Chemical sensor systems for emission control from combustions

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Clean environment through air quality control by sensor systems

Lucia performance (1963)

Sources of emissions: e.g. industry, vehicles and candles (soot)

A clean environment should belong to human rights.

Sensor systems are needed for emission monitoring and control.

Toxic substances include: NO\textsubscript{x}, SO\textsubscript{2}, CO, O\textsubscript{3}, PAH, PM\textsubscript{10}, PM\textsubscript{2.5}, PM\textsubscript{1}
Sensors for emission control
Outline

• SiC-FET improved devices
  ➢ SiC-FET devices for selective monitoring
  ➢ SiC-FET devices, commercialization

• Monitoring of particles by
  ➢ Impedance spectroscopy
  ➢ Heating and detection of desorbing products
  ➢ SiC-FET, future technology
SiC-FET transducer platform for gas sensors

Cross section of SiC-FET
Gate composed by sensing layer e.g. a porous catalytic metal, Pt, Ir

I/V characteristics SiC-FET: presence (red dashed line) of a gas - internal voltage drop at the gate metal/insulator interface - a shift in the I/V-curve
SiC-FET sensors, wafer and mounting

4” wafer, ~2000 chip

Mounting of SiC-FET sensors
Tailoring of SiC based field effect sensors for $O_2$ monitoring

M. Andersson, A. Lloyd Spetz, Tailoring of SiC based field effect gas sensors for improved selectivity to non-hydrogen containing species, IMCS13, Perth, Australia, July 12-14, 2010, 369.
Tailoring of SiC based field effect sensors for CO$_2$ monitoring

SiC based CO$_2$ sensor

Li$_2$CO$_3$-BaCO$_3$ sensing layer

MgO prevents response to hydrogen containing gases

Control of urea injection in power plants

Control of urea injection by an NH₃ sensor

SNCR – Selective Non-Catalytic Reduction of NO/NO₂ by NH₃ through urea injection in the flue gas

SCR-Selectiv Catalytic Reduction of NO/NO₂ in a catalytic converter by NH₃
NH$_3$ sensor mounting for urea control in boilers

Värme forsk projects:
A08-828 and P08-823

Partners: SenSiC AB, Alstom Sweden AB, Tekniska Verken, Vattenfall

Two position sensor mounting
~ 40 cm apart
NH₃ Lab measurements

SiC-FET sensor signal to ammonia versus time for two transistors. Detection limit below 5 ppm in 10% O₂ / N₂.

“Old” sensor batch failed to detect ammonia in low oxygen and high CO background.
NH3 detection using SiC-FET sensor as an alarm system

Sensor signal set to alarm level of 15-20ppm ammonia. Detection in low oxygen and high CO concentration.
Sensor system for control of small and medium sized power plants

Mike Andersson and Magnus Palm: installation of a sensor system for control of a domestic boiler) at Ariterm Sweden AB (key partner)
Nanoparticle sensors

- Nanoparticles show adverse health effect according to
  - Size
  - Shape
  - Content
  - Concentration
- Nanoparticles damage cells:
  - oxidative effect on cells

CHEMPACK project (2011-2014)
FiDiPro position
Oulu University i Finland

Welding nanoparticles
(courtesy of Pam Drake, National Institute for Occupational Safety and Health NIOSH).

Asbestos fibers
(courtesy of the US Geological Survey).
Present commercial particle detectors

**DEKATI ELPI** (Electrical Low Pressure Impactor (6 nm – 10 µm))

**Nano-ID™ NPS500** based on DMA (Differential Mobility Analyzer) technology, portable particle measurement device (5-500nm)

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Present commercial particle detectors

• **NANOSIGHT**
  - optical method to measure size
  - laser light source
  - typical range 10 nm - 1000 nm

• **BECKMAN COULTER**
  - particle size of fluid with nanoparticles
  - laser light
  - for size analysis: electrophoretic light scattering (ELS)

• **LIGHTHOUSE WORLDWIDE SOLUTIONS**
  - handheld and portable particle counters
  - minimum sensitivity: 200 nm

• **AIRMODUS**
  - condensation to grow 1 nm diameter nanoparticles to optically detectable sizes

• **KANOMAX**
  - condensation to grow 15 nm diameter nanoparticles to optically detectable sizes
  - **PEGASOR**
    - Portable real time measuring instrument
    - Detection of total surface area, mass, number of particles
Soot sensor based on Thermophoresis

Thermophoresis:
A force acting on particles in a temperature gradient →
Soot is deposited on the coldest surface

Thermos packaging to decrease temperature on the sensor surface
MD13 Heavy duty truck engine

Robert Bjorklund, Linköping University and Ann Grant, Volvo Technology

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6 World Harmonized Transient Cycles

Heater on, 600°C

Exhaust gas 200°C

Sensor 160°C

30 min/cycle, 18 min response time, 1370 mg/cycle, 40 mg/kWh)

Robert Bjorklund and Ann Grant
Impedance spectra of particles from steel plant and CNTs

- **c)** Steel plant particles
- **d)** CNT

Optical image, airborne particles from steel plant

SEM: CNTs deposited on IDEs

Impedance spectra, potential for on-line measurements

Joni Huotari

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Detection of particle content

Workplace and Indoor Aerosol conference in Lund:
Detection of Pd in particles by the catalytic CO conversion efficiency

First results, detection of ammonia containing fly ash particles. Particles are heated repeatedly to ~ 800°C. A small gas flow brings emissions from heater to SiC-FET sensors.
Future development

Particles are charged, SiC- FET device a possibility

Source and drain contacts need protection by over glass, but also bond wires must be protected

Additional functionality by smart packaging, LTCC packaging (Docent Jari Juuti):

Collection of particles by thermophoresis (cold sensor surface), applied voltage, magnetic field

Detection of content of particles by heating at a hot spot and detection of emissions by a sensor array, smart operation and data evaluation
Conclusions

• Toxic gases and airborne nanoparticles need to be monitored for emission control

• The new generation SiC-FETs provide a powerful sensor platform for detection of gases and potentially nanoparticles

• The content of nanoparticles is important to measure. Our present approach is based on impedance spectroscopy and heating particles and subsequent detection of the emissions
Acknowledgements

Acknowledgement to Prof. Anita Lloyd Spetz, Dr. Mike Andersson, Dr. Robert Bjorklund, Dr. Jens Eriksson, post doc, Zhafira Darmastuti, PhD student, Christian Bur, PhD student (joint with Saarland University), Hossein Fashandi, PhD student, Peter Möller, research engineer.

Microelectronics and Material Science Laboratories, Oulu University
Prof. Heli Jantunen, Prof. Jyrki Lappalainen, Prof. Anita Lloyd Spetz, Joni Huotari, PhD student.

Laboratory for Measurement Technology, Saarland University
Prof. Andreas Schütze, Christian Bur, 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), Värme forsk, The Swedish Research Council and TEKES in Finland

IMCS 2012, A. Lloyd Spetz EuNetAir