Accident Warnings, Fire Detection and Air Quality Monitoring with the Karlsruhe Micronose KAMINA for Flight Compartments

Joachim Goschnick, C. Arnold, D. Häringer, I. Kiselev

- Principle considerations
- Gas analytical & other requirements for low cost air monitor
- Karlsruhe Micronose KAMINA and its gradient microarray
- Application examples for indoor air monitoring
- Summary and future prospects
Noses characterize gas ensembles in an integral manner

- A multitude of gases with appr. constant concentration relations is determined as an entity:
  - The gas ensemble is characterized by quality (type) and quantity (concentration)
- To some extent the integral can be broken down to components
  - But usually (complex mixtures) resolution of all chemicals cannot be achieved

- The human nose is a versatile chemical screening instrument
  - **Food**: checking freshness, cooking, frying and baking control
  - **Fire**: prevention and detection
  - **Health**: breath and skin odor indicate diseases
  - **Air, Water and Soil**: pollution often releases smelling vapours
  - **Solid/Liquid Products**: often emit volatiles used as a signature for quality
An E-Nose Can Be A Versatile Indoor Air Monitor

KAMINA: Online chemical condition monitors for intelligent systems

- Indoor air contains a complex gas ensemble
  - often continuously changing depending on usage
  - but usually keeping within certain limits = normal situation
  - deviation from normal may indicate accidents

- An E-Nose can continuously track indoor gas ensembles in quality & quantity to obtain information for air conditioning or accident management

- Air quality & odor comfort can be obtained for intelligent air conditioning

- Fires, pyrolytic degradations & gas leaks adds a characteristic bouquet of volatiles to room air indicating an accident even in advance allowing early counteractions

- KAMINA is developed to demonstrate how intelligent systems in industry & households can be supplied with detailed condition information simply, sensitively and at low cost
Gas Analytical & Other Requirements for Mass Product Compatibility

- Broad spectrum of detectable gas components
- High gas discrimination power
- High gas sensitivity, i.e. detection limits < 1 ppm
- Rapid enough for on-line measurements: response times < 10 sec

- Affordability: price < 50 US Dollars
- Applicability: low size, low power, robustness, simple handling
- Durability: Functionality over terms of 10y or more

REALIZATION

- Electronic nose based on an array of metal oxide gas sensors is able to detect & discriminate many gases with extreme sensitivity even in rough environment
- Microsystems can provide low price, low size and robustness
HIGHLY INTEGRATED GAS SENSOR MICROARRAY
Segmented Metal Oxide Film with Gradient Technique

MICROARRAY = Segmented MOX film
STANDARD: 9x10 mm² SiO₂/Si/SiO₂ or Al₂O₃
39 Pt strips > 38 gas sensor segments of SnO₂ or WO₃
2 temperature sensors for temp. control
Heating: 4 Pt heating meanders on rear side
Gas permeable membrane: SiO₂ or Al₂O₃

DIFFERENTIATION OF THE SENSOR SEGMENTS
● 2 gradients: chip temperature gradient and thickness gradient across the array differentiate the sensor segments sensitivity spectrum
● Conductivity patterns allow recognition and quantitative determination of gas ensembles
● Pattern analysis allows determination of gas components
1st generation EN: Classical macro-design
Separately housed sensors plugged onto a substrate
Expensive production, large, high energy consumption, mechanically sensitive
Chem. differentiation >> sensor-individual ageing

2nd generation EN: Conventional micro-systems
Sensor pads & interconnection deposited on substrate
Less expensive, small, low power, enhanced mechanical stability
Chem. differentiation >> sensor-individual ageing

3rd generation EN KAMINA: Segmented single metal oxide film
No individual sensor elements
Inexpensive, small, excellent mechanical stability, low power
Phys. differentiation >> collective ageing
Gradient technique: Reliability checks & repairs, Noise reduction without extended measuring time
KAMINA Microarray Dwarf Chip

- Substrates: SiO₂/Si, Al₂O₃
- Metal oxide layer: SnO₂/Pt, WO₃/Au
- Gradient membrane layer consisting of SiO₂ or Al₂O₃
- Detection limits < 1 ppm
- Power consumption < 1 Watt
- High chemical & thermal stability

- Cross-section of a 3X3.5 mm² microarray with 16 sensor segments
  - Substrate: Si/SiO₂ or Al₂O₃
  - Gradient membrane SiO₂ or Al₂O₃, Thickness 2 to 20 nm
  - Platinum electrodes Thickness 1 µm
  - Gas detector layer SnO₂ or WO₃, Pt-endowed, approx. 150 nm
  - Platinum electrodes Thickness 1 µm
  - Gas detector layer SnO₂ or WO₃, Pt-endowed, approx. 150 nm
  - Temperature gradient 50°C / 2mm

- Microarray chip fixed only by bond wires within clearance of ceramic carrier card
- Chip corners attached to edges of the opening achieves vertical stability
Raw Data Obtained in Pulsed Test Gas Exposure Series

- High sensitivity, usual detection limits < 1ppm
- Vast range of detectable gases
  - only inert gases such as rare gases, nitrogen cannot be detected

**Pulsed exposure series alternating test gas & clean air exposure**
**The resistances of 38 sensor segments vs. Time**
**Test gas: octane in humid air**
**Chip: SnO₂/Pt coated with SiO₂ membrane (SP 602.04), temperature: 350 - 270°C**
Gas characteristic signal patterns independent from concentration

Polar diagrams of normalized signal patterns

Signals of the sensor segments displayed as deviation from median
Original signal patterns exist in 38 dimensional signal space
Training assigns pattern areas belonging to gases or gas ensembles
Measured signal patterns are classified for coincidence: gas recognition or “unknown”

Linear Discriminant Analysis (LDA)

LDA is the optimum projection to show the differences of the trained classes
The KAMINA module combines gas sampling, microarray chip and µP-controlled operating electronics.

The electronics provide for:
- measurement of sensor segments at 1 Hz
- supplies chip heating & gas sampling
- serial data interface > computer control
- relais outputs

Gas sampling via ventilator or micro-pump
Indoor Air Monitoring

Linear Discrimination Analysis of signal patterns obtained in a conference room for about 30 people:

- Measurements carried out in empty room day and night 1 m above the floor
- 2 meetings of 3 hours each (second meeting held a week later) with approx. 20 people
- Hazard simulation: isopropanol on paper tissue approx. 0.8 m from point of measurement

Decreasing air quality caused by the presence of people can be detected
Dangers caused by gases can be realized
Set-up to detect overheated wire insulations

Joined Project with NASA/Kennedy Space Flight Center:
Early detection of cable smouldering in Space Shuttle and International Space Station

- Wires with different insulation electrically overheated in closed box
- Vapor exposures from tissues soaked with solvents as possible interferants
- Reference analysis: Conventional sensor array with separated sensors and scattered light detector
Detection of Overheated Cable Insulation to Prevent Smouldering Fires

Joined Project with KSC/NASA: Fire prevention in Space Shuttle and the Intern. Space Station

- All insulations can be distinguished by the gas release during heat up
- All overheated insulations can be classified together as smouldering event and discriminated against normal air or solvent release events
Indoor Air Monitoring
Distinctive & Early Detection of Fire Accidents

3X3.5 mm² Microarray with 16 sensor segments
SnO₂/Pt detector layer and Al₂O₃ gradient membrane

The Al₂O₃ membrane allows better gas discrimination

8X9 mm² Microarray with 38 sensor segments
SnO₂/Pt detector layer and SiO₂ gradient membrane
Fire detection: High discrimination power in fire detection

- Diesel exhaust contains CO, NO₂ and soot particles

> False Alarm: Often classical fire detectors are cheated by Diesel exhaust

- Fire gas is clearly recognized
- Diesel exhaust can be well separated from fire gas
Experimental setup for tests at model fires

Burning & pyrolysis of:
wood, plastics,
printed circuit board,
tobacco, wool, roof materials.

KAMINA: Data acquisition with 1 Hz
0.4 lit/min gas flux

FTIR: TEMEL/Finland Type GASMET
Spectrum span 800-4000 cm\(^{-1}\)
Spectrum duration 20 or 60 sec
3 lit/min gas flux
Discriminative power for material recognition

Materials pyrolyzed:
- Bituminous roofing felts: 7 types with different fire retarding additives
- Polyurethane foam
- Polyvinylchloride rods
- Computer circuit board
- Wood composite (Flakeboard)
- Cigarette tobacco
- Cigarette tobacco + textile: to simulate “smoking in bed”
- Wools: 2 Wools with different additives

Stepwise LDA based Classification

1st step: Primary Classification into 3 major material classes

2nd step: Secondary Classification LDAs of each class
⇒ detailed recognition

⇒ Detailed Classification of pyrolyzed materials feasible
Controlling a Toaster

Toaster with KAMINA

Resistances of the micro-array segments vs. process time

Switch on at 20 sec, toast starts to burn at 40 sec, switch off at 120 sec.
Controlling the Toaster Process

Linear Discrimination Analysis (LDA) of Median & Reference Normalized Data

Advancement classes of process states:
A= raw bread  B= light brown  C= medium brown  D= dark brown  E= burned

Training: Model built from 9 measurements done at Karlsruhe

Model testing: 2 measurements done at HOMETEC fair in Berlin one week after training
Application Areas Of The KAMINA
Under Development and Test

- Household Appliances
  Food processing, Laundry screening

- Commercial Food Process Control

- Building Technology
  Indoor air monitoring: pollution and odor determination, Heating system control

- Automobil Equipment
  Air conditioning, Onboard exhaust gas monitoring

- Space Ship Technology
  Cable smoldering, Air lock surveillance

- Criminal Investigations

- Environmental Analytics
  Air, Water, Soil

- Biogas-Monitoring

- Medical Diagnosis
  Breath and sweat odor Analysis

- Fire Protection Technology
  Early detection, material recognition, fire gas dissemination

- Metal Processing
  Biocide monitoring of lubricants

- Textile Processing
  Fabric recognition, impregnation degassing

- Household Appliances
  Food processing, Laundry screening

- Commercial Food Process Control

- Building Technology
  Indoor air monitoring: pollution and odor determination, Heating system control

- Automobil Equipment
  Air conditioning, Onboard exhaust gas monitoring

- Space Ship Technology
  Cable smoldering, Air lock surveillance

- Criminal Investigations

- Environmental Analytics
  Air, Water, Soil

- Biogas-Monitoring

- Medical Diagnosis
  Breath and sweat odor Analysis

- Fire Protection Technology
  Early detection, material recognition, fire gas dissemination

- Metal Processing
  Biocide monitoring of lubricants

- Textile Processing
  Fabric recognition, impregnation degassing
Electronic Nose Microsystems
Have the potential to be used as
Indoor air monitors applied for
- prenatal fire detection
- open fire detection
- burning material recognition
- air quality measurements
- odor comfort monitoring

KAMINA shows how
Low cost, low size
Can be combined with
High gas analytical power

Status & Prospect

Fabrication of the KAMINA at present
in small series production for
development & demonstration purposes.

Estimated cost in mass production:
KAMINA-Chip < 5€
Operating electronics < 20€

Set-up of commercial production underway
Variety of application projects in work
Questions
Widespread Applications

Off-line applications
Product (food) quality control, scientific applications

Monitoring Modules For Industrial & Environmental
Online production control, Workplace monitoring
Environmental monitoring (e.g. air quality) > onsite

Medical Products & Diagnosis
Analysis of breath, skin odor, and body fluids, pharma products

Mass Products
Automobiles, building technology, household appliances
Even slight differences in the gas release of similar bacteria can be distinguished allowing the distinction of the bacteria.
Standard Microfabrication in 4 Phases On 3” Or 6” Si Substrates

I. HF Sputter Deposition With Shadow Masks
   - Gas detecting MOx layer
   - Electrode Pattern
   - Heating elements
   
   Detection limits 0.05-10ppm
   Response times ca. 1 min

II. Dicing & Assembly
   - Separation of the chips
   - Mounting on carrier
   - Electrical contacts by wire bonds

III. Ion Beam Assisted Deposition (IBAD)
    To Deposit Inhomog. Membrane Coatings
   
   Ion beam converts at RT condensed process
gas phenyl-TEOS to some nm thick Si,O,C film

IV. Final Conditioning
   Annealing to give pure gas permeable SiO₂
   by removal of residual amounts of C
   und stabilisation of the morphology
Raw Data Obtained in Pulsed Test Gas Exposure Series

- High sensitivity, usual detection limits < 1ppm
- Vast range of detectable gases
  only inert gases such as rare gases, nitrogen cannot be detected
LENA: Airship Equipped with an Electronic Nose

- **Mobile Electronic Nose** combined with positioning option provides powerful analytical tool:
  - **Determination of spatial gas distributions**
    - Pollutant gas ensembles from motor traffic, odor clouds, fire gases
  - **Localization of gas sources on the ground**
    - Gas leaks in industrial facilities, smelling objects on landfill sites, odor sources in agriculture, infestated areas of plant diseases, land mine detection

**Operational data:**
- Electrical drive with 3 motors, 37 MHz radio control within sight, max. lateral speed: 60 km/h, payload: 4 kilograms

**Instrumentation:**
- KAMINA, video camera, GPS for current positioning, and board computer with radio data transmission to ground control
The Fourth Triennial International Aircraft Fire and Cabin Safety Research Conference