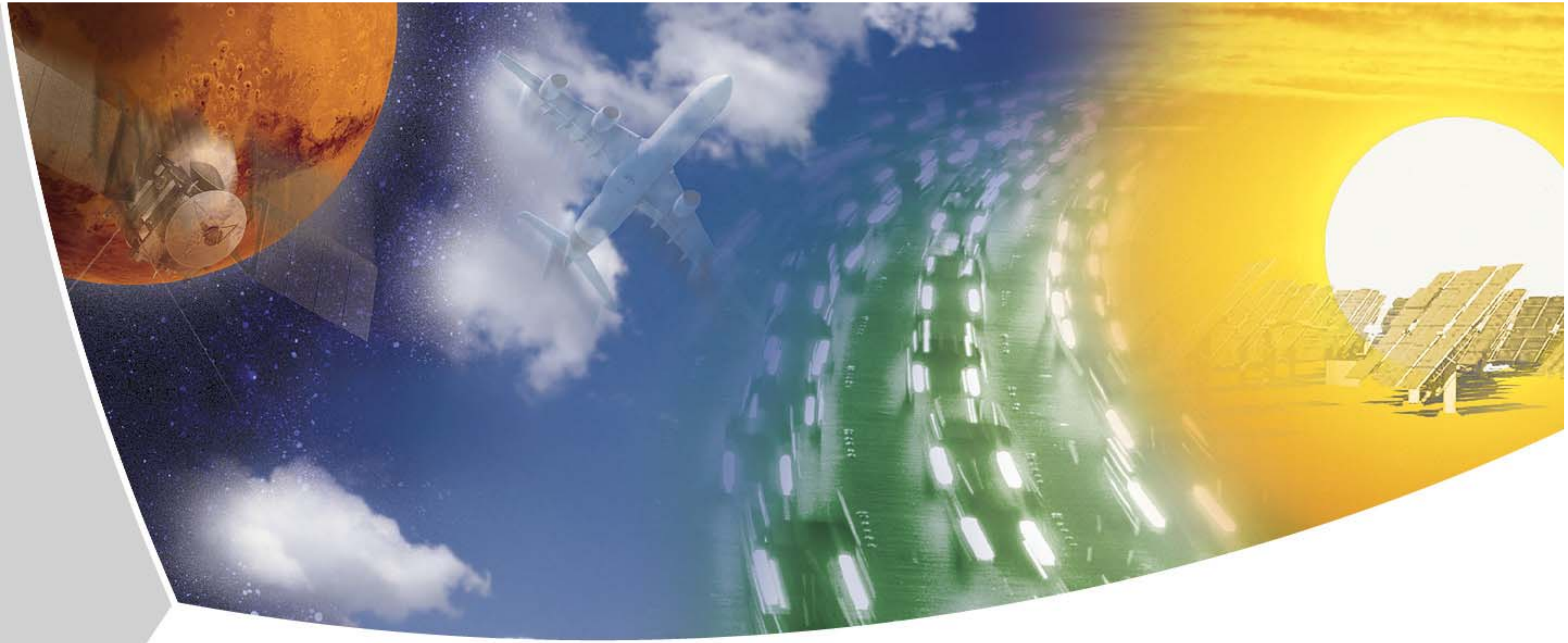

Application of In-Situ Diagnostic Methods for the Study of SOFC Operational Behaviour

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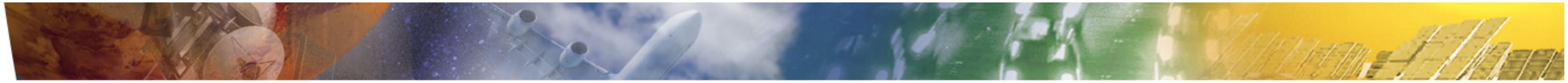
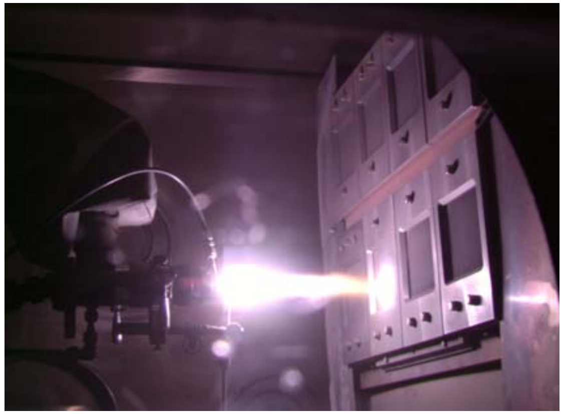
in der Helmholtz-Gemeinschaft

9th European Forum on Solid Oxide Fuel Cells, June 30 – July 2, 2010,
Lucerne, Switzerland



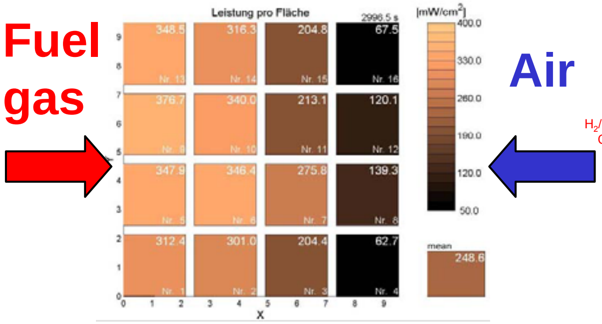
SOFC Activities at DLR

Development of Metal Supported Cells (MSC)

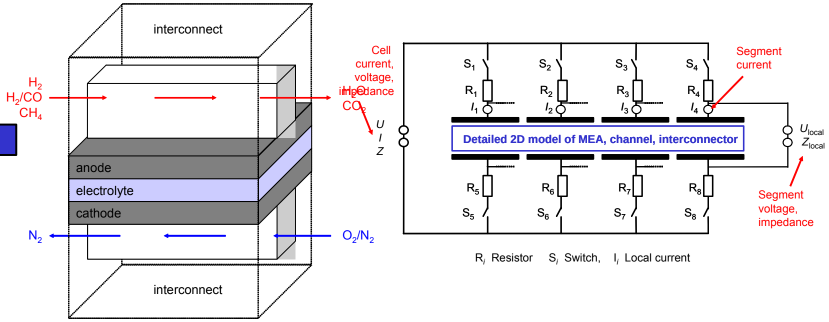


Characterisation of Cells (MSC, ASC)

SOFC Diagnostics



SOFC Modeling



Characterisation of Short stacks and Stacks (ASC, MSC)

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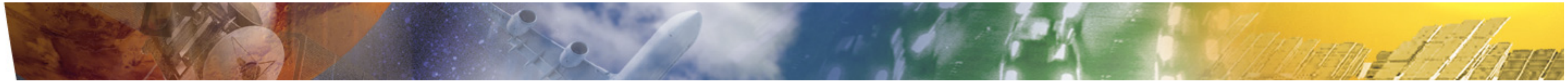
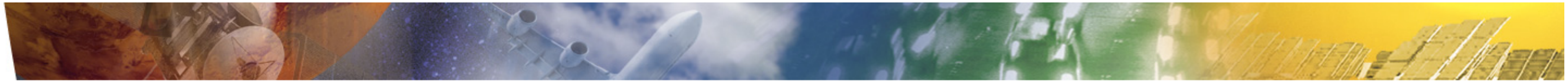
Investigation of Degradation and Cell Failures

- Insufficient understanding of cell degradation and cell failures in SOFC
- Extensive experimental experience is not generally available which would allow accurate analysis and improvements
- Long term experiments are demanding and expensive
- Only few tools and diagnostic methods available for developers due to the restrictions of the elevated temperatures



„Sophisticated“ (non-traditional) In-situ Diagnostics

- Electrochemical impedance spectroscopy on stacks
- Spatially resolved measuring techniques for current, voltage, temperature and gas composition
- Optical imaging
- Optical spectroscopy
- Acoustic emission detection
- X-ray tomography



Outline

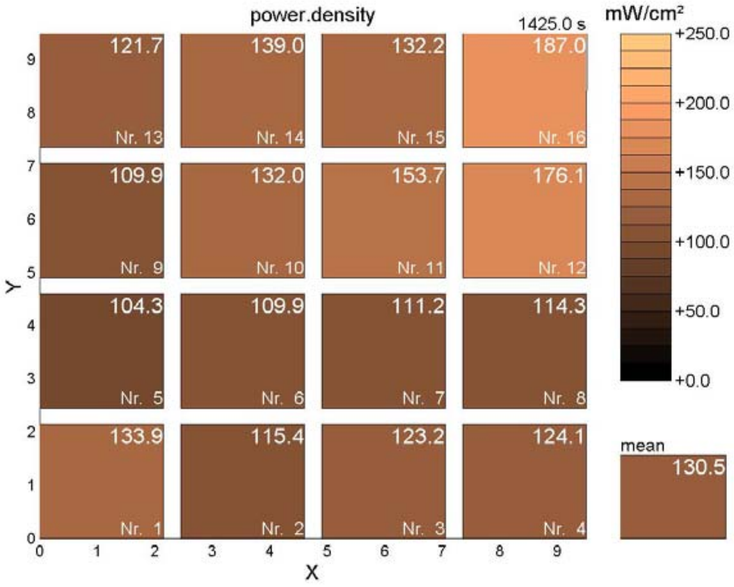
- Introduction
- Experimental setup for spatially resolved measurements
- Exemplary results of spatially resolved measurements:
    - MSC cell
    - ASC cell with high fuel utilisation
    - ASC cell with reformate as fuel gas
- Outlook: Optical microscopy and Raman spectroscopy
- Conclusion

See also: Poster PO22-040

Motivation

Problems in planar cell technology:

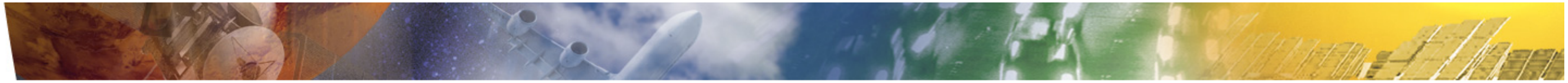
- Strong local variation of gas composition, temperature, and current density
- Distribution of electrical and chemical potential dependent on local concentrations



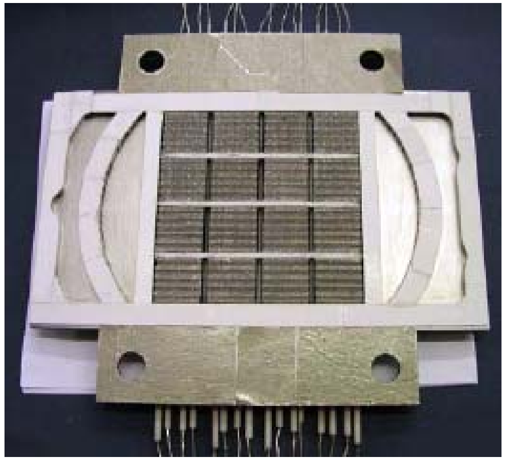
This may lead to:

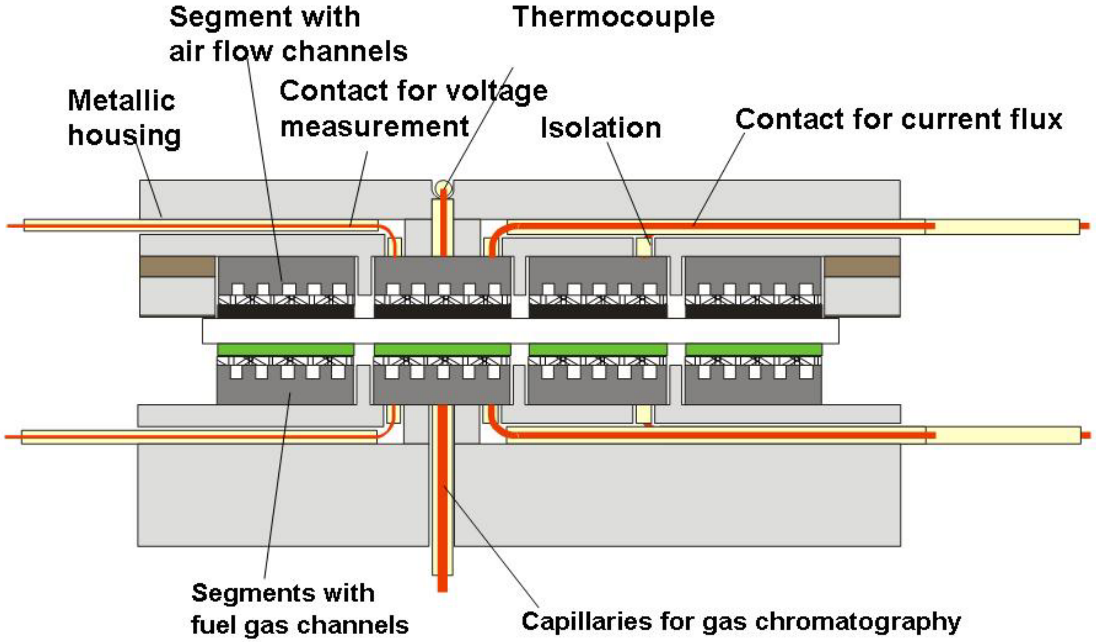
- Reduced efficiency
- Thermo mechanical stress
- Degradation of electrodes

Effects are difficult to understand due to the strong interdependence of gas composition, electrochemical performance and temperature



Measurement Setup for Segmented Cells



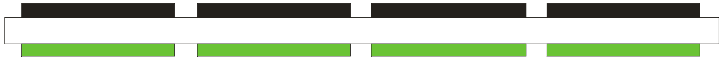


- 16 galvanically isolated segments
- Local and global i-V characteristics
- Local and global impedance measurements
- Local temperature measurements
- Local fuel concentrations
- Flexible design: substrate-, anode-, and electrolyte-supported cells
- Co- and counter-flow

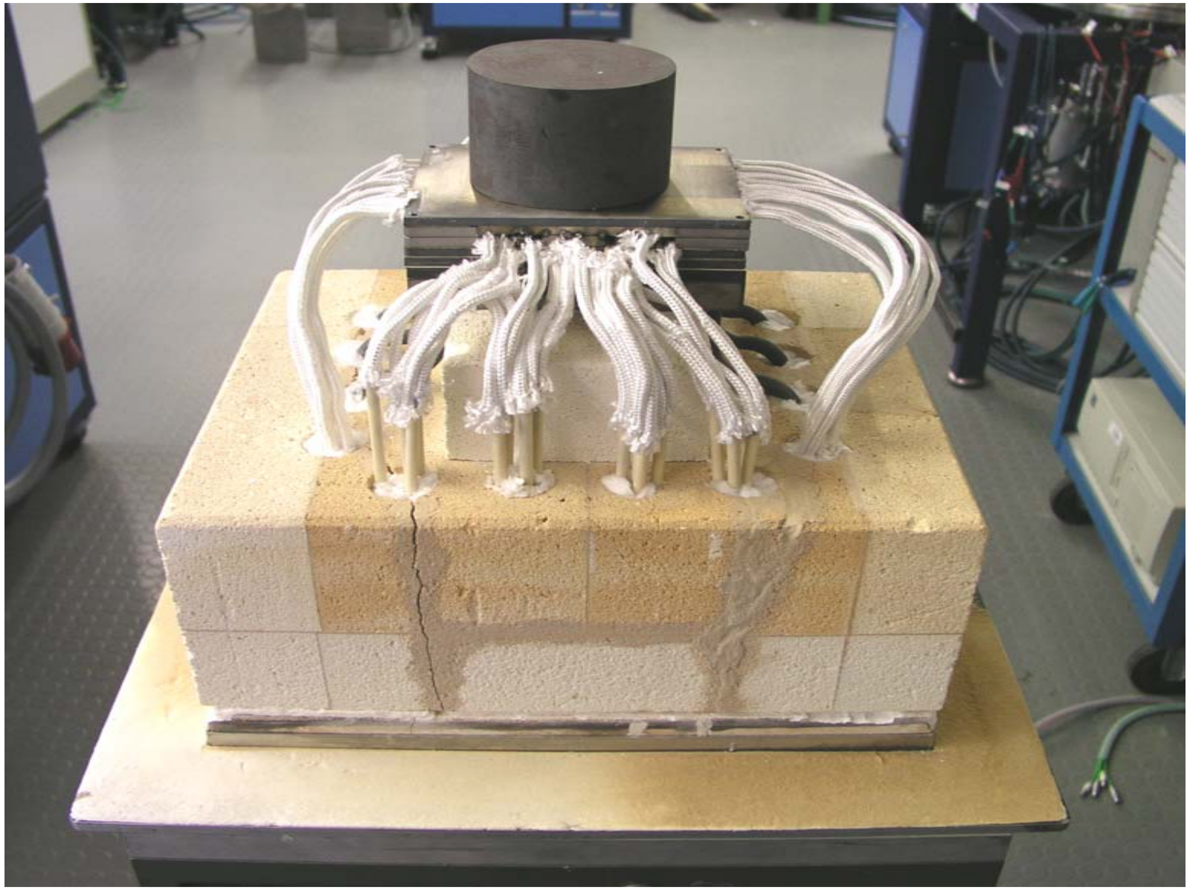
Segmented Cells

- Anode supported cells: Segmented cathode (H.C.Starck/InDEC)

- Electrolyte supported cells: Segmented cathode and anode

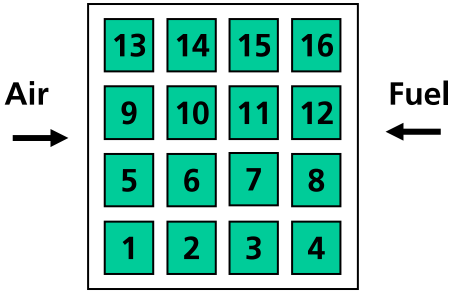


Test Rig



Power Density and Temperature Distribution of a Plasma Sprayed Cell

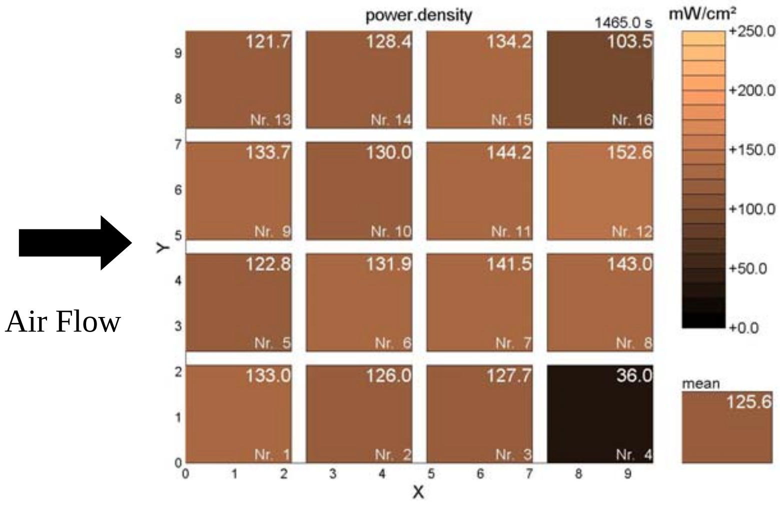
- P und T distribution at standard gas flow rates: 12,5/12,5//80 smlpm/cm² H_2/N_2//Air, 800°C, 0.7 V,

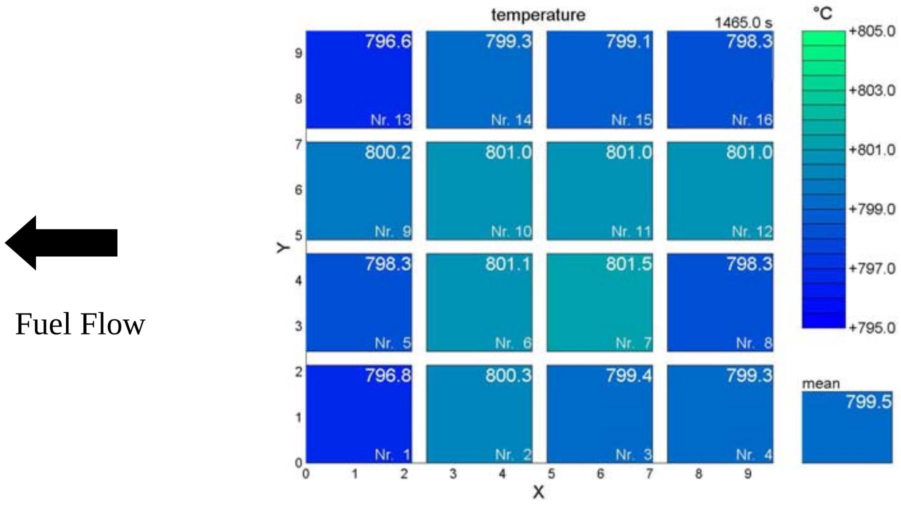


Air →

13	14	15	16
9	10	11	12
5	6	7	8
1	2	3	4

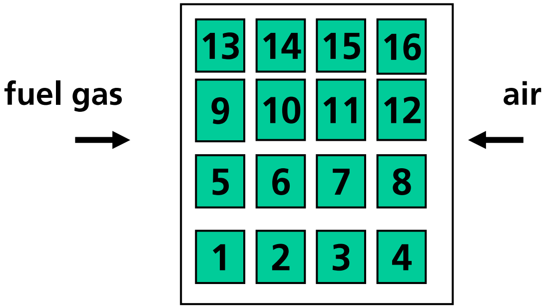
← Fuel

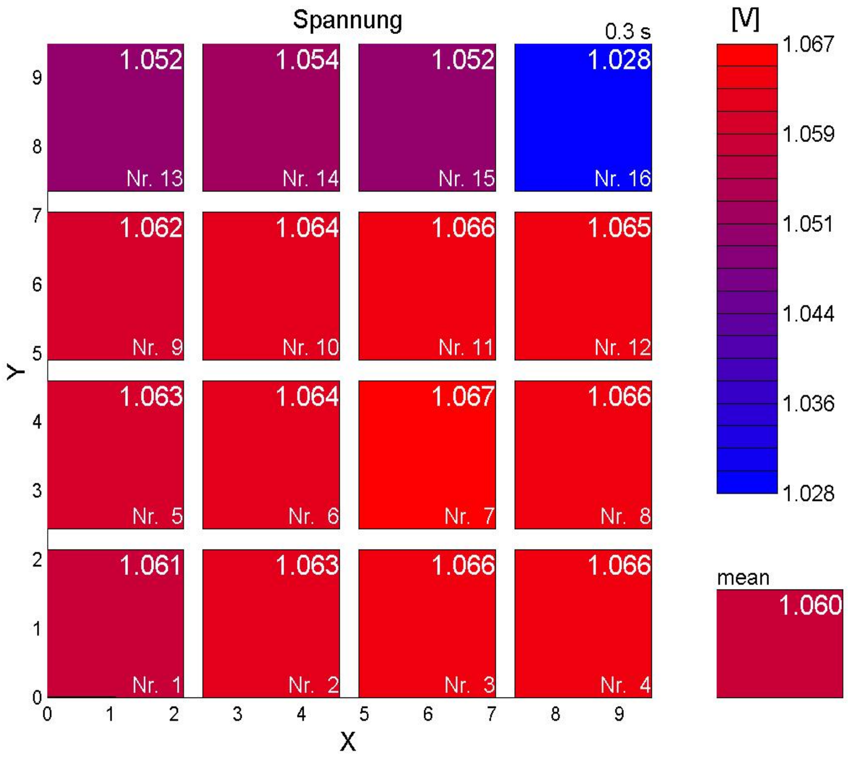




OCV Voltage Measurement for Determination of Humidity

- Voltage distribution at standard flow rates:
- 50% H_2, 50% N_2 + 3% H_2O, 0.08 SlpM/cm² air



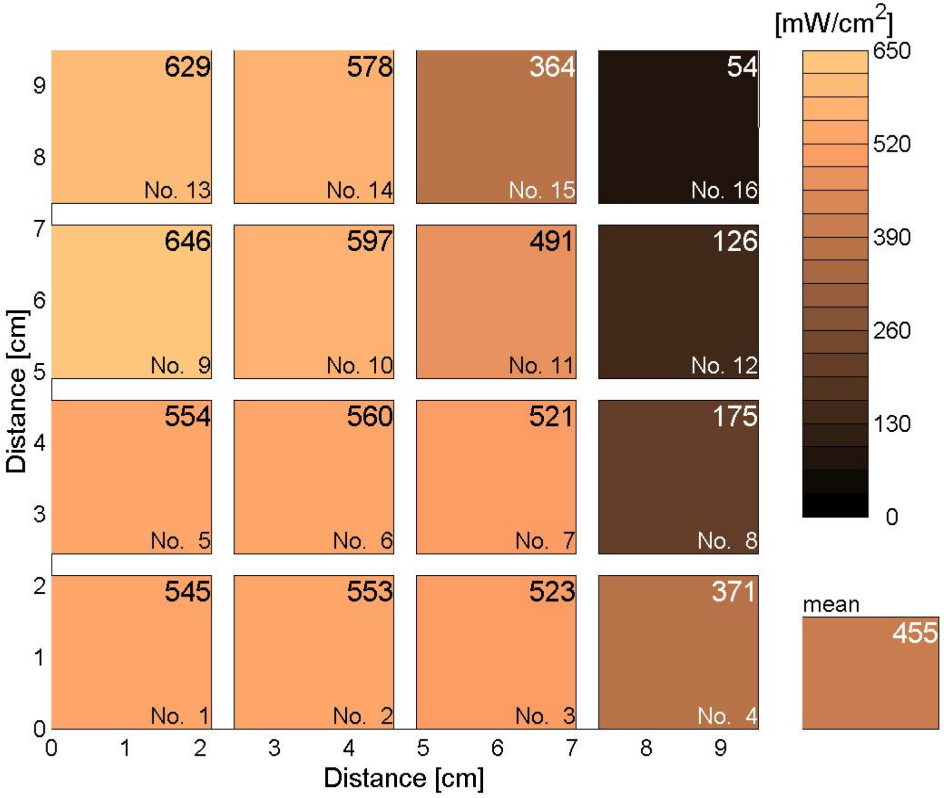


Nernst equation:

$$U_{rev} = U_{rev}^{0} - \frac{RT}{zF} \ln\left(\frac{p_{H2O}}{\sqrt{p_{O2}}\, p_{H2}} \right)$$

Produced water:
S4: 0.61%, S8: 0.72%,
S12: 0.78%, S16: 3.30%

Power Density Distributution under Conditions of High Fuel Utilisation



Counter-flow

Anode: 33% H_2, 1% H_2O, 66% N_2

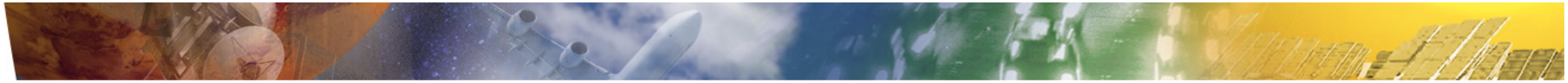
Cathode: air

T = 800 °C

Cell voltage: 0.59 V

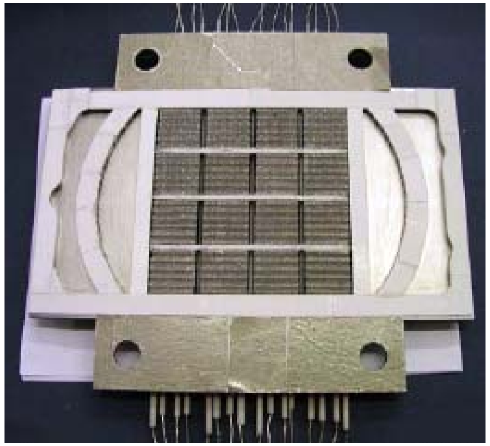
F_u = 80%

Lit.: Fuel Cells, 10 (3), 411-418 (2010)



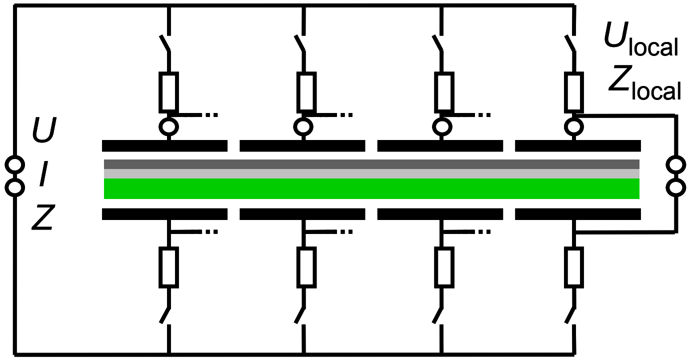
Assessment of Local Performance with Segmented SOFCs

Experiment

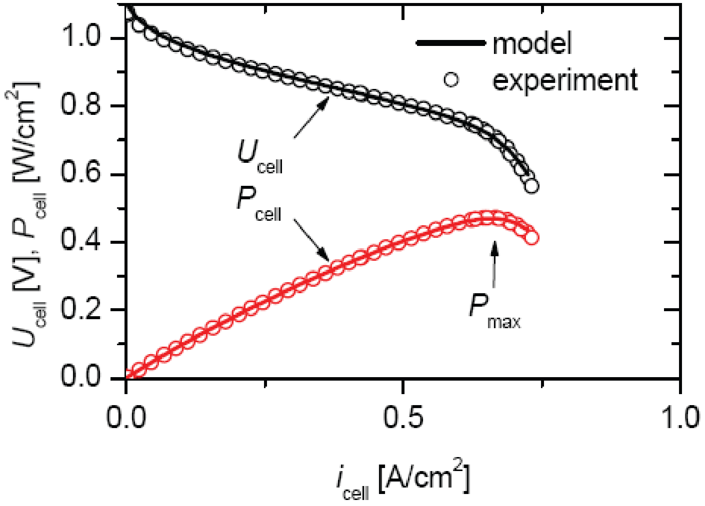


16 segments

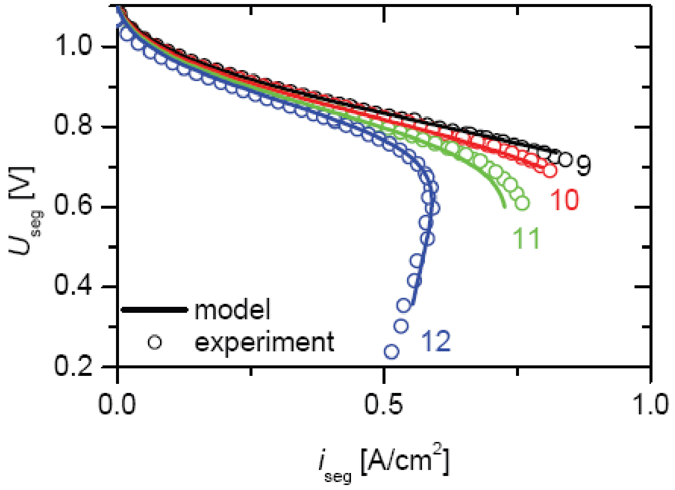
Model



Global behavior

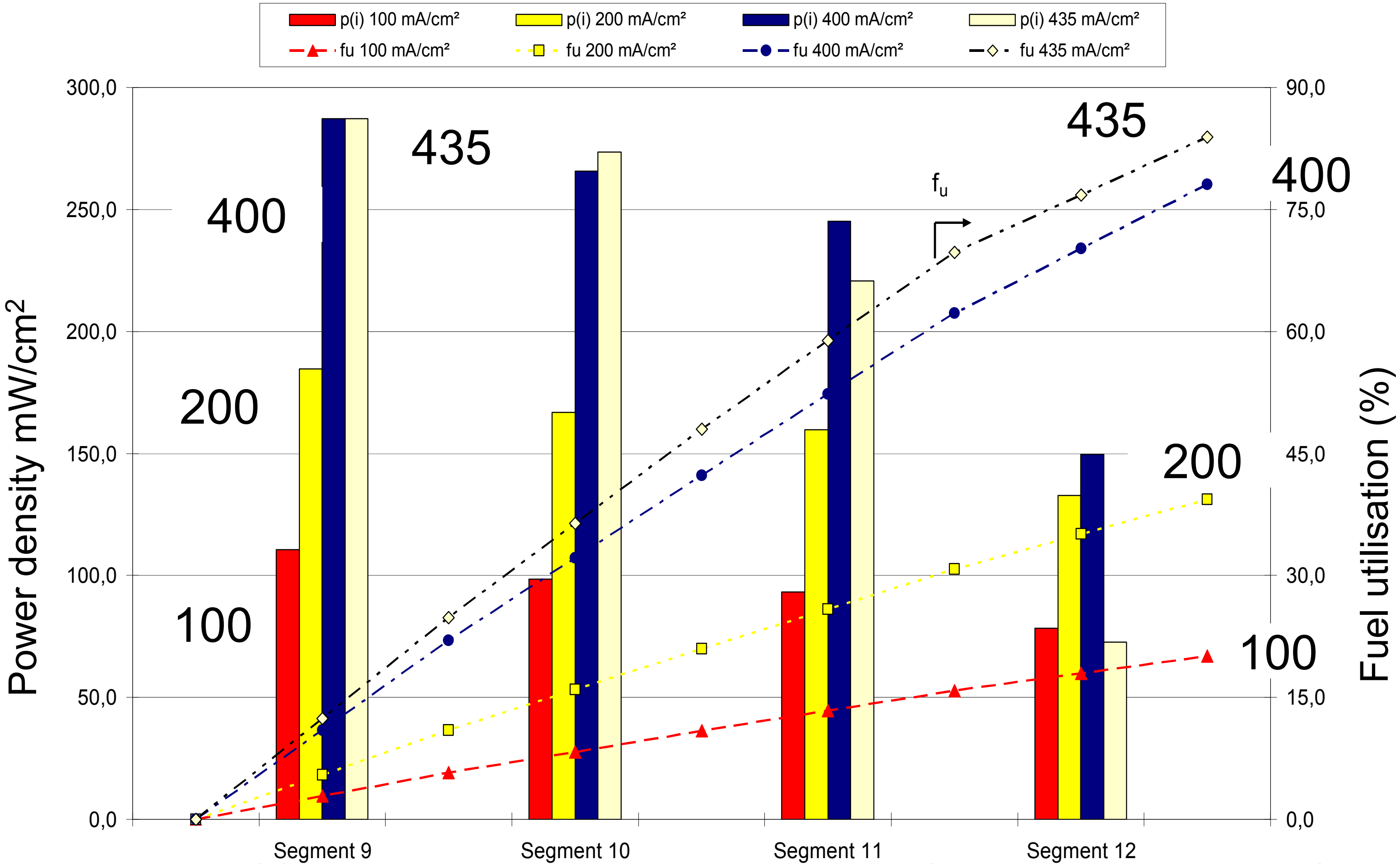


Local behavior



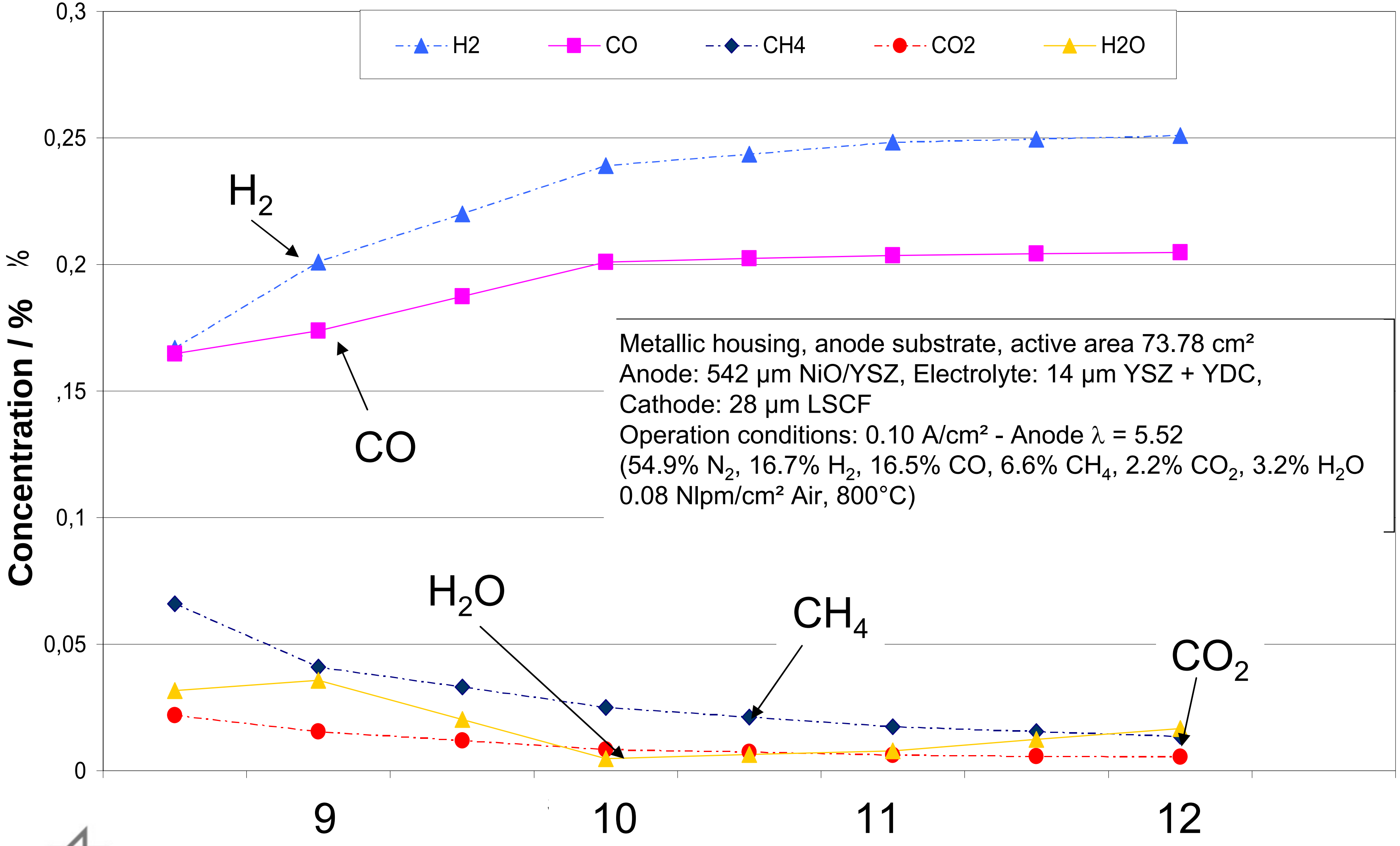
Cell can be locally in critical conditions!

Variation of Load - Reformate



Anode supported cell, LSCF cathode, 73,96 cm², gas concentrations (current density equivalent): 54.9% N_2, 16.7% H_2, 16.5% CO, 6,6% CH_4, 2.2% CO_2, 3.2% H_2O (0.552 A/cm²), 0.02 SlpM/cm² air

Reformate: Changes of the Gas Composition at 0 mA/cm²



Metallic housing, anode substrate, active area 73.78 cm²
Anode: 542 µm NiO/YSZ, Electrolyte: 14 µm YSZ + YDC,
Cathode: 28 µm LSCF
Operation conditions: 0.10 A/cm² - Anode λ = 5.52
(54.9% N_2, 16.7% H_2, 16.5% CO, 6.6% CH_4, 2.2% CO_2, 3.2% H_2O
0.08 Nlpm/cm² Air, 800°C)

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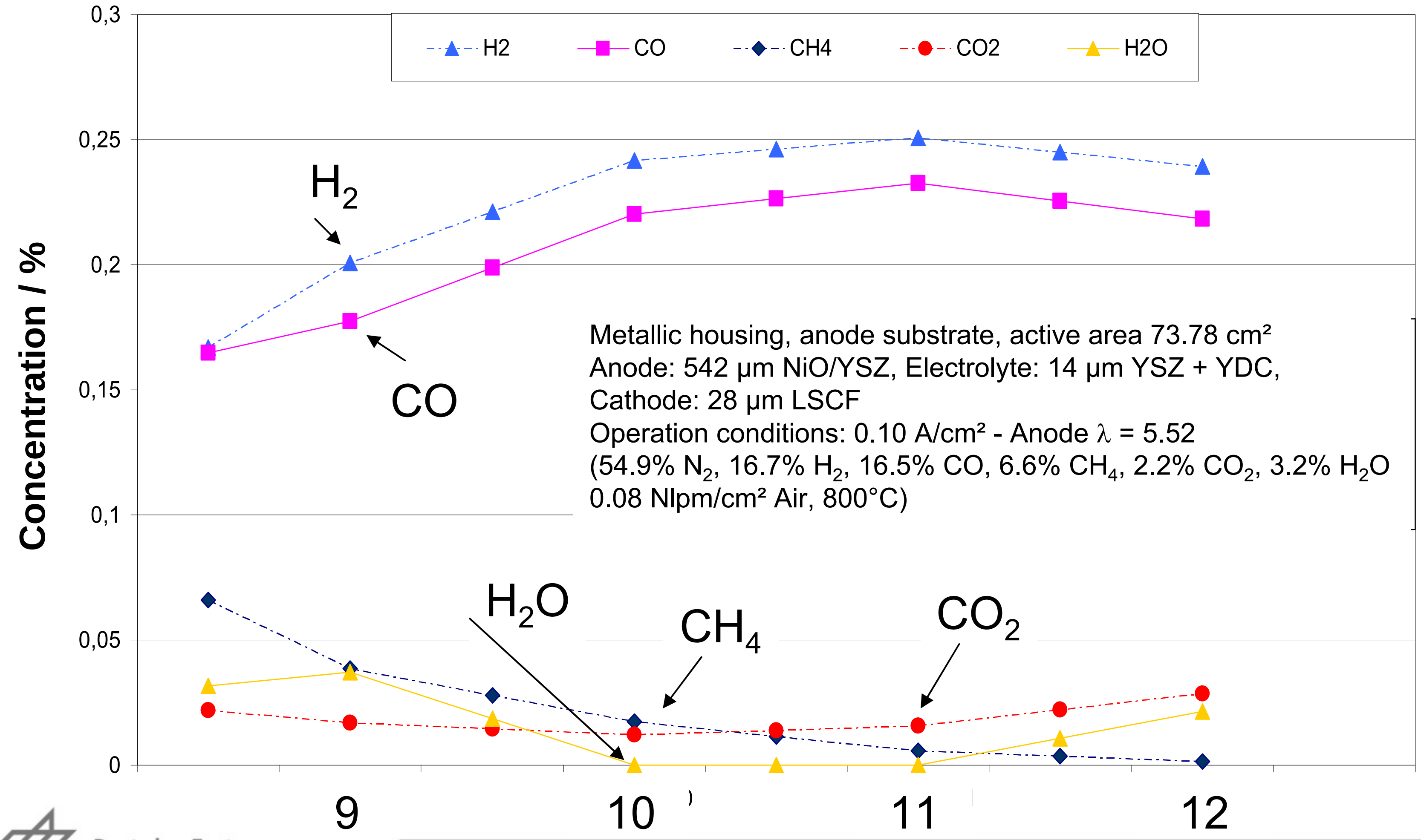
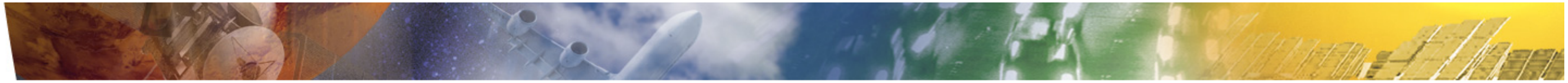
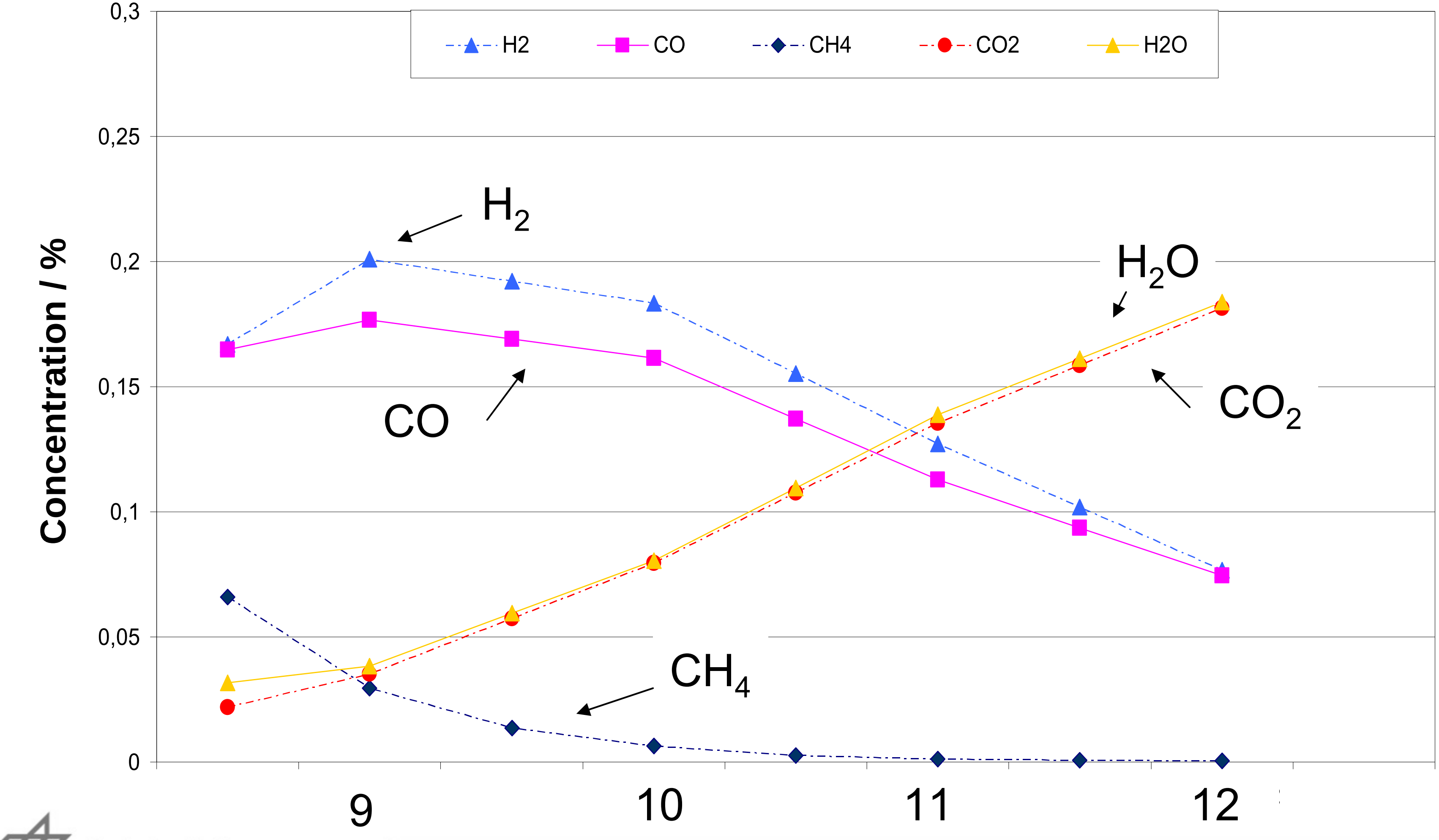
Alteration of the Gas Composition at 100 mA/cm²



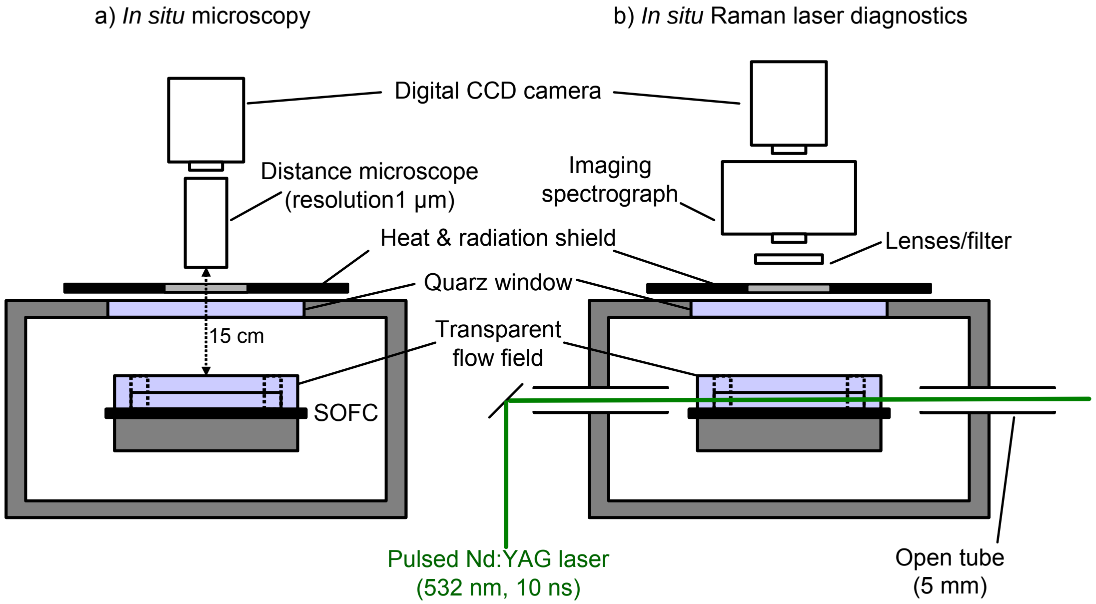
Metallic housing, anode substrate, active area 73.78 cm²
Anode: 542 µm NiO/YSZ, Electrolyte: 14 µm YSZ + YDC,
Cathode: 28 µm LSCF
Operation conditions: 0.10 A/cm² - Anode λ = 5.52
(54.9% N_2, 16.7% H_2, 16.5% CO, 6.6% CH_4, 2.2% CO_2, 3.2% H_2O
0.08 Nlpm/cm² Air, 800°C)



Alteration of the Gas Composition at 435 mA/cm²



Potential for Optical Spectroscopies



Raman spectroscopy
Laser Doppler Anemometry (LDA)
Particle Image Velocimetry (PIV)
Fast-Fourier Infrared (FTIR)
Coherent Anti-Stokes Raman Spectroscopy (CARS)
Electronic Speckle Pattern Interferometry (ESPI)

Setup for 1D-Raman Spectroscopy

3 double pulse Nd:YAG PIV 400 laser systems

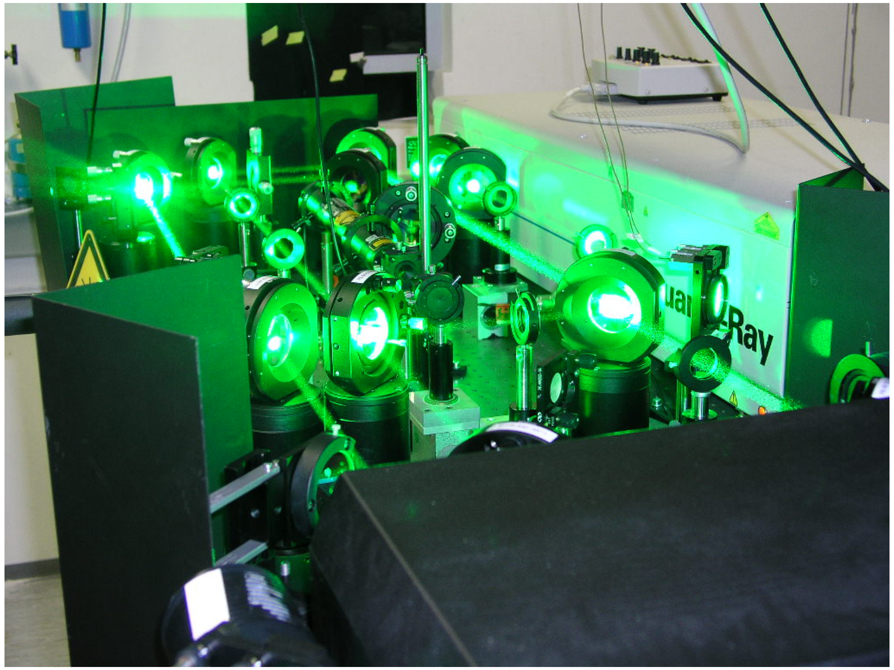
λ = 532 nm

Repetition rate: 10 Hz

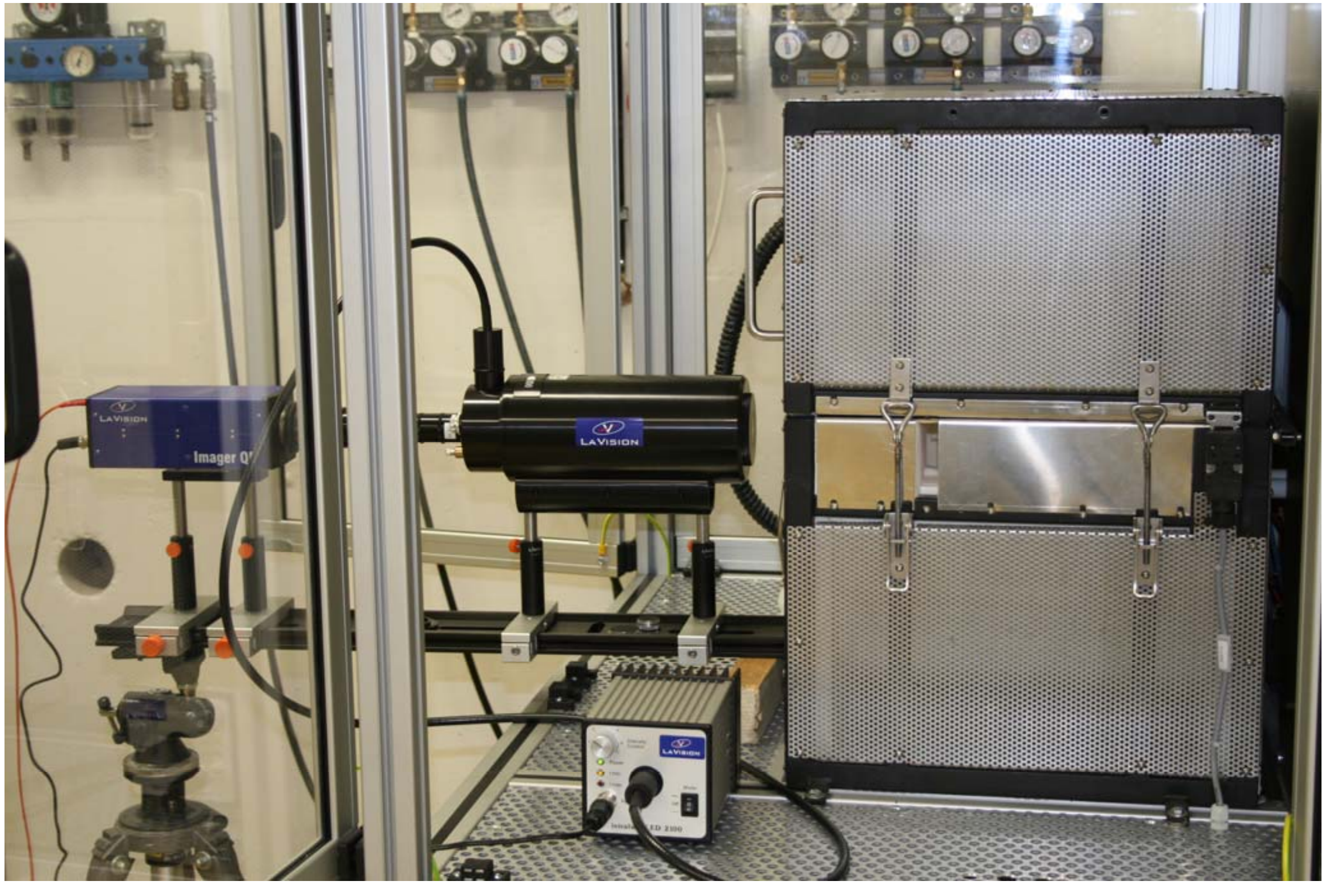
Single pulse: E ≤ 350 mJ / ~7 ns

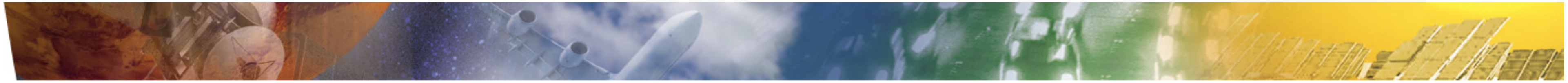
Pulse energy: 6 x 300 mJ

Pulse length: ~380 ns
(temporal resolution)



Setup for In-Situ Optical Microscopy





Conclusion

- In-situ diagnostic techniques allow for a largely extended insight into fuel cell processes (fundamental understanding, optimisation of flow field)

- The potential of spatially resolved diagnostics was demonstrated with some exemplary results

- The obtained data can be used for modeling and simulation for identification of critical operating conditions

- Strong gradients of gas concentrations and current density particularly at operation with high fuel utilisation may result in locally critical operating behaviour

- Additional in-situ diagnostic methods such as optical microscopy and gas-phase Raman spectroscopy are currently built up to provide further information for the understanding of cell reactions and processes