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Preface

The Austrian Working Group on Sensors (ARGE Sensorik) was founded in 2006 aiming at the optimization of the joint utilization of sensor know-how and associated technology distributed over Austria. One major goal of the ARGE Sensorik is the initiation of joint research networks also involving industrial partners. The ARGE now serves as platform representing various facets of interdisciplinary sensor research in Austria. Its members are research institutes and centers of competence working on sensors or dealing with problems where sensors play a major role. The activities of the ARGE have been stimulated and financially supported by the Austrian Research Association (Österreichische Forschungsgemeinschaft, ÖFG) from the very beginning.

One of the main activities of the ARGE is the organization of workshops featuring the presentation of current research topics by major Austrian players in sensor research and leading to scientific exchange among them. This is done in plenary workshops but also in topically focuses small groups. For more information on the ARGE and current activities, please visit www.arge-sensorik.at.

In 2009 the ARGE steering committee decided to have a plenary meeting where young researchers, in particular those who are about to or have recently finished their PhD theses present their work. Further contributions by ARGE-partners have been accepted as poster presentations. The workshop was held on July 1st, 2009, at the Vienna University of Technology. A selection of these contributions is presented in this electronic Proceedings volume.

At this occasion I would like to thank all individuals who helped to organize this event (in particular staff at the Institute of Sensor and Actuator Systems), our financial sponsors (Vienna University of Technology, Austrian Center of Competence in Mechatronics ACCM, Österreichische Forschungsgemeinschaft ÖFG), and of course the contributors for presenting and discussing their work!

Linz, January 2010

Bernhard Jakoby
Workshop Program

ARGE Sensorik
PhD-Summit 2009
Program

July 1st, 2009, Vienna University of Technology,
Gusshausstrasse 27-29, A1040 Wien, Hörsaal El8

Chairmen:
Bernhard Jakoby (Johannes Kepler University Linz),
Michiel Vellekoop (Vienna University of Technology),
Georg Brasseur (Graz University of Technology),
Thilo Sauter (Austrian Academy of Sciences)

General Schedule and Talks

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<th>Title</th>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:30</td>
<td>Welcome and Introduction</td>
<td>Bernhard Jakoby,</td>
<td>JKU &amp; TUV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Michiel Vellekoop</td>
<td></td>
</tr>
<tr>
<td>09:45</td>
<td>Fluidic Microsystems for Biochemical Analysis</td>
<td>Gabriel Hainer</td>
<td>TUW/ISAS</td>
</tr>
<tr>
<td>10:05</td>
<td>Enhanced sensitivity of gas sensors based on thin films and nanowires</td>
<td>Alexandra Zima</td>
<td>ARC</td>
</tr>
<tr>
<td>10:25</td>
<td>Biochip integrating magnetic manipulation and detection of cells</td>
<td>Astart Shoshi</td>
<td>ARC</td>
</tr>
<tr>
<td>10:45</td>
<td>Coffee Break</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:10</td>
<td>Quadruple wavelength IR sensor for biopsy-screening</td>
<td>Sander v.d. Driesche</td>
<td>TUW/ISAS</td>
</tr>
<tr>
<td>11:30</td>
<td>Dynamic Methods for Viscosity and Mass Density Sensing</td>
<td>Erwin Reitshauer</td>
<td>JKU/IME</td>
</tr>
<tr>
<td>11:50</td>
<td>Cell sorting using DEP</td>
<td>Stefan Kostner</td>
<td>TUW/ISAS</td>
</tr>
<tr>
<td>12:10</td>
<td>CE in ceramics</td>
<td>Georg Fischer</td>
<td>TUW &amp; IMA</td>
</tr>
<tr>
<td>12:30</td>
<td>Lunch Break</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13:30</td>
<td>Poster Session</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14:30</td>
<td>Theoretical and Experimental Investigations Towards a Fully Integrated Evanescent Field IR-Absorption Sensor</td>
<td>Jürgen Kastberger</td>
<td>JKU &amp; IMA</td>
</tr>
<tr>
<td>14:50</td>
<td>Interdigitated impedance sensors for analysis of biological cells in microfluidic biochips</td>
<td>Lukas Richter</td>
<td>ARC</td>
</tr>
<tr>
<td>15:10</td>
<td>Uncertainty Evaluation in Vision-Based Measurement Systems</td>
<td>Markus Brandtner</td>
<td>TUW/EMT</td>
</tr>
<tr>
<td>15:30</td>
<td>Coffee Break</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15:50</td>
<td>Stretchable pressure sensor made of ferroelectret-elastomer-composite and elastic gold electrodes</td>
<td>Markus Krause</td>
<td>JKU/SOMAP</td>
</tr>
<tr>
<td>16:10</td>
<td>On Enhanced Clock Synchronization Performance through Dedicated Ethernet Hardware Support</td>
<td>Patrick Loschmidt</td>
<td>ÖAW</td>
</tr>
<tr>
<td>16:30</td>
<td>Introduction of the spatial filtering technique to the capacitive flow measurement</td>
<td>Daniel Hrach</td>
<td>TUG/EMT</td>
</tr>
<tr>
<td>16:50</td>
<td>Electromagnetic-Acoustic Resonators for Remote, Multi-Mode Solid and Liquid Phase Sensing</td>
<td>Frieder LuckoIm</td>
<td>JKU/IME</td>
</tr>
<tr>
<td>17:10</td>
<td>Closing Remarks</td>
<td>Bernhard Jakoby,</td>
<td>JKU &amp; TUV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Michiel Vellekoop</td>
<td></td>
</tr>
</tbody>
</table>
**Poster Contributions**

**Novel Design Approach for Micromachined Flow Sensor featuring Three Different Operating Modes**
- Almir Talic: OAW
- Georg Kaniak: TUW/EMT

**Principles for echo-position determination using airborne ultrasound**
- Ibrahim Atassi: TUW/ISAS

**Studies Concerning the Realization of 3-Dimensional Inductor Structures in LTCC Technology**
- Markus Brandstätter: TUW/AnalChem
- Michael Maser: TUG/EMT

**RFID-based high volume biosensor system**
- Jürgen Wissenwasser: ARC

**Towards an ultrasound enhanced MIR fiber optic sensor**
- Markus Brandstätter: TUW/AnalChem

**Time resolved FTIR spectroscopy using a four-layer lamination micro mixing device**
- Michael Maser: TUG/EMT

**Online Condition Monitoring of High Voltage Overhead Power Lines**
- Michael Unger: TUW/ISAS

**Parameters Governing the Sensor Characteristic of Capacitive Temperature Sensors built up in LTCC-Technology**
- Michael Unger: TUW/ISAS

**Concept for the measurement of finger forces during clarinet playing**
- Michael Weilguni: TUW/ISAS

**Current induced excitations of magnetization in giant magnetoresistive nanocoatings**
- Moritz Eggeling: ARC

**A position control system of a microfluidic sample flow**
- Nicola Moscelli: TUW/ISAS

**Experimental determination of frequency dependent acoustic attenuation for photoacoustic imaging**
- Peter Burgholzer: Recendt

**Ray-Tracing Modellierung und experimentelle Erprobung eines infrarot CO2-Sensors**
- Peter Hauer: JKU/SOMAP

**Tantalum based Multilayers for High Temperature Sensor Applications**
- M. Grosser: TUW/ISAS

**A Two-State Controller Scheme Utilizing a Micromachined Calorimetric Flow Sensor**
- Samir Cerimovic: OAW

**Biomolecular detection by optical relaxation measurements of hybrid nanoparticles**
- Stefan Schrötter: ARC

**Biomimetic Inertia Sensor Based on Nanowires and Magnetoresistance**
- Philipp Schroeder: ARC

**Abbreviations**

<table>
<thead>
<tr>
<th>Affiliation</th>
<th>University/Research Center</th>
<th>Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC</td>
<td>Austrian Research Centers, Wien</td>
<td>Bereich Nano-Systemtechnologien</td>
</tr>
<tr>
<td>IMA</td>
<td>Integrated Microsystems Austria, Wiener Neustadt</td>
<td></td>
</tr>
<tr>
<td>JKU/IME</td>
<td>Johannes Kepler University Linz</td>
<td>Institute for Microelectronics and Microsensors</td>
</tr>
<tr>
<td>JKU/SOMAP</td>
<td>Johannes Kepler University Linz</td>
<td>Soft Matter Physics</td>
</tr>
<tr>
<td>ÖAW</td>
<td>Austrian Academy of Sciences, Wiener Neustadt</td>
<td>Institute for Integrated Sensor Systems</td>
</tr>
<tr>
<td>Recendt</td>
<td>Research Center for Non-Destructive Testing, Linz</td>
<td></td>
</tr>
<tr>
<td>TUG/EMT</td>
<td>Graz University of Technology</td>
<td>Institute of Electrical Measurement and Measurement Signal Processing</td>
</tr>
<tr>
<td>TUW/AnalChem</td>
<td>Vienna University of Technology</td>
<td>Working group on Process Analysis &amp; Vibrational Spectroscopy</td>
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<tr>
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<td>Vienna University of Technology</td>
<td>Institute of Applied Physics</td>
</tr>
<tr>
<td>TUW/ISAS</td>
<td>Vienna University of Technology</td>
<td>Institute of Sensor and Actuator Systems</td>
</tr>
</tbody>
</table>
Selected Contributions

Talks

Note: The name of scientific adviser is listed after that of PhD candidate using the format “PhD Candidate/Adviser”

Uncertainty Evaluation in Vision-Based Measurement Applications, M. Brandner/G. Brasseur

Quadruple wavelength infrared sensor system for label-free tumour screening, S. van den Driesche/M.J. Vellekoop

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Posters

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Notes:
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Page numbers in arabic numerals refer to the bold face italic page numbers given at the top of the respective pages - these were electronically imprinted on the documents provided by the authors (some contributions use independent page numbering)
Uncertainty Evaluation in Vision-Based Measurement Applications

Markus Brandner

Institute of Electrical Measurement and Measurement Signal Processing
Graz University of Technology
Agenda

• Introduction
• Metrological geometry
• Vision-based quality control application
• Summary
Metrological Concepts

Air dryer: Quality control measurements

Tissue machine: On-site manufacturing

Tolerance limits met?
Measurement Uncertainty

Measurement uncertainty (MU) represents the spreading of the measurement values “...that could reasonably be attributed to the measurand” [VIM1993].

The GUM document [GUM1995] differentiates between uncertainties evaluated using statistical methods (type A) and uncertainties obtained by other means (type B).
Traceability

Measurement process is defined as the quantitative comparison of the unknown quantity with a standard.

Traceability ensures that every measurement is linked to an international standard by an unbroken chain of comparisons.

MU of the standard
Vision-Based Measurement

Example: Real-time measurement of the 2D position of a moving object using a perspective camera.

Requirements:

• Multidimensional measurands
• Applicability to different geometric entities
• Handling of type A and type B uncertainties
• Simple propagation through processing blocks
• Processing Speed
Uncertain Geometric Entities

• Euclidean geometry
  – Intuitive formulation
  – Individual construction of entities (e.g. line intersection)
  – Gaussian uncertainties work
  – Special cases need to be considered (e.g. point at infinity)

• Uncertain projective geometry [Förstner 2004]
  – Homogeneous representation of geometric entities
  – Point and line duality
  – No special cases
  – Simple construction using bilinear transforms
  – Gaussian uncertainties can be applied [Heuel 2003, Criminisi 2001]
Measurement Uncertainty

• Standard GUM procedure [GUM1995]
  – Based on classical statistics
  – Bayesian interpretation of coverage probabilities
  – Concept of degrees of freedom
  – Unified treatment of systematic and random effects

• Bayesian Extensions: GUM/Bayes
  – Consistent use of Bayes’ law
  – Relies on proper use of a priori knowledge
  – Required integrations can usually only be solved numerically
Consistent Frame-Work

• Assumptions
  – Homogeneous representation of geometric entities
  – Propagation of uncertainties using mean and covariance
  – All quantities are Gaussian random vectors
  – Prior densities are Gaussian

• Nomenclature
  – Multidimensional quantity
  – Coverage interval

• Modelling procedure
  – Description of the measurement task
  – Cause-Effect relations
  – Measurement model
  – Model equation
### Building Blocks

#### Transformation of uncorrelated input quantities

\[
\begin{align*}
\Sigma_{yy} &= J_g \sum_{\tilde{e}_i} \tilde{e}_i + J_{g, \tilde{x}_i} \sum_{\tilde{x}_i} \tilde{x}_i \sum_{\tilde{x}_j} \tilde{x}_j^T 
\end{align*}
\]

#### Transformation of correlated input quantities

\[
\begin{align*}
\Sigma_{yy} &= J_g \sum_{\tilde{e}_i} \tilde{e}_i + J_{g, \tilde{x}_i} \sum_{\tilde{x}_i} \tilde{x}_i \sum_{\tilde{x}_j} \tilde{x}_j^T 
\end{align*}
\]

### Bayesian Information Update

\[
\begin{align*}
\Sigma_{yy} &= J_g \left[ \sum_{\tilde{e}_i} \tilde{e}_i \sum_{\tilde{x}_i} \tilde{x}_i \sum_{\tilde{x}_j} \tilde{x}_j \right] J_g^T 
\end{align*}
\]

\[
\begin{align*}
\tilde{z}^+ &= \tilde{z}^T \left( \begin{array}{c} \tilde{z}^T \\ \tilde{x}^T \\ \tilde{e}^T \end{array} \right) 
\end{align*}
\]

\[
\begin{align*}
\Sigma_{yy} &= J_g \left[ \sum_{\tilde{e}_i} \sum_{\tilde{x}_i} \sum_{\tilde{x}_j} \sum_{\tilde{x}_j} \right] J_g^T 
\end{align*}
\]
Vision-Based Quality Control Measurement

- Air dryer
- Height 6m
- Diameter 5.5m
- Mass 40t
- Manufactured on turntable

Target measurands:

\[ \text{Displacement} \]

\[ \text{Tilt} \]

\[ \alpha_d \]

\[ d \]

\[ \alpha_t \]

\[ t \]
Measurement Principle

Signal model of general DT periodic function (period N):

\[ x[n] = a_0 + \sum_{k=1}^{N-1} a_k \cos \left( \frac{2\pi kn}{N} \right) + \sum_{k=1}^{N-1} b_k \sin \left( \frac{2\pi kn}{N} \right) \]

Remarks:
- DFT is MVUE for the Fourier series coefficients
- Result does not depend on any DC component \( c_0 \)

Signal model:

\[ c(\alpha) \approx d \cdot \cos(\alpha - \alpha_d) + r \]

\[ c(\alpha) = c_0 + c_1 \cdot \cos(\alpha + \varphi_c) \]
Vision-Based Sensors

[Brandner & Thurner 2006, IEEE Trans. IM]
Measurement Uncertainty Analysis

- Calibration
- Algorithms
- Range Sensors
- Contamination
- Sensor Mount
- Rate of Turn
- User
- Surface Properties
- Model Error
- Measurement Principle

- Turn-Table Parameters
  - Barrel Height
  - Lid Radius
  - Geometry of Setup
- Sensor Coordinate Systems
- Vibration
  - Temperature
  - Illumination
- Environmental Conditions

$(t, \alpha_t), (d, \alpha_d)$
Graphical Representation

Linear model: det. Signal in coloured noise.

\[ \mathbf{P} = \mathbf{D}\theta + \mathbf{W}_D \]

\[ \mathbf{D} = \begin{bmatrix} d_1 \\ \vdots \\ d_{2N} \end{bmatrix} \]

\[ d_{2i-1} = \left( \cos \frac{2\pi}{N}(i-1), \sin \frac{2\pi}{N}(i-1), 0, 0 \right) \]

\[ d_{2i} = \left( 0, 0, \cos \frac{2\pi}{N}(i-1), \sin \frac{2\pi}{N}(i-1) \right) \]

\[ \theta = (a_x, b_x, a_y, b_y)^T \]

\[ \hat{\theta} = (\mathbf{D}^T\Sigma_{PP}^{-1}\mathbf{D})^{-1}\mathbf{D}^T\Sigma_{PP}^{-1}\mathbf{P} \]

\[ \Sigma_{\hat{\theta}\theta} = (\mathbf{D}^T\Sigma_{PP}^{-1}\mathbf{D})^{-1} \]
Measurement Results (k=1.96, p=95%)
Uncertainty Budget

Displacement:

Tilt:

Displacement Angle:

Tilt Angle:
Summary

• Metrological geometry
  – Integration of uncertain projective geometry with GUM/Bayes
  – Simplified graphical representation
  – Analytical computation of MU using Gaussian quantities

• Vision-Based QC application
  • Real-time uncertainty budget
    - Simulation experiments feasible
    - Data-dependent uncertainty budget
    - “Smart sensor”
  • Insights to the application
    - Quality of the surface
    - Quality of the mount
Uncertain geometric entities can be represented by Gaussian homogeneous vectors in a way that is consistent with the current GUM/Bayes concept provided some (feasible) requirements are met. Correlations between parameters can in general not be neglected. The analytic propagation of uncertainties allows for a real-time computation of the uncertainty budget.

Future work will focus on …

• Improvements of the frame-work
  – Integration of non-linear models
  – Integration of non-Gaussian quantities

• Applications of the frame-work
  – Active calibration strategy
  – Active metrology
  – Embedded vision
Quadruple wavelength infrared sensor system for label-free tumour screening

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Vienna University of Technology
http://iss.isas.tuwien.ac.at/
http://www.cellcheck.eu/

Overview

• Motivation
• Sensor concept
• Sensor validation
• Tumour screening
• Conclusions
**Motivation**

**Tumour screening**
- Labelling and staining
  - Expensive chemicals
  - Time consuming
  - Visual inspection by highly trained personnel
- **Infrared spectroscopy**
  - Liquid nitrogen cooled detectors
  - Expensive equipment

**Goal:** label-free and low cost tumour screening device

---

**IR absorbance based cell-type discrimination**

- **Infrared absorbance** spectra comparison of healthy and tumour cells (breast, oesophagus, blood, brain) shows **differences** in the wavelength region between 3 and 4 µm

- **Functional infrared absorbance bands:**

<table>
<thead>
<tr>
<th>Wavelength (µm)</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.38</td>
<td>CH$_3$ antisymmetric stretch</td>
</tr>
<tr>
<td>3.42</td>
<td>CH$_2$ antisymmetric stretch</td>
</tr>
<tr>
<td>3.48</td>
<td>CH$_3$ symmetric stretch</td>
</tr>
<tr>
<td>3.51</td>
<td>CH$_2$ symmetric stretch</td>
</tr>
</tbody>
</table>
IR absorbance based cell-type discrimination (2)

Record IR absorbance values at specific functional wavelengths!

Cell-type discrimination by comparing peak ratio’s
- e.g. CH$_2$-stretch
- baseline correction
- normalization

Quadruple Wavelength Sensor System

Adjustable driver settings:
- pulse duration: 0.6 - 20 µs
- current amplitude: 0 - 2 A
- TC temperature: 0 - 22 °C
Sensor validation

Yeast sample:
- Easy to prepare biological sample
- Also contains the CH$_2$ and CH$_3$ stretch bands

IR spectroscope settings:
- 1 mm diameter beam
- 4 cm$^{-1}$ resolution
- 128 scans per spectrum

Sensor settings:
- 4 spots each measured 4 times
- 500 pulses per wavelength
Sensor validation (2)

IR spectroscopy vs. Sensor => Similar CH$_2$-stretch ratio

Sensor: cell-type discrimination experiment

Epithelial kidney cells:
- MDCK (healthy) and A-498 & Caki-1 (carcinoma)
- Grown in monolayer on calcium-fluoride slides
- Washed in phosphate buffered saline (PBS)
- Air dried for 4 hours in a laminar flow cabinet
Conclusions

• **Quadruple-wavelength IR sensor** system was built

• The sensor system yields similar **CH$_2$-stretch** ratio results of *yeast* compared to IR spectroscopy measurements

• **Detectable CH$_2$-stretch ratio** differences between healthy and carcinoma kidney cell lines

• Potential to be used for **low cost** and **label-free biopsy screening**
Acknowledgements

Institute of Chemical Technologies and Analytics, TU Vienna
  Prof. B. Lendl
  Dr. S. Armenta

Institute of Electrodynamics, Microwave and Circuit Engineering, TU Vienna
  Dr. K. Futschik

Institute of Virology, Slovak Academy of Sciences
  Prof. S. Pastorekova
  W. Witarski

Institute of Sensor and Actuator Systems, TU Vienna
  Prof. M.J. Vellekoop
  S. Kostner
  C. Riesch

Thank you for your attention!

Quadruple wavelength infrared sensor system for label-free tumour screening

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Vienna University of Technology
http://iss.isas.tuwien.ac.at/
http://www.cellcheck.eu/
On-Chip Electrophoresis Device Fabricated in LTCC Technology

Georg Fercher, MSc
Overview

- Motivation
- Working principle of capillary electrophoresis (CE)
- Ceramics (LTCC) for microfluidic CE devices
- On-chip contactless conductivity detection
- Results
- Outlook
Capillary electrophoresis (CE): Separation of ionic species

Advantages of on-chip CE devices:

- Reduced measurement time
- Smaller dimensions -> “Point-of-use” applications
- Less sample uptake
- Robust

Challenges:

- Separation efficiency
- Detection sensitivity
Under the influence of an external electric field, ions migrate at different velocities from one another due to their inherent mobilities.

Mobilities:
\[
\mu_{ep} = \frac{Q}{6\pi\eta r} \quad Q \ldots \text{Ion charge} \\
\eta \ldots \text{Viscosity} \\
r \ldots \text{Stokes radius}
\]

\[
\mu_{eof} = \frac{\varepsilon_r \zeta}{\eta} \\
\zeta \ldots \text{Zeta potential} \\
\varepsilon_r \ldots \text{Permittivity}
\]

Separation speed proportional to the electric field:
\[
\vec{v}_{sep} = \vec{E}(\mu_{ep} + \mu_{eof})
\]
Basic principles – Electroosmotic flow (EOF)

- Hydrated cations in the solution associate with ionized SiO$^-$ groups at pH>3 and form an electric double layer.
- Upon application of an electric field, cations in the diffuse layer move toward the cathode, creating a net flow of the liquid.

Diagram showing a capillary wall, a compact layer, a diffuse layer, and a bulk solution with hydrated cations forming an electric double layer.
Advantages of Low temperature co-fired ceramics for microfluidics:

- Formation of almost arbitrary shapes of channels and cavities
- Biocompatible
- Withstands chemically aggressive environments
Detection principle: C⁴M

Capacitively Coupled Contactless Conductivity Measurement: C⁴M

- Direct contact between electrodes and fluid is avoided
  - Longer lifetime
  - No interferences between detection circuitry and HV
  - Higher separation efficiency

Reduced coupling of the measurement signal into the channel
Detection principle: C4M

- High coupling capacitance $C_{cpl}$
  - High values of material permittivity
- Low stray capacitance $C_{stray}$
  - Opposite electrode arrangement
Graphical representation of the output signal: Electropherogram

Separation of potassium, sodium and lithium; $E = 200 \text{ V/cm}$

$1)^{1}$Accepted for publication in “Electrophoresis”
• Miniatuised LTCC-CE module for analytical applications
• High values of material permittivity enhance detection sensitivity
• LTCC is an attractive alternative to glass or polymer substrates
• Separation efficiency yet to be improved
• Alternative measurement methods for even higher detection sensitivities
Thank you very much!

Contact details:
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+43 (0) 1 58801 36667
Fluidic Microsystems for Biochemical Analysis

Institute of Sensor and Actuator Systems

Industrial Sensor Systems

Gabriel Hairer
Supervisor: Prof. Dr. Michiel J. Vellekoop

Vienna University of Technology

Overview

• On-chip DNA Amplification (PCR)

• Capacitive µ-Sensor for DNA detection

• Miniaturised Analysis System
  – Temperature control
  – Sensor read-out
  – Fluidic transportation

• Conclusion and Outlook
Motivation

Integrated analysis systems for amplifying and detecting specific DNA sequences feature several advantages:

- Point-of-care tests
- Less amount of sample (ml → µl)
- Fast system systems (3h → 30min)
- Cost efficient analysis

Application fields:
Environmental monitoring, forensics and biomedical diagnostics.

On-chip DNA Amplification (PCR)
Polymerase Chain Reaction (PCR)

- PCR copies a DNA sequence up to a billion times
- Process consists up to 40 heat cycles (DNA doubling/cycle)
- One PCR cycle involves 3 temperature steps
  - Denaturation (95 °C)
  - Annealing (~58 °C)
  - Extension (72 °C)

Fabrication of the PCR Chip

- Si
  - DRIE processing
  - Thermal oxidation
- Pyrex 7740 glass
- Glass drilling
- Glass to silicon-dioxide anodic bonding

Photo of the PCR chip

Size: 20 × 15 × 1 mm³
Access holes: 1 mm
Chamber volume: 25 µl
Proof of Functionality

- PCR mastermix with *E. Coli* DNA
- PCR chips into a conventional thermal cycler
- Standard PCR program
  (each temperature step for 1min, 40 cycles)
- Agarose gel electrophoresis

PTC-200 Thermal Cycler

Agarose gel electrophoresis of 16S rRNA PCR products
(497 base pair fragment) amplified from *E. coli* DNA.

Lane 1 and 2: PCR Chip
Lane 3: 100 base pair ladder
Lane 4 and 5: conventional PCR reaction tubes

3D Numerical Simulation

Orange area: 95.0°C to 95.5°C

G. Hairer, ARGE Sensorik PhD-Summit, July 1st, 2009, page 7
**Temperature cycling**

**PCR microsystem**

Temperature sequence

Heating rate: 8 °C/s compared to 0.1 – 1 °C/s
Cooling rate: 6 °C/s compared to 0.1 - 1 °C/s
Heating time: 5 sec compared to about 80 sec

L1: 100 bp latter
L2: PCR System
L3: PCR in tube

G. Hairer, ARGE Sensorik PhD-Summit, July 1st, 2009, page 9

G. Hairer, ARGE Sensorik PhD-Summit, July 1st, 2009, page 10
Capacitive µ-Sensor for DNA detection

DNA Detection Principle

Affinity-based DNA detection via label-free capacitive DNA sensor.

Interdigitated electrodes (IDE) of gold form a capacitance.
Modified single-stranded DNA sequences (probes) covalent bond on gold (thiol-group).

Binding of complementary DNA stands (targets) replaces solution.
→ capacitance change
Chip size: $9 \times 9 \text{ mm}^2$

- 16 IDEs on chip
- Sensing area of IDE: $100 \times 100 \text{ µm}^2$
- Lines and spaces: 500 nm

Photograph of DNA Sensor

Wire bonded chip on PCB.
**Equivalent Circuit / Setup**

Electrode Measurements

**DNA concentration measurements**

36mer oligonucleotides with different concentrations solved in DI-water.

Increasing DNA amount
- Increasing of $C_{dl}$
- Shift to higher frequency

**DNA hybridisation**

Hybridisation of Eco3 target DNA to a complimentary DNA probe (covalent bonded on the electrode) in DigEasy buffer.

Capacitance drop of 26 pF results in a measurement change of ~10 %
Miniaturised Analysis System

Control / Measurement Unit

Size: $3 \times 8 \times 12 \text{ cm}^3$

Features:
- Menu to set parameters
- Temperature control of PCR chip
- Measurement of DNA sensor
**Fluidic**

DNA sensor on PCR with PDMS ring

PCR chip with foil heater and Pt100

Cooling fan

---

**Miniaturised Analysis System**

Syringe for transportation

DNA sensor

USB

Power supply

PCR chip with foil heater and Pt100

Temperature sequence of PCR chip

Sedimentation
Conclusions / Outlook

• On-chip PCR for fast and cost-efficient DNA amplification has been shown.

• A label-free DNA sensor has been successfully tested.

• The realisation of an miniaturised analysis system has been demonstrated.

→ Test the analysis system for DNA amplification / detection

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Introduction of the spatial filtering technique to the capacitive flow measurement

Daniel Hrach
Institute of Electrical Measurement and Measurement Signal Processing
Graz University of Technology
Austria
Agenda

• Introduction
• State of the Art of Granular Flow Sensors
• Capacitive correlator
• Optical / capacitive spatial filter
• Advanced electrode layouts and excitation scheme
• Experimental setup and results
• Conclusion
Introduction to granular flow measurement

Pneumatic conveying:

- Solid particles in gas
- Clean, flexible and reliable conveying solution
- Applicable for coal, wooden- or plastic pellets, salt, sugar, flour, ...
State of the Art Granular Flow Sensors

- **Optical:**
  - PIV
  - problems with dust

- **Ultrasonic:**
  - Doppler shift
  - works only in special cases (low particle number, problems with sound distribution in the pipe material)

- **Gamma rays:**
  - correlative principle
  - expensive personal, safety, import/export, environment, ..

- **Capacitive:**
  - correlative principle

Granular flow measurement is challenging!
Capacitive Correlator

Correlative principles are also used with light, gamma rays, magnetic principles.

Two sensor positions with known distance in flow direction result in a time shifted measurement signal.

\[
\text{velocity} = \frac{\text{sensor distance}}{T}
\]
Development of the spatial filter

Work on master thesis:

- On board 2D velocity determination of racing cars
- On board mounted camera takes images of the ground surface with known time-lag
- **Correlative** displacement measurement

\[
\text{velocity} = \text{displacement} \cdot \frac{1}{T}
\]
Optical spatial filter

There is an alternative approach!

Advantages:
- Low complexity, low cost
- High sensitivity
- High measurement velocities possible

velocity = frequency \cdot\text{griddistance}
Capacitive Spatial Filter

- Principle well known from the optics
- Pipe interior separated in a regular array of different sensitive areas
- Particles with constant velocity cause quasi periodic signal

\[
\text{velocity} = \text{electrode distance} \cdot \frac{1}{T}
\]
Capacitive Spatial Filter II

- many concurrent particles in the volume cause large offset capacitance
- low signal power

advanced excitation pattern required

\[
velocity = \text{electrode distance} \cdot \frac{2}{T}
\]
Advanced Excitation Scheme

FEM Simulation shows:

- lower number of periods
- mean free measurement signal
- increased signal power
Advanced Excitation Scheme II

FEM of the Equipotential lines

Contour: Electric potential [V]

regular excitation

Contour: Electric potential [V]

differential excitation
Axial field electrode layout

- Uniform sensitivity around circumference
- Again offset variation due to varying amount of particles inside volume

Differential excitation

Differential receiver
Experimental Setup

- Spatial filtering sensor
- Throttle flap
- Hot film airflow meter
- DSP and capacitance to digital converter ASIC
- Fan
Experimental Setup II

- in-/quadrature phase measurement
- sampling rate approx. 8 kHz

Particle velocity determination by means of frequency estimation
Experimental Setup III

Periodogram calculation:

- Frequency estimation using overlapping FFTs
- Sensor principle works!
- higher airflow velocity (higher particle number) causes higher amplitude in frequency spectrum
Conclusion

- non-invasive measurement system for particle velocity
- based on capacitive spatial filtering
- differential excitation allows higher gains
- axial field electrode layout for uniform sensitivity
- laboratory test results presented

Principle of spatial filtering is applicable to capacitive flow measurement
Introduction of the spatial filtering technique to the capacitive flow measurement

Thank you!
Fully Integrated IR - Absorption Sensor

Jürgen Kasberger, Integrated Microsystems Austria
Bernhard Jakoby, Johannes Kepler University Linz
Infrared Absorption Spectroscopy

- Offline Application
  - Laboratory method (high fidelity)

- Online Application
  - Condition monitoring & process control
  - Restrictions regarding accuracy
  - Possible robust & accurate implementation:
    Monitoring of absorption @ defined wavelength (application-specific)

- Pilot Application
  - Oil deterioration (absorption due to oil oxidation)
  - Samples provided by AC²T research

![Diagram of Infrared Absorption Spectroscopy](image)
Integrated Microsystem Concept

• Transducer
  – Utilize evanescent field of waveguide to achieve absorption

• System Components
  – Thermal IR-emitter/detector (simple non-coherent, non-polarized source)
  – Grating coupler
    • Broadband coupling
    • Filtering by diffractive coupler behavior (coupling angle depends on λ)
  – Mono-mode Waveguide
Analysis of system properties supporting optimized design

1. Analysis of waveguide properties

2. Properties of a grating coupler
3. Selective thermal emitter / detector
4. Experimental results
1. Waveguide as absorption element

- Selected materials:
  - SiN (n=2) / MgF_2 (n=1.33) are translucent in a wide IR-range
  - Index of refraction influences penetration depth into sample
  - Approaching cutoff thickness increases penetration depth if \( n_{\text{Sample}} > n_{\text{Subs}} \)

\[
E_0 e^{-\gamma z} = \frac{1}{e} \implies d_p = \frac{1}{e}
\]

- Similar sensitivity of all modes close to related cutoff
- Different features (cutoff thickness) of TE and TM-mode

*Mono-mode waveguide to prevent mode conversion*
1. Waveguide as absorption element

- Attenuation of guided mode $\beta''$ approaches attenuation in bulk material $n''k_0$ ($n_{\text{Oil}} = 1.5 > n_{\text{Subs}}$) if waveguide thickness is reduced.

- Specific application yields optimum length of waveguide:
  - Propagation constant must be calculated numerically.
  - Complex $\beta$ is related to sample properties (e.g., oil from AC²T).
  - $\Delta \beta''$ due to change in sample (fresh to old oil).

\[
L_{\text{Opt}} = \frac{1}{2(\beta'' + \Delta \beta'')}
\]
1. Waveguide step transition

- Confinement wall introduces step transition
- Aimed evanescent field induces scattering losses

- Numerical integration yields a system of algebraic equations by matching field at transition

\[ E^T + a_R E^R + \int q_R(k_x) E^R(k_x) dk_x \]
\[ = c_T E^T + \int q_T(k_x) E^T(k_x) dk_x \]

- Guided, evanescent and radiation modes have to be considered

With oil \((n_{oil} \approx n_{BCB})\) scattering losses are negligible
1. Waveguide Roughness

- **Scattering losses**
  - Surface scattering losses are important for the choice of the required quality of the substrate
  - Volume scattering losses induced at impurities of waveguide

- **Numerical method**
  - Equivalent current method
  - Surface roughness induces radiating fields

\[
E_s = (n_c^2 - n_f^2)k_0^2 \\
\int \int G(x,x',z,z')U(f(x))E_0(x',z')\,dz'\,dx' + \ldots
\]

- \(U\)...step function depending on surface profile
- \(E_0\)...undisturbed field
- \(G\)... Green function for homogeneous medium

**RMS of measurements of surface profile ≈ 5nm**
Analysis of system properties supporting optimized design

1. Analysis of waveguide properties
2. Properties of a grating coupler
3. Selective thermal emitter / detector
4. Experimental results
2. Grating Coupler

- Coupling efficiency of a grating coupler
  - Rigorous coupled wave analysis (RCWA)
    - Complex propagation constant of the leaky mode
    - Reflectivity (R1) represents fraction of power radiated towards IR-detector in case of homogenous problem
  - Reciprocity theorem
    - Relates spatial distribution of incident beam to grating behavior
    - Collimated limited beam
      \[
      \eta = R1 \left( 1 - e^{-2\text{Im}(\alpha_p)L} \right) \frac{\left( \int I_{in}(x)I_{out}(x)dx \right)^2}{\int I_{in}(x)dx \int I_{out}(x)dx}
      \]
    - Coupling of a particular wavelength at the related coupling angle
2. Grating Coupler

- Coupling of thermal radiation into the waveguide
  - Near normal coupling to prevent second order Bragg coupling
  - Pole of transmission matrix reveals narrow coupling around $k_0$, $\Theta_0$
    \[
    \frac{I_{WG}}{I_{WG,0}} = \frac{\text{Im}(\beta_0)^2}{(k_{||} - \text{Re}(\beta_0))^2 + \text{Im}(\beta_0)^2}
    \]
  - Integration of transmission function results in FOM for thermal radiation

Maximum efficiency $\approx 39%$

$h_{\text{Grating}} \approx 1.3\mu m$, $L_{\text{Coupler}} \approx 40\mu m$
2. Grating Coupler

- Power coupled into the waveguide
  - Maximum power is demanded (not efficiency)
  - Constant intensity (boxcar beam) permits multiplication of efficiency with length of the coupler (beam) to determine power

Saturation for thermal radiation at $L_{\text{Coupler}} \approx 250 \mu m$
Analysis of system properties supporting optimized design

1. Analysis of waveguide properties
2. Properties of a grating coupler
3. Selective thermal emitter / detector

4. Experimental results
3. Thermal IR - detection

- Integration of the intensity profile of the beam at the IR-detector yields the absorbed power
  - Optimization with respect to the signal to noise ratio
  - $L_{d,\text{opt}} = 20\mu\text{m}$

- Two peaks in IR-absorption at the IR-detector
  - Appear due to different propagation constants of TE and TM-mode

- Possible solutions
  - Wavelength selective IR-detector (Fabry-Perot)
  - Increase thickness of waveguide
    - reduces difference of propagation constants
  - Design of waveguide to cutoff TE-mode
  - Additional interference / polarization filter
Analysis of system properties supporting optimized design

1. Analysis of waveguide properties
2. Properties of a grating coupler
3. Selective thermal emitter / detector
4. Experimental results
4. Measurement with FTIR-spectrometer

- FTIR-spectrometer (Vertex 80)
  - Chopped IR-beam
  - External detector with Lock-in amplifier

- Limited transmission through device
  - Due to particular angular characteristic of focused IR-beam

- Transmission through entire device
  - Without oil for reference measurement
  - Loaded with aged oil samples
4. Measurement Translation Stage

- Rough positioning of the commercial IR-emitter regarding targeted wavelength
- Aperture to suppress scattered waves
- IR-detection
  - Spectral separation through angular measurement of the beam coupled out of the waveguide
  - Increased gap increases spatial resolution
  - Actuated IR-detector can be replaced by a detector array
4. Measurement Translation Stage

- Characterization of spatial resolution
  - Through intrinsic absorption peak of SiN
  - FWHM of SiN notch ≈ 300nm
- Measurement of artificially aged oil
  - Reference and oil measurement for normalization purpose.
  - Limited performance due to big IR-detector (1.3 x 1.3mm instead of 20µm)
Summary

• High sensitivity of evanescent field absorption
  – Adjustable for particular application
  – Comparable to transmission setup for liquid application
  – Scattering losses induced by roughness and transition step are negligible

• Grating coupling
  – Optimized regarding input and output coupling
  – Spectral separation at output coupling
  – Experiments carried out at fabricated devices confirm simulation results

• Thermal emission / detection
  – Optimized detector size to improve sensor performance
  – Necessary suppression of one polarization peak (e.g., TM-mode) by Fabry-Perot absorber structure
Cell separation using dielectrophoresis

Stefan Kostner
Institute of Sensor and Actuator Systems
July-1-2009
Introduction and motivation

- Cell separation is widely used in therapy and research
- Mostly based on centrifugal force and density gradients (equilibrium methods)
- Why miniaturized separators?
  - Reduce sample amount
  - Integration into analysis devices to eliminate labor-intensive / error prone sample processing
  - Allow for totally automated point-of-care diagnostic instruments
- Why dielectrophoresis?
  - Purely electrical control of the separation process
  - No moving parts
  - Separation based on electrical properties (such as cell membrane capacitance) possible
Theory of dielectrophoresis (DEP)

First order dipole approximation:

$$F_{\text{DEP}} = 2\pi \varepsilon_1 R^3 K \nabla E_{0,\text{RMS}}^2$$

$$K = \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_2 + 2\varepsilon_1}$$

$$\varepsilon_1 > \varepsilon_2 \text{ nDEP}$$

$$\varepsilon_1 < \varepsilon_2 \text{ pDEP}$$

Induced dipole
Theory of dielectrophoresis (DEP)

Extension to complex permittivity $\varepsilon = \varepsilon + \frac{\sigma}{j\omega}$:

$$\mathbf{F}_{\text{DEP}} = 2\pi \varepsilon_1 R^3 \Re[K] \nabla E_{0,\text{RMS}}^2$$

$\Re[K]$ represents the real part of the complex permittivity $K$. The diagram illustrates the behavior of $\Re[K]$ with frequency for different material properties $\varepsilon_1, \sigma_1$ and $\varepsilon_2, \sigma_2$. The transition between normal DEP (nDEP) and reversed DEP occurs at different frequencies depending on the material properties.

- $\varepsilon_1 > \varepsilon_2$ for nDEP
- $\sigma_1 > \sigma_2$
- $\varepsilon_1 < \varepsilon_2$
- $\sigma_1 < \sigma_2$

The characteristic frequencies $\omega_m$ and $\omega_m'$ are also shown for different conductivities $\sigma = 0.4$ and $\sigma = 40$ mS/m.
Separation based on lateral DEP guiding

Principle
Experimental setup
Separation based on lateral DEP guiding

Demonstration of the principle (movie)
Separation based on lateral DEP guiding

Simulation results 12µm polystyrene particles and 12µm Protoplasts
Separation based on lateral DEP guiding

Particle detection, removing the background
Separation based on lateral DEP guiding

Measurement results with cells and 12µm diameter polystyrene beads
Conclusions and outlook

• Lateral guiding: robust method for pDEP/nDEP separation, distinct outlet positions.
• Future designs will focus on
  – Robustness of the separation process
  – Possibility to harvest separated cells
  – Investigation of DEP affinity for special cell cultures
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Thanks for your attention!
On Enhanced Clock Synchronization Performance through Dedicated Ethernet Hardware Support

Themenicher Überblick der Dissertation von
Patrick Loschmidt

Institut für integrierte Sensorsysteme
Mission Statement

- Find out about the limits of Ethernet based clock synchronization
- Identifizierung der relevanten Einflussfaktoren
  - Physikalisch
  - Strukturell
- Entwurf effizienter Strukturen
  - Anforderungen von Anwendungen
  - Interaktion zwischen Hardware und Software
  - Hardware Entwurf
- Vorhandene Vorgaben durch den Standard mit Zielrichtung höchster Präzision und Langzeitstabilität erweitern
Network-based Control Systems

- Fieldbus/Ethernet bedeutet
  - Abtasten von Daten
  - Netzwerk-/Verarbeitungszeit
  - Variable Verzögerungen
  - Synchronisierte Uhren ermöglichen fixen Zeitraster
  - Koordination von Sensor/Aktuator Operationen
IEEE 1588 Funktionsprinzip

• Master-Slave basierend
• Unabhängig von der konkreten Netzwerktechnologie
• Strategie
  – Sync Nachrichten
  – Delay_Req und Delay_Resp Nachrichten
• Netzwerkverzögerung wird kompensiert
• Andere Ansätze (z.B. NTP) arbeiten ähnlich aber nicht gleich
• Probleme
  – Ausfall des Masters
  – Asymmetrische Verzögerungen

\[ d = \frac{1}{2} [(t_2 - t_1) + (t_4 - t_3)] \]
\[ o = \frac{1}{2} [(t_2 - t_1) - (t_4 - t_3)] \]
Syn1588 PCI-NIC Plattform

- Flexible Testplattform
- Ethernet MAC
  - 10/100(/1000) Base-T support
  - PCIe
  - Linux Umgebung
- Clock synchronization core
  - bis zu 2 ns Auflösung
  - 1 ns Genauigkeit (100 Base-T)
  - getrennte Taktdomaine
Überblick Uhrensynchronisationszelle

- Hochauflösende Addierer basierende Uhr
  - gleichmäßig kontinuierliche Amortisierung
  - Unabhängig vom Oszillatortakt
- Einammlige und periodische Timer
  - verteilte PLL
  - koordinierte Aktionen (1 PPS)
- programmierbarer MII scanner
- Status, Raten und Interval basierte Synchronisation
  - Temporäre Schrittweite
  - Kompensierte Timer
IEEE 1588 basierte Uhrensynchronisation

- Software für Protokolloperation
- Kernelsicherheit für Hardwarezugriffe
- HW unterstützt Zeitstempel für Ethernet Pakete
  - Paketpuffer und zeitgesteuerte Parameteradaptionen
Verbleibende Jitter Quellen / Störungen

- Oszillatoren
  - PHY
  - Uhrensynchronisationszelle (Taktübergänge)
- PLLs
  - PHY
  - FPGA
- Netzwerk
  - Switches
  - Asymmetrie
  - Temperatureinflüsse (Kabel)
  - Rauschen
Einfluss der Übertragung auf die Verzögerung

- 10 Base-T
  - pro Paket
  - 100ns Raster
- 100 Base-T
  - kontinuierlich
  - 8ns Raster
- Hub
  - gleichverteilt, 400ns
- Switch
  - Hersteller, Last, usw. abhängig
Physical Layer Chip (100BaseTX)

- Daten werden mit 125 Msymbols/s übertragen
- 5B4B Decoder formt Nibbles für das Media Independent Interface (MII) bei 25 MHz
- Optional: elastische Pufferung und PHY mit internem Takt für RMII
Physical Layer Chip Messungen

- Lock-in Verhalten ist vom Hersteller des PHY abhängig
- Taktrückgewinnung: Jitter Oszillator abhängig
Oszillator

- Charakterisierung durch Messung der Allan Varianz
- The Allan Varianz kann aus den gemessenen Periodendauern ermittelt werden.
- Synchronisationsperiode sollte auf den Oszillator abgestimmt sein
Einfluss des Synchronisations Intervals

• Die Synchronisationsqualität wird von der Oszillatorstabilität bestimmt und ergibt
  – 50 ppm XO: Optimum $\sigma = 4.8 \text{ ns}$
  – 0.3 ppm OCXO: Optimum $\sigma = 0.52 \text{ ns}$
Zeitstempelauflösung vs. Sync Interval

- Results:
  - Große Zeitstempel erhöhen die Standardabweichung
  - Kürzere Intervalle können grobe Zeitstempel kompensieren

- Grafik: Die Standardabweichung steigt mit der Vergrößerung des Synchronisationsintervalls an. Drei verschiedene Zeitstempellösungen (2 ns, 8 ns, 16 ns) sind dargestellt.
Synchrone Ansätze

- Synchronous Ethernet
  - standardisiert
  - durchgängige Infrastruktur notwendig
- Optical Gigabit Ethernet
  - single mode erlaubt fast symmetrische Verzögerungen
- White Rabbit
  - Entwicklung eines Felbus ähnlichen Kontrolnetzwerkes
  - optische Verbindungen bis 10km
  - 10ppt nach ITU G.811 Langzeitstabilität
  - Kompensation der Verzögerung < 1ns
Danke für die Aufmerksamkeit!

Patrick.Loschmidt@OEAW.ac.at
Electromagnetic-Acoustic Resonators for Remote, Multi-Mode Solid and Liquid Phase Sensing

PhD Summit ARGE Sensorik
01.07.2009

Frieder Lucklum, Bernhard Jakoby
Institute for Microelectronics and Microsensors, Johannes Kepler University Linz, Austria

Overview

- Fundamental Concept
- FEM and Equivalent Circuit Simulation
- Non-contact Mass Microbalance
- Liquid Density and Viscosity Sensing
- Liquid Level Measurement
- Conclusions
Fundamental Concept

- Electromagnetic excitation and detection of acoustic waves:
  - Eddy current induction
  - Generation of Lorentz forces
  - Vibration of resonator element
  - Induction of secondary voltage

Finite Element Modeling

- Available Shear Modes:
  - Circular TSM for viscosity-density sensing (bottom left)
  - Radial FSM with strong flexural component (top left) for liquid volume sensing
**Equivalent Circuit**

- **Equivalent Circuit Model:**
  - Electromechanic transformer coupling electric side (excitation circuit, eddy currents) to mechanical side (resonator)
  - $U \leftrightarrow v$
  - $I \leftrightarrow F$

**Experimental Setup**

- Remote excitation and detection
  - Resonator element inside fluidic chamber or part of chamber
  - Excitation coil and permanent magnet outside of measurement cell
Mass Microbalance

- (100) Si - membrane
  - Thickness: 190 μm
  - Fundamental TSM frequency:
    calculated: ≈ 15.5 MHz
    measured: 15.82 MHz
    Q-factor: > 100,000
- Sensor response
  - Frequency shift due to acoustic mass load (300 nm polystyrene)
  - Δf of fundamental TSM:
    calculated: -6.95 kHz
    measured: -6.60 kHz
  - Sauerbrey-like behavior
  - Only minimal damping

Liquid Density and Viscosity

- Liquid property sensing
  - Improved sensitivity for face shear modes
  - Pure in-plane vibration
  - Circular FSM
  - Frequency shift and damping due to viscous liquid loading (density-viscosity product)

$$\Delta f = -f_0 \frac{1}{2} \left( \frac{\rho \eta_l}{\pi \rho_R \mu_R} \right)^{1/2}$$
Liquid Density and Viscosity

<table>
<thead>
<tr>
<th>Liquid</th>
<th>$\rho$ (kg/m$^3$)</th>
<th>$\eta$ (mPas)</th>
<th>$\Delta Z$ (m$\Omega$)</th>
<th>$\Delta \Theta$ (m$^\circ$)</th>
<th>$\Delta f$ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Propanol</td>
<td>803.5</td>
<td>1.898</td>
<td>10.01</td>
<td>94.20</td>
<td>-250</td>
</tr>
<tr>
<td>1-Butanol</td>
<td>809.8</td>
<td>2.524</td>
<td>7.16</td>
<td>87.93</td>
<td>-300</td>
</tr>
<tr>
<td>1-Pentanol</td>
<td>814.4</td>
<td>3.441</td>
<td>6.57</td>
<td>77.54</td>
<td>-340</td>
</tr>
<tr>
<td>1-Heptanol</td>
<td>821.9</td>
<td>5.942</td>
<td>5.44</td>
<td>61.56</td>
<td>-370</td>
</tr>
<tr>
<td>1-Octanol</td>
<td>827.0</td>
<td>7.368</td>
<td>5.31</td>
<td>56.56</td>
<td>-400</td>
</tr>
<tr>
<td>1-Decanol</td>
<td>829.7</td>
<td>10.974</td>
<td>4.41</td>
<td>47.36</td>
<td>-460</td>
</tr>
</tbody>
</table>

- (111) Si-membrane – linear FSM
- Set of different alcohols
  - Out-of-plane components of diagonal vibration
  - $\Rightarrow$ Constant offset due to secondary influence of liquid volume

Influence of viscosity
- Linear relationship with frequency shift
- Non-linear ($\sim 1/\sqrt{x}$) relation to impedance magnitude

Influence of density
- Linear relationship with impedance phase shift
  $\Rightarrow$ Frequency and impedance evaluation
Liquid Level Measurement

- Flexural plate mode
  - Radial Lorentz forces
  - Strong out-of-plane component at resonator center
- ⇒ Standing compressional waves radiated into liquid
  - Interference of reflected wave with resonator motion
  - Constructive and destructive interference effects
  - ⇒ Cyclic frequency pattern
- Possibility to measure ultrasonic velocity for known liquid levels

Liquid Level Measurement

- Liquid level resolution down to 3 µm
  - Improved resolution and accuracy for higher levels
- Comparison between measurement and equivalent circuit
  - Similar cyclic behavior with transmission line
  - Differences due to 3-D radiation pattern vs. 1-D transmission line
Sensor Arrays

- Variations of coil layout, magnet alignment, and excitation frequency
- Experimental possibilities:
  - Single mode excitation
  - Multi mode excitation
  - Increased redundancy with single-mode measurements
  - Measurement of different properties (e.g. liquid volume, density-viscosity) with multi-mode excitation

Summary

- Remote electromagnetic excitation of acoustic resonators
  - Silicon membranes
  - Aluminum plates
  - Sensor arrays
- Sensitivity depending on vibration mode shape
  - Mass microbalance
  - Liquid density and viscosity
  - Liquid level, ultrasonic velocity and compressibility
- Simultaneous measurement by multi-mode arrays

Thank you for your interest!
References


Dynamic Methods for Viscosity and Mass–Density Sensing

Erwin K. Reichel

1. Juli 2009
Motivation

- Measurement of deformation properties in process
- Condition monitoring (e.g. lubricant, fuel)
- Small sample volume
- Disposable sensors (e.g. biomedical analysis)
Laboratory Methods

- Sliding plates
- Concentric cylinders (Couette flow)
- Cone and plate
- Parallel disks
- Capillary (Poiseuille)
- Slit flow
- Axial annulus flow
- Falling ball
- Falling cylinder
- Rolling ball
Sensor Principles

- Cantilever / paddle
- Flexural Plate
- Tuning fork
- Torsional cylinder
- Thickness shear quartz
- Surface acoustic shear waves

common  micromachined  millimeter-sized
Resonant structure in contact with test liquid:

- mass–density $\rho$
- viscosity $\eta = \eta(\omega)$ (for complex liquids)

Evaluate (for specific eigenmodes):

- resonance frequency
- damping factor

Mechanical 2nd–order system
Calculation of energy terms from velocity field (modal solution)

Stored energies:

- elastic:
  \[ \hat{E}_{\text{elastic}} = \int_V \frac{S : c : S^*}{2} dV \]
- kinetic:
  \[ \hat{E}_{\text{kin}} = \int_V \frac{\rho |v|^2}{2} dV \]

Dissipated energy:

- viscous losses:
  \[ P_{\text{diss}} = \omega^2 \int_V \frac{S : \eta : S^*}{2} dV \]

\( S \) \ldots strain tensor \quad \( c \) \ldots stiffness matrix \quad \( v \) \ldots velocity field
Calculation of energy terms from velocity field (modal solution)

Undamped resonance frequency:

\[ \omega_r^2 = 2 \frac{\hat{E}_{\text{elastic}}}{\hat{E}_{\text{kin}}} \]

Damping factor:

\[ D = \frac{1}{Q} = \omega \frac{P_{\text{diss}}}{\hat{E}_{\text{kin}}} \]
Energy Consideration

Calculation of energy terms from velocity field (modal solution)

Undamped resonance frequency:

\[
\omega_r^2 = 2 \frac{\hat{E}_{\text{elastic}}}{\hat{E}_{\text{kin}}}
\]

Damping factor:

\[
D = \frac{1}{Q} = \omega \frac{P_{\text{diss}}}{\hat{E}_{\text{kin}}}
\]

- relate to measured parameters
Fluid motion in vicinity of vibrating structure

General method (for incompressible fluid):

- Solution of Laplace’s equation (velocity potential):

\[ \mathbf{v}' = \nabla \Phi \]
\[ \Delta \Phi = 0 \]
Fluid motion in vicinity of vibrating structure

General method (for incompressible fluid):

- Solution of Laplace’s equation (velocity potential):
  \[ \mathbf{v}' = \nabla \Phi \]
  \[ \triangle \Phi = 0 \]

- Superposition with 1D shear wave solution:
  \[ \nu_t(n) = [\nu_t(0) - \nu_t'|_{\partial \Omega}] e^{i(\omega t - n/\delta)} \]
Fluid motion in vicinity of vibrating structure

General method (for incompressible fluid):

- Solution of Laplace’s equation (velocity potential):
  \[ \mathbf{v}' = \nabla \Phi \]
  \[ \nabla^2 \Phi = 0 \]

- Superposition with 1D shear wave solution:
  \[ v_t(n) = [v_t(0) - v'_t|_{\partial \Omega}] e^{i(\omega t - n/\delta)} \]

- Limitation: small gaps (liquid trapping)
Sensor Examples

- Clamped–clamped beam
- Double foil cell
- Metallic in–plane resonator
Sensor Examples

- Clamped–clamped beam
- Double foil cell
- Metallic in–plane resonator

Common features:
- low resonance frequency: < 15kHz
- Lorentz force excitation
- inductive readout
Double Foil Cell

liquid between two vibrating foils
Cross sectional velocity fields:

(a) potential flow solution

(b) with boundary shear wave
Simulated and Measured resonance frequency and Q–factor
Metallic In–Plane Resonator

fully immersible four–port device
Metallic In–Plane Resonator

finite elements analysis

comparison to measurements (in water)

Erwin K. Reichel
Dynamic Methods for Viscosity and Mass–Density Sensing
Metallic In–Plane Resonator

![Graph showing viscosity and density relationship](image)

- red symbols: calibration liquids
- blue +: silica nanosuspension
- · · · line: pure shear wave damping

log $D$ vs. log ($\eta\rho$)

Symbols:
- * ethanol
- □ 2–propanol
- △ water
- ◊ 70% glycerine–water
- + silica suspension
Dynamic Methods for Viscosity and Mass–Density Sensing

- Resonance principle (sensors in kHz–range)
- Modeling by energy / semi–numerical methods
- Fluid–structure interaction in viscous incompressible fluids
- Measurements of complex liquids
Enhanced Sensitivity of Gas Sensors Based on Thin Films and Nanowires

Dipl.-Ing. Alexandra Zima
1. Introduction

2. Metal Oxide Gas Sensors: SnO$_2$
   a. Production
   b. Experimental Results

3. Strategies for enhanced Selectivity and Stability
   a. Nanowire Production
   b. Doping / Surface Doping

4. Comparison of experimental results

5. Outlook
1. Introduction: Metal Oxide Gas Sensors: Why?

- **Applications:**
  - Medicine
  - Safety
  - Air quality monitoring
  - Environment
  - Food quality monitoring
  - Industrial production
  - Automobile industry

- **Advantages:**
  - Cheap
  - High sensitivity
  - Small and light
  - Short response times
  - Compatibility with Si technology
2. Metal Oxide Gas Sensors

- Detection Principle: Chemisorption of gas molecules at surface leads to change in conductance (band bending, electron transfer)

- SnO₂ surface is covered by oxygen species (O⁻, O₂⁻, O²⁻) at operating temperatures (T > 200°C)

- Reducing Gas:
  
  \[ \text{CO} + \text{O}^- \rightarrow \text{CO}_2 + e^- \]

  Increase of Electrical Conductance

- Oxidising Gas:

  \[ \text{NO}_2 + e^- \rightarrow \text{NO}_2^- \]

  Decrease of Electrical Conductance
2. a) Production Process

Spray Pyrolysis:

Optimization:
- Vertical/Parallel Spray Flow
- Siphon Height
- $N_2$ Pressure
- Temperature
2. a) Production Process

- Processing:
  - Photolithography and Reactive Ion Etching for mesa structures

- Contacts:
  - 20 nm Ti
  - 200 nm Au

- Chip:
  - Microheater
  - Thermocouple
2. b) Experimental Results

Measurement of sensor response towards gas species

Sensor Resistance
2. b) Experimental Results

Automated measurement setup in atmospheric chamber:

- precise adjustment of the gaseous environment and temperature
- synthetic air as background gas
- constant DC current (~ 200 μA) for measuring voltage drop
- Measurement Temperature: 200 - 400°C
3. b) Experimental Results

**H₂:**

Detection of H₂, CH₄ and CO:
- Best sensitivity for H₂
- Small ppm values also for CO and CH₄
- Cross sensitivity with water

**CH₄:**
### Gas Sensor Requirements

<table>
<thead>
<tr>
<th>The ‘6S’-rule</th>
<th>SnO$_2$ gas sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>high for many gases</td>
</tr>
<tr>
<td>Selectivity</td>
<td>poor</td>
</tr>
<tr>
<td>Speed of response:</td>
<td>good for operating temperature of 250-400°C</td>
</tr>
<tr>
<td>- reaction time</td>
<td></td>
</tr>
<tr>
<td>- recovery time</td>
<td></td>
</tr>
<tr>
<td>Stability:</td>
<td>poor</td>
</tr>
<tr>
<td>- drift</td>
<td></td>
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<tr>
<td>- long term stability</td>
<td></td>
</tr>
<tr>
<td>Size/Shape</td>
<td>small and light</td>
</tr>
<tr>
<td>$/$Cost</td>
<td>inexpensive</td>
</tr>
</tbody>
</table>
3. Enhanced Selectivity and Stability: Two approaches

a. Doping / Surface Doping
   - Catalytic effects of metals/semimetals on sensor surface: Pt, Pd, Sb, In
   - Stabilization of electronic resistance
   - Lower operation temperature
   - Selectivity

b. Nanowire gas sensors:
   - 2 quantum confined directions, 1 direction for electronic conductance
   - significant differences in electronic, mechanic, chemical, optical and magnetic properties in comparison with bulk counterpart
   - Extremely high sensitivity because of high surface-to-volume-ratio
3. a) Doping / Surface Doping

During spray pyrolysis doping with In and Sb:

- Sensitivity [%] vs. H₂ Flow [ppm]
  - Pure Sn
  - 10% In
  - 10% Sb

- Sensitivity [%] vs. CO Flow [ppm]
  - Pure Sn
  - 10% In
  - 10% Sb

After spray pyrolysis
Surface doping with Pt:

- CO flow and Sensor R [Ω] vs. Time [s]
  - Pure Sn
  - 10% In
  - 10% Sb

- CH₄ Flow [ppm] vs. Time [s]
  - Pure Sn
  - 10% In
  - 10% Sb
3. b) Nanowires

Two-step atmospheric pressure fabrication process:

1. Spray Pyrolysis
   a) Duration: 90 – 180 s
   b) SnO$_2$ film thickness: 150 - 200 nm

2. Annealing at 800-1000°C in Ar-atmosphere

Advantages:
- directly on Si chip
- simple process
- no vacuum
Single Nanowire as gas sensing element:
- diameter 85 nm
- length 55 µm

**CO:**
- 4 ppm

**CH₄:**
- 30 ppm
4. Comparison of experimental results

- In-doped sensors:
  - High CO and CH₄ Sensitivity
  - Less H₂ Sensitivity

- Sb-doped sensors:
  - Extremely high H₂ Sensitivity
  - Selectivity

- Pt-surface-doped sensors:
  - CO detection in presence of humidity leads to better results
  - High Stability, Less Drift
  - Higher Sensitivity (2 ppm CO)

- Nanowire Sensors:
  - Response and Recovery time shorter (limited by experimental setup)
  - Higher Sensitivity (CH₄)
  - Lower Operating Temperature
  - Water dependence: no improvement
5. Outlook

- Doping /Surface Doping:
  - Different metals and composites
  - Thickness variation (Pt, Pd)
  - Spray pyrolysis process with different concentrations (SnO$_2$ + In, SnO$_2$ + Sb)

- Nanowires:
  - Nanowires on-chip growth
  - Adaption of Process Technology: Photolithography, Contacting
  - Doping of nanowires
Ultrasonic particle manipulation for mid-infrared spectroscopy of suspensions

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Introduction
An acoustic standing wave field, acting on a suspension, results in the separation of the suspended particles from the host fluid. This separation effect was employed to enable mid-infrared absorption measurements of particles and host fluid separately by using ATR (Attenuated Total Reflection) spectroscopy. Different stages in the development process of this technology are presented. Starting with an on-line measurement system based on a horizontal flow cell, this technology was improved by using an ATR fibre probe and the design of an attachable ultrasonic resonator.

On-line measurement
Fast suspension analysis for reaction monitoring was achieved by particle manipulation in a flow cell using 2 MHz ultrasound waves.

In-line measurement
A flexible ATR fibre probe replaces a stationary flow cell.

Sample suspension: Polystyrene beads in methanol
Ultrasound field is adjusted to push suspended particles towards the ATR crystal → Absorption spectrum of particles is acquired (broad line).

Ultrasonic enhanced ATR in-line fibre probe
Prototype for semi-industrial environment.

Mounting to bioreactor wall or plate through a standard port.
Novel Design Approach for Micromachined Flow Sensor featuring Three Different Operating Modes

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In this work we investigate a novel design approach and signal transduction concepts for micromachined calorimetric flow sensors. Maintaining a constant average excess temperature of the membrane by means of a simple two-state electronic controller, a pulse modulated actuation signal is obtained. The sensitivity of the output signal can be influenced by altering the amplitude of the heating pulse. The proposed novel sensor design offers three different operating modes. Beside the conventional calorimetric transduction, such sensors are also operable in a mixed calorimetric-anemometric mode featuring low power consumption, high flow sensitivity, and an unambiguous transduction characteristic over a wide flow range.

Introduction

Commonly used micromachined calorimetric flow sensors feature heat source(s) and spatially separated temperature sensors, both embedded in a thin membrane [1]. These sensors exploit the flow dependent heat transfer altering the temperature distribution near the heater. Operating the flow sensor at a constant heating voltage, tantamount to a constant heating power, a high sensitivity is feasible only within a limited flow range. Due to efficient convective cooling at higher flow rates the output characteristic becomes ambiguous. For a wider measurement range, a constant temperature difference between the membrane and the fluid is necessary. This operational mode can be achieved using an electronic controller. Applying a standard PI-controller results in an unambiguous characteristic with moderate sensitivity at higher flow rates. In order to achieve better sensitivity, we investigated a novel signal transduction concept for the existing sensor layout as well as an improved sensor design.

Common Sensor Design

Figure 1 illustrates the membrane arrangement of the utilized flow sensor. Two thermistors (MT1, MT2) measure the local temperature at a position upstream and downstream of the heat source (thin-film heating resistor H). Without the flow, the generated temperature profile inside the membrane is symmetrical and both thermistors measure the same value. The convective heat transfer induced by the media flowing across the sensor surface disturbs the thermal symmetry. This change can be converted into an output voltage and evaluated for the determination of essential flow parameters such as flow velocity or mass flow.
The fluid temperature, which is typically close to the substrate temperature, can be measured with two additional thermistors arranged at the rim of the silicon chip (not shown in Fig. 1). The membrane consists of a SiO$_2$-Si$_3$N$_4$-SiN$_x$-sandwich with an overall thickness of 1.6µm. The chip dimensions are 2x4mm$^2$ (membrane area: 0.5x1mm$^2$). Further details of the technology and key specifications of such sensors can be found in [2], [3].

In the constant temperature excess mode, a constant difference between the temperature mean of the two membrane thermistors and the temperature mean of both substrate thermistors is maintained using an electronic controller. Instead of the commonly applied analogue controller we investigated the application of a two-state controller. For the design and optimization of the control loop a comprehensive SPICE model of the sensor’s thermal system capable to fully cover its static and dynamic behavior was developed. This approach has proved to be a convenient method to investigate the interaction of the sensor and its evaluation/controlling circuit.

**Implementation of a Two-State Controller**

Figure 2 shows the scheme of the novel sensor operational mode based on a comparator operating in a negative-feedback closed-loop configuration. A constant bias of 0.5 V is applied to all germanium thermistors and each thermistor current is converted into a temperature-proportional signal by means of a current-to-voltage converter. The difference between the mean membrane temperature and the mean bulk temperature is compared with the equivalent of the excess temperature set point. The two-state controller establishes a train of voltage pulses at the heater. The pulse duration and repetition rate are determined by the selected amplitude and the dynamic characteristics of the thermal system, which in turn depend on flow velocity [4].

**Fig. 2:** Scheme of the novel operational mode using two-state closed loop controller which keeps the average excess temperature ($\Delta \theta$) of the membrane constant.
This approach offers the ratio of high to low pulse duration ($T_H/T_L$) as an output quantity in addition to the temperature difference signal ($U_{out}$). The basic properties of this flow dependent oscillator have been successfully modeled using PSpice. Related measurement results are depicted in Fig. 3 (left). The sensor is flush mounted into the wall of a rectangular flow channel (cross section $1.2 \times 0.5 \text{mm}^2$). Due to convective cooling, the pulse duration increases and the pulse gap becomes smaller with increasing flow velocity. On the other hand, reducing the amplitude of the heating pulses at constant velocity evokes the same effect. In order to keep the average excess temperature ($\Delta \vartheta$) of the membrane constant, the controller must increase the average heating power and hence the ratio of high to low pulse duration ($T_H/T_L$) increases too. Thus, by altering the amplitude of the heating pulses one can influence the slope of the output characteristic in order to achieve better sensitivity.

In addition to the ratio of high to low pulse duration ($T_H/T_L$), the temperature difference signal ($U_{out}$) can also be used. For low flow velocities, this signal provides the highest sensitivity whereas the ratio $T_H/T_L$ becomes the preferable output quantity at higher flow rates (Fig. 3, right).

![Fig. 3: Measured output characteristic for different amplitudes of the heating pulse ($U_h$). The ratio $T_H/T_L$ serves as output signal. The average excess temperature amounts $\Delta \vartheta_{ref} \sim 5^\circ \text{C}$ (left). The comparison of two output quantities in case of an amplitude of heating voltage $U_h = 3.67 \text{ V}$ (right).](image)

**Novel Design Approach**

A novel sensor design approach was first investigated by means of finite element simulations (COMSOL). This FE analysis is based on the schematic cross section indicated in Fig. 4 (left). A two dimensional model seems reasonable since all thin-film components on the membrane exhibit a large extension perpendicular to the flow direction. Two pairs of high-resolution thermistors are placed symmetrically to a thin-film heater on the sensor membrane. Additional substrate thermistors (ST) measure the fluid temperature. The air flow channel above the sensor membrane is $1 \text{ mm}$ high with a parabolic flow profile [5]. This novel design offers three different operating modes.

The first operating mode features the thin-film chromium resistor as a heat source and the pair of inner or, alternatively, outer thermistors as temperature sensors. The simulated output characteristic for constant heater voltage is depicted in Fig. 5 (left). For lower flow velocities, an excellent sensitivity is found. For higher velocities, however, the output characteristic saturates or it even becomes ambiguous. To solve...
this problem the heater voltage must be controlled to compensate for convective heat transfer, as described in the first paragraph. In this case the two substrate thermistors provide reference values of the fluid temperature.

Fig. 4: Schematic cross section of the novel flow sensor design comprising four membrane thermistors, which can be connected to form a Wheatstone bridge.

In the second operating mode the four membrane thermistors are connected to form a Wheatstone bridge (Fig. 4, right). The chromium resistor remains as the heat source. The simulated output characteristic is similar with the previous one (Fig. 5, right). The bridge is supplied with low voltage (1V) in order to reduce the self-heating effect of the thermistors. The main advantage of this mode is that the Wheatstone bridge can be easily read-out, e.g., with a high-impedance galvanometer, without any need for complicated subsequent evaluation circuits. Moreover the calculations showed that this arrangement is insensitive to ambient temperature changes. Thus, the second mode does not need pre-calibration with respect to fluid and ambient temperatures.

Fig. 5: Simulated output characteristics for the first (left) and second operating mode (right). In the first case, the output signal is proportional to the temperature difference of the membrane thermistor pair. In the second case, the voltage across the bridge $U_B$ is used as an output quantity.

Finally, the third operating mode (mixed calorimetric-anemometric mode) utilizes the self-heating effect of the membrane thermistors as a heat source. The chromium heater is switched off. In order to avoid the self-destruction of the thermistors due to their NTC characteristic the bridge is supplied with a constant current $I_{SUP} = 50 \mu A$, rather than with a constant voltage as it was case in the second mode. The bridge
voltage $U_B$ as well as the voltage at the bridge supply terminals $U_{SUP}$ depend on the thermistor resistance values and hence on the flow velocity

$$U_B = I_{SUP} \frac{R_{th2}R_{th3} - R_{th1}R_{th4}}{R_{th1} + R_{th2} + R_{th3} + R_{th4}}, \quad U_{SUP} = I_{SUP} \frac{(R_{th1} + R_{th2})(R_{th3} + R_{th4})}{R_{th1} + R_{th2} + R_{th3} + R_{th4}}.$$ (1)

The simulated output characteristics for both quantities are shown in Fig. 6. Evaluating the bridge voltage, an excellent sensitivity for flow velocities below 2 m/s is found. However, for higher velocities, the output characteristic becomes ambiguous as in the previous modes. Therefore the use of $U_{SUP}$ as an output quantity is desired, resulting in a wider measurement range but moderate sensitivity for lower flow velocities.

The power consumption in the first two modes amounts to approximately 3 mW, mainly dissipated in a chromium heater. In the third mode, however, the rated supply current limits the power consumption of all bridge thermistors to only ~ 0.3 mW. Thus, the third mode combines the very low power consumption with high flow sensitivity or an unambiguous transduction characteristic.

**Conclusion**

We investigated novel design ideas and signal transduction concepts for micromachined calorimetric flow sensors. Maintaining a constant average excess membrane temperature by means of a simple two-state electronic controller, a pulse modulated actuation signal is obtained. This approach offers the ratio of high to low pulse duration as an output quantity in addition to the temperature difference signal. The sensitivity of the output signal can be optimized for specific applications by altering the amplitude of the heating pulse.

The proposed novel sensor design offers three different operating modes. Comprehensive finite element analyses revealed that beside the conventional calorimetric transduction such sensors are also operable in a mixed calorimetric-anemometric mode. Based on the self heating effect of the employed high resolution thermistors, this operational mode combines extremely low power consumption with high flow sensitivity or, alternatively, an unambiguous transduction characteristic over a wide flow range.
Acknowledgements

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References


Time resolved FTIR spectroscopy using a four-layer lamination micro mixing device

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Abstract

Time resolved measurements are a hot topic in IR spectroscopy today. Two well established techniques, step scan and rapid scan measurements, suffer from the same major drawback. For both techniques the (bio)chemical reaction under investigation needs to be triggered and additionally, the classical step scan experiment can only be applied for cyclic reactions.

A promising approach to overcome the triggering problem is to use micro mixers for time resolved measurements. The basic principle of this technique is to mix two liquids through diffusion in a mixing channel that also serves as measurement area. The actual measurements take place at well defined spots along this channel, corresponding to specific reaction times: moving the measurement spot towards the entry yields shorter reaction times, moving it towards the channel’s end gives longer reaction times.

For time resolved FTIR measurements, utilising micro mixers, fast mixing times are crucial to ensure a well defined starting point of the (bio)chemical reaction. This is challenging to achieve in small dimensions, limited by the experimental parameters, due to the laminar flow regime present.

Design & Fabrication [1]

In a laminar flow mixer the mixing time is proportional to the diffusion length of the channel ($l_{diff} = \frac{D}{2}$). At a given depth of the observation channel (in our case 8 µm for a decent S/N ratio in the Amide I region) faster mixing can only be achieved by multiple layers of the two fluids. Kaufmann et al. [2] used three layers in their design but also needed 3 connectors from the outside world to feed them. Our new development features 4 layers but only needs 2 connectors because each liquid is split into two streams within the chip. If the inlet channels would be straight-shaped a non uniform mixing pattern over the width of the mixing channel (200 µm) would occur. To overcome this problem we developed wedge shaped inlet channels which open towards the end. The optimum geometry was determined by CFD simulation and resulted in wedges widening from 10 µm to 22 µm in width.

The CFD simulation above shows the concentration distribution at the channel inlets over the depth of the mixing channel. Shortly after the last inlet channel the four layers of liquid can be seen.

This CFD simulation shows the concentration distribution over the width of the mixing channel at a) 50 µm, b) 100 µm and c) 150 µm far along the channel length. In a) the first two liquid layers can be seen, Fig. b) already shows the four layers and in c) the two liquids are almost mixed. Only at the very edges of the mixing channel a non uniform concentration profile can be observed.

The fabrication process of the mixer starts with spincoating the lower side of the silicon wafer with a photoresist. After photolithography the inlet holes are etched with KOH. After that the upper side is structured with photolithography and the 200 µm deep inlet channels are formed by deep reactive ion etching (DRIE). The channel is realised using a photopatternable silicone polymer which is spincoated onto the SiF₄ wafer and photostructured afterwards. The last processing steps include the bonding of the Si and CaF₂ wafers and cutting out the mixers.

Evaluation

To evaluate the mixing performance of our new four layer lamination micromixer the chemical reaction of Na₂SO₃ with formalin was investigated. The 0.2 M solutions were pumped through the mixer by a kDp 100 µl syringe pump equipped with two 500 µl syringes. The size of the measurement spot was 100x180 µm and 86 spectra have been recorded with a Bruker Hyperion 3000 microscope along the mixing channel. The occurring reaction can be seen in the figure above. The Na₂SO₃ band at 942 cm⁻¹ decreases whereas the product band of CH₃(OH)SO₃⁻ at 1180 cm⁻¹ increases. The formalin band at 1025 cm⁻¹ splits into two bands during the reaction.

In the figures below the influence of different pumping speeds to the mixing process was evaluated. The speed was varied from 4 to 7 µl/min and as can be seen below had hardly any effect on the mixing. Compared to our previous two-layer mixer design [3] the mixing time improved by a factor of ~25.

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A RFID based high volume biosensor system

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Abstract
The development of medicaments, medicine products or chemicals demands high throughput procedures for the active substance testing at cells and tissues. In this work we present a bio-sensor system which is designed for high volume production and for a continuous, non invasive monitoring of permanent cultures. The background colours correspond to the upper block diagram. The sensor electrodes are connected to the phase trigger and the analog-to-digital-converter (ADC). Furthermore it does the measurement and data communication with a reader unit using a so called load modulation. Power consumption (without RFID part): appr. 25 mW

Motivation
• Reduction of manpower and materials for toxicological tests
• Compatibility to established systems and materials increases the acceptance
• Wireless systems allow easier handling and batteryless energy supply.
• Automatized data acquisition

Sensor Basics
Basic layout of an IDES (Interdigitated Electrode Structures) by Al-Fattani et al.[1]. IDES layout with Au-metallization. Biological cells adhere, spread and grow on these structures. That causes an impedance change of the sensor. This information can be used to get information about the cells behaviour and/or their metabolic state.

Change in Impedance Spectroscopy
Measurement results by Ehret et al.[2]. Dotted lines show the phase. Measurement (i) shows the impedance with a monolayer of cells (3T3 mousefibroblasts) on an IDES, measurement (ii) without cells (only culture media DMEM).

Circuit Design

Signal Quality
Probe sinusoidal wave with an amplitude of approximately 50 mV is impressed between the sensor electrodes. Spikes result from the µC clock. Mismatches on the analog chain are due to resistor and capacitor tolerances. Reference resistor R12 is used for calibration.

Long term impedance measurement on Mousefibroblasts 3T3

Experiment description
• 0h: Measurement started with culture medium without cells (reference lines).
• 4h: Cells added at 2 sensors (500 cell per sensor).
• 24h: Exchange of culture medium (30 µl culture medium per well evaporated during the first day).
• 119h: Optical check. 50 % confluence at cell samples.
• 145h: Exchange of culture medium. Significant change of ohmic part on all samples. Caused by increased ionic conductivity due to evaporated water from medium.
• 145h: Exchange of culture medium. Cell Sample #1 and Blank #0 got 0.1 vol% of Triton X 100. Triton X 100 dissolves membrane proteins and cells die.
• 190h: Cell sample #0 showed cell growth for 2 further days.

References