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

COST Action TD1105

WGs & MC Meeting at SOFIA (BG), 16-18 December 2015

New Sensing Technologies for Indoor Air Quality Monitoring: Trends and Challenges

Action Start date: 01/07/2012 - Action End date: 30/04/2016 - Year 4: 1 July 2015 - 30 April 2016

FUNCTIONAL PACKAGING OF GAS AND PARTICLE SENSORS USING LOW TEMPERATURE CO-FIRED CERAMIC, LTCC

Anita Lloyd Spetz
Linköping University & University of Oulu

Action Vice-Chair
Toxic substances needed to be measured:

$\text{NO}_x$, $\text{NH}_3$, $\text{SO}_2$, $\text{CO}$, $\text{O}_3$, PAH/VOC, $\text{PM}_{10}$, $\text{PM}_{2.5}$, $\text{PM}_1$

EuNetAir provide a diversity of sensor technologies, knowledge and important experience
Outline

- LTCC technology:
  - Smart packaging of
    - chemical gas sensors
    - Portable particle detectors
  - The Cell clinic
LTCC processing of different structures

- Membranes
- Contact lines and via holes
- Finger electrodes
- High aspect ratio

Processing on green sheets (typically 10 x 10 cm)
Stacking and firing in one (fast) step possible
LTCC platform for sensor devices

Benefits of LTCC (Low Temperature Co-fired Ceramics)

✓ Fast processing
✓ Durable, hermetic, resistant in high temperature and corrosive environment
✓ Relatively cheap

The different layers in one LTCC module
SiC-FET sensors wafer and mounting

4” SiC wafer up to 2000 chips
Design and processing, SenSiC AB/ (Ascatron AB)

SiC-FET sensor system
Traditional mounting
LTCC platform for SiC–FET sensors

SiC FET chip inserted during stacking of the printed sheets

10MPa  
75°C,  
10 min  
860°C

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

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

Temperature modulation and tailor made sensing layer enhances selectivity and sensitivity: H₂, CO, NH₃, SO₂, NOₓ, VOC
SiC-FET in LTCC module
Gas sensing characteristics

- Relative sensor response $\Delta V/V$
  - As-processed
  - LTCC-packaged

- Sensor Signal [V]
  - As-processed
  - LTCC-packaged
  - Carrier gas comp: 6% $O_2$ in $N_2$
  - Operation temp: 300 °C

- $I_{ds}$ [mA]
  - Air
  - 1000 ppm CO
  - As-processed
  - LTCC-packaged

- $V_{ds}$ [V]
  - Air
  - 1000 ppm CO
  - As-processed
  - LTCC-packaged

- $NH_3$ concentration [ppm]
  - Carrier gas comp: 6% $O_2$ in $N_2$
VOC detection by SiC-FET sensors

Measurements performed by Donatella Puglisi, Linköping University at Saarland University in an STSM activity within the EuNetAir
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 black carbon detector for work places

H.S. Wasisto et al, Handheld personal airborne nanoparticle detector based on microelectromechanical silicon resonant cantilever, Microelectronic Engineering, 145 (2015) 96-103. (Braunschweig Germany)

Gunter Hagen et al. Capacitive soot sensor, Eurosensors 2015 (Bayreuth)
LTCC platform for Portable particle detectors

Functional packaging

A. Particle collection

B. Particle separation (T and bias gradient)

C1. Chemical characterization (content, adsorbed matter)

C. Particle characterization

Finger electrodes

High aspect ratio
Drip-casted NCP (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
Ink-jet printed NCuP

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

- 5 and 10 finger capacitors work ok
- Visible response to NCuP – increasing capacitance
- Blue shows clean sensor
- Pink shows exposed sensor
- 1-10 GHz
Cell Clinic: Measurement of Toxic effect of particles on cells

CMOS sensorchip with Kidney cells

Sensor chip, Cu leads, epoxy

Packaged chip by epoxy molding

Capacitive measurement principle
LTCC packaging for the cell clinic

LTCC packaging for the cell clinic

Zero insertion force (ZIF) connector
Development of microincubator

- The saponine test: BEAS2B cells were cultivated on the chip and
- After 24 h of the cell deposition they were killed with saponine
- Microincubator liquid flue system possible to include in the LTCC technology
The LTCC (Low Temperature Co-fired Ceramic) facilitates as sensor platform for

- SiC-FET Gas sensors
- Portable nanoparticle detector
- The cell clinic/microincubator
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
Peter Möller, research engineer

Laboratory for Measurement Technology, Saarland University
Prof. Andreas Schütze
Dr Christian Bur
Manuel Bastuck, PhD student

Microelectronics and Material Science Laboratories
University of Oulu
Prof. Heli Jantunen
Prof. Jyrki Lappalainen
Prof. Krisztian Kordas
Prof. Anita Lloyd Spetz
Ass. Prof. Jari Juuti
Ass. Prof. Mike Andersson
Dr Niina Halonen
Dr Maciej Soboskinkij
Joni Huotari, PhD student
Joni Kilpijärvi, Master student

Maryland University, USA
Prof Elisabeth Smela
Prof. Pamela Abshire
Timir Datta, PhD student
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
COST ACTION EuNetAir TD1105 (STSM)
Bake-up Slides
2. STATUS OF CELL MEASUREMENTS

- The LTCC packaged chip has been tested with BEAS2B cells (human lung epithelial cells) to study the response of the chip.

- About 2 mV increase in the output signal as cell growth media or media with cells is added.

Figure 2: The LTCC packaged sensor chip inside incubator (a) empty; (b) with cell growth media; (d) with BEAS2B cells in growth media. Values for each sensor row are averages of the 5 SEMS; (d) Average output values of 80 sensors of the chip as the chip is empty, with cell growth media and with the BEAS2B cells in media. In the inset is the magnification of the first recorded 12 minutes.
2.2 Inductors

- Line and 5 turn meander ok.
- NCuP decrease inductance
- Maybe thicker lines?

- Blue shows clean sensor
- Red shows exposed sensor
2. STATUS OF CELL MEASUREMENTS

- The saponine test: BEAS2B cells were cultivated on the chip and after 24 h of the cell deposition they were killed with saponine; clear drop in the signal as expected.
- More detailed data analysis under process.

![Figure 3: Sensor response (from the row2 column 4) to cell growth media, the cells and killing of the cells.](image-url)
LTCC processing of dedicated structures for particle detectors

Finger electrodes, high aspect ratio: concentration size, content

Membranes: heating collected particles, detecting emitted gases for content/adsorbent analysis

Carbon black (soot) measurements

- Particle size 45 nm
- 0.01 wt% concentration
- Small amount of surfactant 0.0005 wt%
- Drip cast 1 µl on 100 °C substrates
- Used 10 finger capacitor structures
Development of microincubator

LTCC packaging of the chip potential as microincubator

LTCC packaged chip with electronics in the incubator
Particle detector, commercial device

Particle Sense P600

Measures PM1, PM2.5 and PM10
1. Status of sensor chip Package

- 1st generation LTCC package is ready and found biocompatible and durable for the cell clinic application
- 2nd generation package will include also a microfluidic system

*Figure 1: The LTCC package at different stages*