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

COST Action TD1105

Final Meeting at PRAGUE (CZ), 5-7 October 2016

New Sensing Technologies for Air Quality Monitoring

Action Start date: 01/07/2012 - Action End date: 15/05/2016 - EXTENSION: 15/11/2016

HIGH PERFORMANCE SiC-FET GAS SENSORS FOR HIGHLY SENSITIVE DETECTION OF HAZARDOUS INDOOR AIR POLLUTANTS

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ESF provides the COST Office through a European Commission contract

Scientific context and objectives in the Action

Why Indoor Air Pollution is such an important issue?

- **Background / Problem statement**

Inadequate ventilation as a primary cause of indoor air pollution.

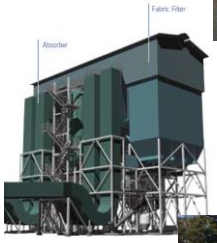
Indoor air is 2x... 5x (even 100x) more polluted than outdoor air (EPA).

Adverse effects on health, environment, economy.

- **Brief reminder of MoU objectives:**
  - **WG1:** Development of gas-sensitive nanomaterials for detection of specific air pollutants, and integration in gas sensor devices for indoor AQC
  - **WG2:** Design, fabrication, testing, characterization of low-cost, high-performance gas sensors using innovative SiC-FET sensor technology

Current research activities at Linköping University

- **Current research topics / Problem statement:**
  - Highly sensitive, selective, low-cost gas sensors for indoor/outdoor AQC applications (NO_x, NH_3, SO_2, methane, VOCs,…), e.g.:
    - Combustion control in car exhausts
    - Monitoring ammonia slip in selective catalytic reduction (SCR) systems of diesel trucks
    - Sulfur dioxide monitoring in power plants
    - Particle detectors

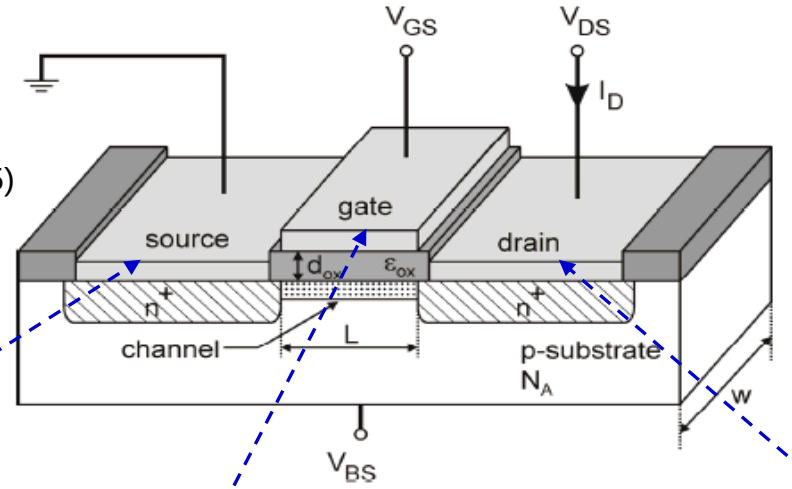


- **Within SENSIndoor:**
  - Development of high performance SiC-FETs (LiU, SenSiC)
  - Characterization of optimized sensing layers (LiU, U. Oulu, Picodeon)
  - Smart operation and advanced data evaluation (USAAR)
  - Field tests (ongoing)

SiC-FET – Transducer platform

Highly favorable for gas sensing applications

Adapted from C. Bur, Doctoral Thesis (2015)



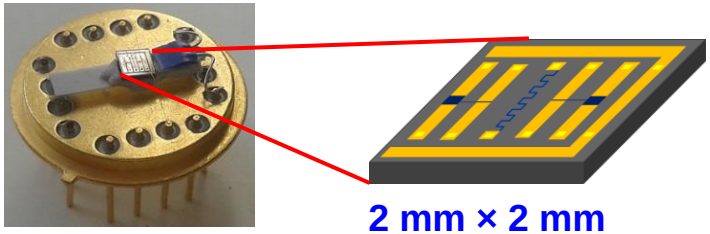
Source of the charge carriers

Metal contact, crucial to make a MISFET gas sensitive

The current I_D flows from drain to source

Innovation SiC-FET:

- Detection limits under threshold of legal requirements
- Discrimination and quantification of specific VOCs
- Stability during long-term operation



2 mm × 2 mm

SENSIC
Sensors for cleaner air

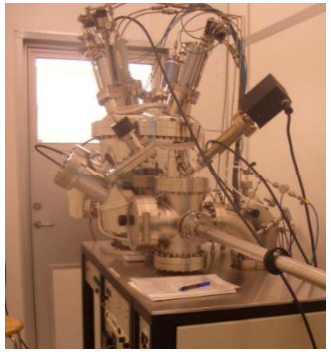
Fabrication of the sensing layer

- **Pure metal (Ir, Pt)**
- **Pure metal oxide (WO_3, V_2O_5)**
- **Metal/Metal oxide (Ir/WO_3, Pt/WO_3)**

Reproducibility of chemical composition

Control of crystal structure, stochiometry

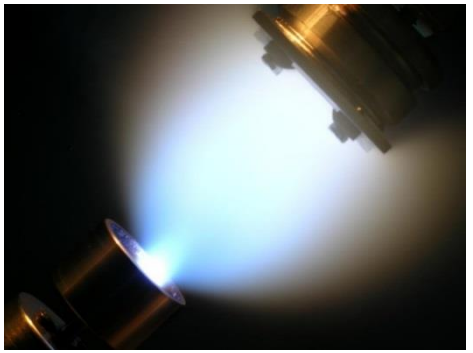
DC Magnetron Sputtering



LINKÖPING UNIVERSITY

Ir, Pt

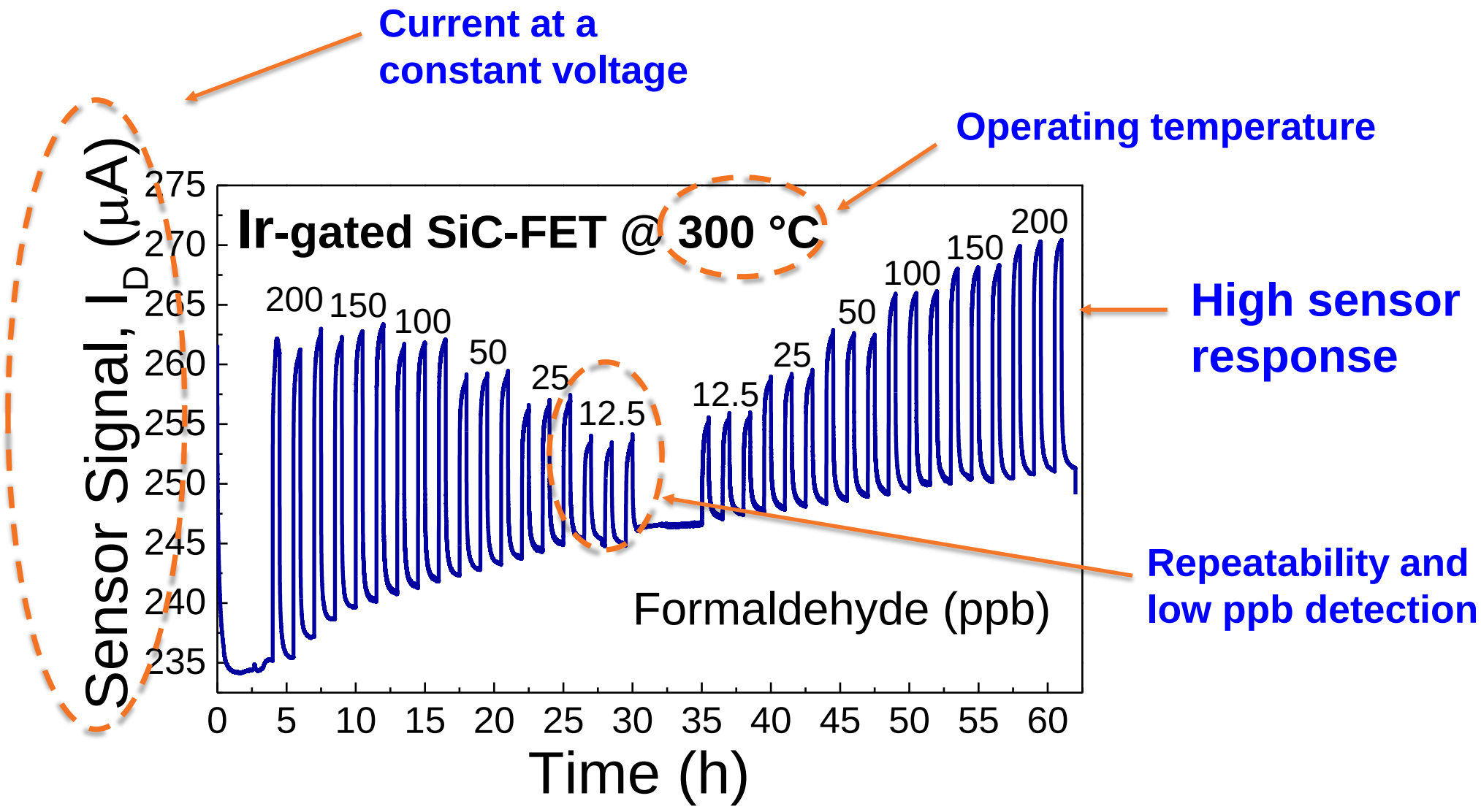
Pulsed Laser Deposition (PLD)



UNIVERSITY of OULU
OULUN YLIOPISTO

WO_3, (V_2O_5)

Sensor Signal

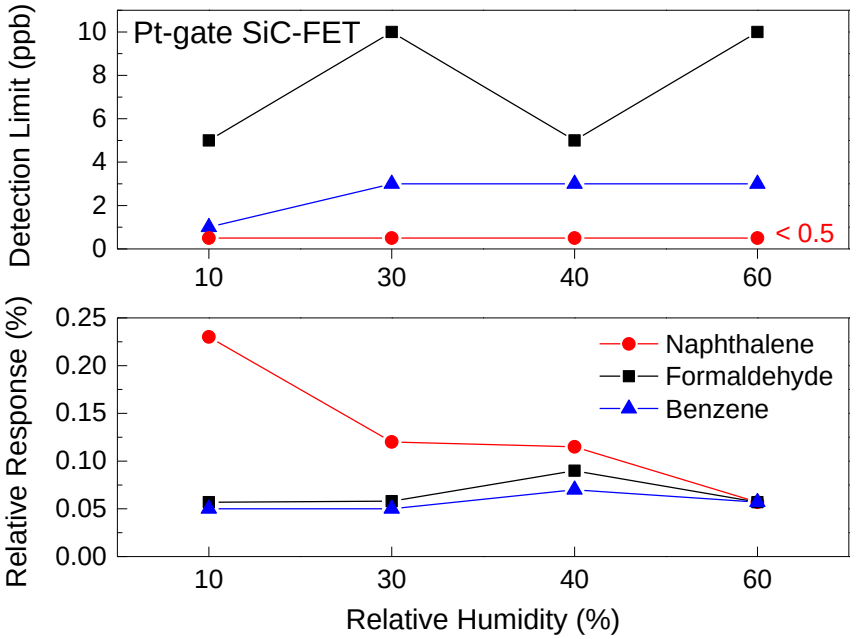


Challenge addressed: extremely high sensitivity

Pt-gate

Detection limits under threshold of legal requirements

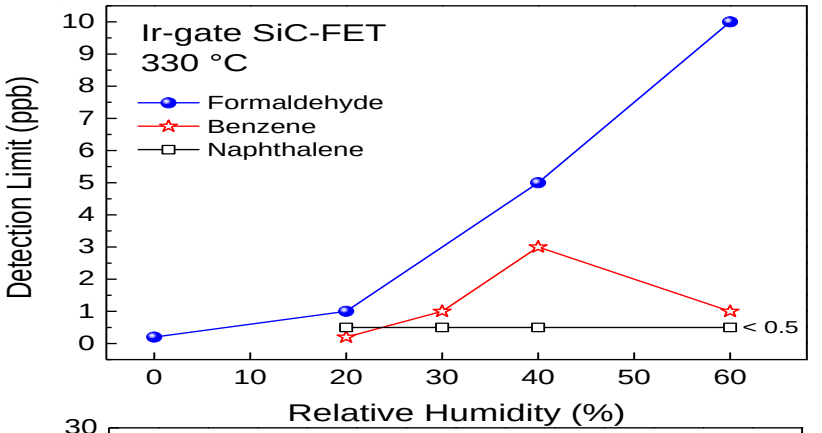
Faster response time

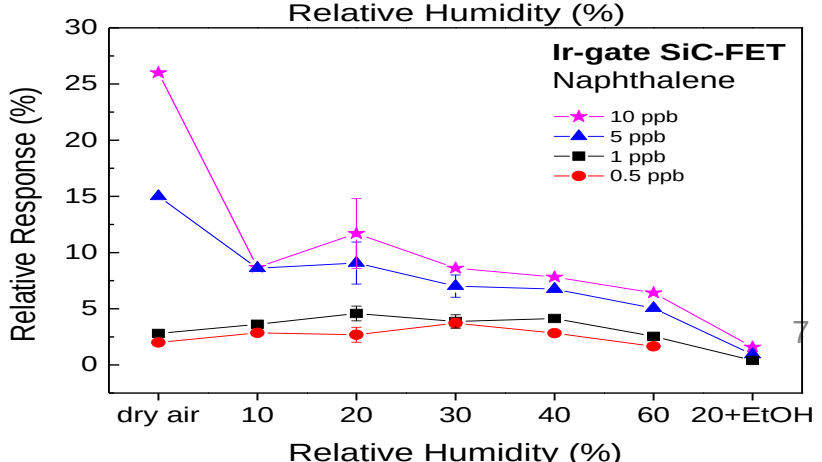


Ir-gate

Detection limits under threshold of legal requirements

Higher relative response



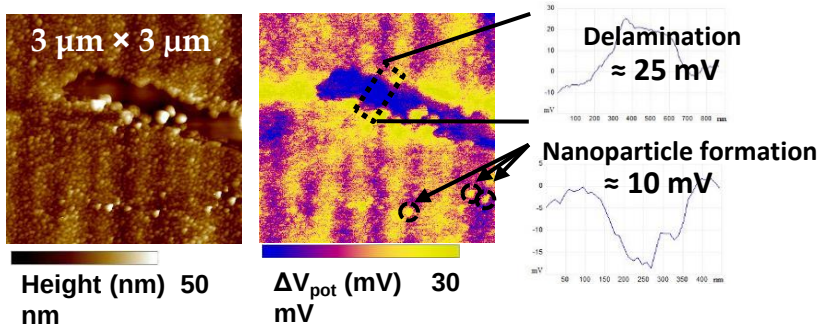


cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Challenge addressed: long-term operation

Pt-gate

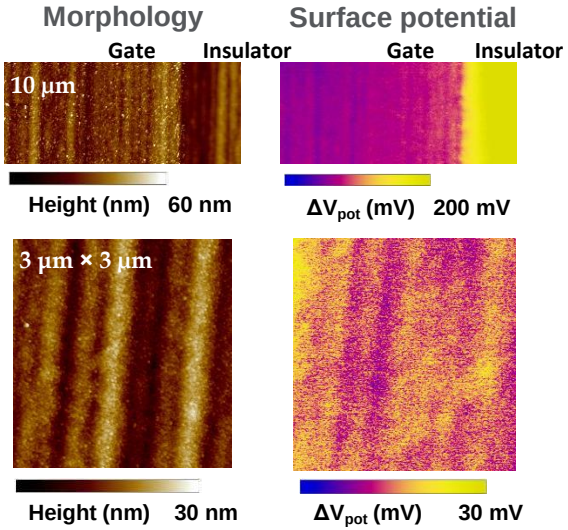
Degradation of sensing layer



J. Eriksson (2014)

Ir-gate

No degradation of sensing layer

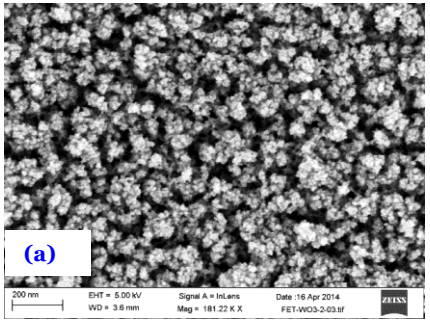


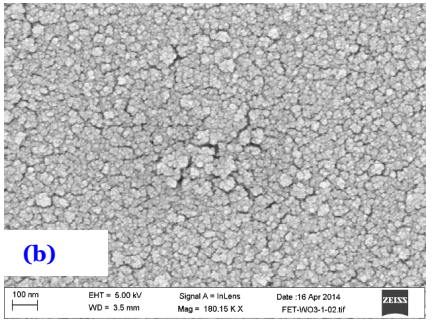
➢ **Ir-gate SiC-FET: extremely high sensitivity and robustness!**

WO_3: porous or thin film?

PLD depositions at Univ. Oulu

- **Porous** as-deposited **WO_3 layers** by PLD at RT and (a) p(O_2) = 0.2 mbar or (b) 0.08 mbar (SEM images).

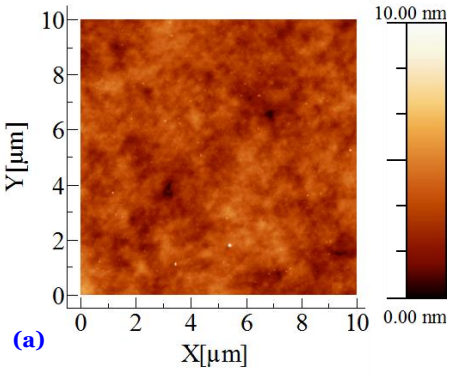


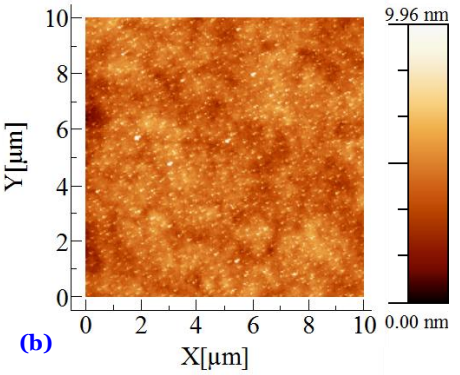


The gate contact is pure WO_3.

- Poor sensitivity and lack of selectivity due to
  - Wide band gap, high resistivity, low reactivity of the MOX
- Short life time, lack of stability

- **Dense WO_3 thin films** deposited in-situ by PLD at 450 °C and (a) p(O_2) = 0.02 mbar or (b) 0.05 mbar (AFM images).

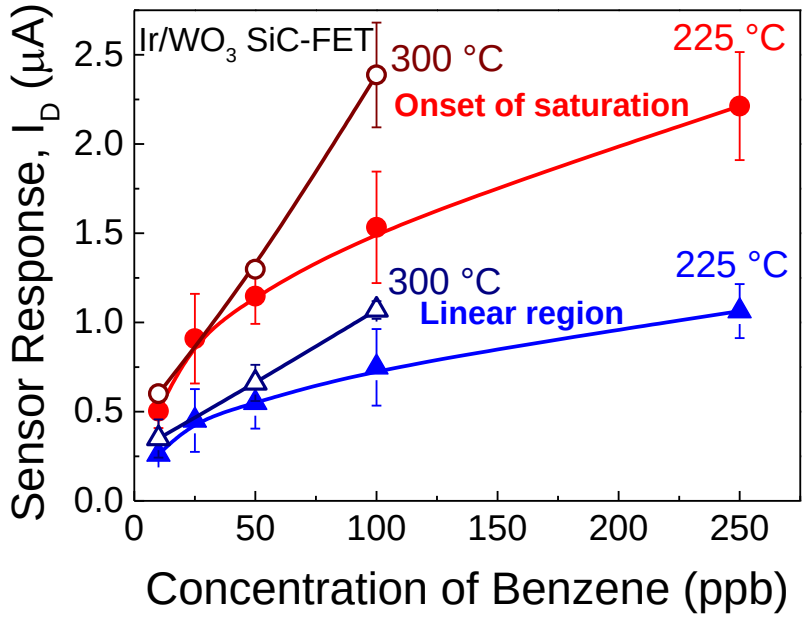


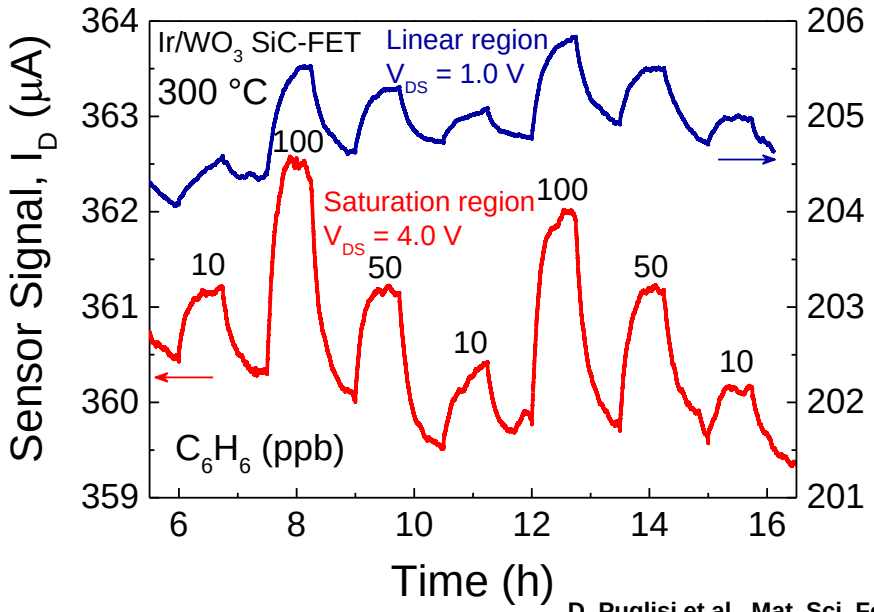


The gate contact is processed by sputter deposition of porous Ir on top of WO_3 (Ir/WO_3).

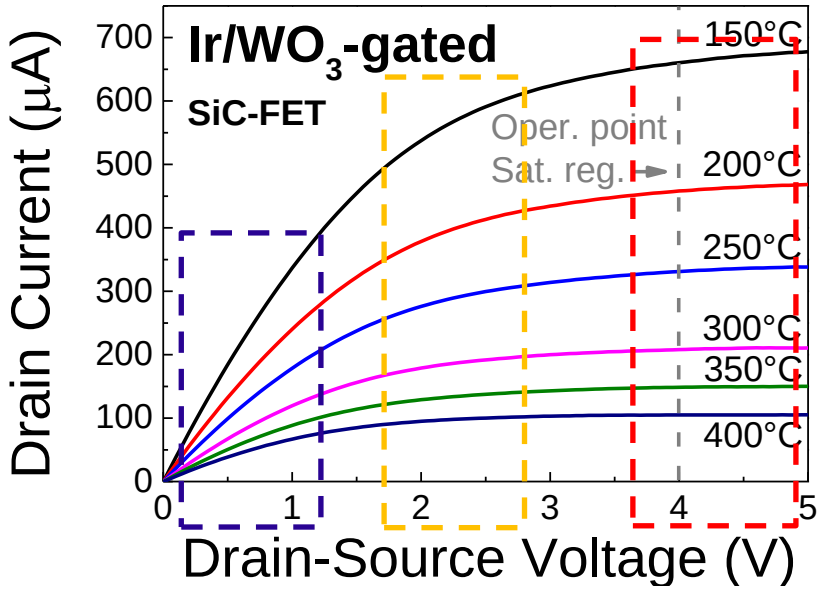
- Addition of a noble metal to enhance sensitivity and selectivity
- Ir is among the most effective catalysts for sensing reducing gases (e.g. HC)

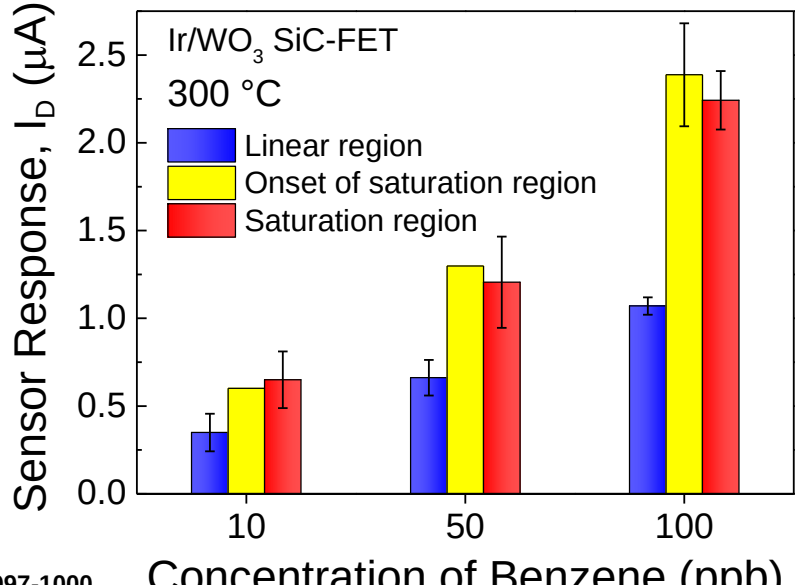
Temperature dependence





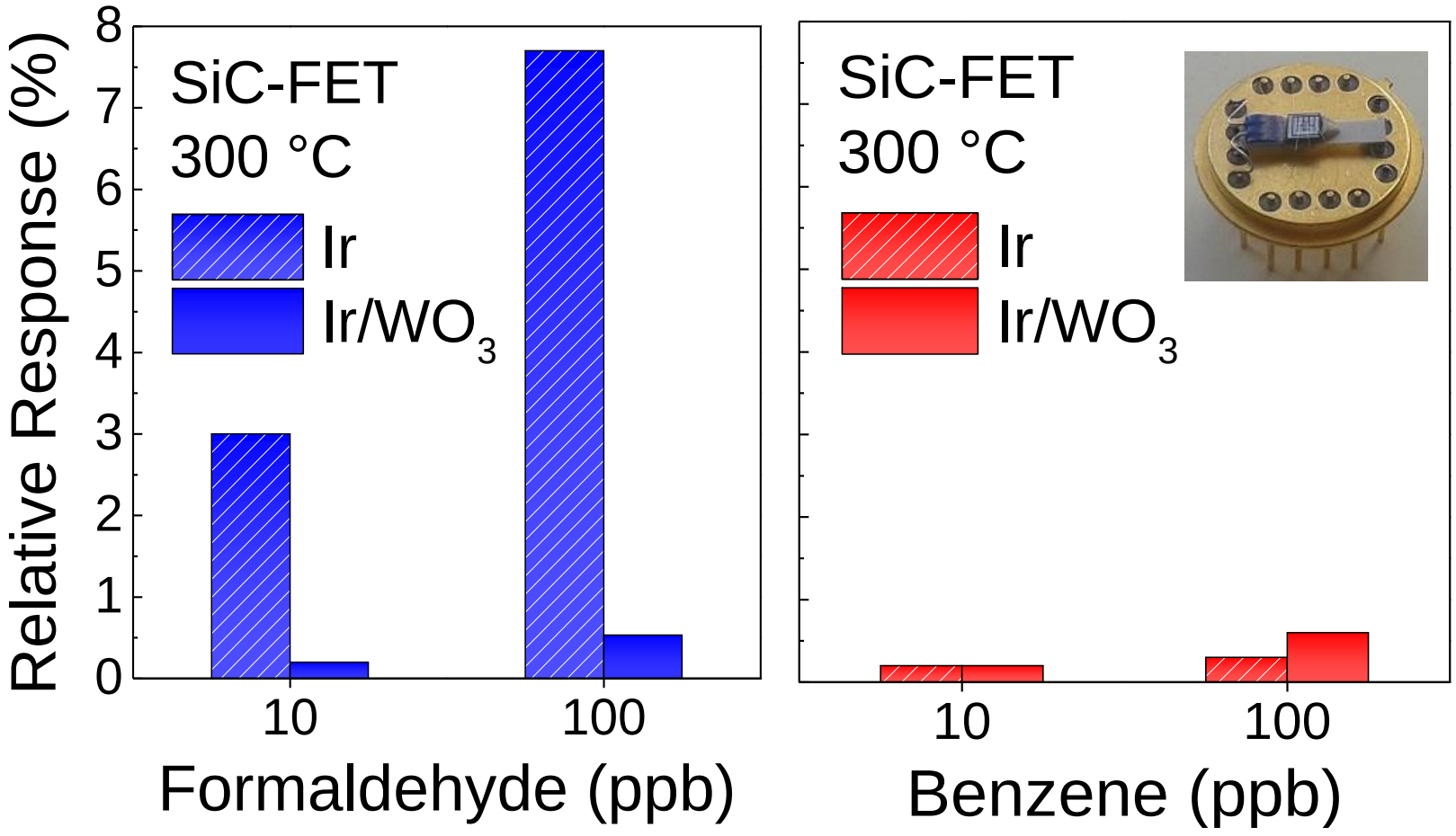
Effect of the electrical operating point





D. Puglisi et al., Mat. Sci. Forum 858 (2016) 997-1000.

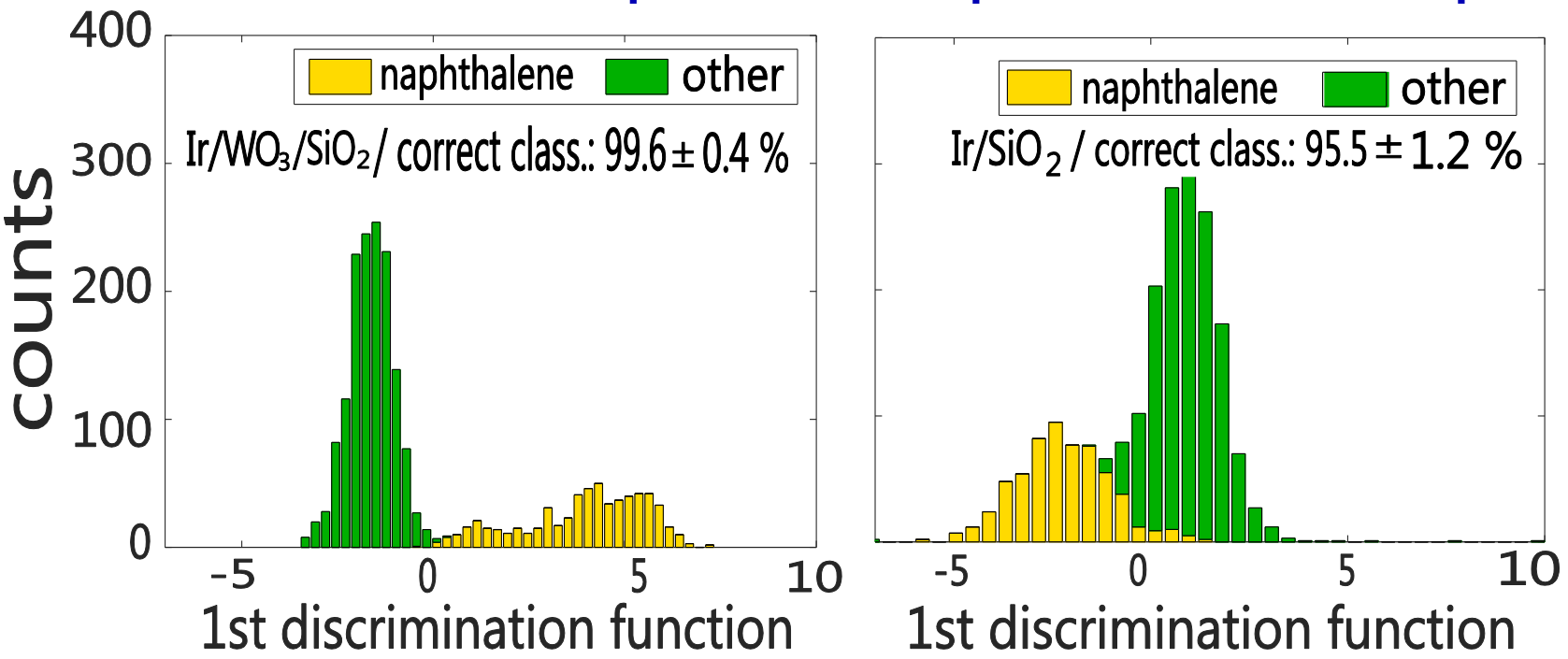
Sensitivity Ir vs Ir/WO_3 SiC-FETs

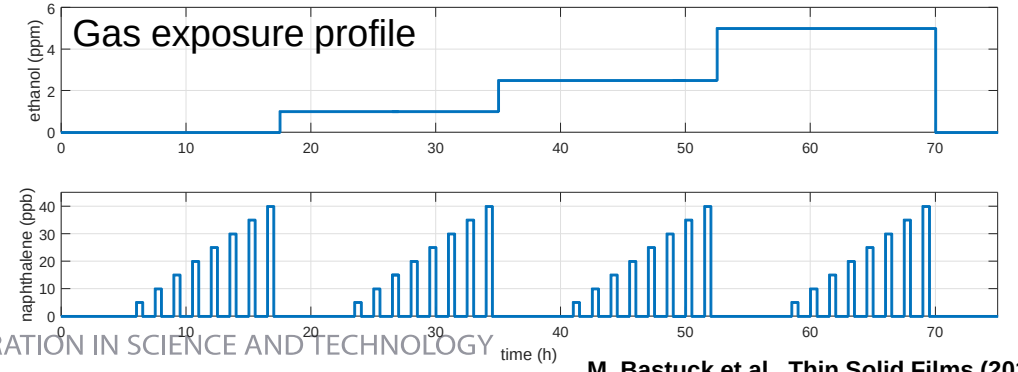


D. Puglisi et al., Conf. Proc. Indoor Air 2016.

Challenge addressed: **Enhanced selectivity to naphthalene with Ir/WO_3**

Discrimination of naphthalene independent of ethanol's presence

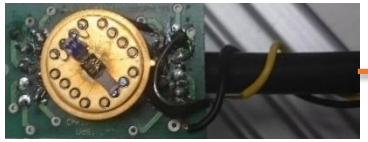




M. Bastuck et al., Thin Solid Films (2016), in press.

Field test **setup**

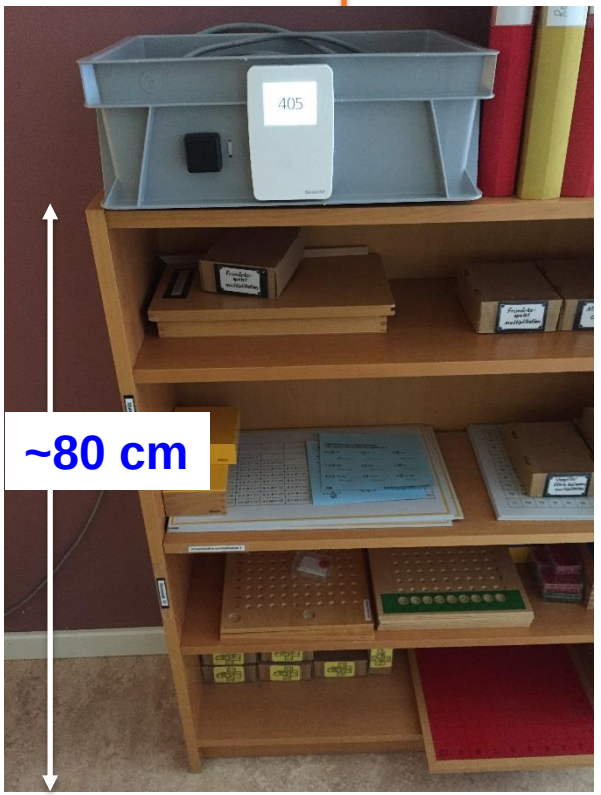
Montessoriskolan Trilobiten, Linköping
Jun. – Sept. 2016



FET

3S electronics

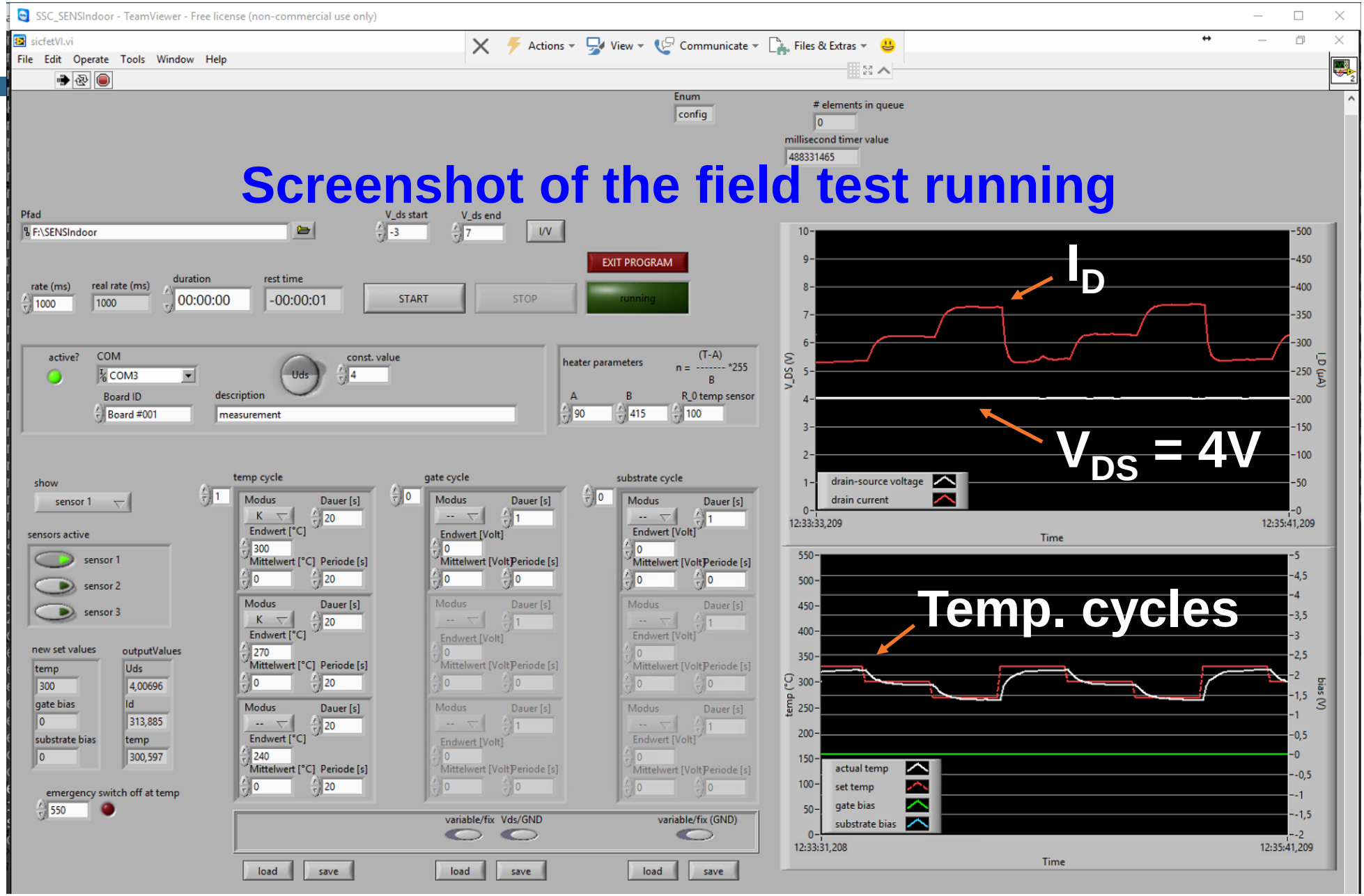
FM-801
CH_2O monitor



Mini-PC/
Computer stick
4G modem
NI-DAQ 6215

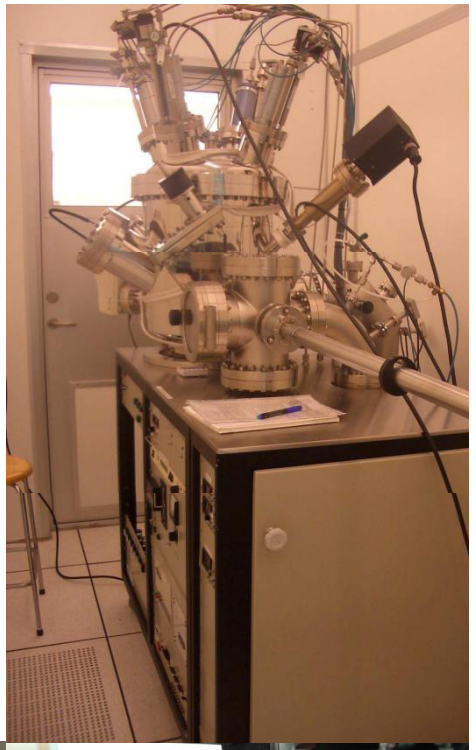
SenseAir
CO_2
Temp.
Hum.

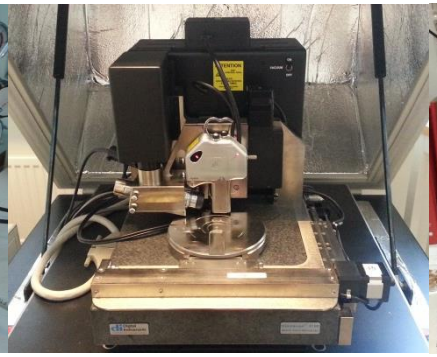
Screenshot of the field test running

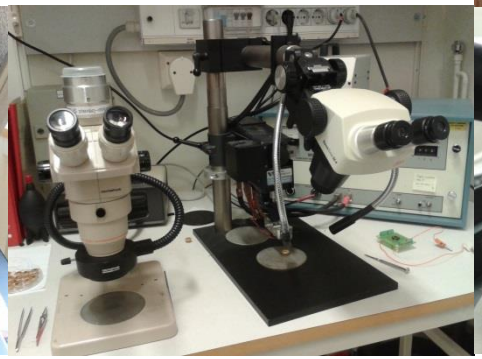


Research Facilities available for current research

- Clean room, ISO 6 (magnetron sputtering, lithography, CVD, etc.)
- Sensor processing and characterization (gas mixing systems, readout electronics, bonding machine, spot welding, scribers, thermal evaporation, shadow masks, optical microscopes, AFM, SEM, etc.)
- Hardware and software for data acquisition and data analysis
- Gas bottles: CH_2O, C_6H_6, CO, NO, NO_2, NH_3, N_2, O_2, synthetic air
- Other facilities available at: Saarland University, SenSiC, University of Oulu, Picodeon, 3S







Suggested R&I Needs for future research

Research direction

- Field tests: evaluation and testing
- Networking / complementary cooperation
- Dissemination of results / press release within and outside Europe, web

R&I Needs

- Creation of a sustainable environment for the future generations and ourselves: healthy, comfortable, energy-efficient
- Development of low cost, user-friendly sensors/sensor systems for detection of specific hazardous VOCs (formaldehyde is hot topic) – today CO_2, TVOC

Innovation SiC-FET

- Versatile technology – operation over a wide temperature range
- Extremely high sensitivity – detection limits under threshold of current legal requirements
- Enhanced selectivity through optimization of the sensing layer and dynamic operation (TCO) – discrimination and quantification (formaldehyde, benzene, naphthalene)

Benefits

- Our SiC-FET sensor will work as a switcher: for on demand ventilation, «below threshold» means ventilation not needed – low cost, energy-efficient, user-friendly

Acknowledgements

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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

SENSIndoor

FunMat

SENSIC
Sensors for cleaner air

incl. STSM at USAAR (2013)

Thank you for your attention!