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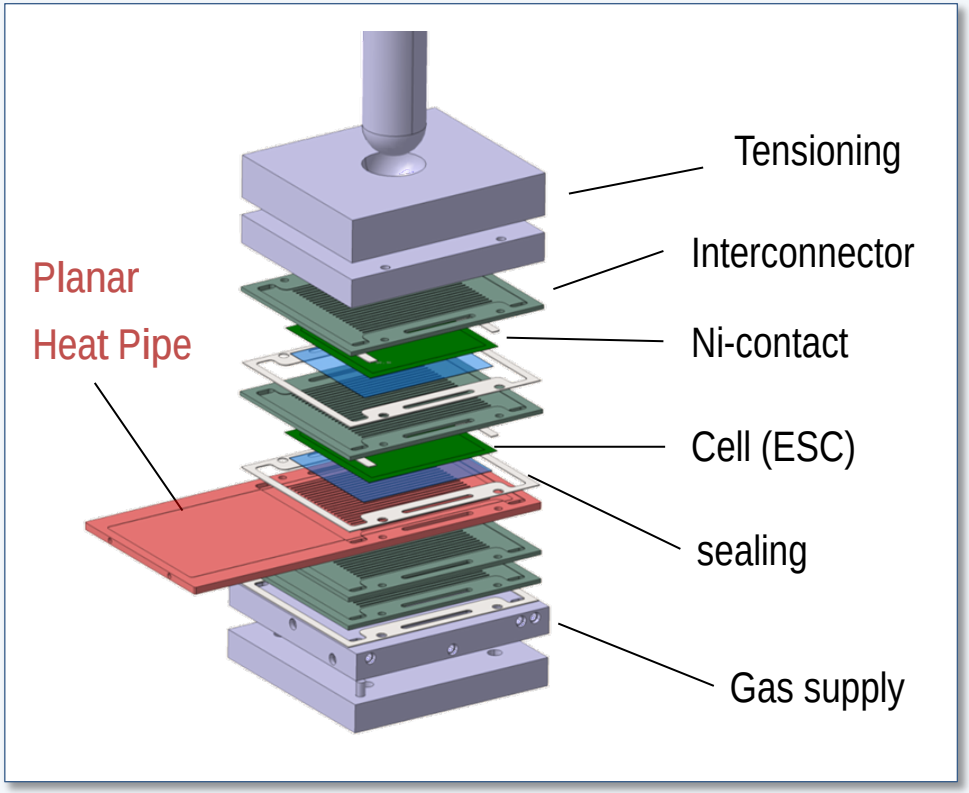
Hydrogen Days 2015, Prague. 18 - 20 March 2015

Thermal control of solid oxide electrolyser cells / fuel cells with high temperature heat pipes



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Outline

I 1. Motivation – SOFC /SOEC & Heat Pipes
- Improved thermal management
- Dynamic operation

II 2. Planar Heat Pipe development
- Heat Pipe Design
- Experimental results

III 3. Short stack design & Experiments
- Stack design and Heat Pipe integration
- First experimental results

IV 4. Conclusions

1. Motivation – SOFC & Heat Pipes

- Improved thermal management
- Dynamic operation

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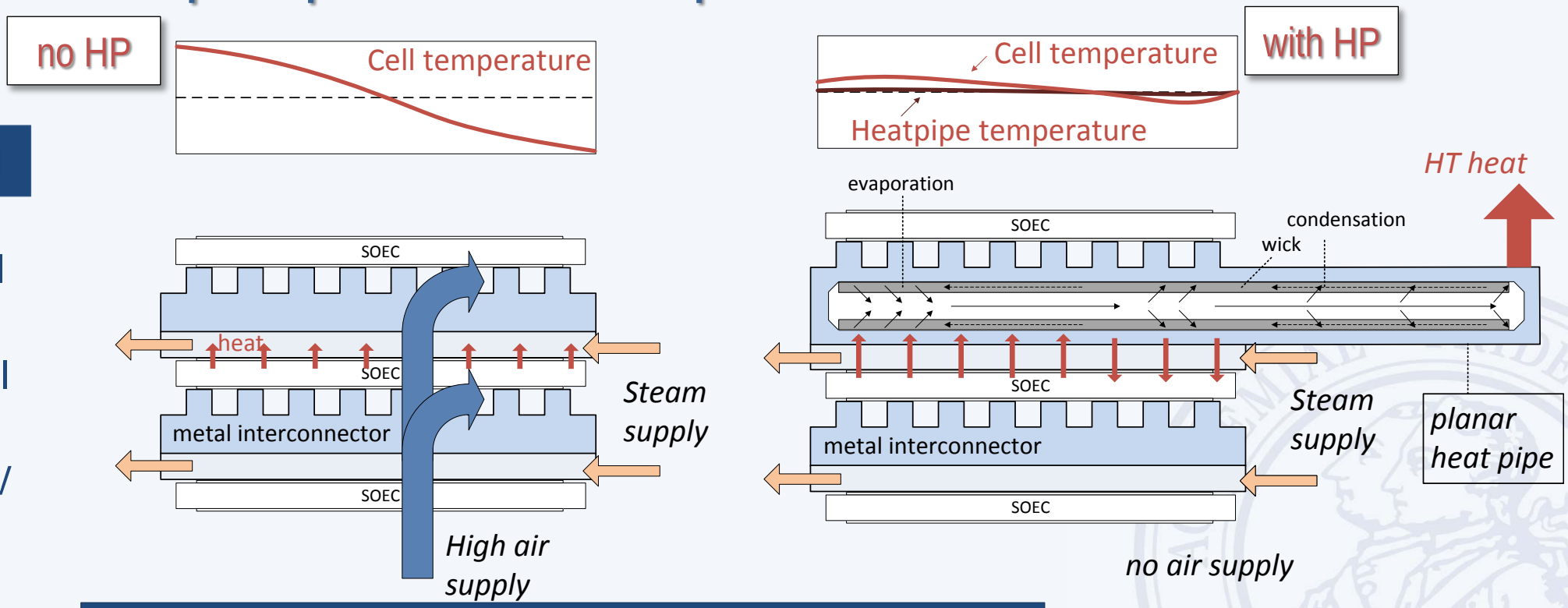
Concept – planar Heat Pipe Interconnector

I

II

III

IV



2 main goals of integrated planar heat pipe:

- Internal temperature gradient reduction
  → dynamic operation of stacks
  → reduction of cooling air
- Isothermal heat extraction from SOFC stack
  → high temperature heat supply to secondary processes

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Load flexible SOFC / SOEC

I

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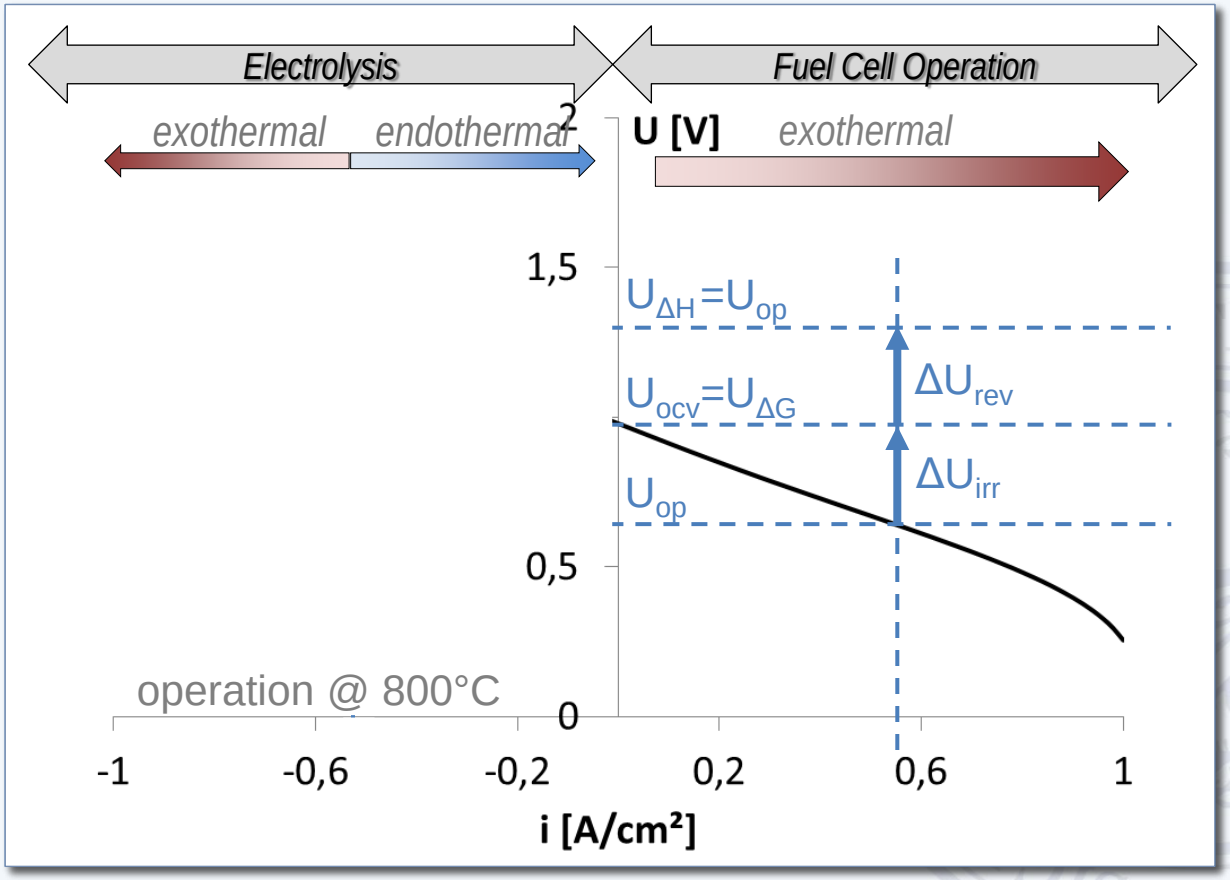
Stack Thermal Balance:

Heat production depending on operation mode:

- Exothermal
- Endothermal
- Thermoneutral operation



Current –Voltage Diagram of Solid Oxide Cell

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Load flexible SOCs

Thermal gradients in stacks in cell layer

I → Dynamic stress

→Cell degradation:

II →Microcracking

→Delamination

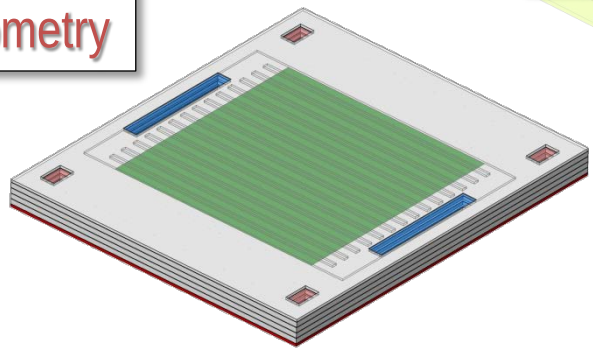
III →Sealing degradation

IV Heat Pipe integration:

→ Internal thermal balancing in cell layer

→ Heat supply / removal

geometry



endothermal SOEC

1.16 V, 0,27 A/cm², SU=0.13

T_{fuel}= 800°C, no inlet air

no HP

cell5

cell1

1000 K

steam supply

exothermal SOEC

1.34 V, 0,96 A/cm², SU=0.78

T_{fuel}= 800°C, no inlet air

no HP

1108 K

1.16 V, 0,43 A/cm², SU=0.28

T_{fuel}= 800°C, no inlet air

with HP

cell5

cell1

1051 K

1.34 V, 0,82 A/cm², SU=0.78

T_{fuel}= 800°C, no inlet air

with HP

1083 K

planar HP, 1073 K

988 996 1004 1012 1019 1027 1035 1043 1051 1058 1066 1074 1082 1090 1097 1105 1113

Temperature [K]

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Process integration

I

Direct **thermal integration** of SOFC stacks and **endothermal** fuel preparation:

II

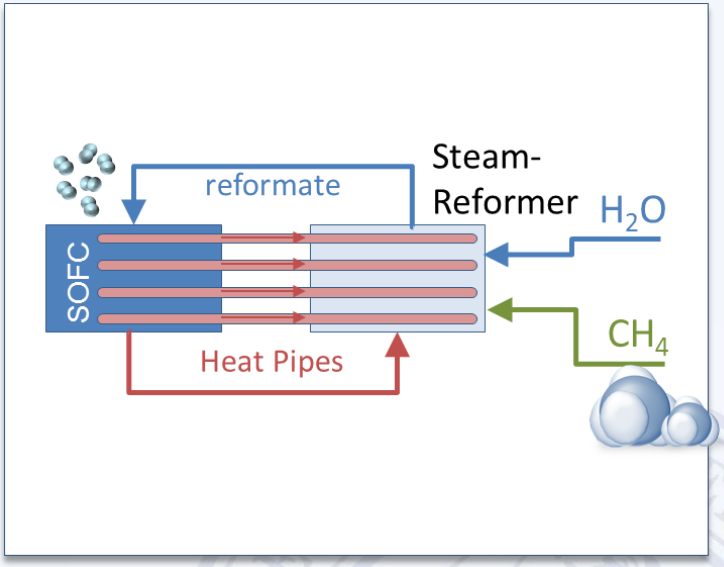
- CH_4 (pre-) Reforming
- H_2 – release from H_2 storage media (LOHC*)

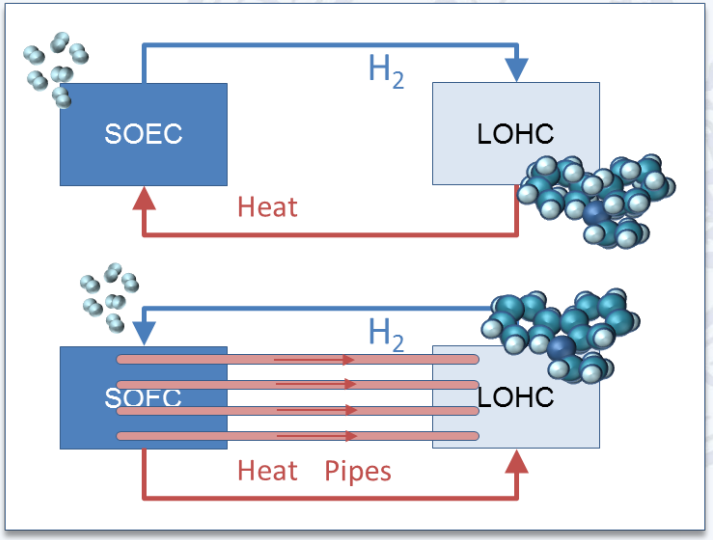
III

*Liquid organic hydrogen carriers:

D. Teichmann, W. Arlt, P. Wasserscheid, Int. J. Hydrogen Energy 2012, 37, 18118-18132.

IV





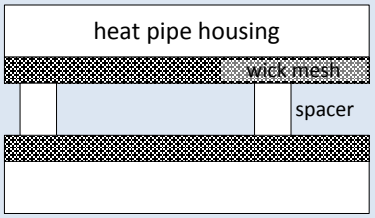
SOFC / SOEC system (0,75V,AR=2)	Heat from SOFC stack [W/cm²]	Heat demand [W/cm²]
100% pre SR** CH_4	0,30	0,19 (SR CH4)
25% pre SR CH_4	0,14	0,05 (SR CH4)
H_2 from LOHC	0,29	0,28 (LOHC)

**Steam Reforming.

2. Planar Heat Pipe development

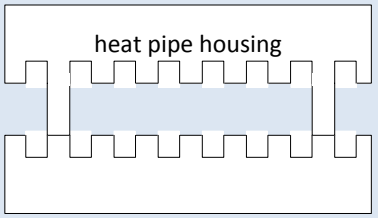
- Heat Pipe Design
- Experimental results

HP Interconnector: Design and production



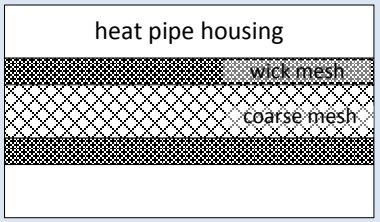
a) Screen mesh layers as wick structure separated by spacing elements

Mesh sizes 60 - 200



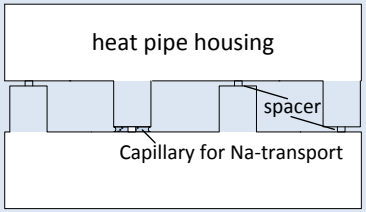
b) Rectangular axial grooves with vapour space separators

Grooves size 200 – 500 µm



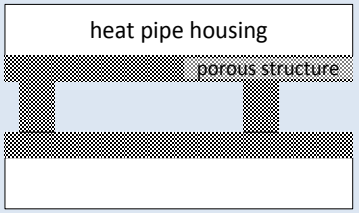
c) Sandwich design with fine screen mesh layers as wick and coarse mesh as vapour space separator

Mesh size: 10; 60-200



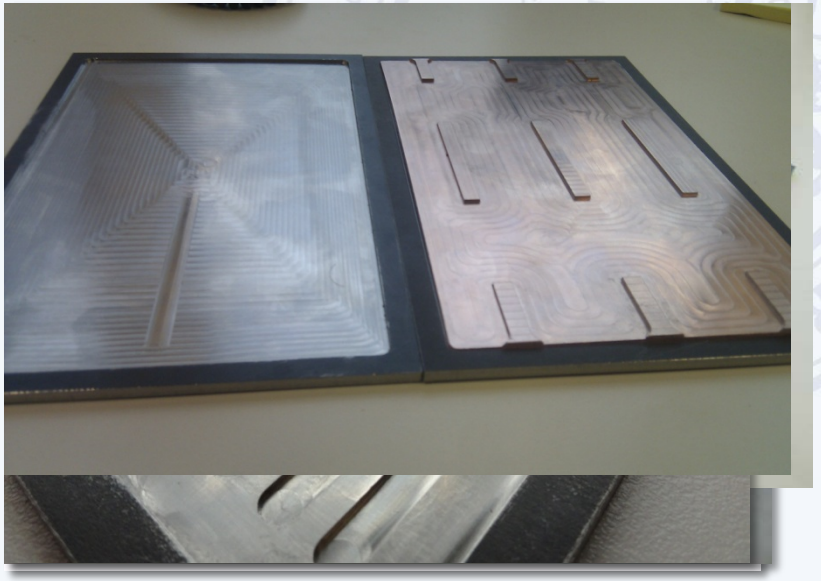
d) Small flat housing gap as planar capillary structure

Capillary height 50 -100 µm

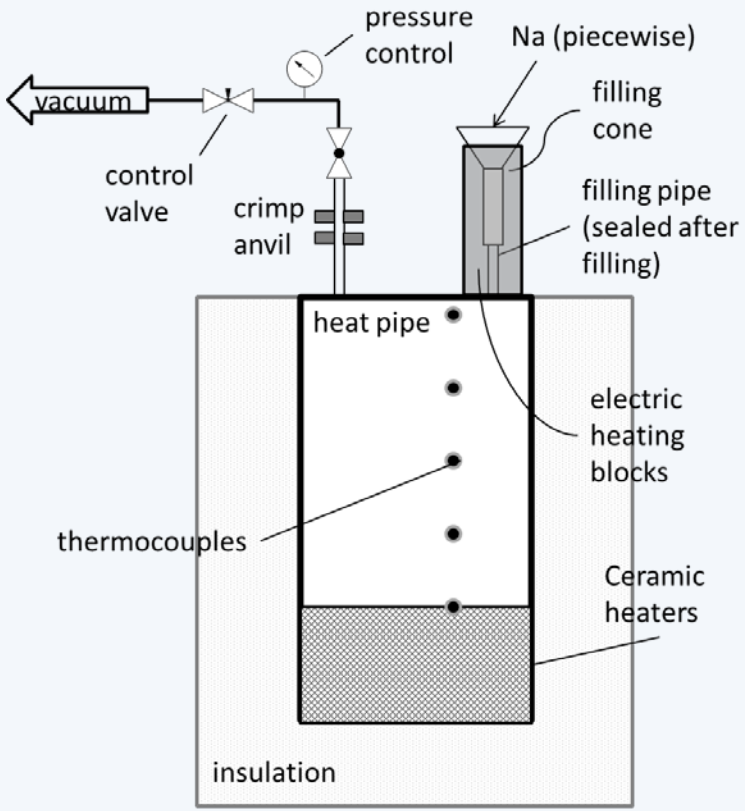


e) Porous medium as wick structure and vapour space separator

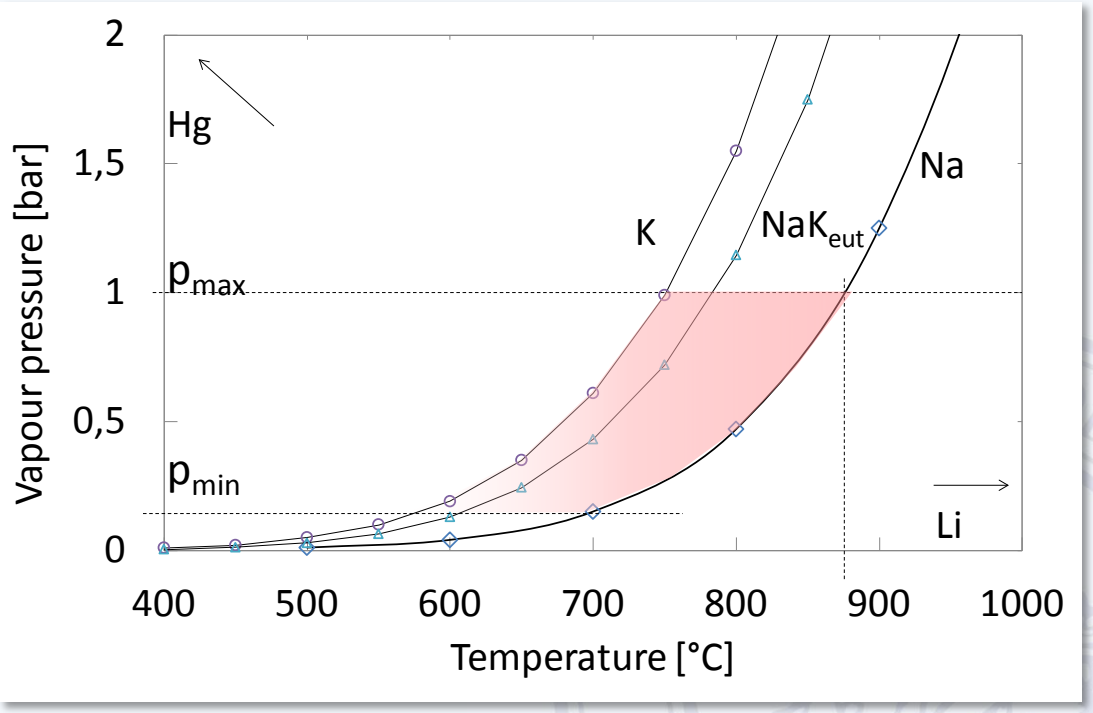
Pore sizes: ca. 50 -200 µm



HP Interconnector: Design and production



Filling and degassing procedure



Planar high temp. Heat Pipes:

Heat transfer fluid (max p_{sat}=1 bar):
→ Sodium (Na) , Potassium (K) or NaK

Wick material: →1.4841
Casing: →Crofer 22H

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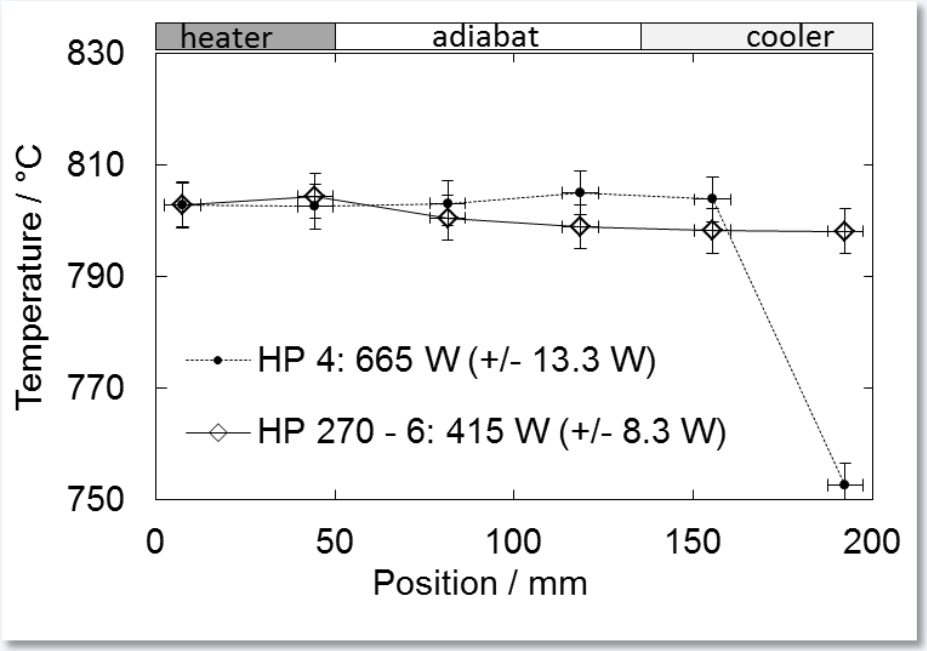
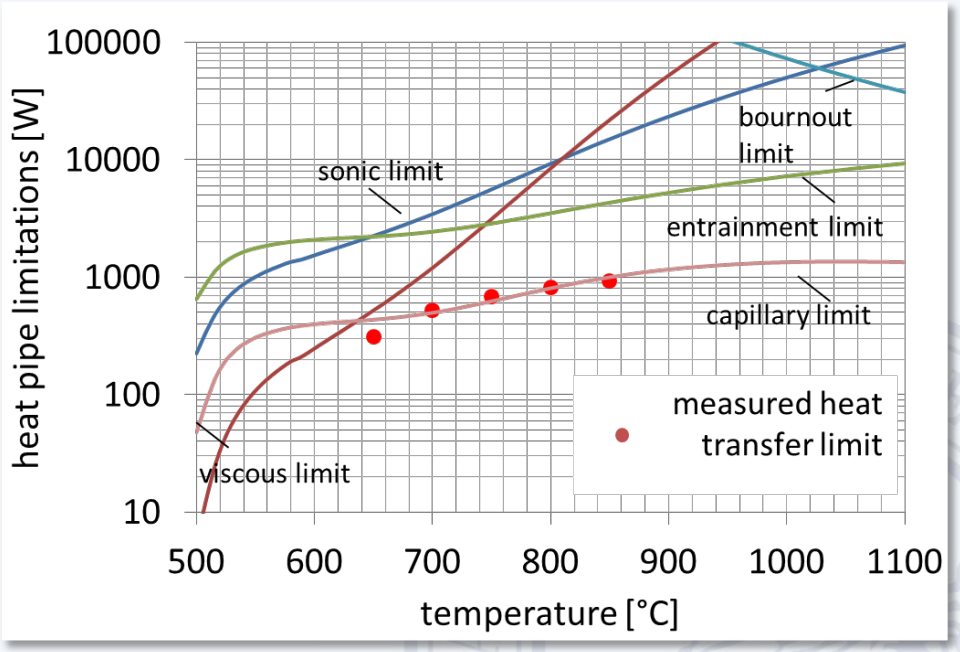
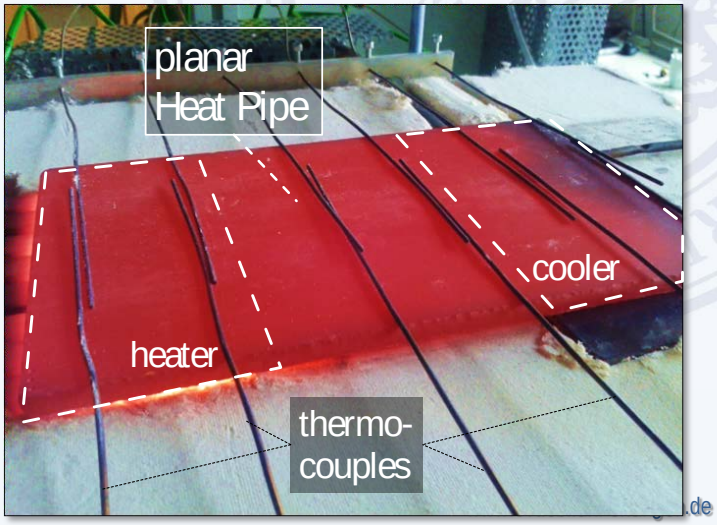
Heat Pipe performance - results





- → almost <u>isothermal operation</u> (only few K of dT in casing) for horizontal operation
- → axial heat transfer rates up to 1000 W per planar HP (to 100 W/cm² HP cross section)
- → grooved structures and pourous media still under evaluation
- → screen meshed heat pipes with best results (mesh:80 | 8 | 80)



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3. Short stack design & Experiments

- Stack design and Heat Pipe integration
- First experimental results

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Stack Design:

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Cell:

ESC 10Sc1CeSZ

100 x 100 mm

Interconnector:

Crofer 22H

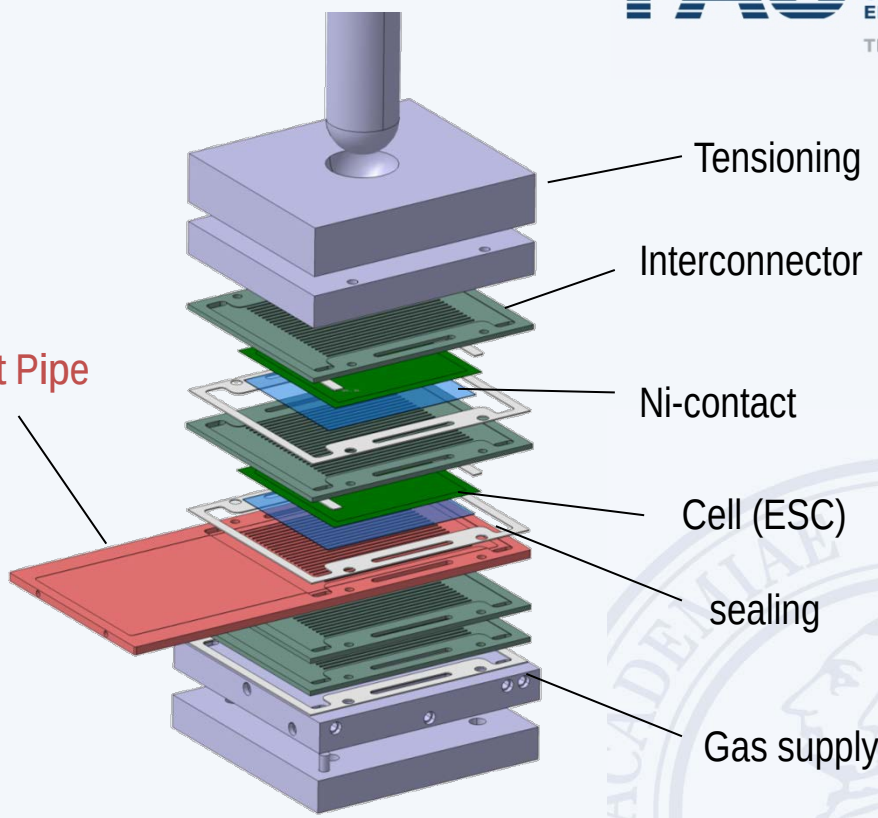
milled flow field, crossflow

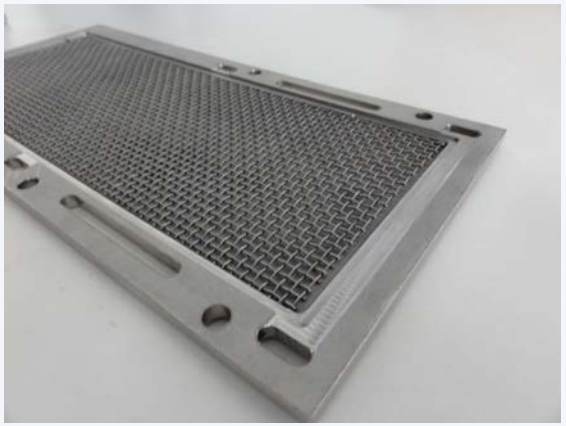
Heatpipe - Interconnector:

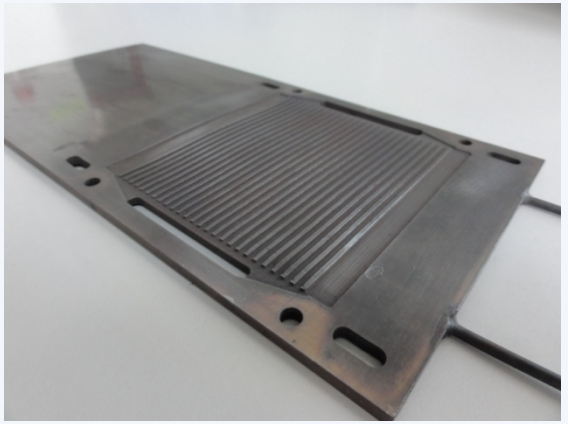
270 x 130 mm, t = 4 mm, Sandwich Design (Mesh 80, 8), 1.4841

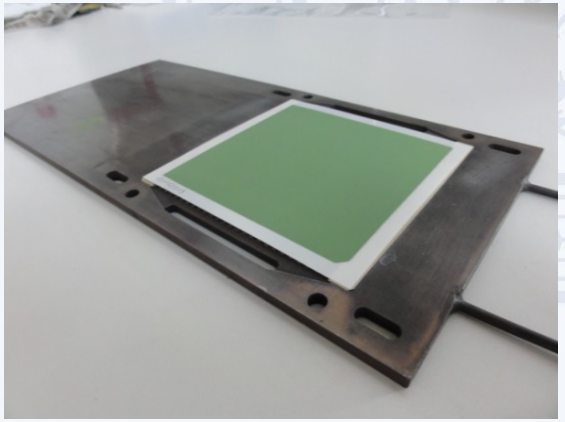
Sealing:

Thermiculite 866, 0,2-0,4 MPa









Shortstack test – set up

→ 2-cell shortstack set up with integrated HP
→ Placing of thermocouples within stack structure

I
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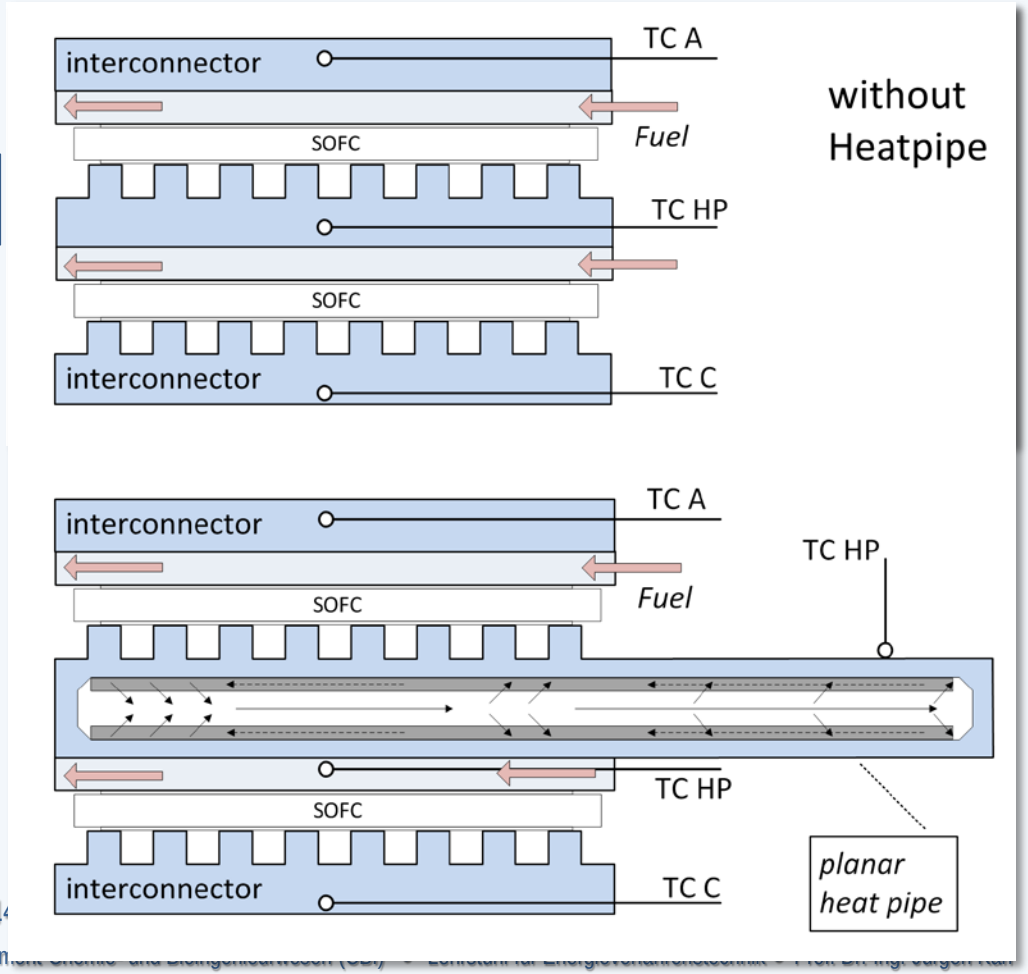

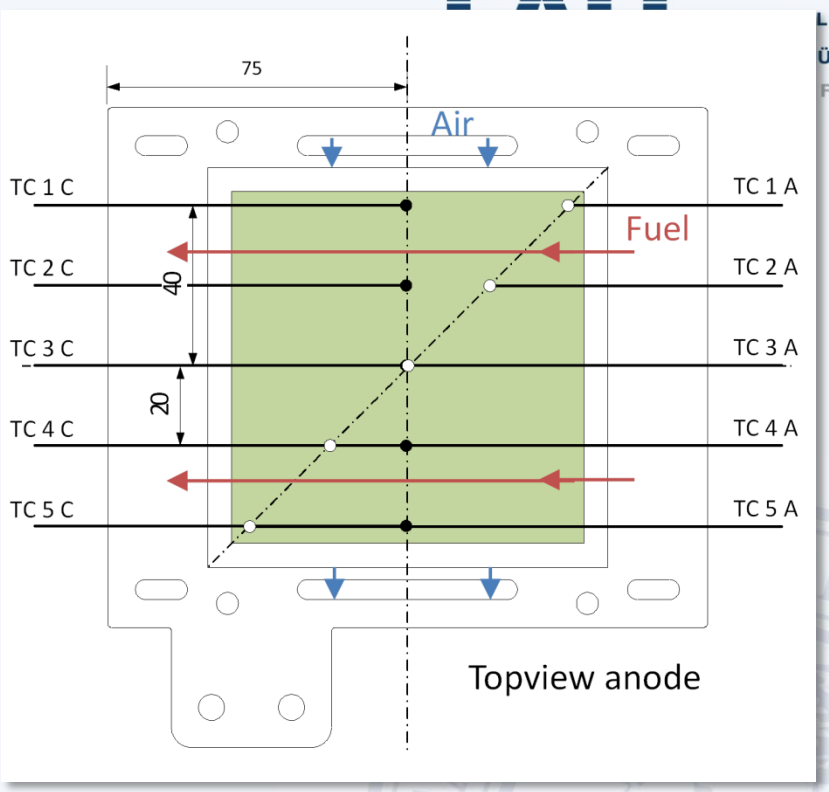

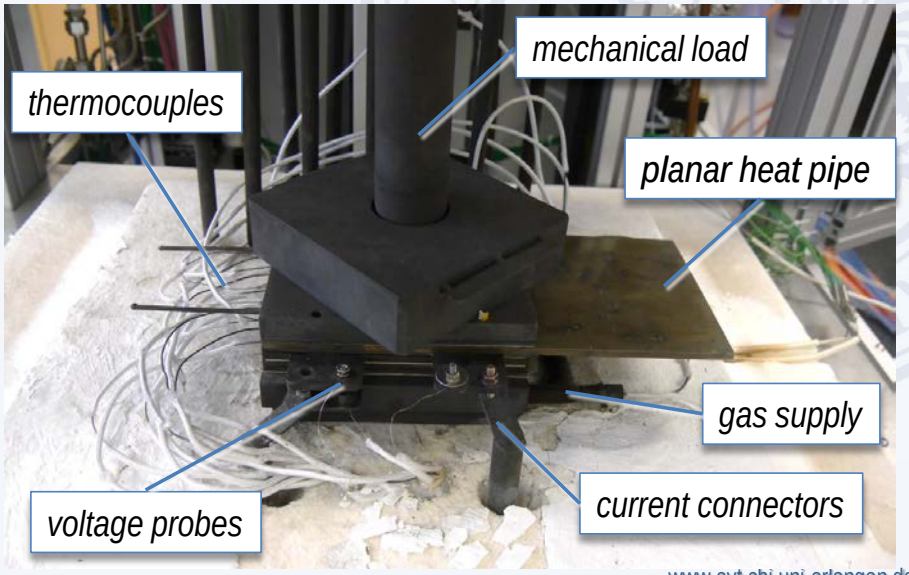

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SOFC / SOEC shortstack tests

I

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Results:

Dynamic operation possible:

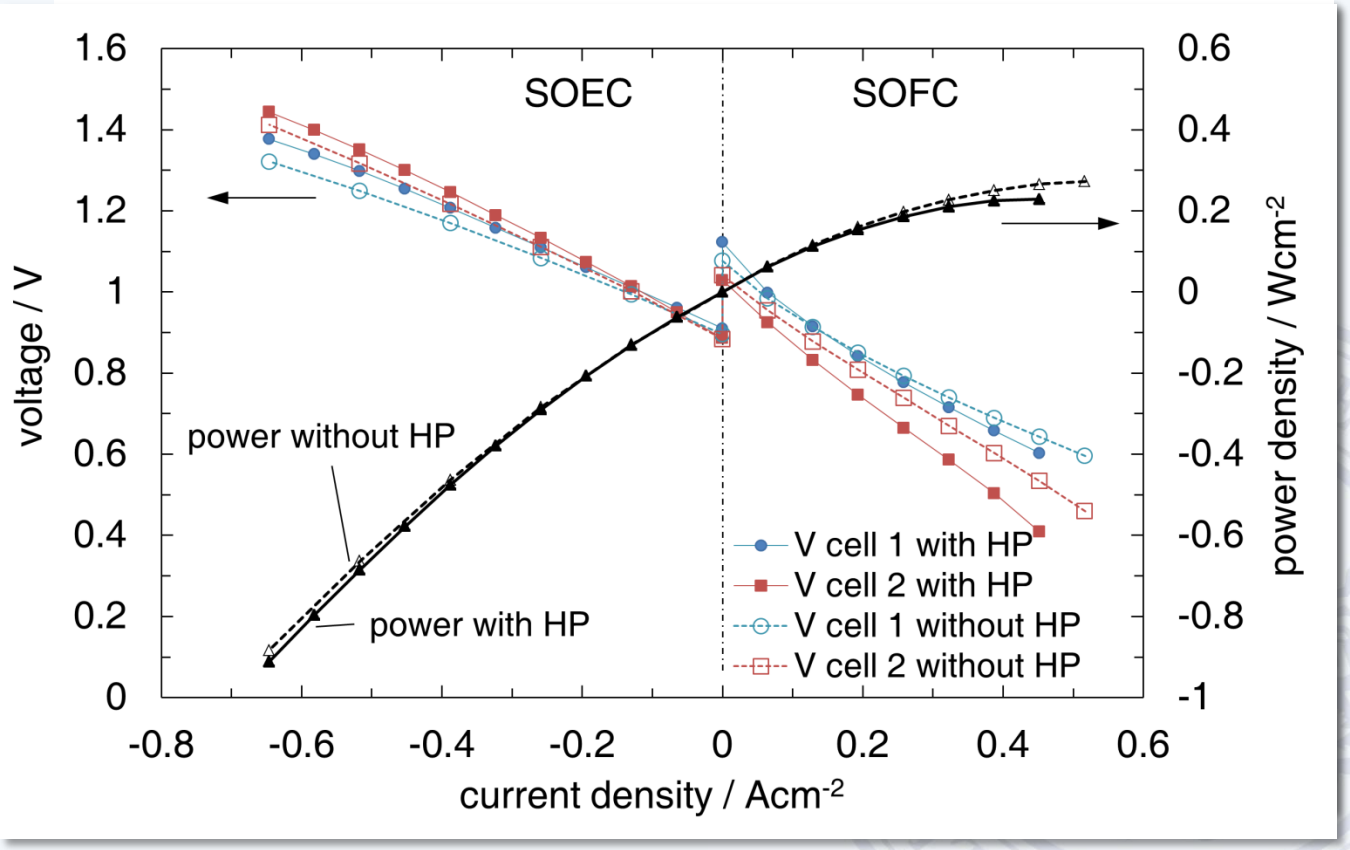
300 SOFC / SOEC cycles

SOFC: 0,20 A/cm²; 0,70 V

SOEC: 0,32 A/cm²; 1,10 V

→ differences in cell contacting due to planarity problems of „planar“ heat pipe

→ Sealing, Contacting to be improved



SOEC operation: 850°C, 90 g/h H2O, 1.8 Nl/min H2, 3.0 Nl/min Air

SOFC operation: 850°C, 1.5 Nl/min H2, 1.5 Nl/min N2, 3.0 Nl/min Air

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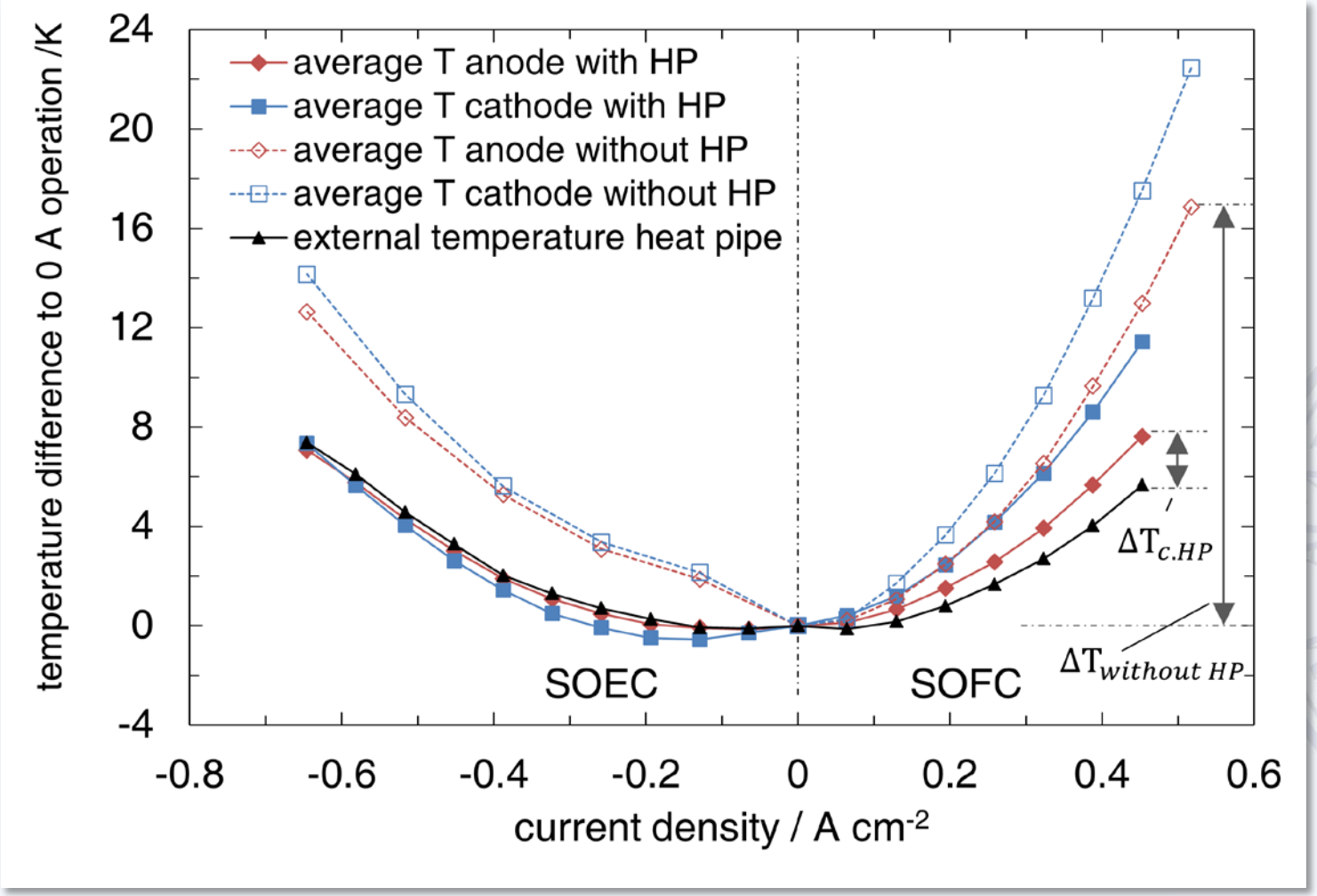
SOFC / SOEC 2 - cell shortstack tests with HP



Results:

→ Increase in heat pipe temperature shows thermal heat pipe integration

→ Anode temperature is kept very close to heat pipe temperature

SOEC operation: 850°C, 90 g/h H2O, 1.8 Nl/min H2, 3.0 Nl/min Air

SOFC operation: 850°C, 1.5 Nl/min H2, 1.5 Nl/min N2, 3.0 Nl/min Air

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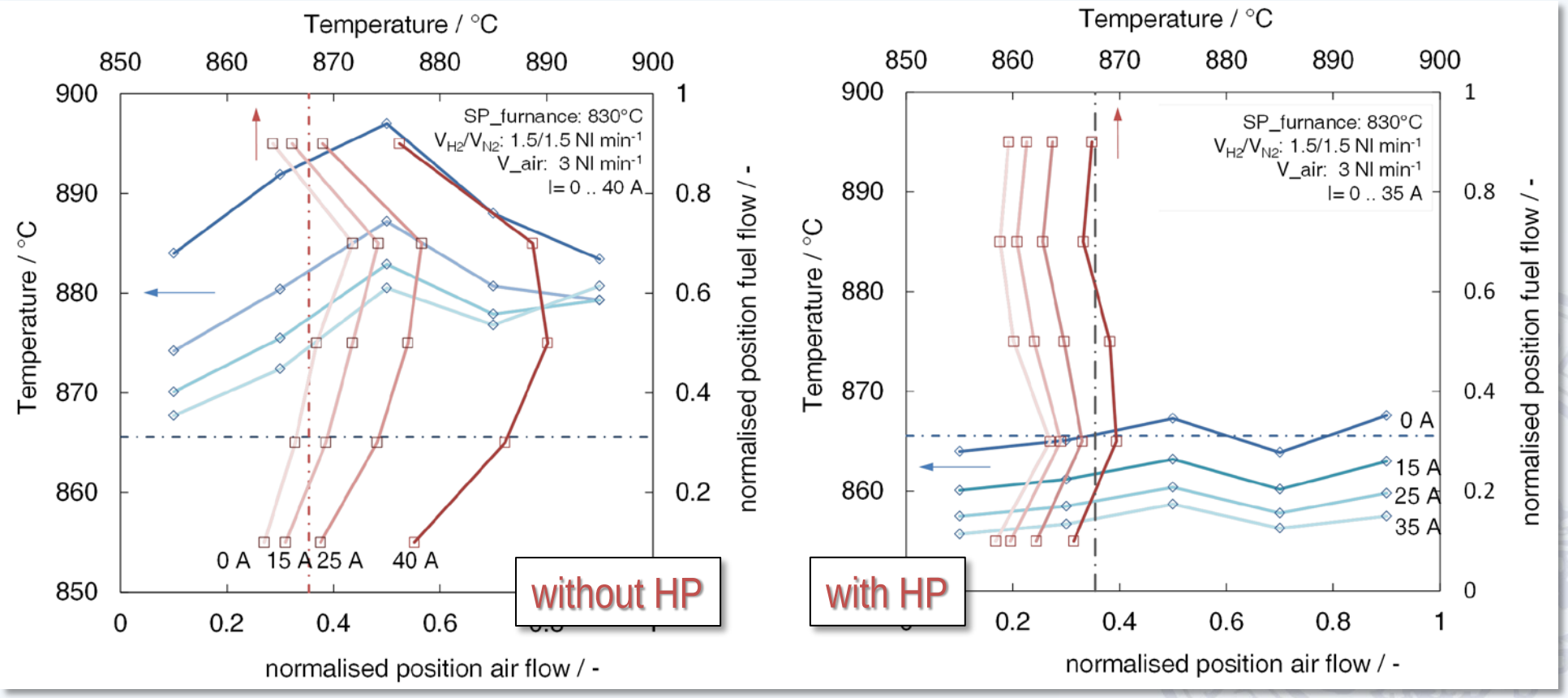
Shortstack tests with HP

I
II
III
IV



Results:

→ Thermal integration of heat pipe

→ Isothermal temperature profiles for SOFC and SOEC operation

4. Conclusions

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Conclusions

Summary

I → Development of planar heat pipe interconnectors, stack integration

II → Up to 1000 W at isothermal operation, (t=4mm)
- inert gas buffers, H_2 buffers

III
- capillary limit for horizontal operation

IV → Isothermal stack operation in SOFC /SOEC

Outlook

→ Temperature distributions in HP stacks under dynamic operation (start up bahviour)

→ full scale stack layout & process integration