Understanding SOEC Degradation Processes by means of a Systematic Parameter Study

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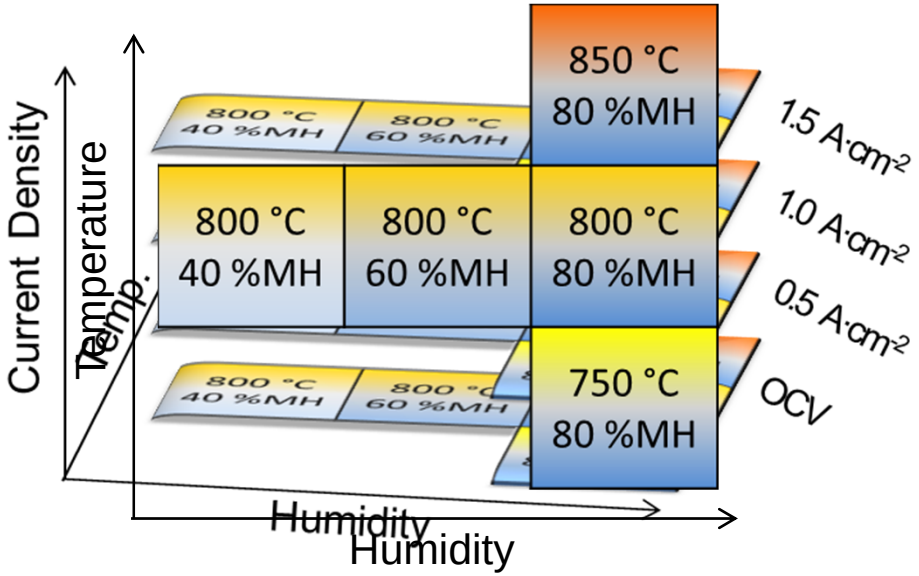
Experimental concept and data interpretation

Systematic study: operating parameters → degradation

- Temperature (T)
- Fuel gas humidity (MH)
- Current density (i)

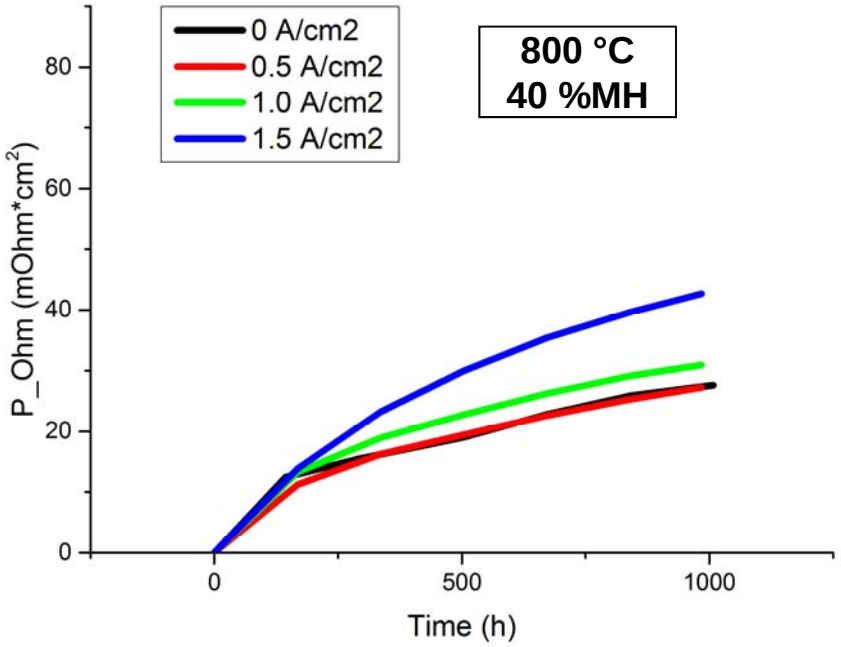


Experimental concept:

- 20 comparable degradation experiments over 1000 h
- Identical measurements except for investigated parameter
- Fuel electrode supported cells from CeramTec (16 cm^2)

  → Ni-8YSZ support | Ni-8YSZ | 8YSZ | CGO | LSCF

Degradation results: Ohmic resistance

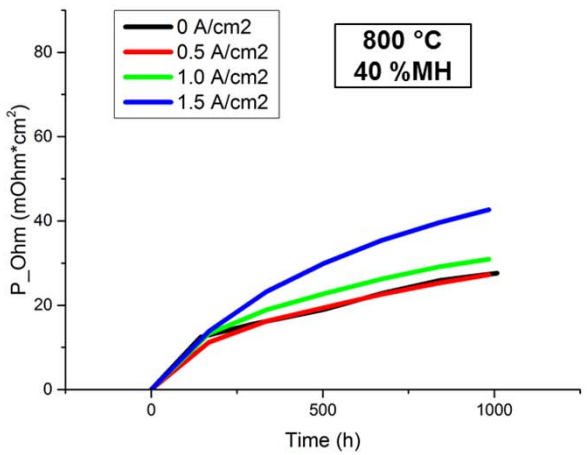


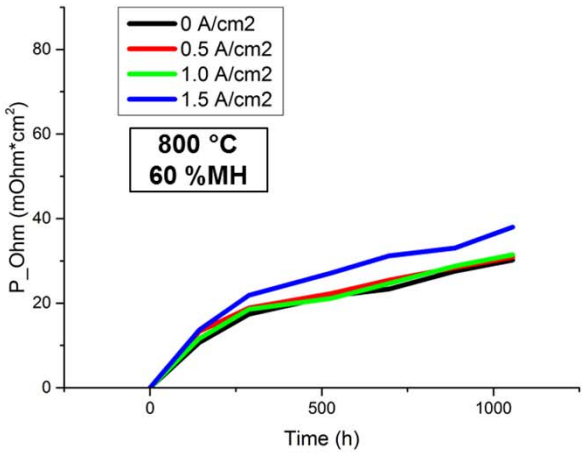
- Ohmic degradation at all current densities
- Influence of current density only at high current densities
  → effect rather limited

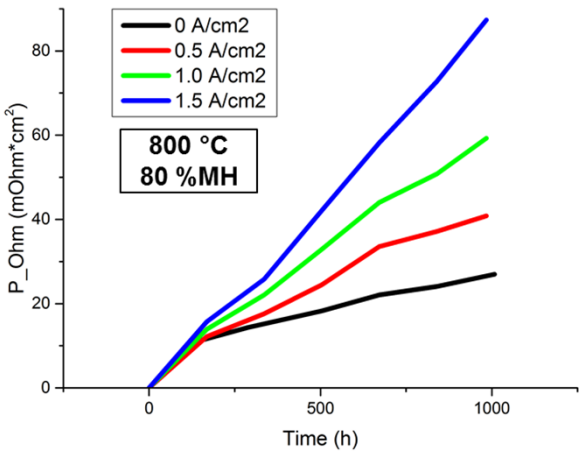
Degradation results: Ohmic resistance

40 %MH and 60 %MH	80 %MH

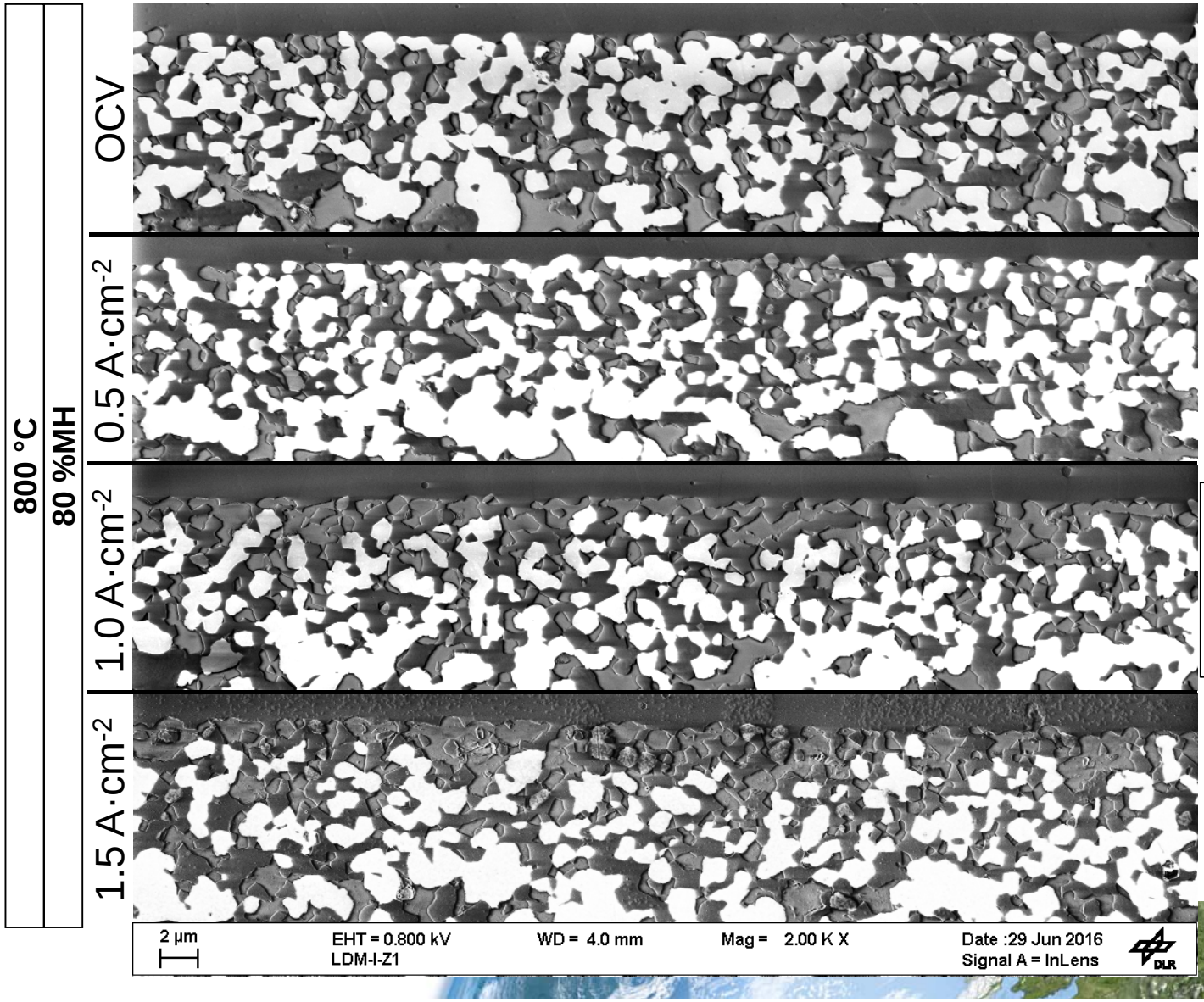
- Degradation of ohmic resistance similar
- Influence of current density much stronger
- Current density has effect even at low current densities







Degradation results: Ohmic resistance

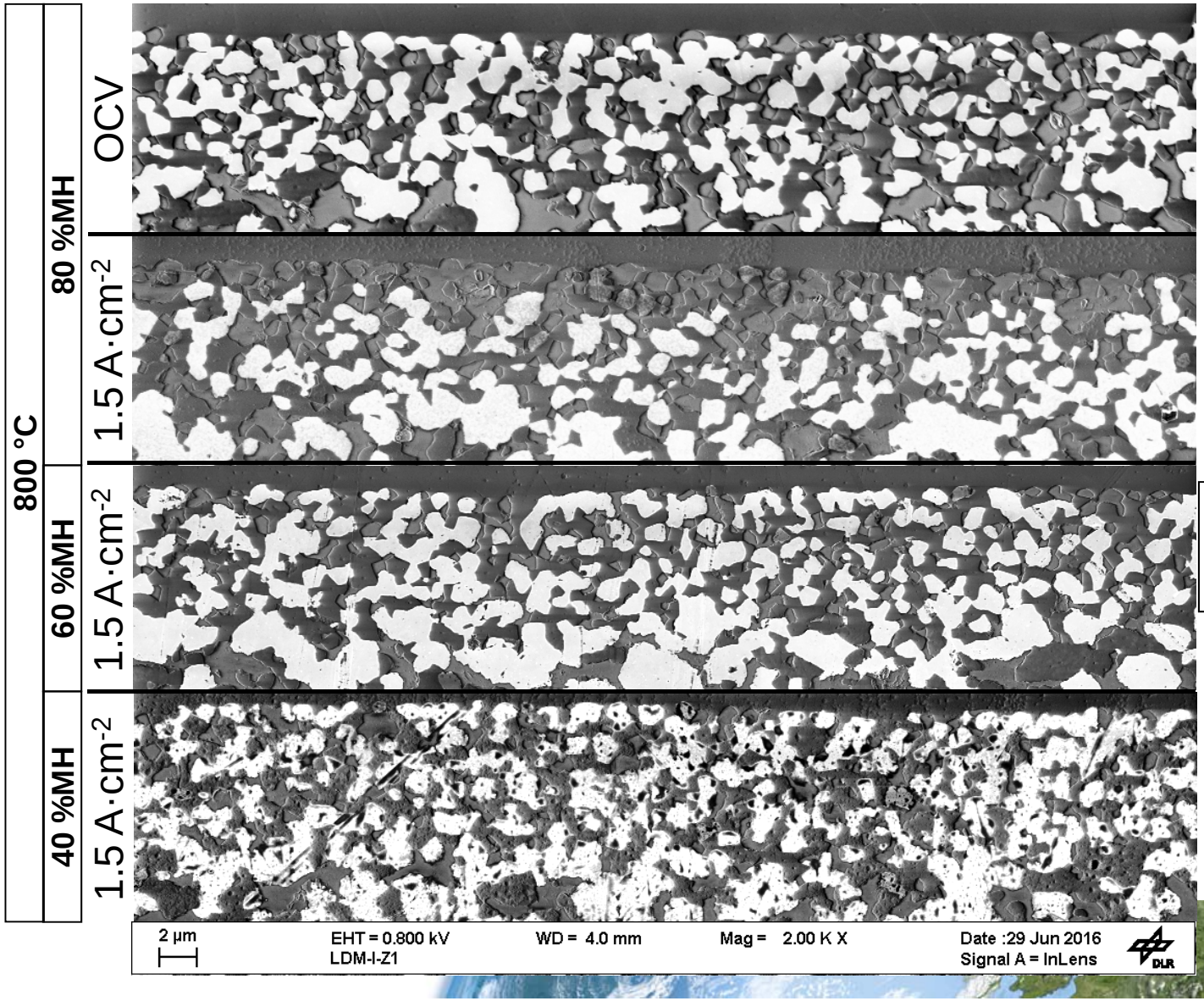


Ni-depletion at Electrode|Electrolyte interface

→ Effectively increasing electrolyte thickness

Direct correlation between Ni-depletion and current density

Degradation results: Ohmic resistance

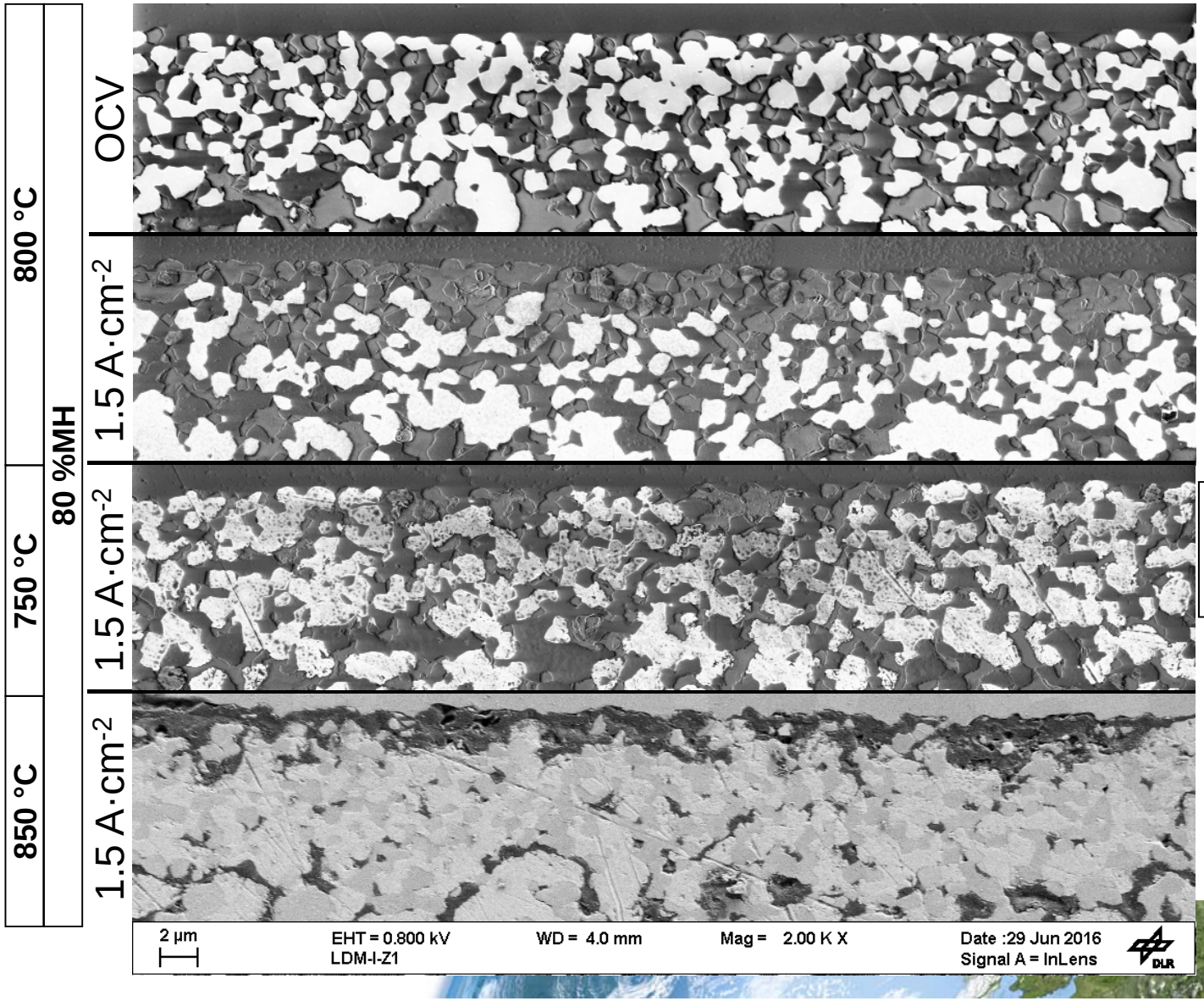


Ni-depletion at Electrode|Electrolyte interface

→ Effectively increasing electrolyte thickness

No Ni-depletion at lower humitidy

Degradation results: Ohmic resistance



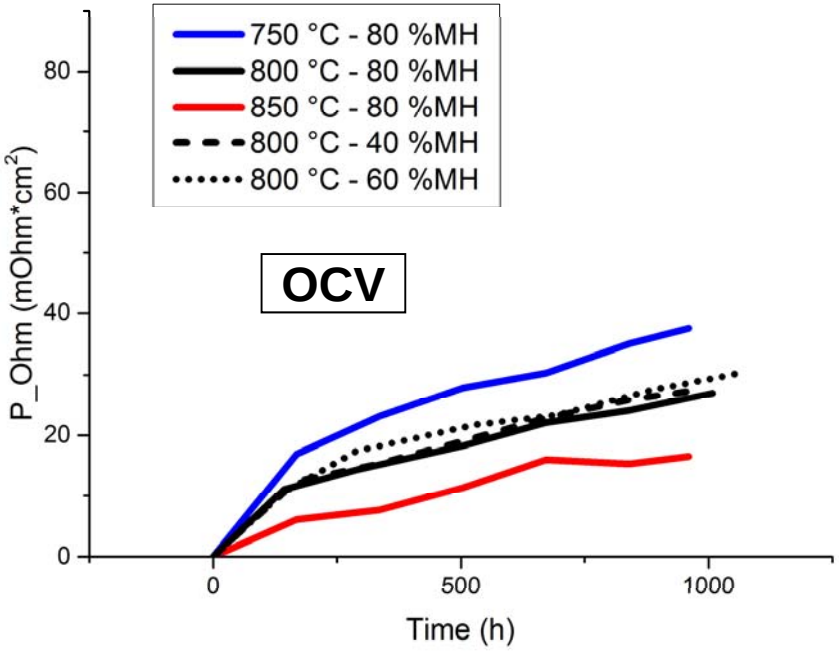
Ni-depletion at Electrode|Electrolyte interface

→ Effectively increasing electrolyte thickness

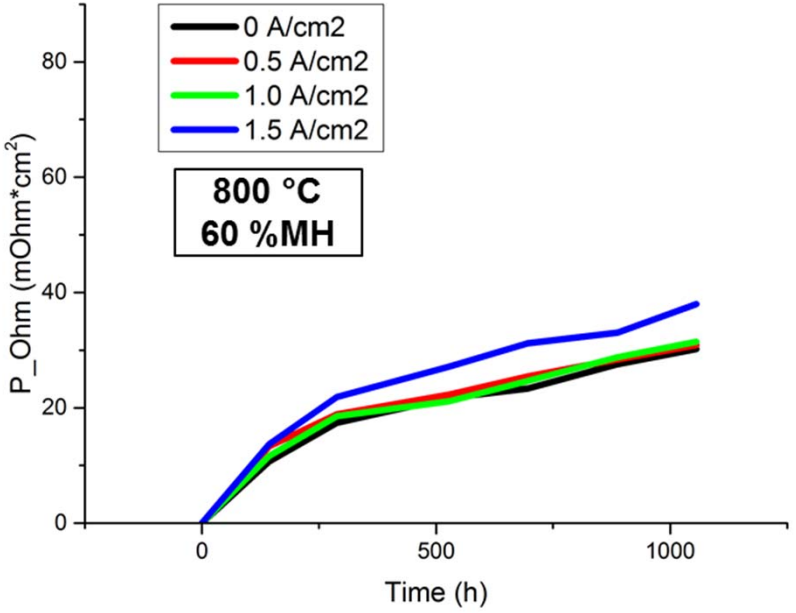
Less Ni-depletion at lower temperature

Degradation results: Ohmic resistance

"Underlying" Degradation:



- Higher temperature leads to lower degradation
- Independent of humidity
- Little influence of current density



Degradation results: Ohmic resistance - Summary

Two major degradation processes

Ni-Depletion:

- Direct correlation between current density and Ni-Depletion
- Minimum temperature and humidity threshold

“Underlying” Degradation:

- Temperature dependence: higher temperature → lower degradation
- No influence of humidity or current density

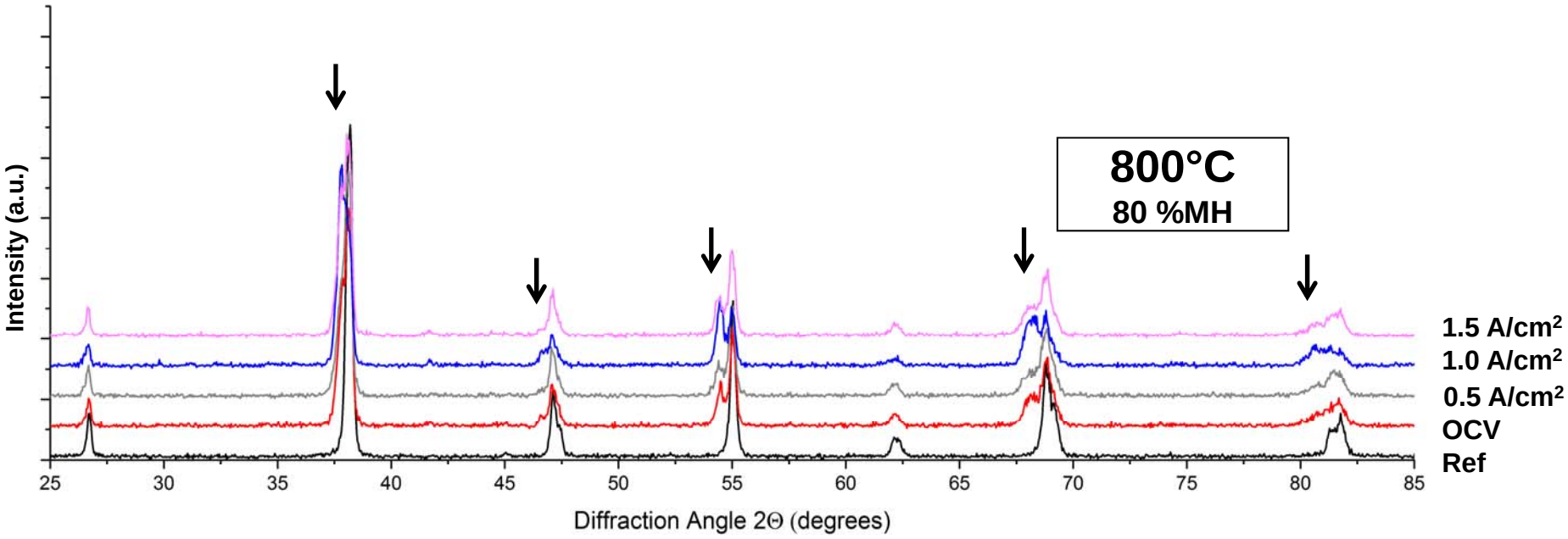
Deterioration of YSZ integrity

- Weakening of YSZ structure at high current densities

Not observed

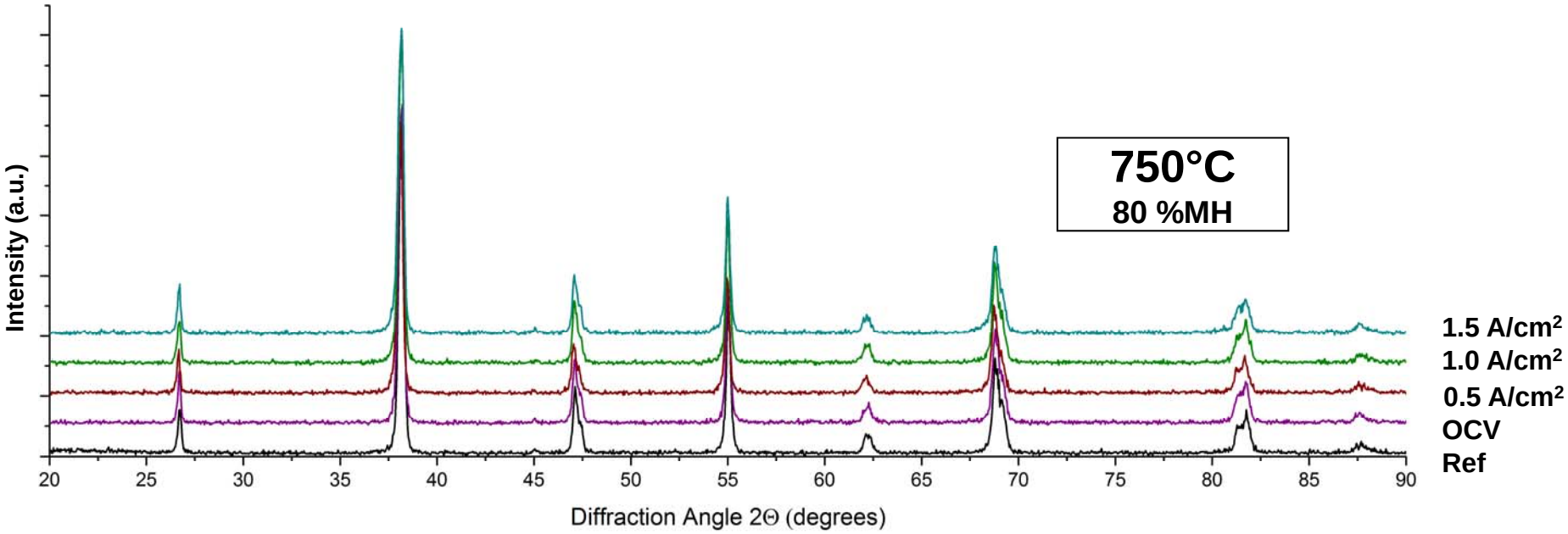
- Correlation between YSZ deterioration and significant increase in ohmic resistance
- SrZrO3 formation

Degradation results: Oxygen Electrode



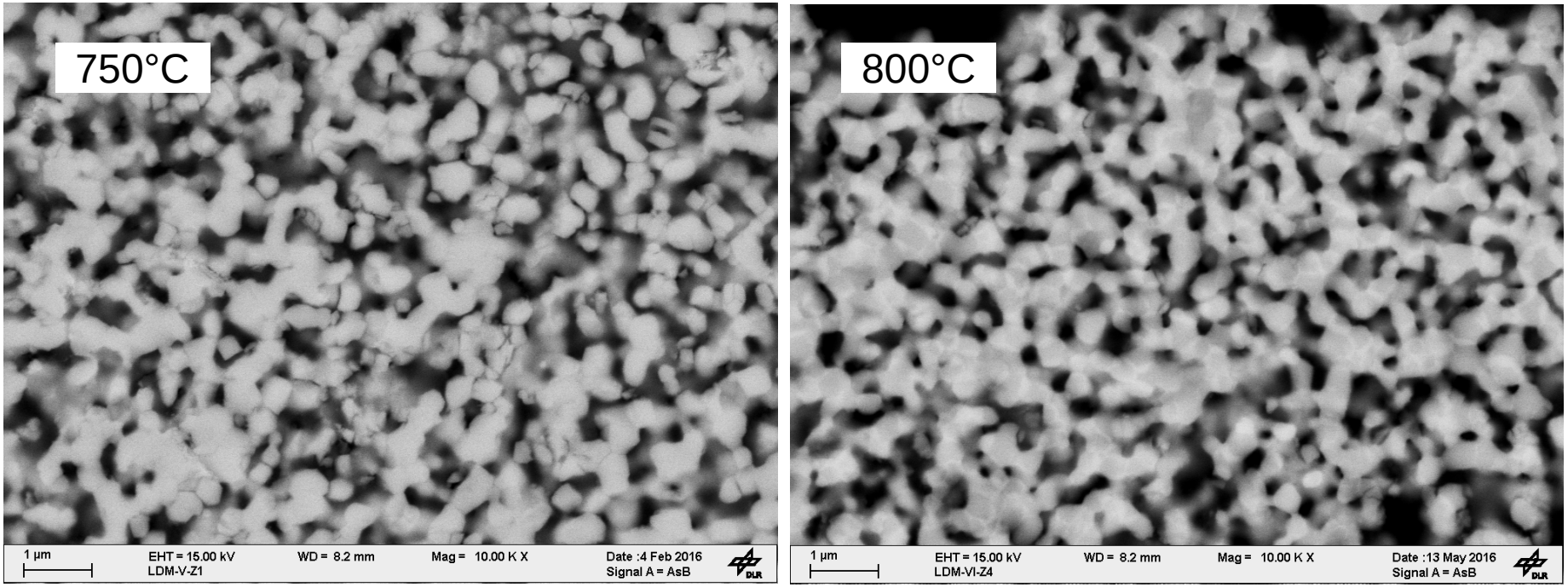
- New peaks in XRD pattern → suggest formation of new crystalline phase
- Observable at all current densities, but no clear trend
- Similar at 800 °C and 850 °C

Degradation results: Oxygen Electrode



- New peaks in XRD pattern → suggest formation of new crystalline phase
- Observable at all current densities, but no clear trend
- Similar at 850 °C and 800 °C
- Not detectable at 750 °C

Degradation results: Oxygen Electrode



- Change in phase composition observable in BSE-SEM
- Correlates with new Peaks on XRD-Pattern
- Correlate with degradation of electrochemical activity

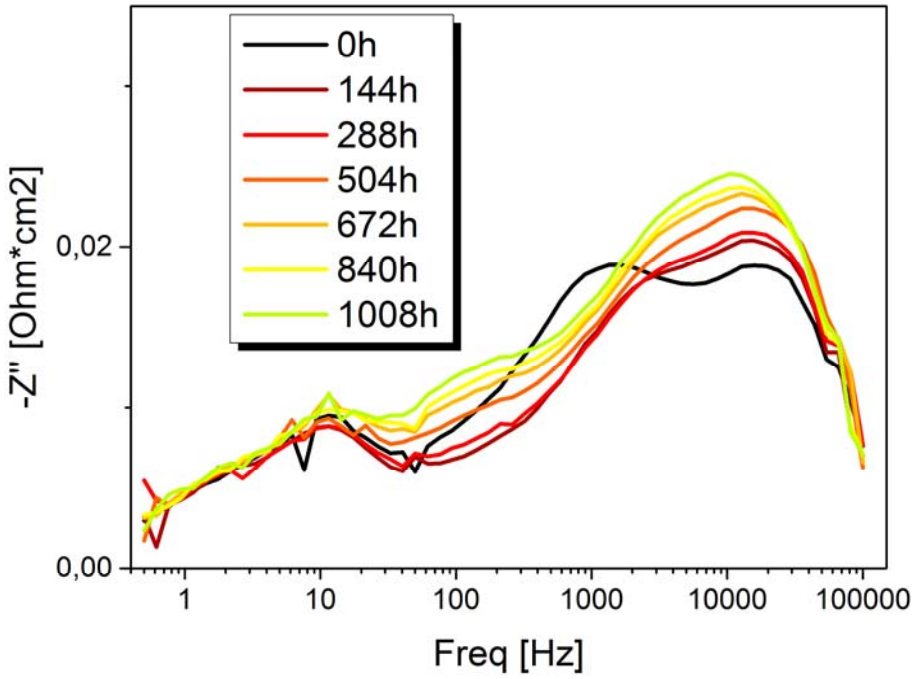
Degradation results: Fuel electrode

- Generally less significant
- Generally stronger at higher current density
- Ni-agglomeration at 850°C

Depending on conditions even activation!

Two fuel electrode processes
→ Behave differently

Discussion wanted!



Summary

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- Ohmic degradation dominates overall degradation
- Two major ohmic degradation processes:
  - Ni-depletion: f(i) above T and humidity threshold
  - “Underlying” Degradation: lower at higher temperatures, ~~f(i, humidity)~~
- *Changes in the oxygen electrode:*
  - *XRD and BSE-SEM images show change of phase composition*
  - *Correlates with degradation of electrochemical activity*
- Fuel electrode degradation:
  - Stronger at higher current densities
  - Ni-agglomeration at high T

Thank you for your attention

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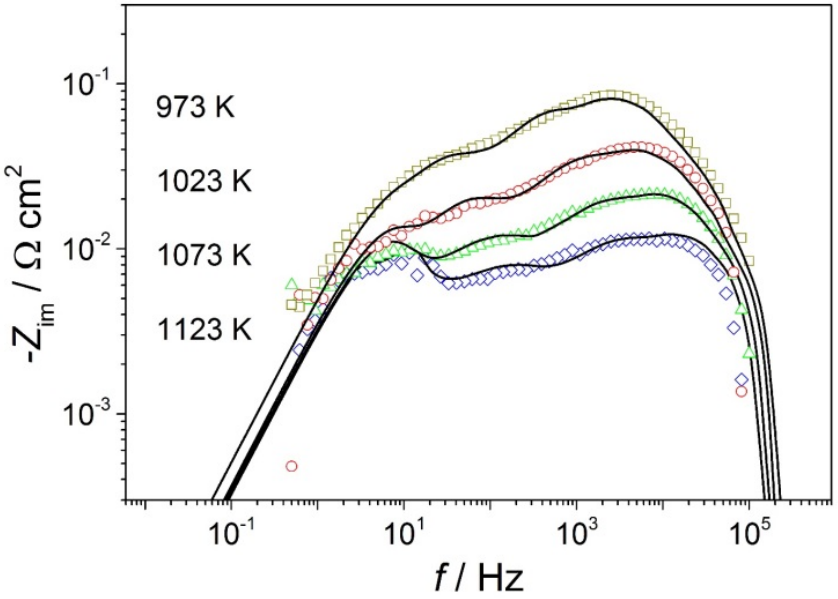
Experimental concept and data interpretation

Understanding and interpreting impedance data:

1) DRT-Analysis
2) Use of a physico-chemical model (B0811)



Measured and simulated impedance spectra at various temperatures, at OCV and 60 %MH

→ Better identification and understanding of individual rate limiting processes