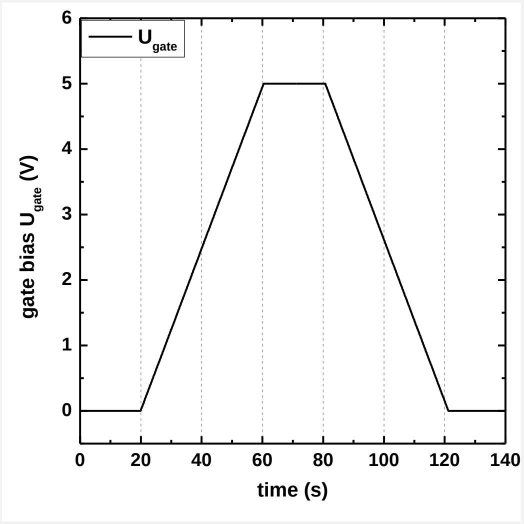




C. Bur et al.: Detecting Volatile Organic Compounds in the ppb Range with Pt-gate SiC-Field Effect Transistors, Proc. IEEE Sensors 2013; Baltimore, USA, Nov. 3-6, 2013

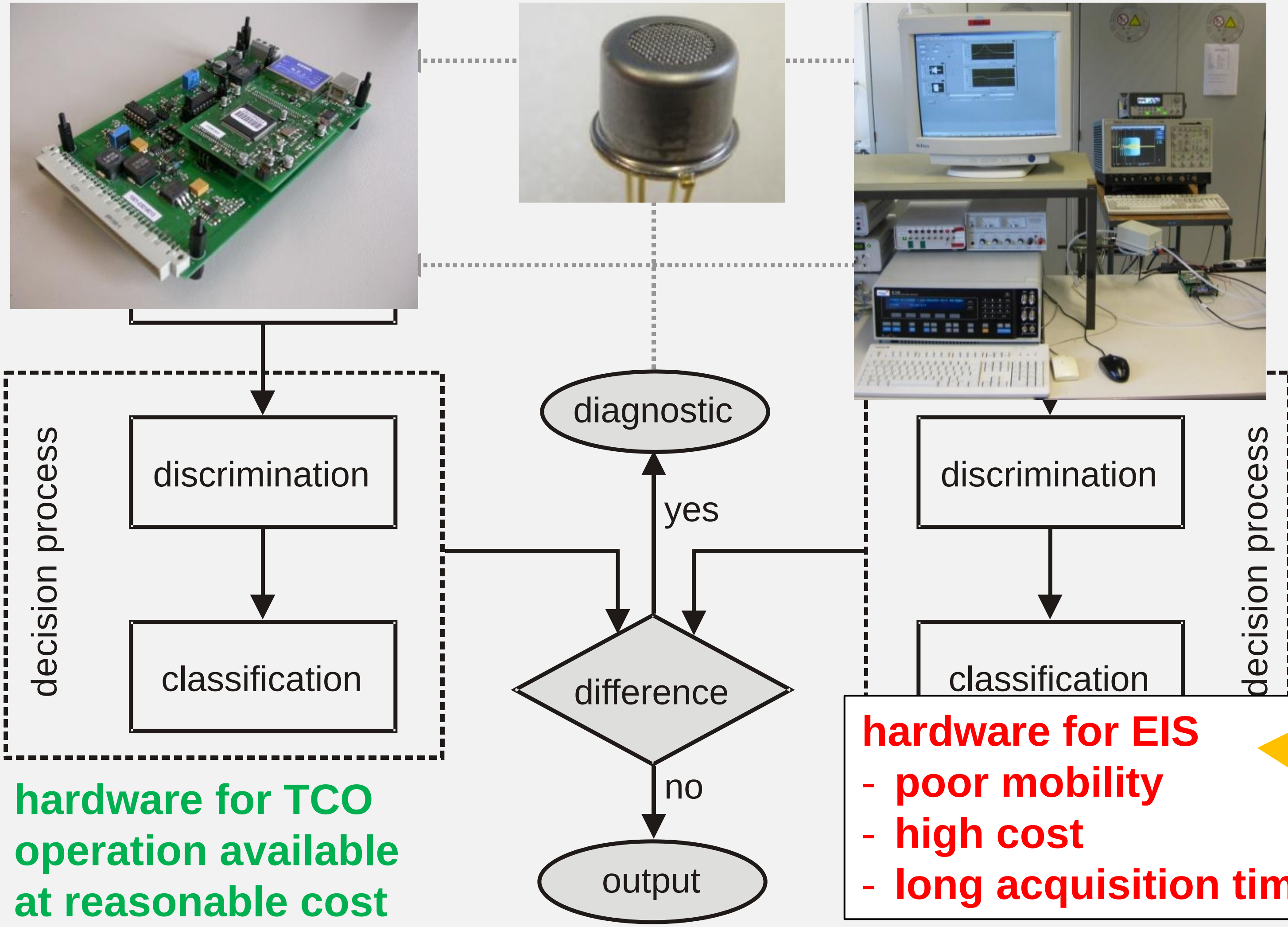
System integration: Gate Bias Cycled Operation for SiC-GasFETs





C. Bur et al.: Influence of a Changing Gate Bias on the Sensing Properties of SiC Field Effect Gas Sensors, IMCS 2012

Sensor self-monitoring with combination of TCO and EIS



hardware for TCO operation available at reasonable cost

hardware for EIS
- **poor mobility**
- **high cost**
- **long acquisition time**

A. Schütze et al.: Improving MOS Virtual Multisensor Systems by Combining Temperature Cycled Operation with Impedance Spectroscopy, ISOEN 2011