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: 30/06/2016 - EXTENSION: 15/11/2016

Gas and Particle sensors in the framework of EuNetAir

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Deputy Chair

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University of Oulu, Finland

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COST is supported by the EU Framework Programme

ESF provides the COST Office through a European Commission contract

COST Action TD1105 *EuNetAir*: 31 COST Countries (Parties) have signed Memorandum of Understanding (MoU)

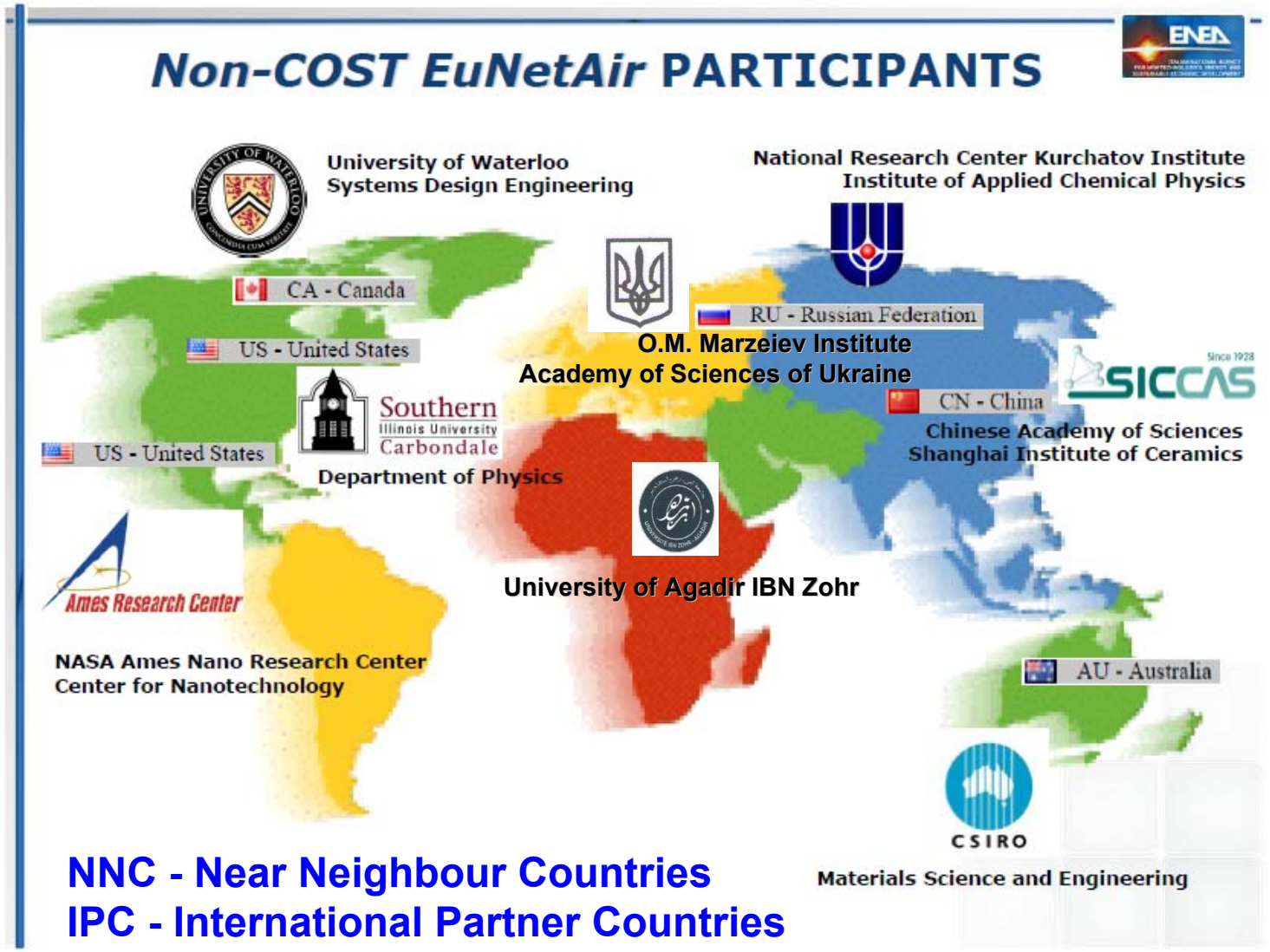
PARTIES:
already accepted
MoU: 28 Countries
Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, The Former Yugoslav Republic of Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom.

http://www.eunetair.it/

COST Action TD1105 *EuNetAir*: 7 Non-COST Countries and 8 Non-COST Institutions

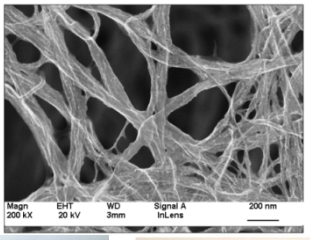
Non-COST Countries:
Australia, Canada, China, Morocco, Russia, Ukraine, USA

Non-COST Institutions:
CSIRO (Australia); University of Waterloo (Canada); Chinese Academy of Sciences, Shanghai Institute of Ceramics (China); University of Agadir IBN Zohr (Morocco); National Research Center Kurchatov Institute (Russia); O.M. Marzeiev Institute for Hygiene and Medical Ecology of Academy of Science of Ukraine (Ukraine); Southern Illinois University Carbondale, NASA Ames Research Center (USA).

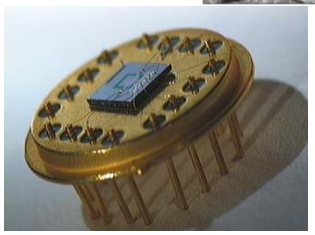


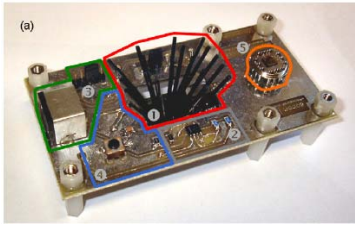
http://www.eunetair.it/

Challenges addressed by Action TD1105

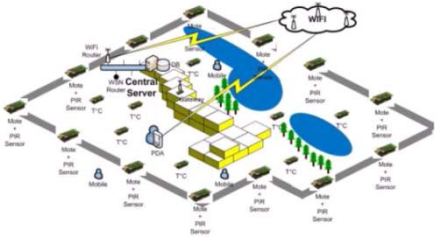


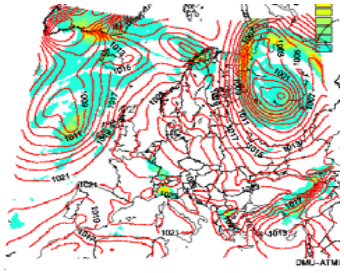
- **Nanomaterials for AQC sensors**
- Low-cost Gas Sensors



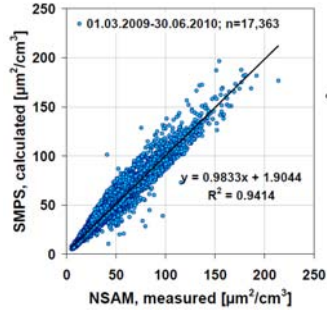


- **Low-power Sensor-Systems**
- **Wireless Technology (*Environmental Sensors Network*)**



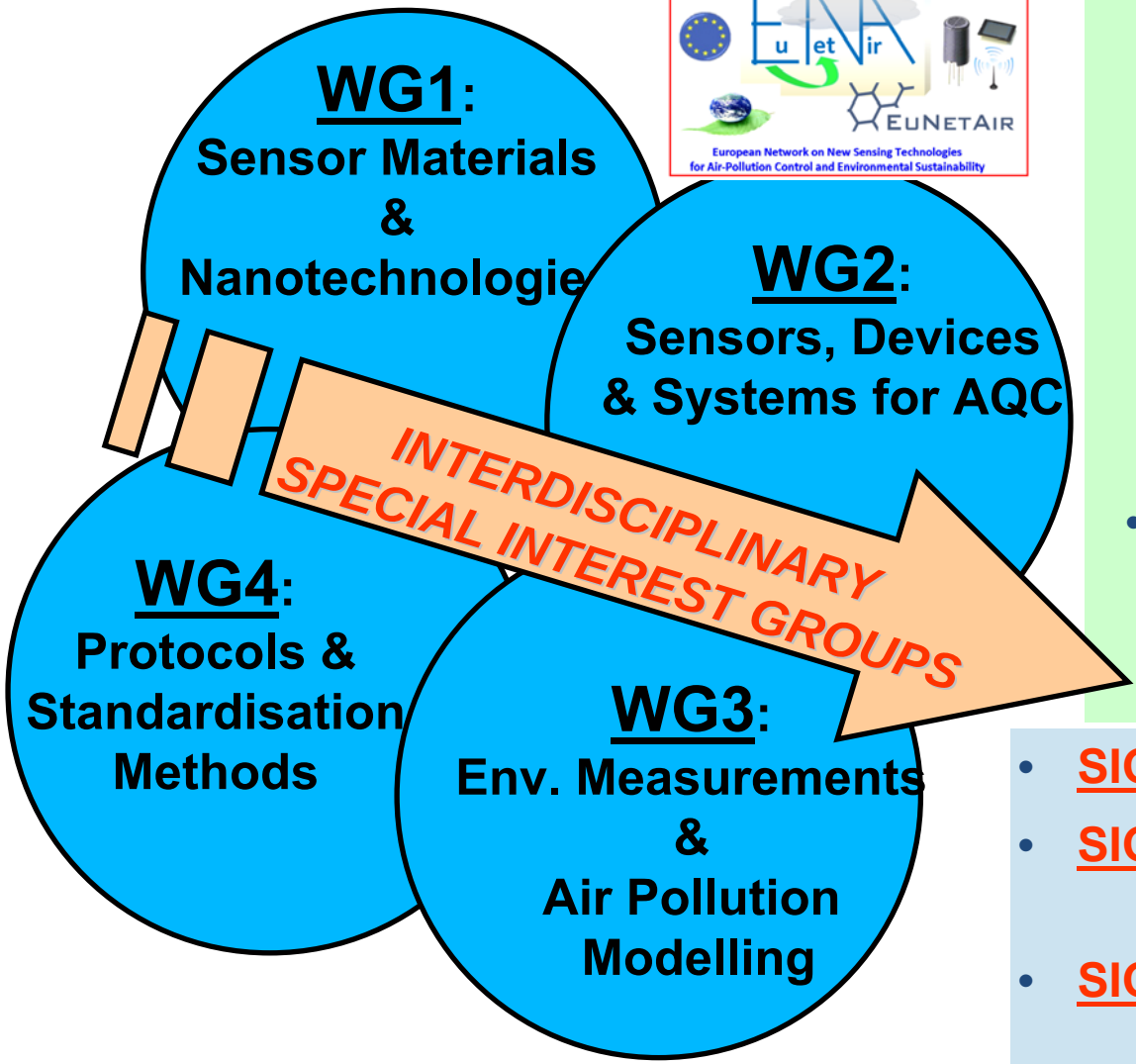


- **Air Quality Modelling**
- **Environmental Measurements**
- **Standards and Protocols**



Activities covers the whole sensor system area for AQC

Action TD1105 *EuNetAir*: Working Groups



cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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

MANAGEMENT COMMITTEE:

CORE-GROUP & STEERING COMMITTEE

- *Editorial Board*
- *Dissemination*
- *Training Schools*
- *Gender Balance*
- *Early Stage Researchers (ESR)*
- *Short-Term Scientific Mission (STSM)*
- *Intellectual Property Rights (IPR)*
- *Local Organizing Committee (LOC)*

- SIG 1: *Network of Spin-offs*
- SIG 2: *Smart Sensors for Urban Air Monitoring in Cities*
- SIG 3: *Guidelines for Best Coupling Air Pollutant-Transducer*
- SIG 4: *Expert comments for the Revision of the Air Quality EU Directive*

cost
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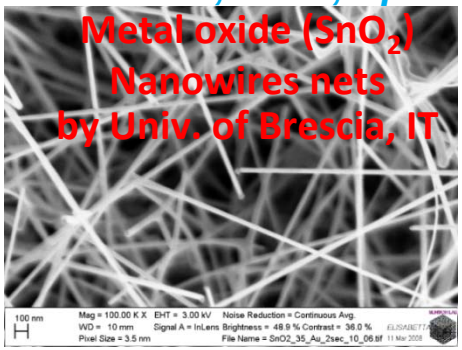
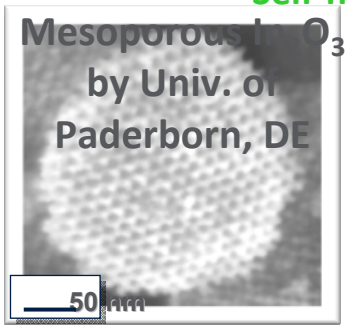
TD1105 *EuNetAir* WG1: Sensor Materials & Nanotechnologies

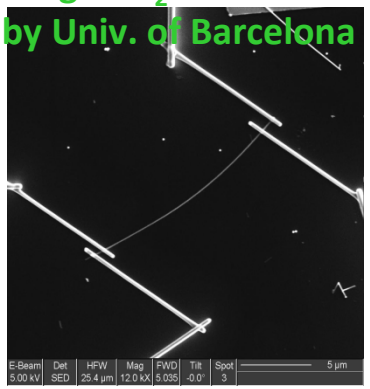
WG1 Chair: Prof. Juan Ramon Morante, IREC, Spain

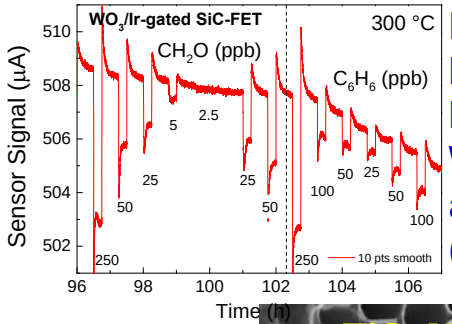
- **Sub-Working Group 1.1**: Metal oxides nanostructures for AQC gas sensors.
- **Sub-Working Group 1.2**: Carbon nanomaterials for AQC gas sensors.
- **Sub-Working Group 1.3**: Emerging sensor materials (organic/inorganic, hybrid, nanocomposites, polymers, functional, etc.).



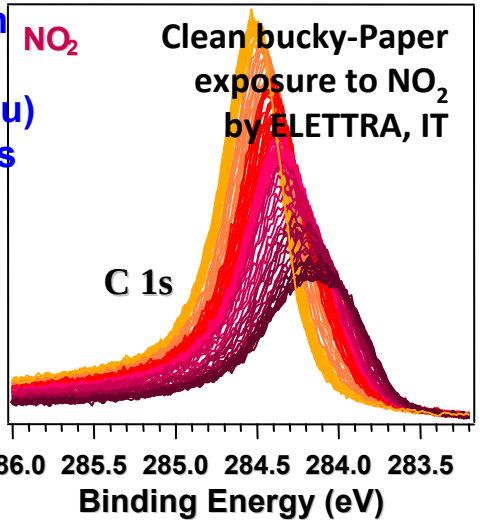


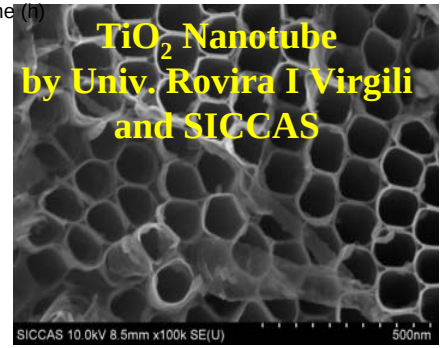
Self-heating SnO_2 Nanowires
by Univ. of Barcelona



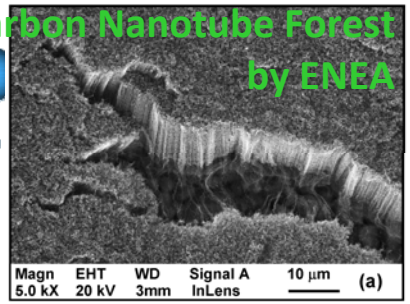


Formaldehyde and benzene detection by PLD deposited WO3 (Univ. of Oulu) and Ir on SiC-FETs (Linköping Univ.)

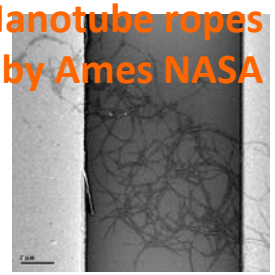




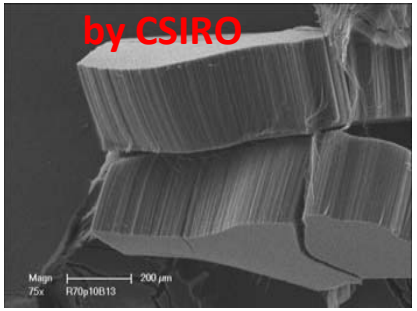
New molecular materials of polymer-macrocycles as transducers for polluting gas sensing by University of Bourgogne



Carbon Nanotube ropes by Ames NASA



Carbon Nanotube yarns by CSIRO



Nanotechnology provides reproducible nanostructured sensor materials due to the possibility to characterize and control on the nanolevel

http://www.eunetair.it/

TD1105 *EuNetAir* WG2: Sensors, Devices and Systems for AQC

WG2 Chair: Prof. Andreas Schuetze, Saarland University, Germany

- **Sub-Working Group 2.1**:

  Gas sensors and new transducers.

- **Sub-Working Group 2.2**:

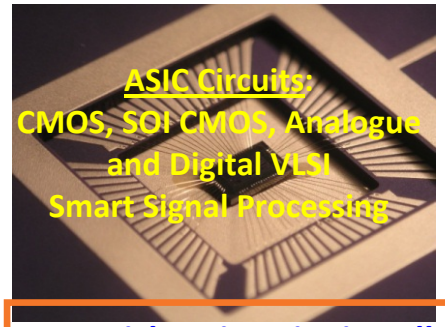
  Portable gas sensor-systems.

- **Sub-Working Group 2.3**:

  Wireless technology and AQC sensors network.

- **Sub-Working Group 2.4**:

  Intelligence algorithms and distributed computing for networked AQC gas sensors.

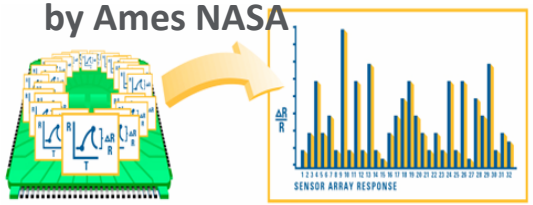


Warwick University in collaboration with Cambridge University, EPFL, PennState.

IT PATENT ENEA
Carbon Nanotube Gas Sensors

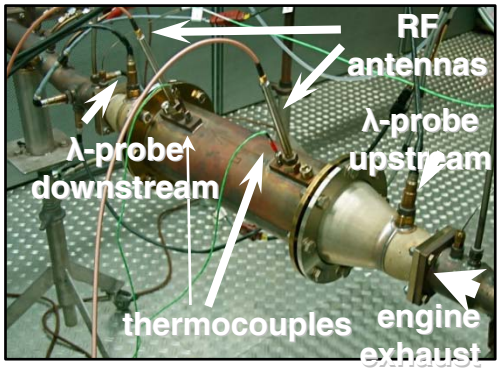
EnviroWatch mote by Newcastle University

by Ames NASA



Using pattern matching algorithms, the data is converted into a unique response pattern

A versatile platform for the efficient development of gas detection systems based on automatic device adaptation by University of Saarland.

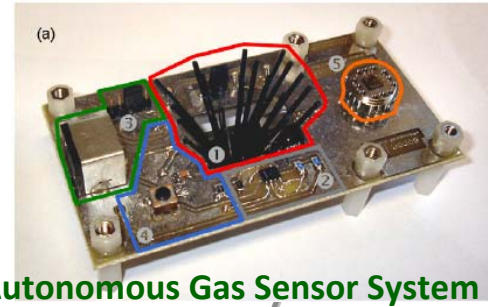


Direct status measurement of automotive catalysts by radio-frequency technique by University of Bayreuth, DE.

"Your own" sensors best, all needed, complementary information, numerous applications

Environmental Sensor demo by IMEC, NL

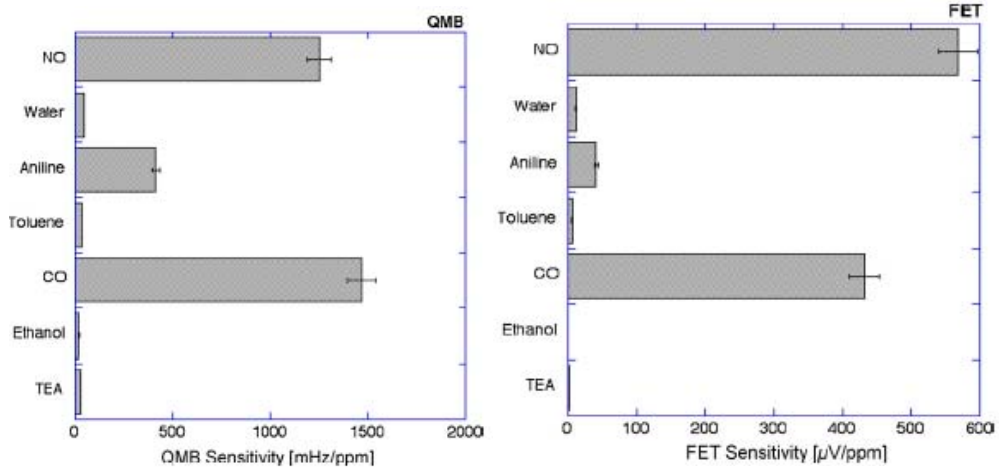
Low-ppb sensitivity for NO_2
GaN-based sensor concept



Autonomous Gas Sensor System by IREC and Univ. of Barcelona

Improvement of selectivity, sensitivity…

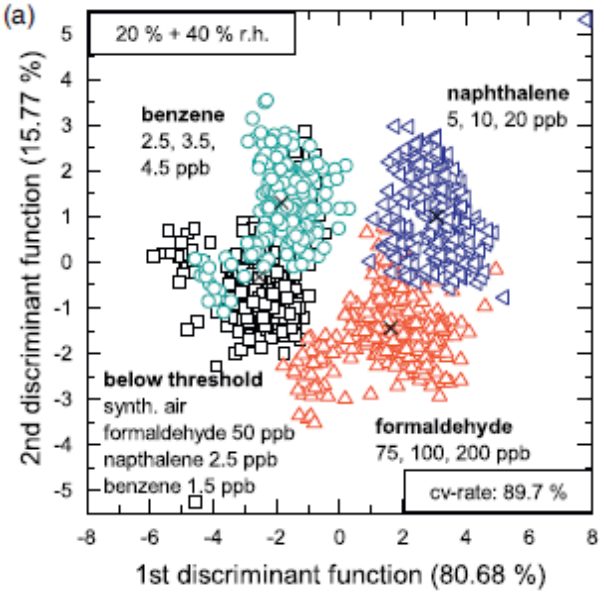
- Complementary sensor technologies



QCM and FETs functionalized by CoTPPSH (tetraphenylporphyrine with Co and sulfur handle) show slightly different response pattern to NO, aniline and CO

C. Di Natale et al. Sensors and Actuators B, 135 (2009) 560-567.

- Advanced sensor operation, temperature and gate bias cycling, and advanced data evaluation
- Functional packaging



C. Bur et al, Sensors and Actuators B Chem., 214 (2015) 225-233.

TD1105 WG3: Environmental Measurements and Air-Pollution Modelling

WG3 Chair: Prof. Ole Hertel, Aarhus University, Denmark

- **Sub-Working Group 3.1**:

  Environmental measurements at laboratory and in field air-quality stations.

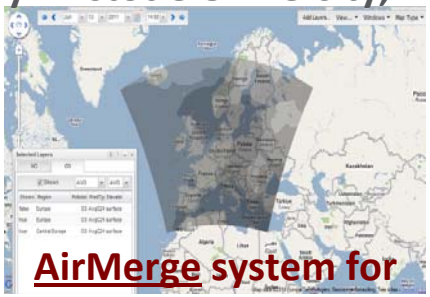
- **Sub-Working Group 3.2**:

  Air-quality modelling and chemical weather forecasting.

- **Sub-Working Group 3.3**:

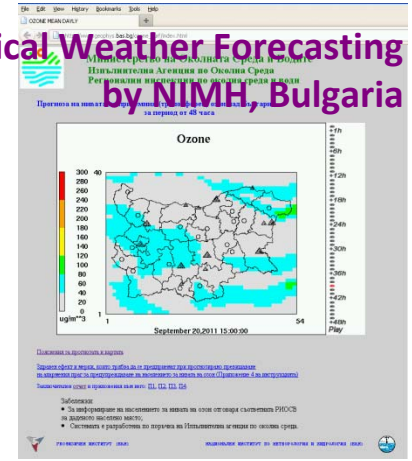
  Harmonisation of environmental measurements.

by Aristotle University, EL

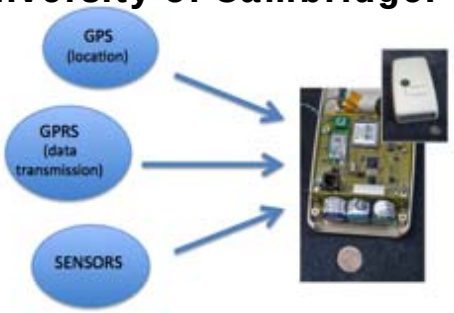


AirMerge system for Chemical Weather Models

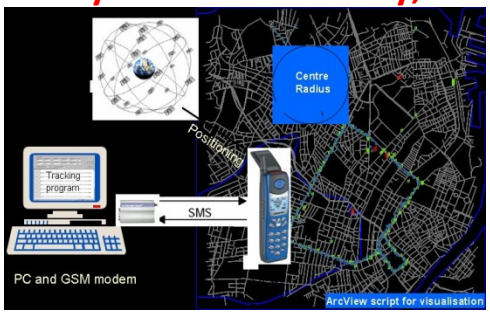
Chemical Weather Forecasting by NIMH, Bulgaria



Mobile and static sensor network configurations by University of Cambridge.



AQ Modeling: Tracking routes by Aarhus University, DK



Environmental measurements of PM and air pollution by CSIC, ES

AQ monitoring station by ARPA-PUGLIA, IT

AQ monitoring station by Aarhus University, DK

AQ monitoring station by Lithuanian EPA

We all need field tests to get our sensors to the market.

TD1105 *EuNetAir* WG4: Protocols and Standardisation Methods

WG4 Chair: Prof. Ingrid Bryntse, SenseAir AB, Sweden

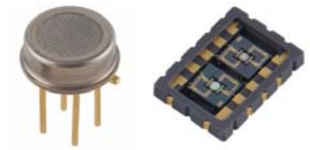
- **Sub-Working Group 4.1**: Protocols, standards and methods for AQC by analyzers/instruments (no-sensors) technologies.
- **Sub-Working Group 4.2**: Protocols, standards and methods for AQC by sensors (no-analyzers) technologies.
- **Sub-Working Group 4.3**: Benchmarking of new products and market of commercial AQC sensors.

European Directive 2008/50/EC: Ambient Air Quality

EU standard EN 13725/2003: Dynamic Olfactometry

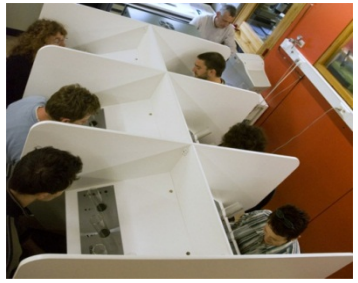
Protocols and Standardised Methods for Gas Sensors

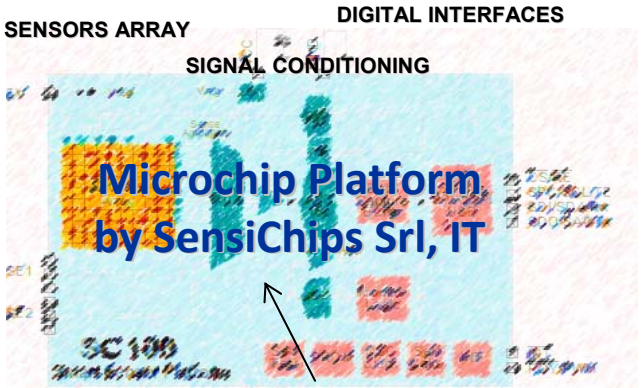
Guidelines of Best Transducers applied to specific gases



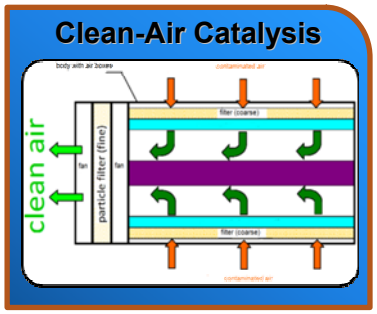
Packaged Sensors by E2V, CH

Dynamic olfactometry EN13725 by Univ. of Liege, Odometric SA, Univ. of Bari, Lenviros srl.

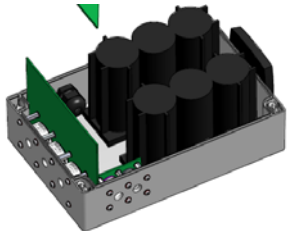




New precision multi-parametric analytical tool



Becker Gruppe, DE

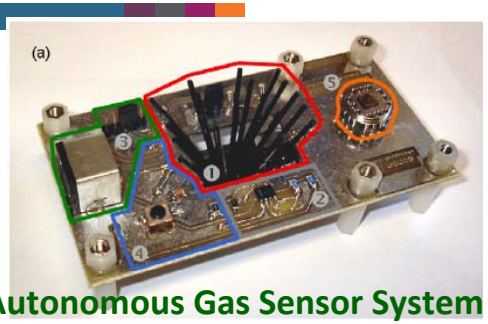


Battery-Powered Sensors by Alphasense Ltd, UK

CO_2 IR sensor for alarm System by SenseAir AB, Sweden

Standardization very important and we need more time for this. Still concensus around many issues like definitions of sensitivity, speed of response etc.

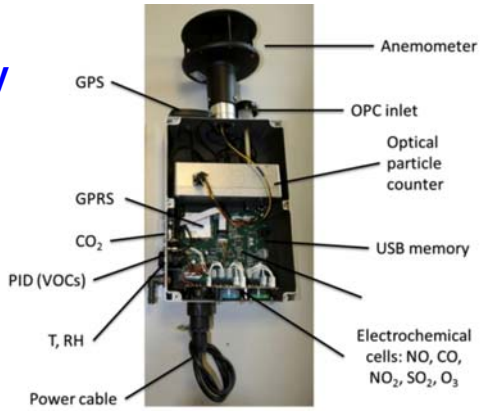
EuNetAir INNOVATION on AIR QUALITY MONITORING

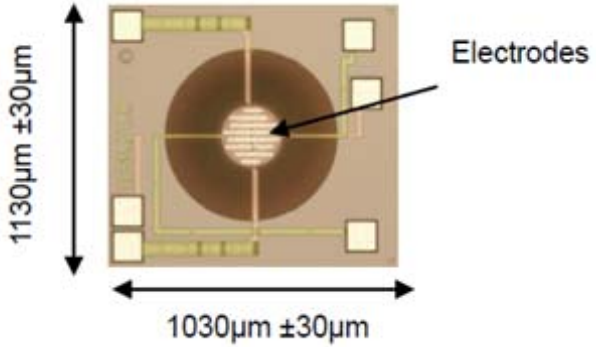


Autonomous Gas Sensor System
bv IREC and Univ. of Barcelona

Autonomous EC Gas AQ Sensor System by ENEA, Italy

Wireless sensor network for air-quality monitoring around Heathrow airport by University of Cambridge and Alphasense Ltd, UK





Miniaturized CMOS Sensor
by CCMOS Sensors Ltd and Warwick University

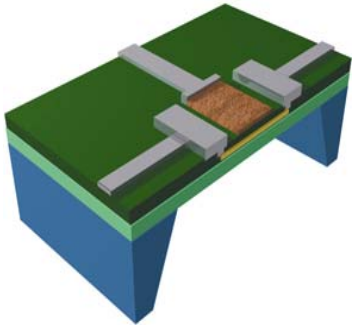
Air Quality Bike (Aeroflex) for Mobile AQ Measurements by VITO, Belgium

SiC based gas sensor system for high temperature and harsh environment by SenSiC AB, Sweden

A low-cost modular sensor platform combining IR spectrometry and MOX gas sensors for IAQ monitoring (CO_2, VOC) and medical applications
by 3S GmbH and Saarland University, Germany

Non-Dispersive Infra Red (NDIR) Gas Sensors (CO2) by SenseAir, Sweden

SGX-Sensortech MOX Gas Sensors for Automotive AQ Measurements by SGX-Sensortech, Switzerland



The network has high number of high performance, interesting and innovative sensor systems

COST
EUROPEAN COOPERATION IN SCI

Aveiro Joint-Exercise Intercomparison & WG Meeting

13 October 2014: Starting Joint-Exercise (2 weeks duration)

14 - 15 October 2014: EuNetAir WG1-WG4 Meeting

EuNetAir Air Quality Joint-Exercise Intercomparison 2014

Local Organizers: Prof. Carlos Borrego and Dr. Ana Margarida Costa (IDAD)

Air quality campaign at Aveiro (Portugal) city centre 2014

Continuous measurements: CO, benzene, NOx, SO_2, PM_{10}, VOC
Temperature, humidity, wind velocity, wind direction, solar radiation, precipitation

COST partners (15 teams joined) are invited to install their microsensors side-by-side to compare performance with referenced equipment in the Air-Quality Mobile Laboratory

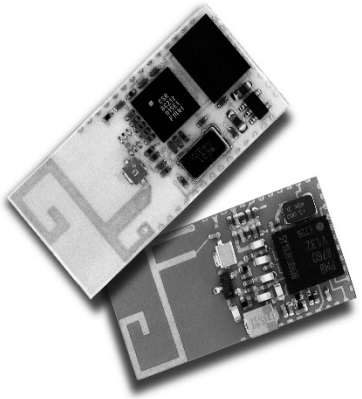
Functional Packaging Outline

LTCC technology for smart packaging of

- chemical gas sensors
- Portable particle detectors
- The Cell clinic

LOW TEMPERATURE CO-FIRED CERAMIC

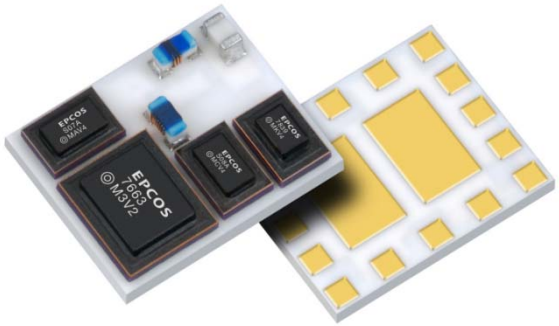
- Cornerstone of modern electronics
- Presented in the 80s of XX century
- Dielectric tapes and functional thick film pastes



©IMST

Benefits of LTCC

- ✓ Fast prototyping
- ✓ Parallel processing
- ✓ Durable, hermetic, resistant
- ✓ Relatively cheap



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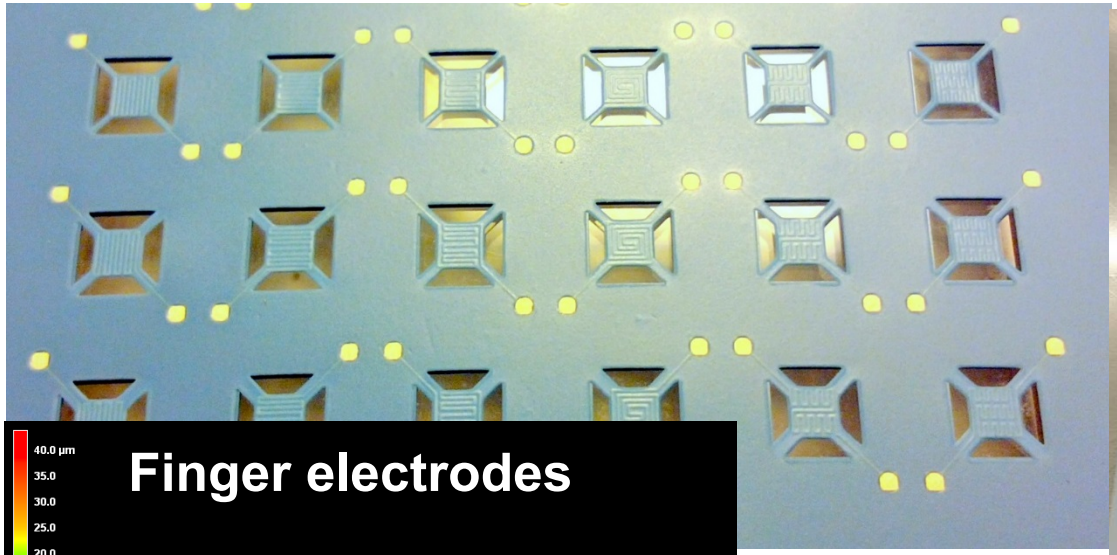
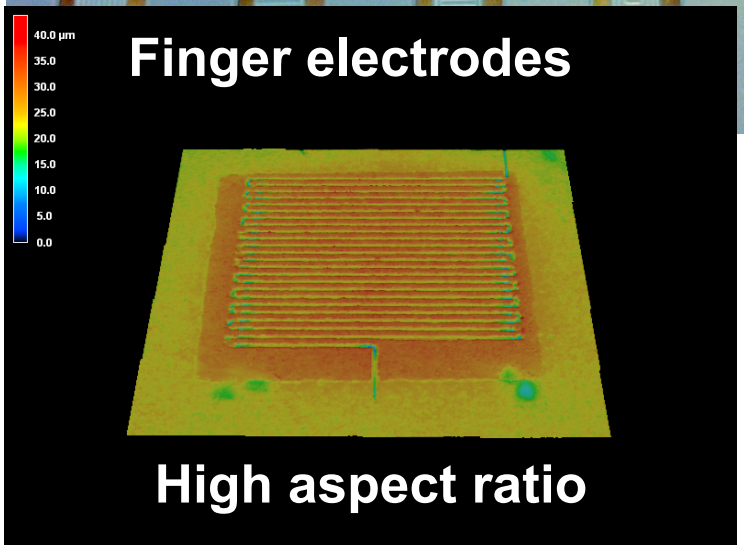
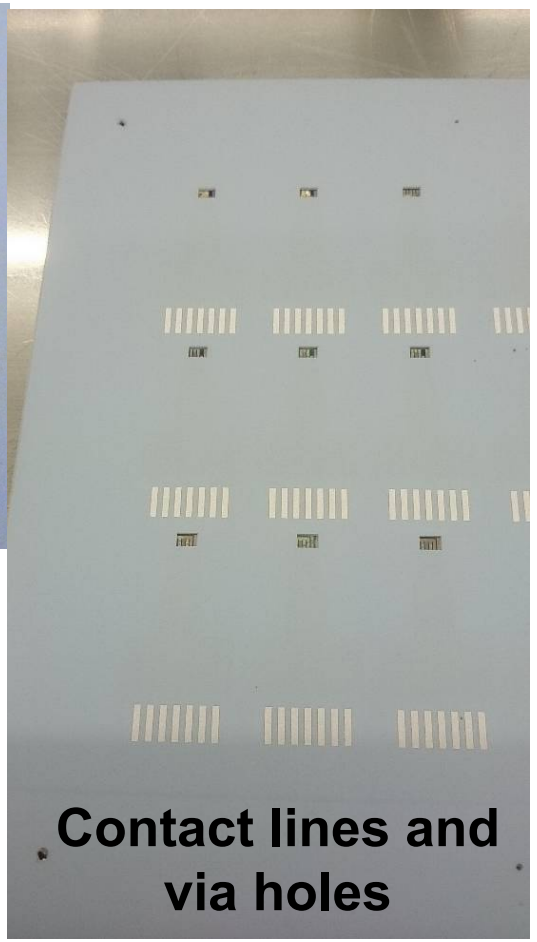
Microelectronics Research Unit,
University of Oulu, Maciej Sobocinski

LTCC processing of different structures

Membranes



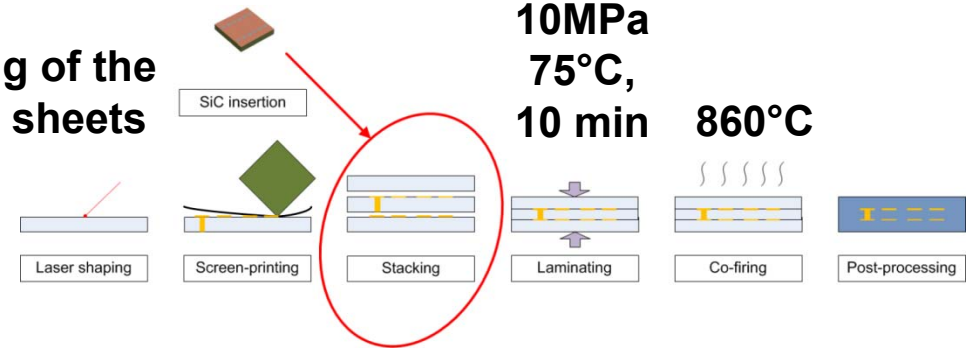


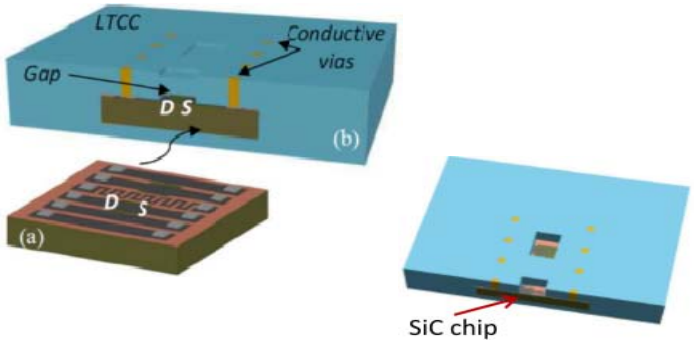


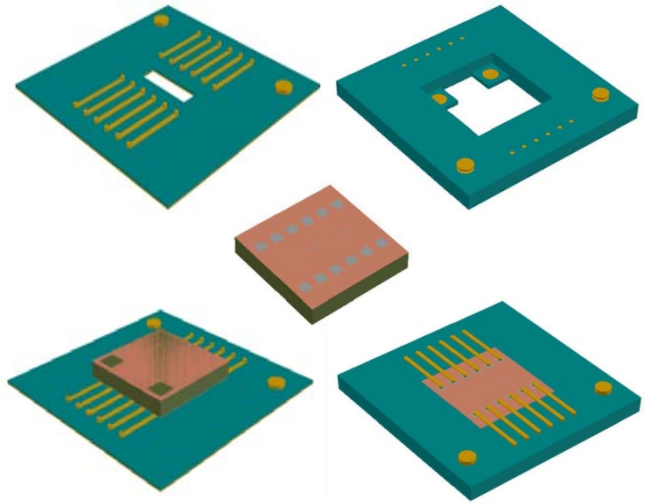
Processing on green sheets (typically 10 x 10 cm)
Stacking and firing in one (fast) step possible

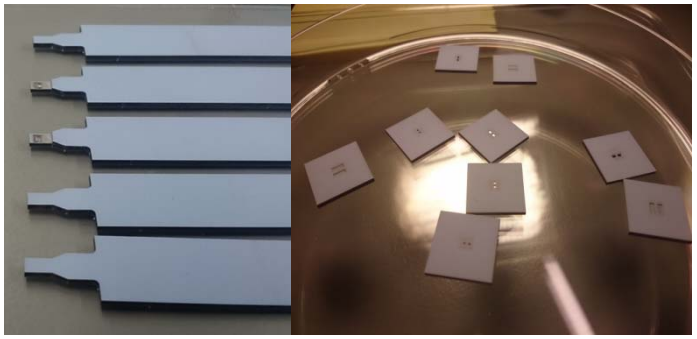
LTCC platform for SiC–FET sensors

SiC FET chip inserted during stacking of the printed sheets





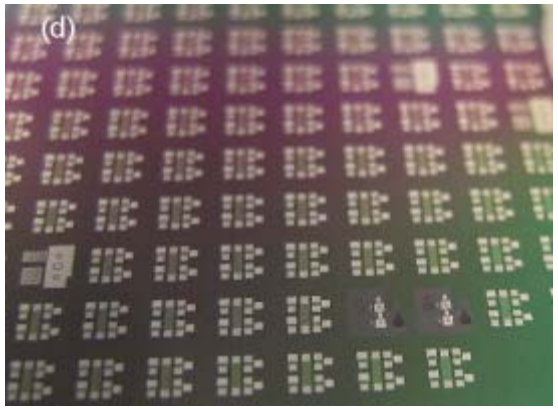




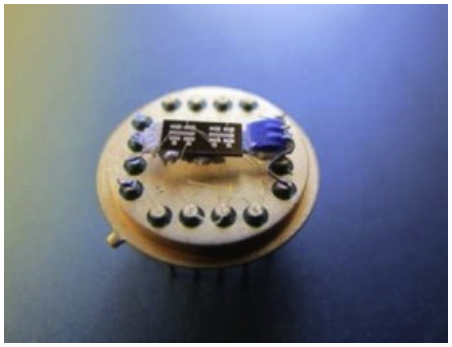
The chip/LTCC module forms one solid object which hermetically protects the sensor no die attachment, no bonding, no post-seal

M. Sobocinski and M. Andersson , et al,,
Procedia Engineering, 120 (2015) 253-256

TRADITIONAL AND STATE OF THE ART PACKAGING



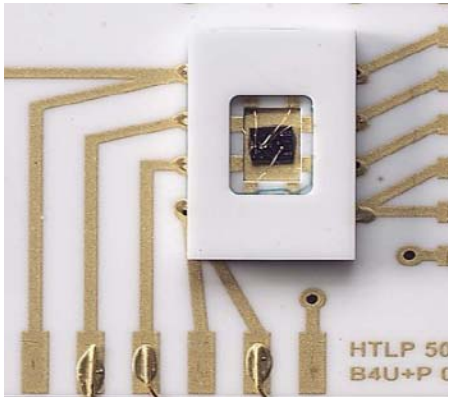
Design and Proc sing
SenSiC AB



Mike Andersson *et al. (2013)*

Traditional packaging includes:
- Die attachment
- Wire bonding
- Encapsulation through brazing etc

Max temperature 350 °C



NASA *(2013)*

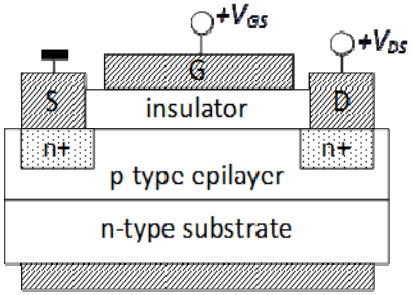
State of the art packaging includes:
- Die attachment
- Thick wire bonding
- Ceramic encapsulation

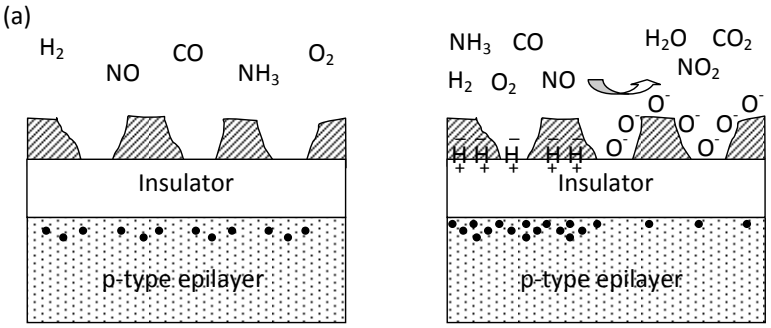
Max Temperature: 500 °C

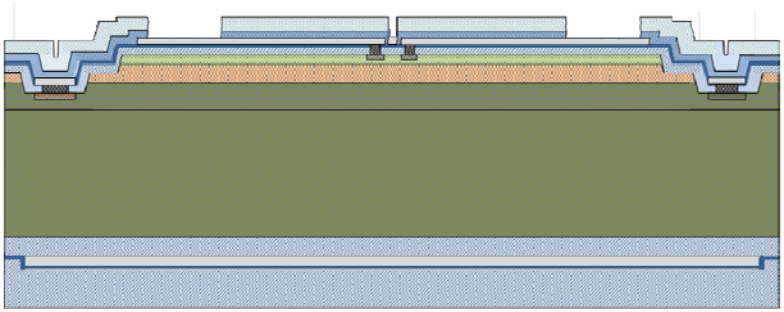
LTCC: Microelectronics Research Unit, Univ. of Oulu
Maciej Sobocinski

SiC-FET gas sensor technology

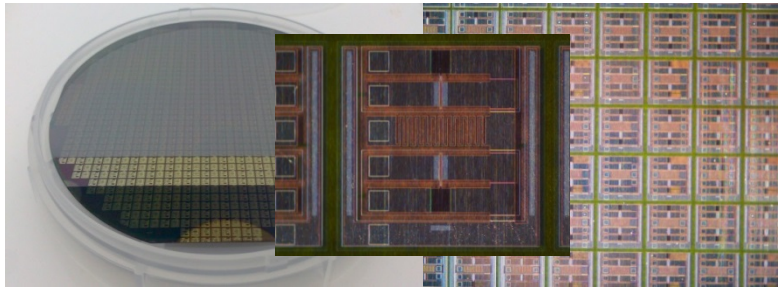
SiC based FET platform
Gate metal: porous Ir or Pt



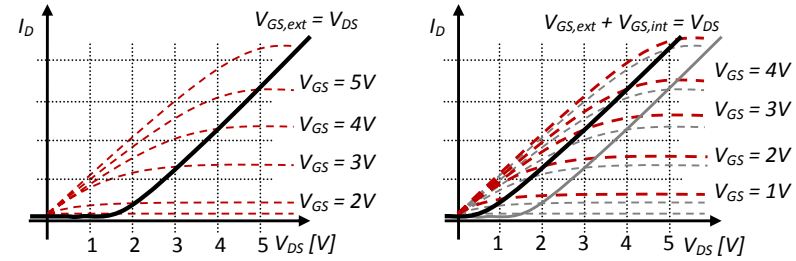




Decomposition and reactions of molecules on the catalytic metal – spill over to the oxide - charging of the gate area - a change in the current through the transistor



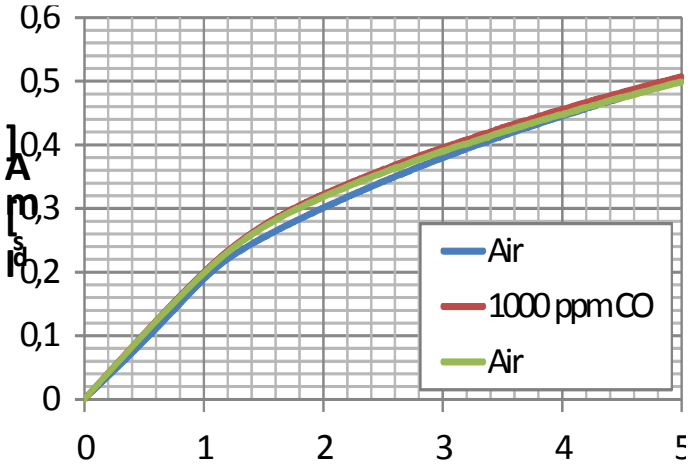
(c)

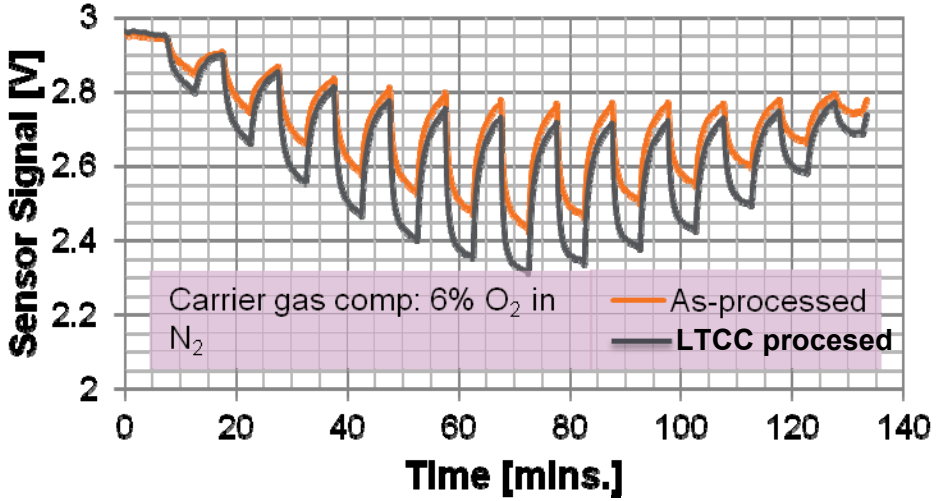


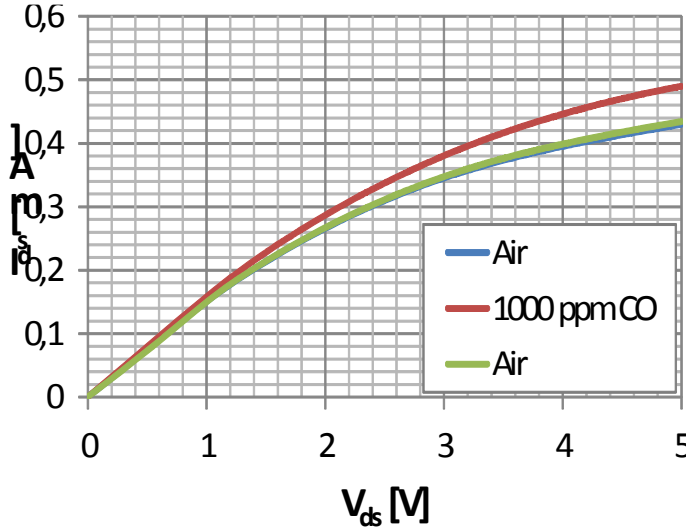
Temperature modulation and tailor made sensing layer enhances selectivity and sensitivity:

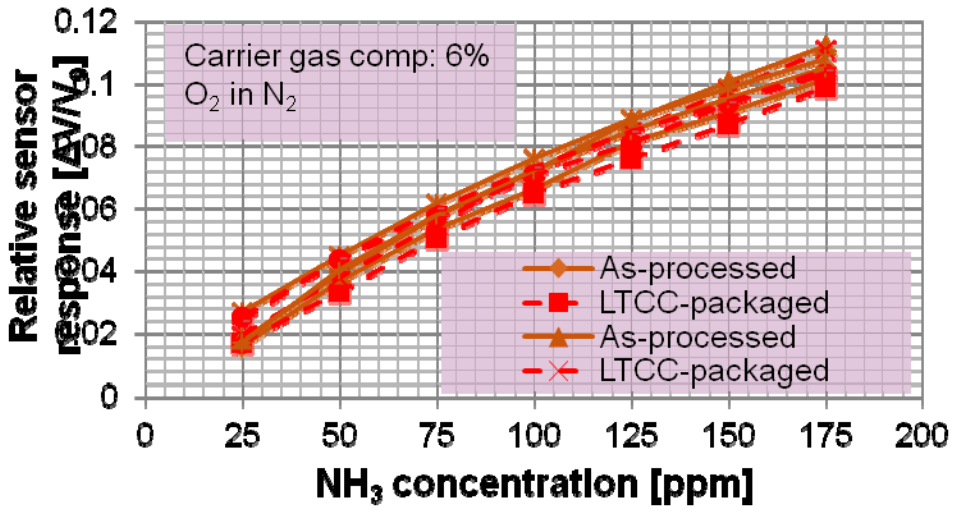
H_2, CO, NH_3, SO_2, NO_x, VOC

SiC-FET in LTCC module
Gas sensing characteristics







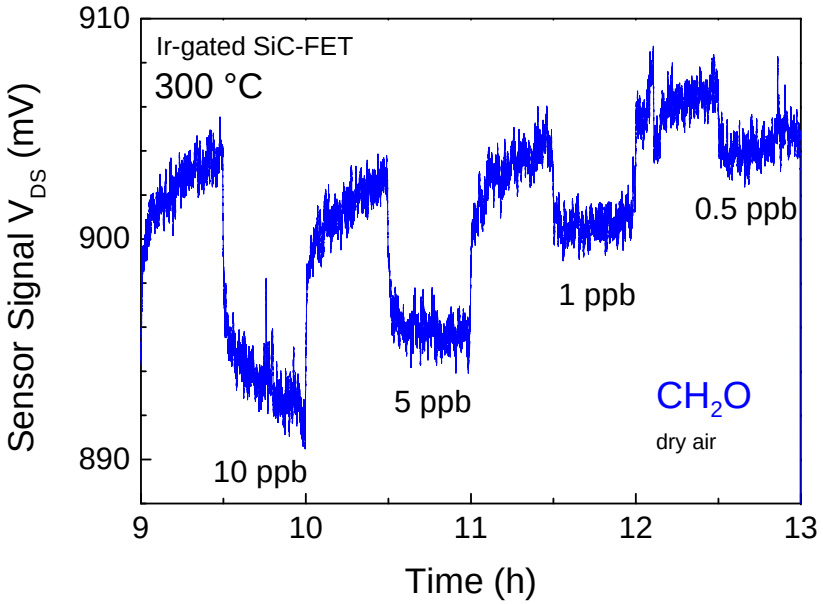


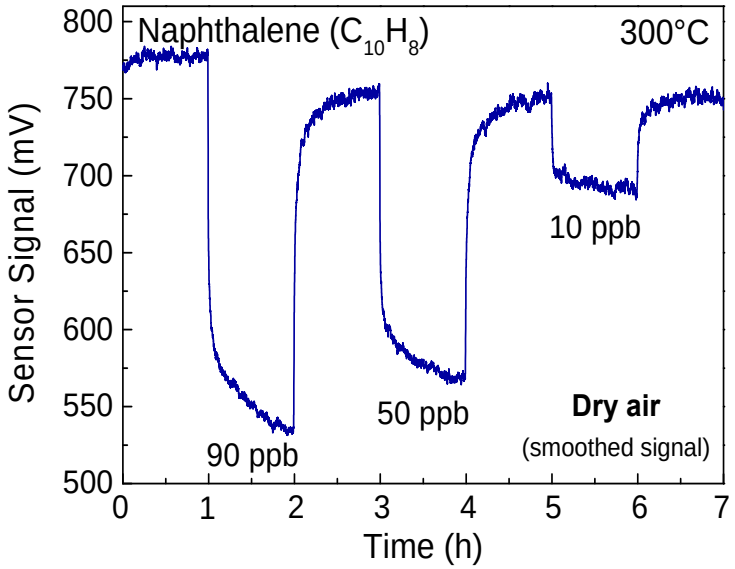
The SiC-FETs for control of SCR

SCR (selective catalytic reduction) in trucks by both Volvo and Scania

SCR interesting also for large ships and stationary engines

VOC detection by SiC-FET sensors





Measurements performed by Donatella Puglisi, Linköping University at Saarland University in an STSM activity within the EuNetAir

Collaboration with Saarland University regarding advanced sensing and data evaluation methods

Portable particle detectors

Miniaturized devices for the on-line monitoring of particles for

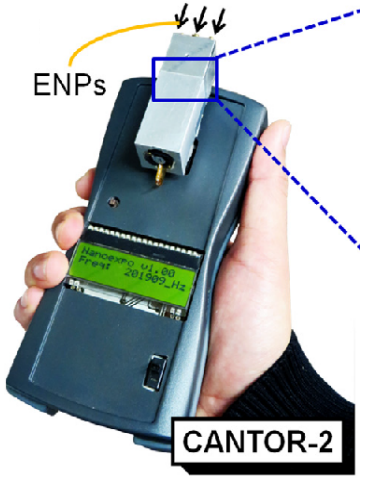
- **Work places**
- **Public use**

Giving information about particle

- **number (concentration)**
- **Size**
- **Shape (needle like, asbestos like (branched needles)**
- **Content (CNTs containing Ni, Fe, Co has shown adverse effect in animal studies)**

Since these parameters influence the adverse health effect of particles

Portable device
Research level



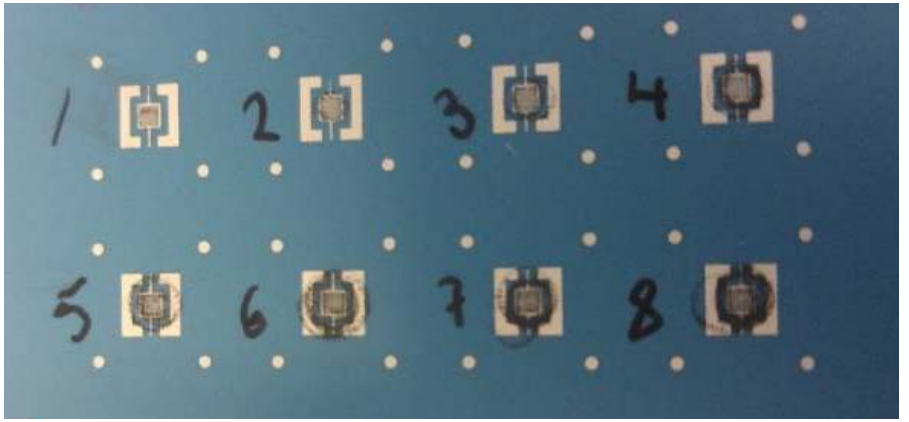
Commercial device
Particle Sense P600

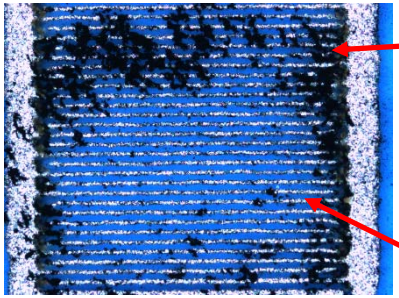
PM1, PM2.5, PM10

Reference sample development for nanoparticle detector

Drip-casted NCoP (Nano-cobalt particles)

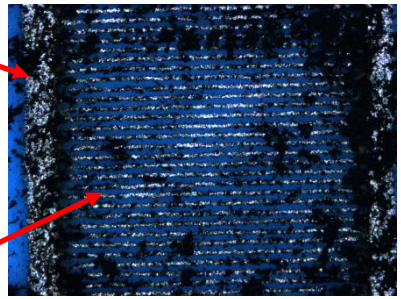
- 8 similar structures with different concentration of NCP
- Drip casted with a pipet from unstable, constantly sonicated solution
- Very high concentration (visible with naked eye)
- Finger width 20 µm, gap 30 µm





NCP

Finger electrodes



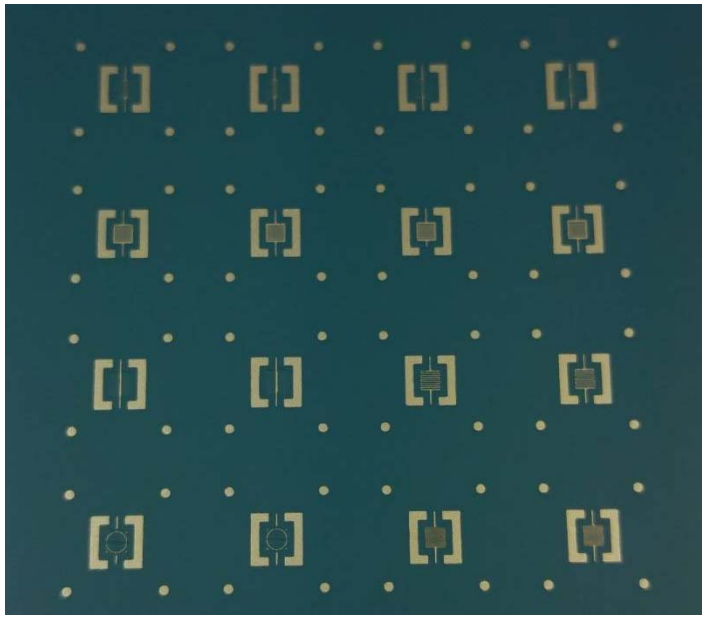
Structure 1

Structure 8

Reference sample development for nanoparticle detector

Ink-jet printed NCuP (nano Cu particles)

- Resolution of print: 500dpi
- 5 layers printed on every component
- Heated substrate (50°C)
- 0.1 % solution

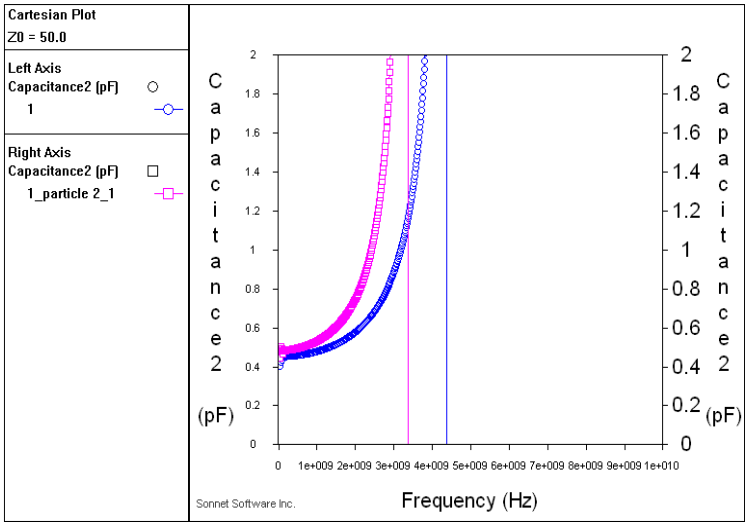


Miko Nello, Maciej Sobocinski

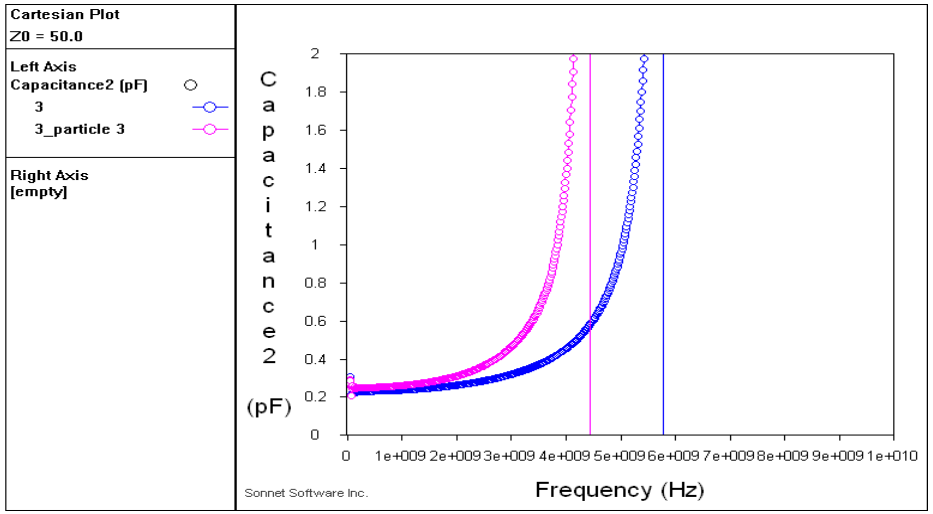
OULUN YLIOPISTO
UNIVERSITY of OULU

Impedance spectroscopy investigation

10 fingers



5 fingers



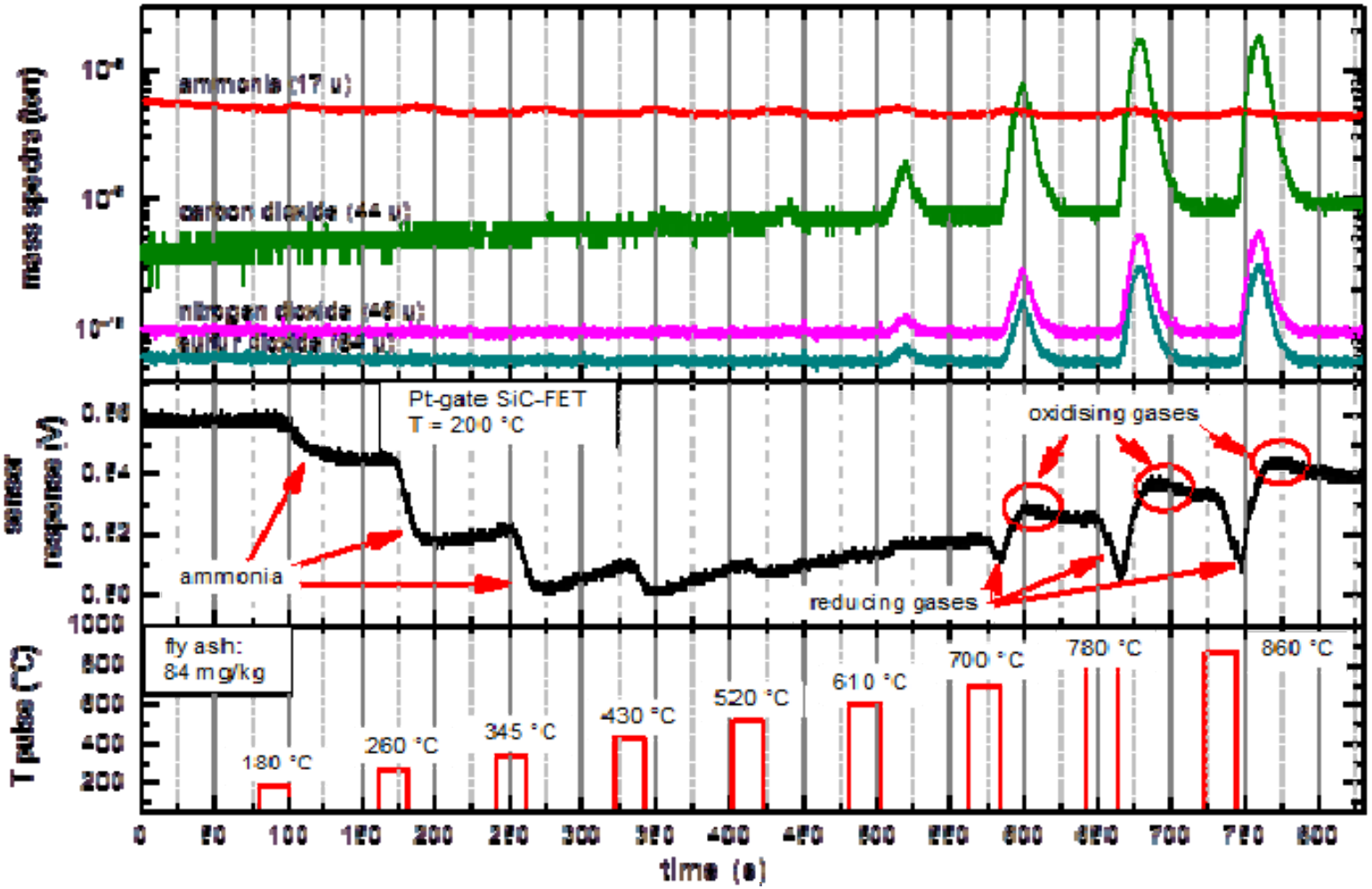
5 and 10 finger capacitors work ok

Visible response to NCuP – increasing capactiance

Blue shows clean sensor
Pink shows exposed sensor
1-10 GHz

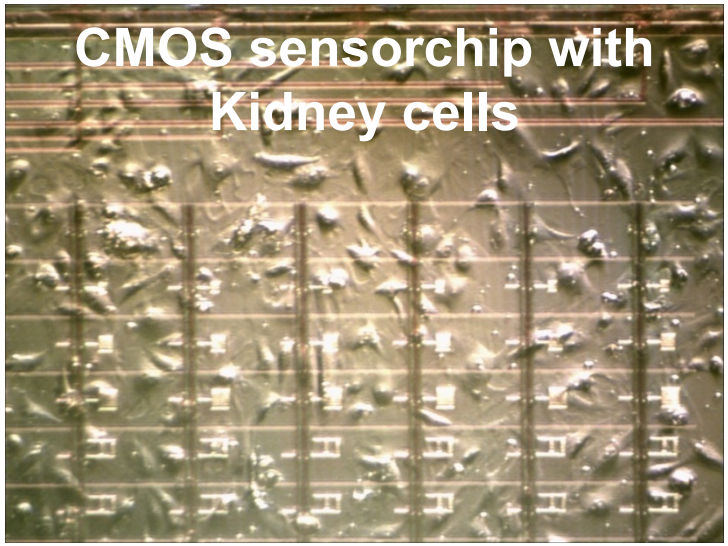
Sami Myllymäki, Maceij Sobocinski

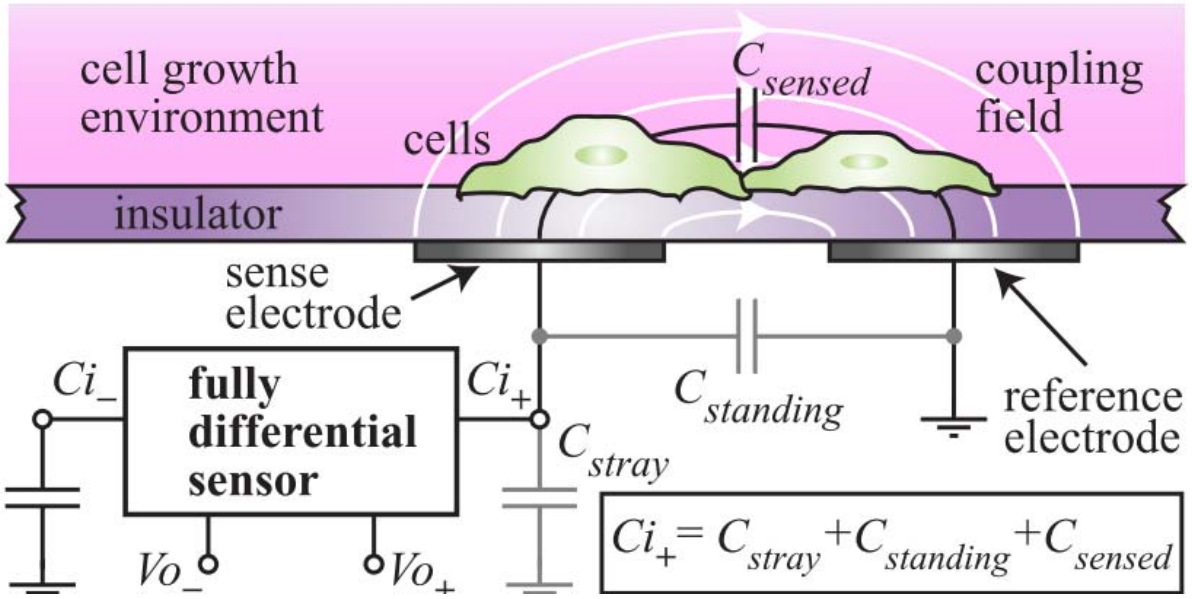
Gas sensor based particle content assessment - example



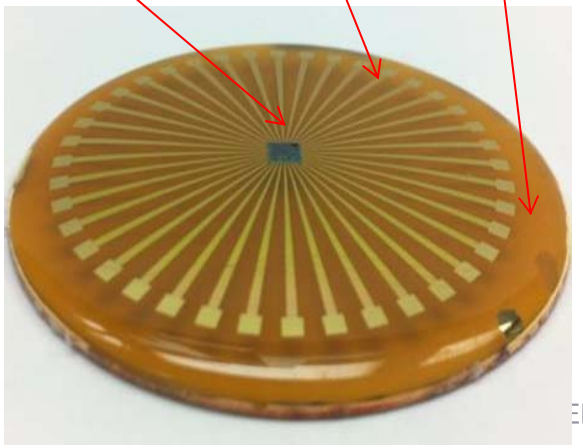
C. Bur, M. Bastuck, A. Schütze, J. Juuti, A. Lloyd Spetz, M. Andersson,
Characterization of ash paricles with a micro heater
and gas sensitive SiC field effect transistors,
Journal of Sensors and Sensor Systems, JSSS, 3 (2014) 305-313.

Cell Clinic: Measurement of Toxic effect of particles on cells





Sensor chip, Cu leads, epoxy



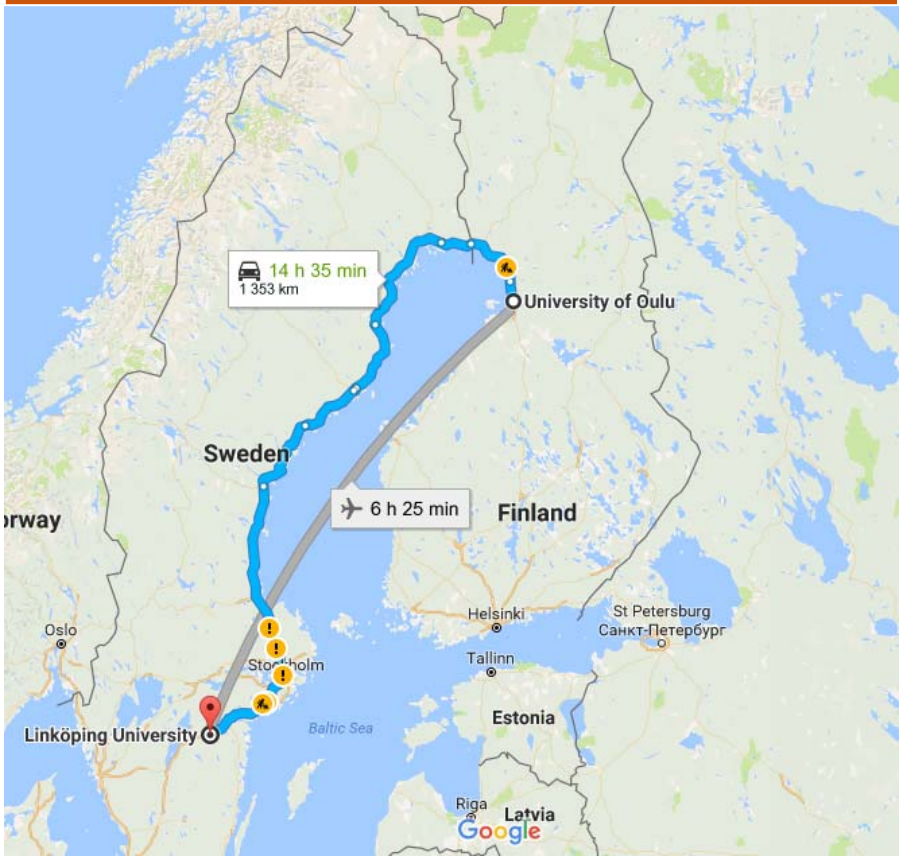
Capacitive measurement principle

Packaged chip by epoxy molding

Sensor chip designed and processed at Maryland University, USA

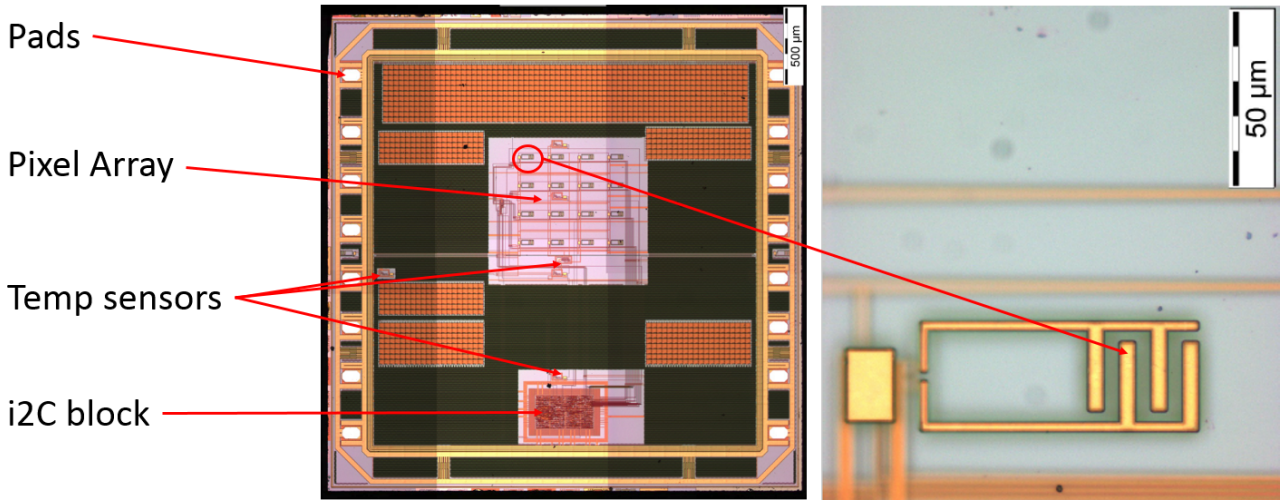
STSM by Joni Kilpijärvi,
University of Oulu, Microelectronics Research Unit, Finland to University of Linköping, group of Professor Kajsa Uvdal, (also participating, Natalia Abrikossova, Kalle Bunnfors, Caroline Brommesson, Peter Möller and Anita Lloyd Spetz)

Just 1353 km by car

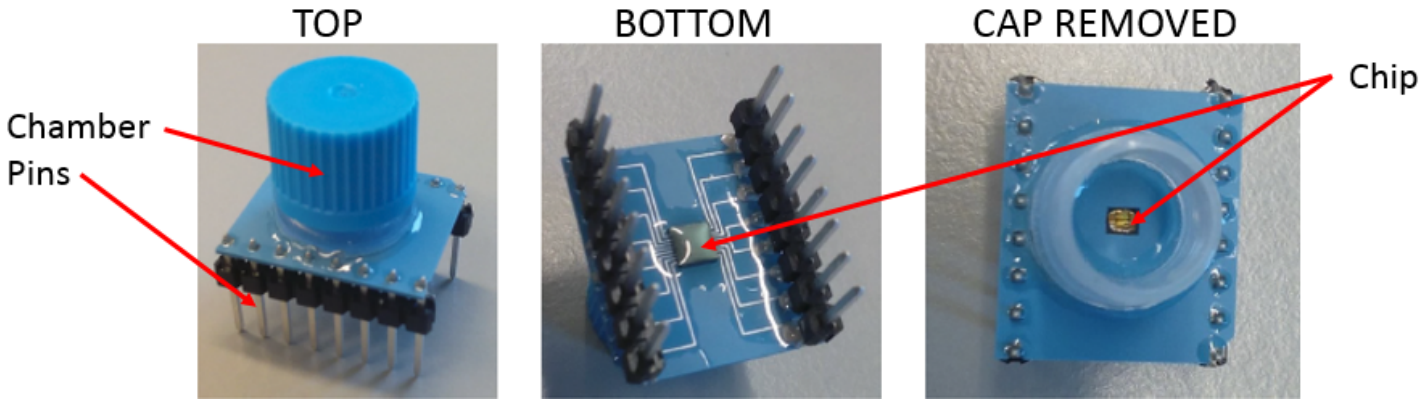


The sensor chip in LTCC package

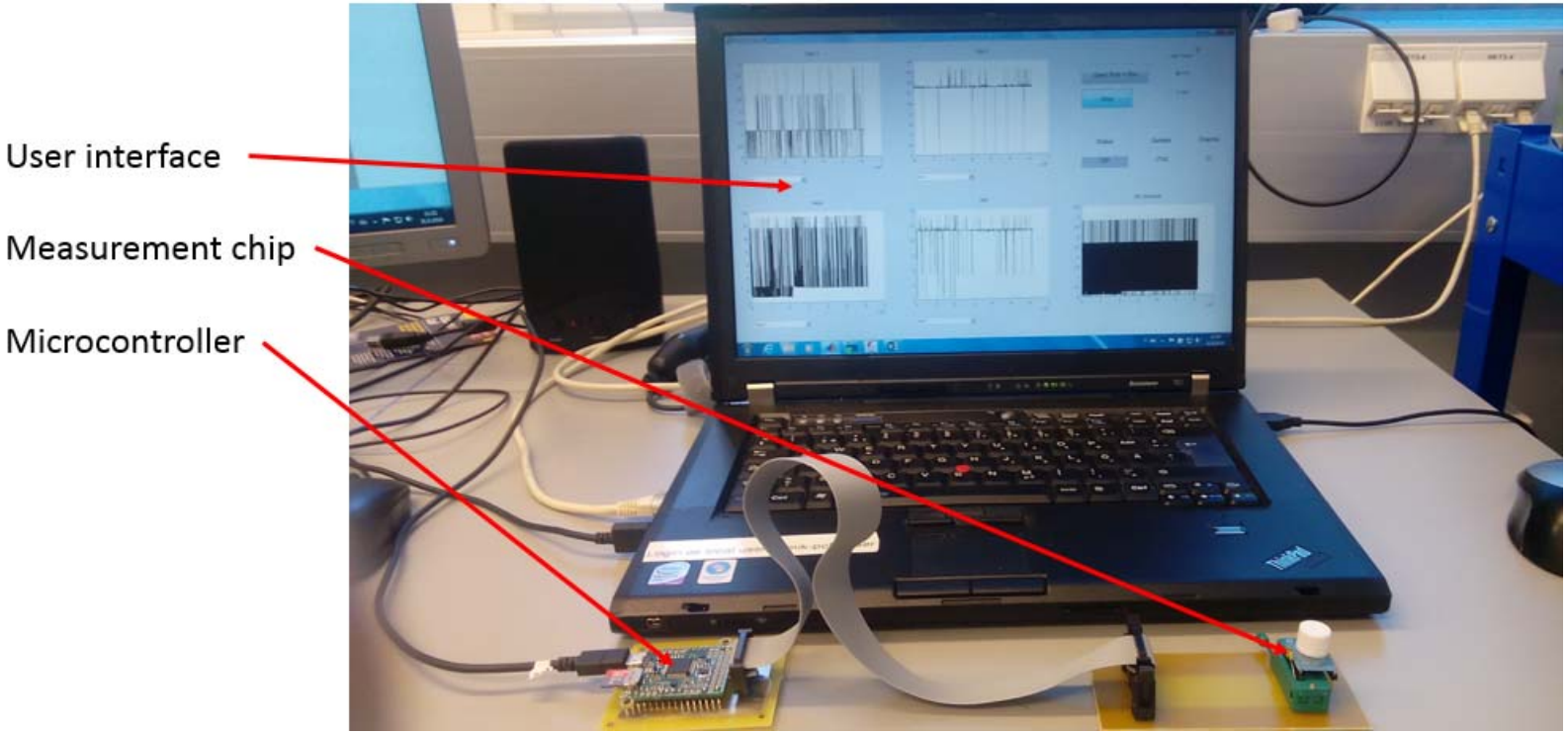
The chip



The package



The cell clinic measurement system



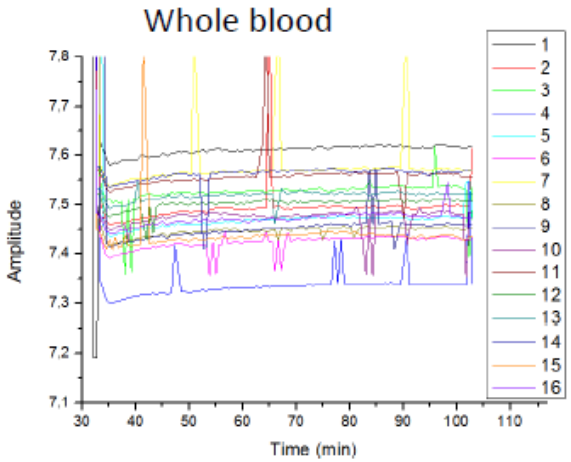
For the cell studies incubator was used

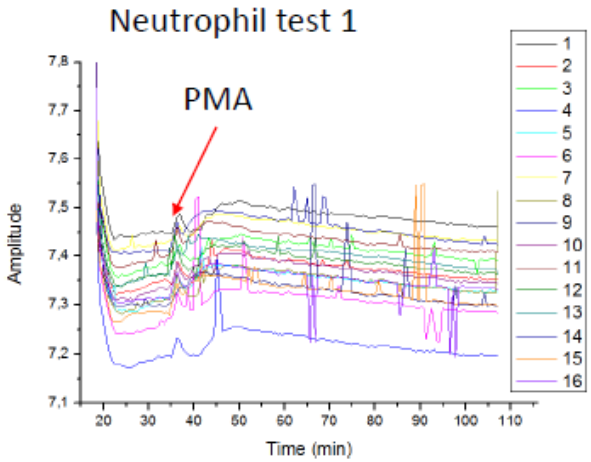
Neutrophils for cell studies

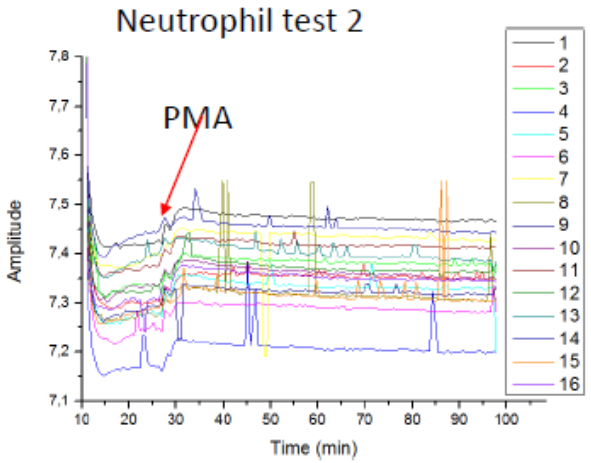
Neutrophils are part of the immune system in the body. Advantage, visible cell growth within hours

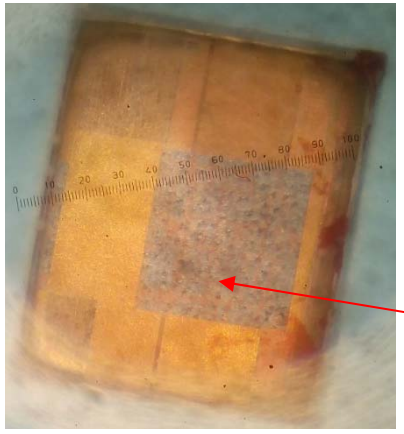
Neutrophil extraction from blood, Natalia Abrikossova

The cell clinic measurement







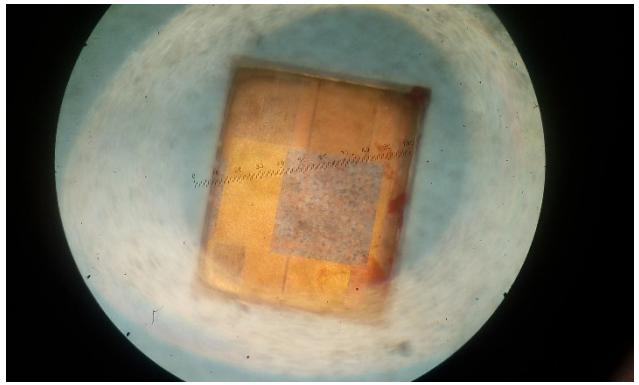


PMA (phorbol 12-myristate 13-acetate)
activates metabolic oxygenation
Shape change from round to flat

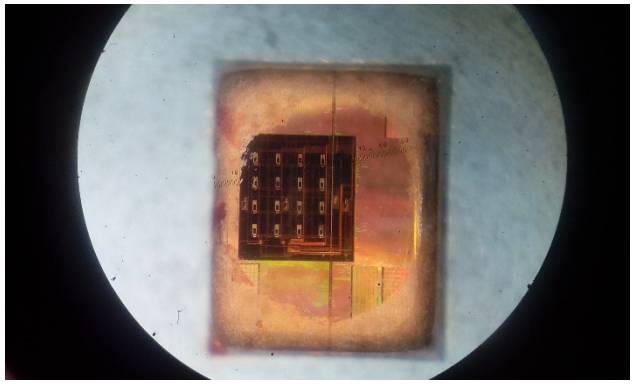
Neutrophil granulocytes spread on the chip

Measurements: Joni Kilipijärvi

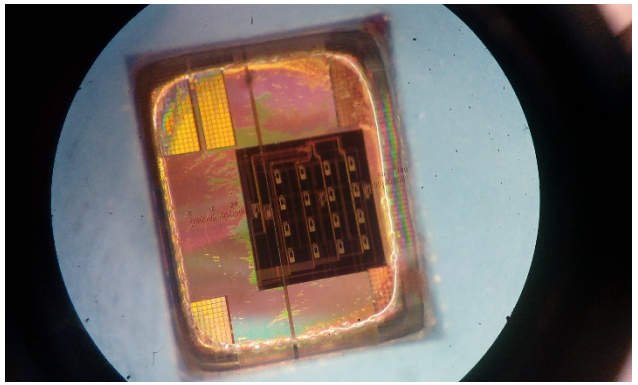
The cell clinic measurement
Cleaning the sensor chip



Chip covered by cells



DI water and ethanol clean



Tergazyme clean (different chip)

Optical microscopy: Kalle Bunnfors

Collaborators

Applied Sensor Science at Linköping University

Prof. Anita Lloyd Spetz
Associate Prof. Mike Andersson
Assistant Prof. Donatella Puglisi
Dr Christian Bur
Hossein Fashandi, PhD student
Lida Khavalezadeh, PhD student
Manuel Bastuck, PhD student
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Ass. Prof. Jari Juuti
Ass. Prof. Mike Andersson
Dr Niina Halonen
Dr Maciej Soboskinskij
Joni Huotari, PhD student
Joni Kilpijärvi, Master student

Maryland University, USA

Prof Elisabeth Smela
Prof. Pamela Abshire
Timir Datta, PhD student

Conclusions

- The EuNetAir network has had a big impact on chemical sensor systems and their applications
- The large number of participants also means efficient dissemination of our results
- Hopefully we will find suitable calls in the near future to continue this, for the environment, important work

Acknowledgement

COST ACTION EuNetAir TD1105 (STSM)

Grant support is acknowledged from:

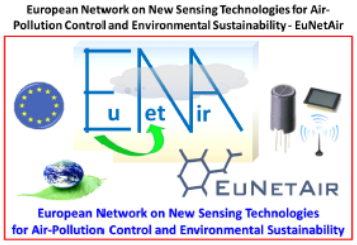
The VINN Excellence Center in Research & Innovation on Functional Nanostructured Materials (FunMat)

The Swedish Agency for Innovation Systems (VINNOVA)

The Swedish Research Council

TEKES (Finland)

Academy of Finland



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ACKNOWLEDGEMENTS

KICK-OFF MEETING of Action TD1105
COST Office, Brussels, 16 May 2012

TD1105 MANAGEMENT COMMITTEE

THANK YOU VERY MUCH FOR YOUR KIND ATTENTION !

www.cost.eunetair.it

EuNetAir meetings, excellent dissemination, large competent group, we want to show excellent results

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