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

COST Action TD1105

2nd International Workshop *EuNetAir* on

New Sensing Technologies for Indoor and Outdoor Air Quality Control

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DETECTION OF LOW CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS WITH SiC-FETs

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SENSIC

Sensors for cleaner air

Ulf Thole, **CEO**

Mike Andersson (25%)

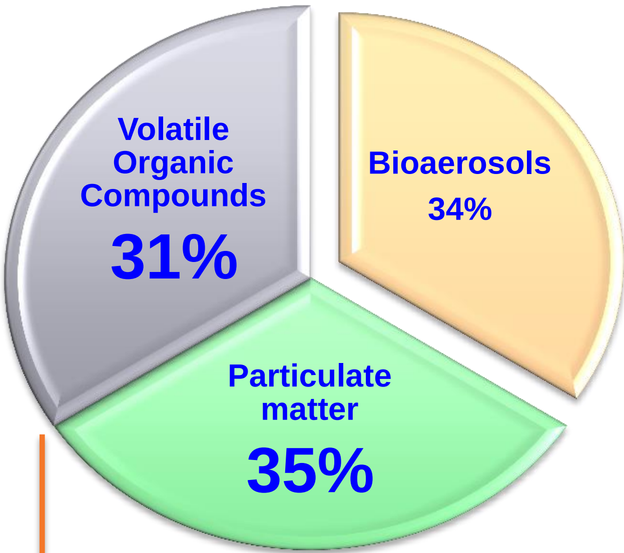
cost

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Outline

- Motivation
- Why SiC-FET for indoor AQC
- Issues: evaluation/optimization of sensors' performance and characteristics
  - Sensitivity
  - Stability
  - Detection limit
  - Response/recovery time
  - Temperature dependence
  - Effect of relative humidity
- Main achievements and open problems

Motivation



Dangerous VOCs from:

Furniture, paints, cleaners, carpeting, fuel combustion for cooking or heating, etc.

Prolonged or continuous exposure causes **health effects**, even fatal

Adequate **control** of emissions **for** more efficient **reduction** of hazardous air pollutants

Development of **highly-sensitive low cost** gas sensors able to detect **ppb** concentrations of specific VOCs for **indoor** AQC.

Why SiC-FET sensors?

- Wide band gap
- Chemical inertness

of SiC

→ **HIGH-TEMPERATURE OPERATION**

ADVANTAGES

Possibility to operate the sensor over a wide temperature range with high, stable, reproducible performance

Flexibility when using temperature cycling mode and also possibility to use high temperature for regeneration of the sensor surface

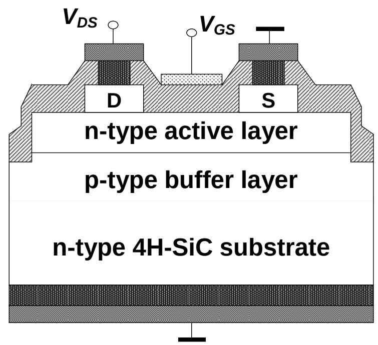
Manufacturing based on proven semiconductor processes allowing cost-efficient mass production

Large experience on FET technology and high performance commercial transistor devices available

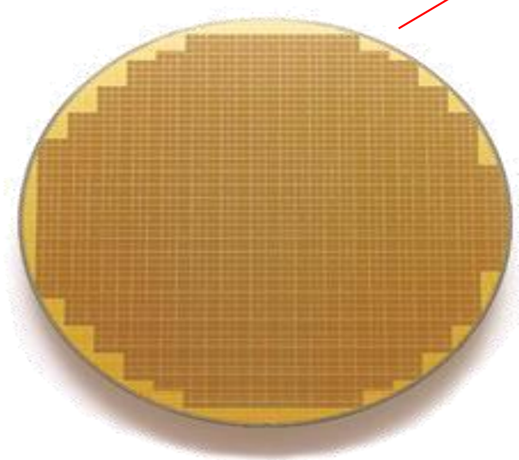
SiC-FET gas sensors fabrication

The SiC-FETs are supplied by SenSiC AB, SME company, and EuNetAir partner. Different sensing layers and operation temperatures enables detection of H_2, NH_3, CO, NO_x, HC like VOCs, H_2S, SO_2

- 30 nm Ir total thickness
- 300 µm gate width
- 10 µm gate length
- 5 µm separation between gate and source/drain

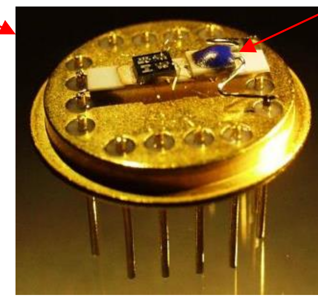


M. Andersson, R. Pearce, A. Lloyd Spetz, Sens. & Act. B 179 (2013) 95-106.



4" wafer ~ 1800 chips

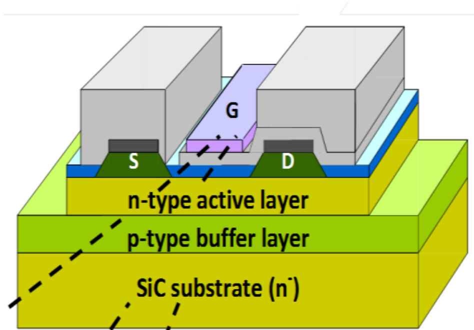
Pt-100 resistance thermometer



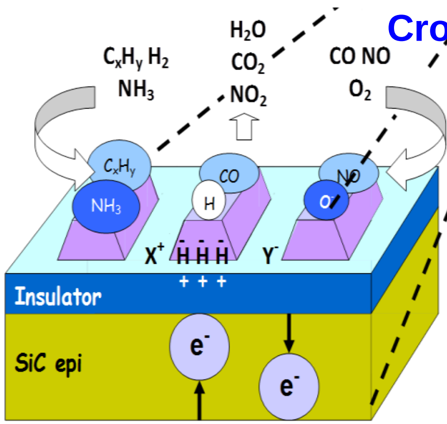
Mounting of a SiC-FET chip and Pt-100 on heater on 16 pin holder

SenSiC AB
sensors for a clean environment
www.sensic.se

FE Sensor platform

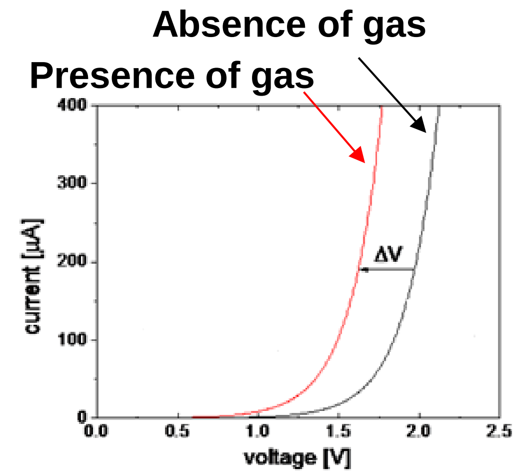


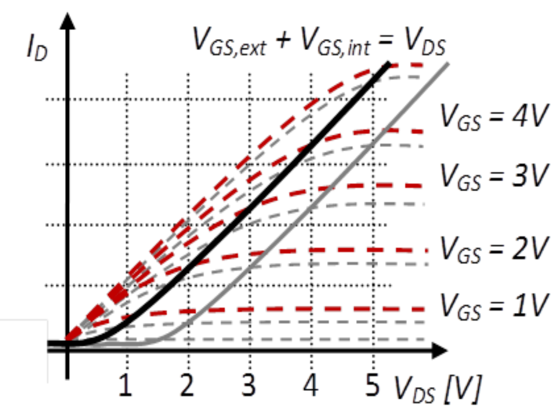
Cross section of a SiC-FET



Gate composed by a porous catalytic metal (Ir, Pt) as sensing layer

- FET current controlled by V_{GS}
- Gas molecules decompose and react on the catalytic metal
- Simple electronics





Sensitivity by

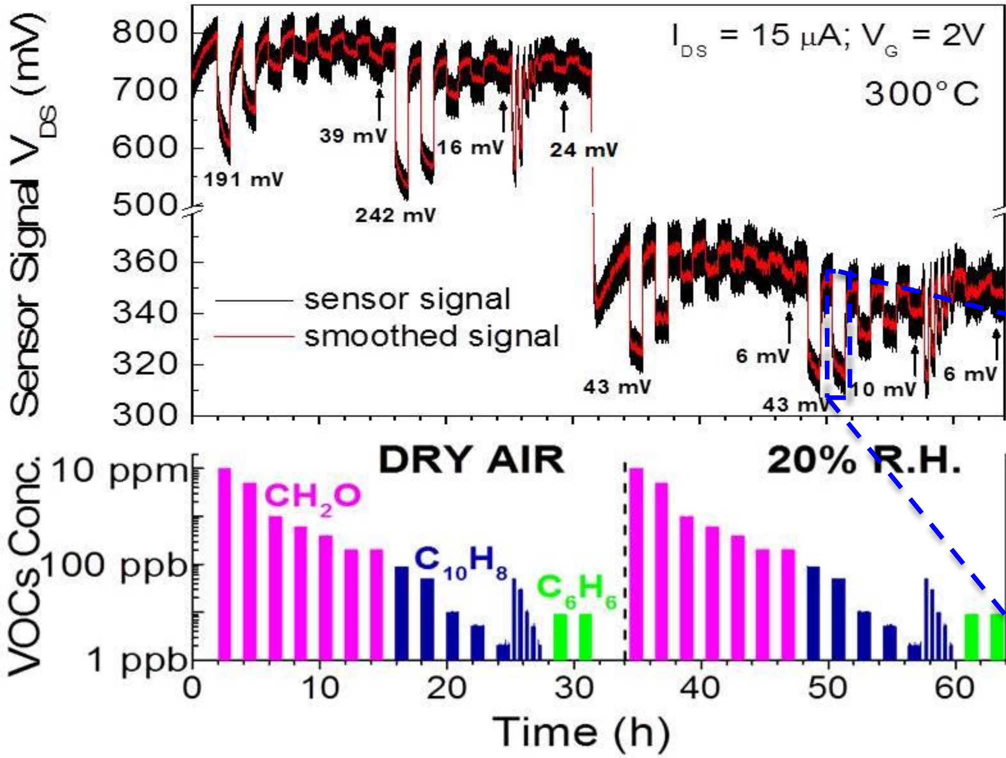
- ➢ Number of **three phase boundaries** gas-metal-oxide
- ➢ Adsorption **sites on the insulator**

Selectivity by

- ➢ Choice of **temperature**
- ➢ Different **catalytic materials**
- ➢ **Structure** of the metal

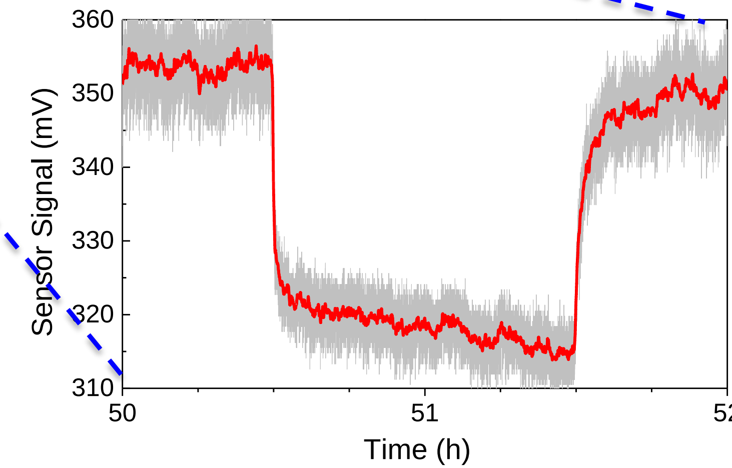
Gas adsorption/reaction at the gate contact => I-V shift

Experimental



Sensor response to ppb concentrations of **formaldehyde**, **naphthalene** and **benzene** in dry air and under 20% r.h.

- T = 260°C, 300°C, and 330°C
- Formaldehyde, naphthalene, benzene as typical VOCs
- Tests in dry air and under r.h.
- Gate bias V_G = 1-3 V to adjust sensor baseline



- Sensor signal V_{DS}: voltage at a constant current

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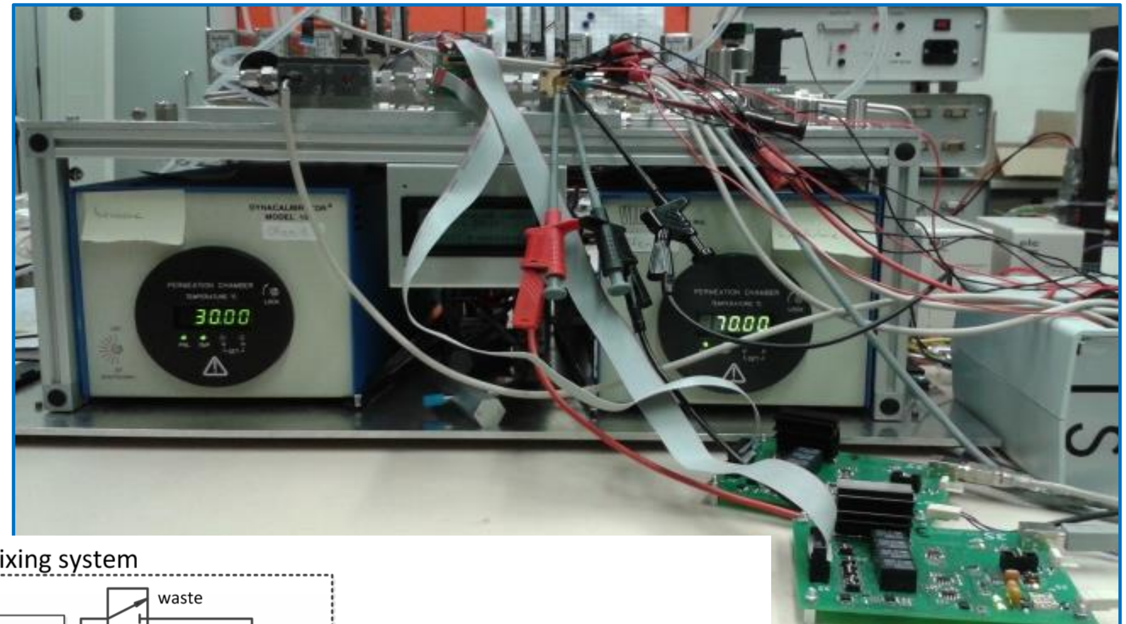
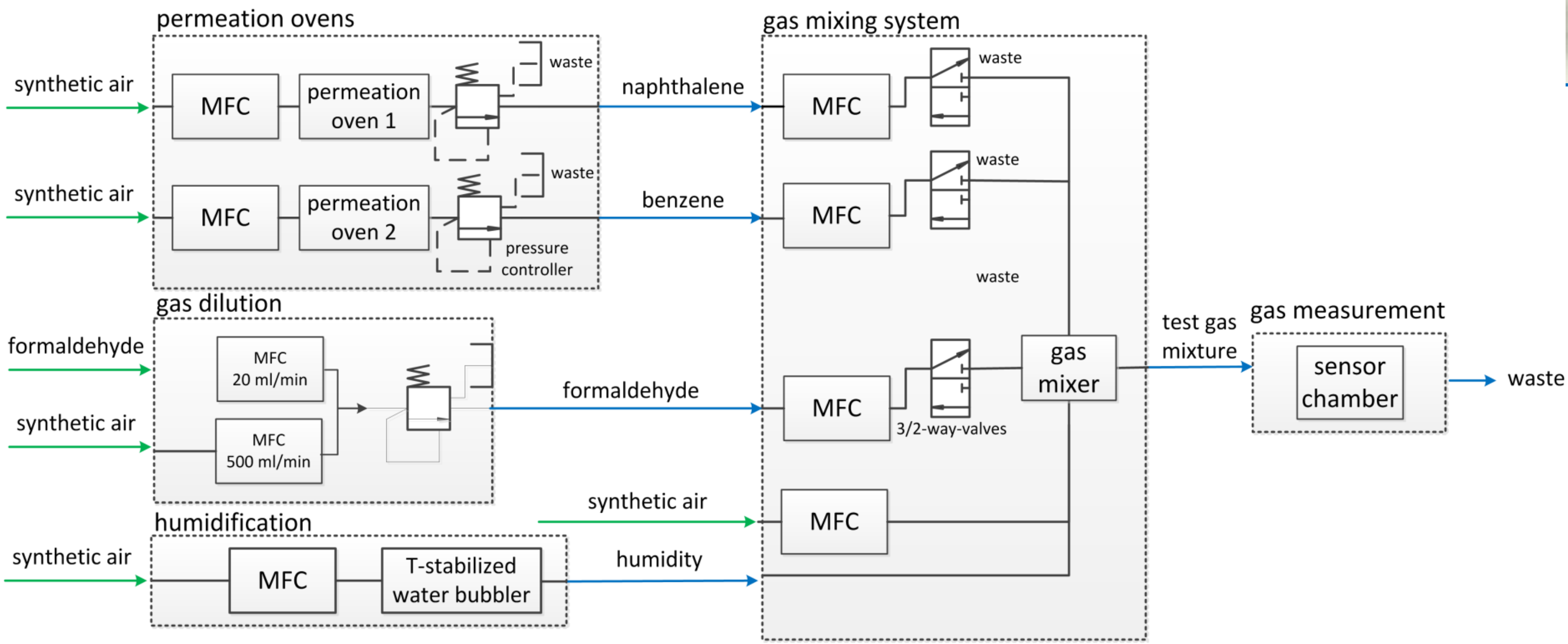
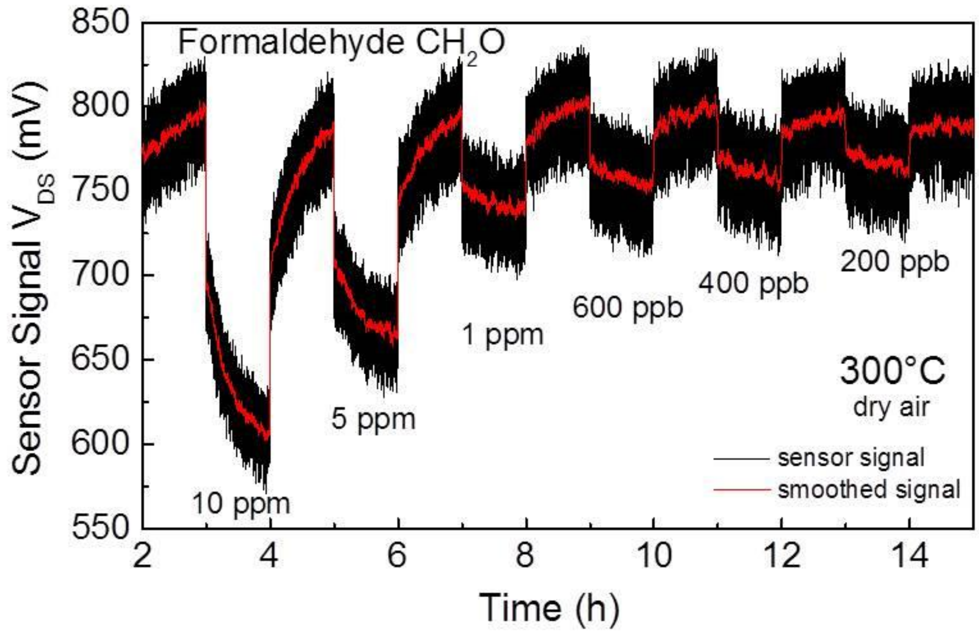
Gas mixing system at Saarland University, Laboratory for Measurement Technology, Germany

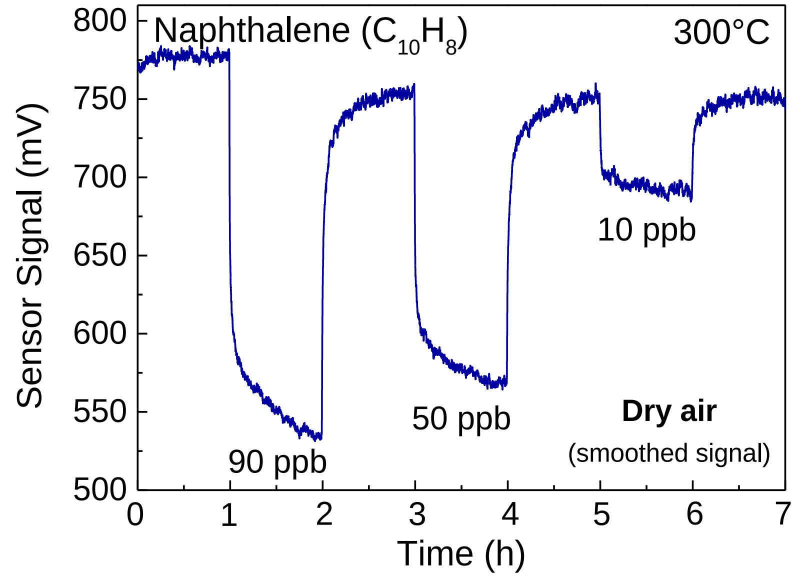




N. Helwig, M. Schueler, C. Bur, A. Schuetze, T. Sauerwald, Meas. Sci. Technol. 25 (2014) 055903 (9 pp).

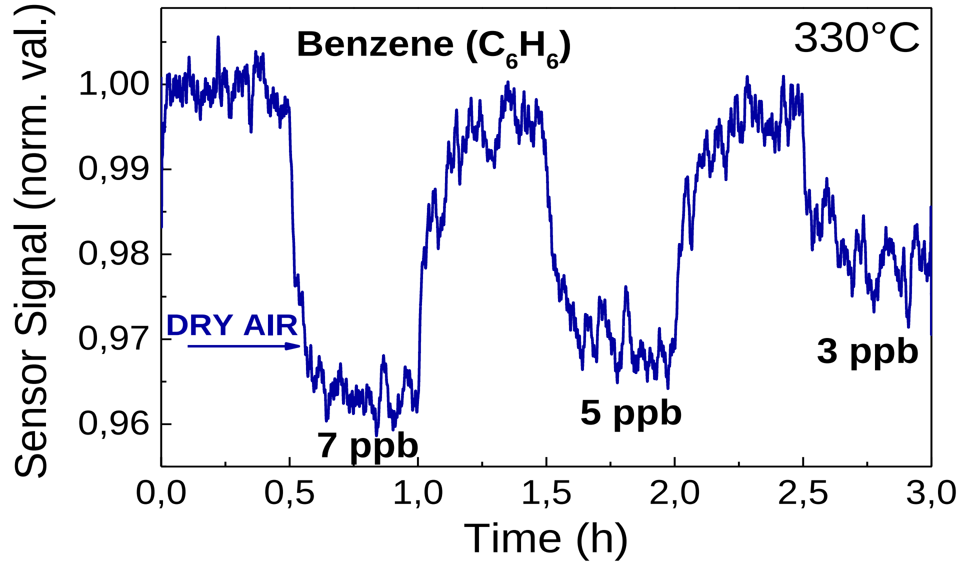


FORMALDEHYDE @ 330°C DRY AIR			
Conc. (ppb)	**Response (mV)**	**Response time (min)**	**Recovery time (min)**
100 ppb	29	9.4	22.8
1 ppb	13	3.8	2.4
500 ppt	10	4.5	13.2
200 ppt	7	2.4	1.2



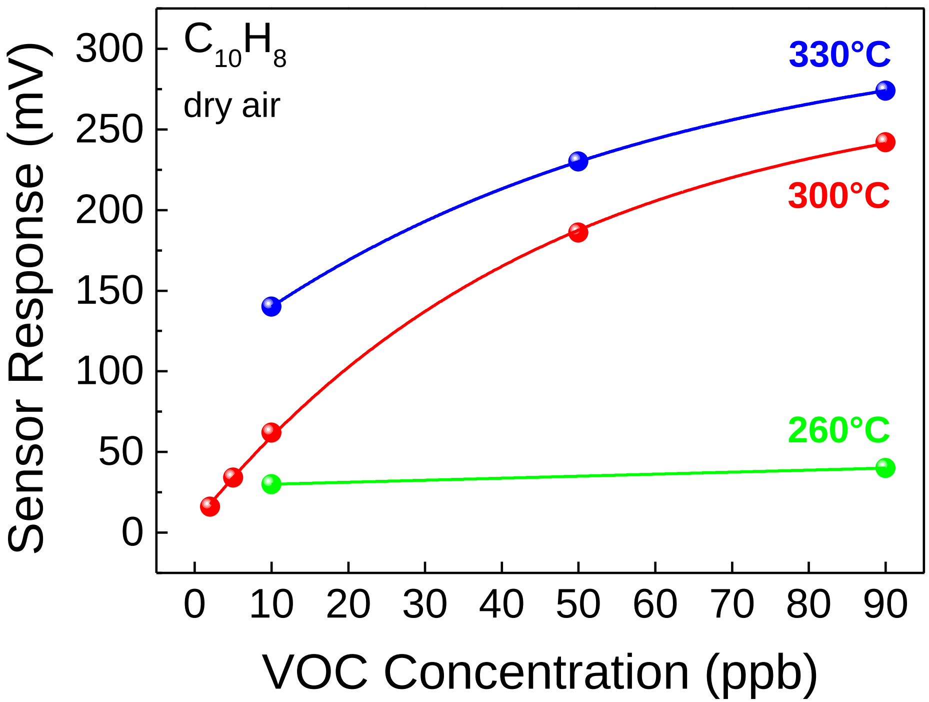
COST Action TD1105 EuNetAir Newsletter, Iss. 3/Dec. 2013.

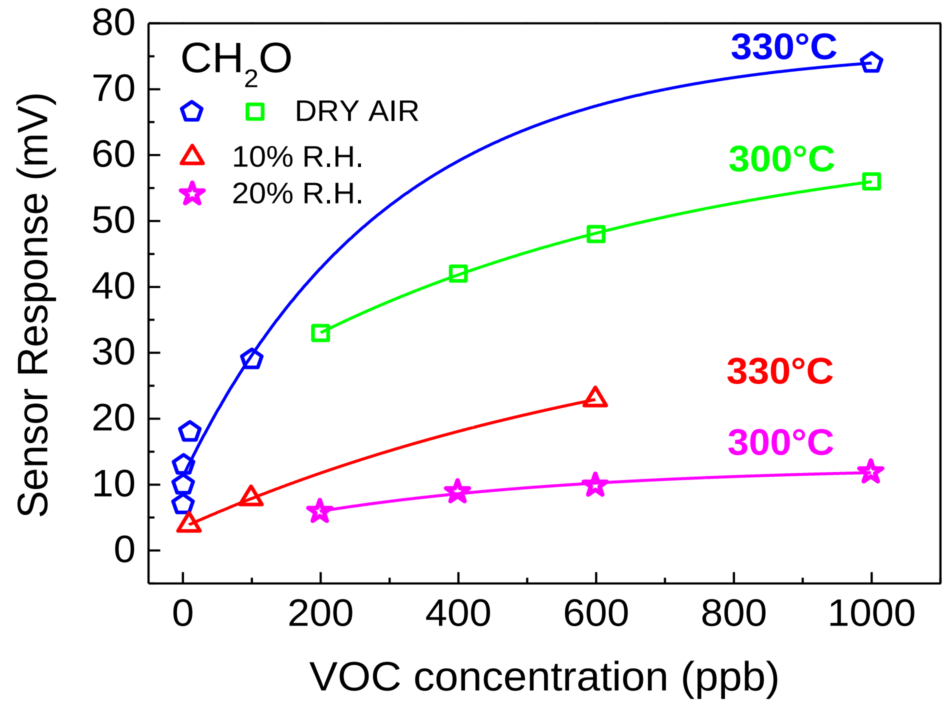
NAPHTHALENE @ 330°C						
Conc. (ppb)	**Response (mV)**		**Response time (min)**		**Recovery time (min)**	
	DRY AIR	**10% R.H.**	**DRY AIR**	**10% R.H.**	**DRY AIR**	**10% R.H.**
90 ppb	274	46	2.4	0.8	6.0	6.6
10 ppb	140	26	10.2	6.6	4.8	3.6



BENZENE @ 330°C						
Conc. (ppb)	**Response (mV)**		**Response time (min)**		**Recovery time (min)**	
	DRY AIR	**10% R.H.**	**DRY AIR**	**10% R.H.**	**DRY AIR**	**10% R.H.**
7	21	9	5.6	2.4	10.8	4.8
5	18	9	3.9	n.a.	11.8	16.0
3	12	9	8.3	7.9	n.a.	9.5

Temperature dependence and effect of relative humidity





D. Puglisi, J. Eriksson, C. Bur, A. Schuetze, A. Lloyd Spetz, M. Andersson, Mat.Sci. Forum 778-780 (2014) 1067-1070.

CONCLUSIONS

Main achievements

- Optimization of sensor performance in static operation (T_{BEST} = 330°C)
- High sensitivity to specific VOCs
- Very low detection limits (sub-ppb; few ppb)
- Good long-term stability, repeatability, reproducibility (T = const.)
- Not critical effect of high r.h. for naphthalene and benzene

Open problems

- Further investigation on how r.h. affects emission of formaldehyde
- Evaluation/Optimization of selectivity using smart operation and smart data evaluation
- Quantitative study

Upcoming activities

- Use of interferying gases (e.g. ethanol) and mixture of VOCs
- Stability of device in terms of contact degradation and impact of gate material (Ir, Pt)
- Evaluation of device performance also in comparison to different sensor designs/materials
- Characterization of structural and electrical properties of the deposited sensing layer (Ir, Pt) using SEM, TEM, c-AFM, KP, and XRD
- Field tests

Financial support / Partnership

Basis results obtained during a two-week **STSM** at Saarland University (20 May - 4 June 2013)

Grant agreement no. *604311-2*, start January 2014

Travel grant from KAW Foundation, IMCS in Buenos Aires (16-19 March 2014)

Contributions to EuNetAir events available at: http://sensindoor.eu/publications/