ENABLING THE OPTIMIZATION OF THE WETTABILITY OF GAS DIFFUSION ELECTRODES FOR ZINC-AIR BATTERIES BY EXPLORING NEW MANUFACTURING METHODS

GDE Symposium 04.09.2025

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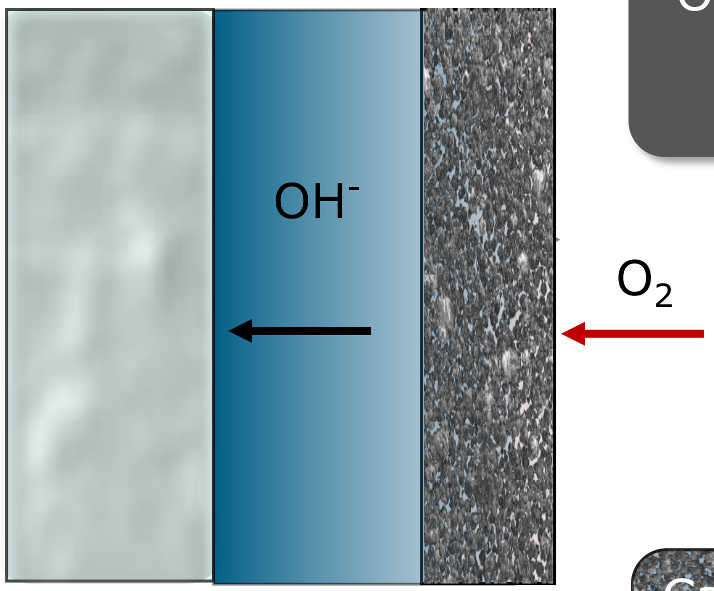
State-of-the-Art ZABs
PRIMARY cells

ΔU = 1.6V / 1.4V (Theo./Real)

$$2\,Zn + 8\,OH^- \rightleftharpoons 2\,Zn(OH)_4^{2-} + 4\,e^-$$

$$O_2 + 2\,H_2O + 4e^- \rightleftharpoons 4\,OH^-$$

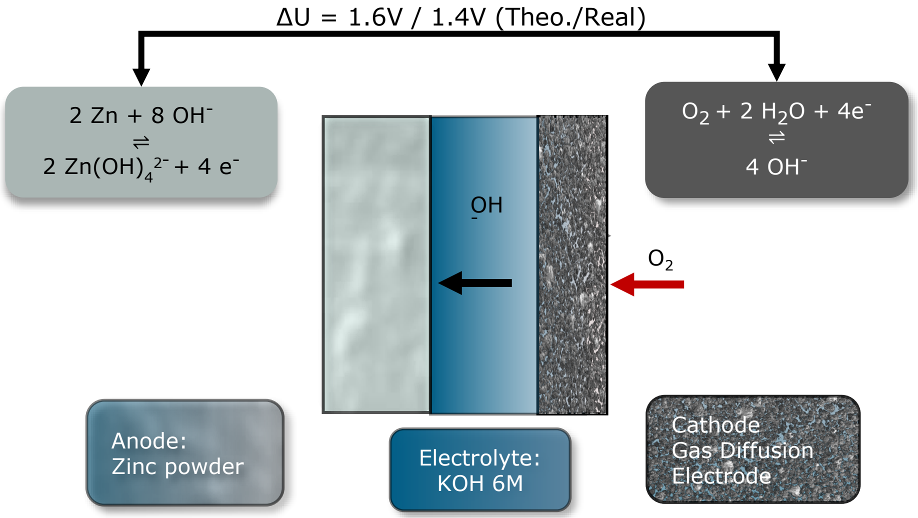


Anode:
Zinc powder

Electrolyte:
KOH 6M

Cathode
Gas Diffusion
Electrode

Design parameters for bifunctional GDEs for secondary ZABs



OER and ORR needs differ

- Pore size
- Electrolyte distribution

Compromise needs to be found

Finetune wettability essential

GDES @ DLR-TT-ECE-BAT

GDEs @ DLR-TT-ECE-Bat – Dry Pressing

Manufacturing Step | **Parameters**

Milling

Catalyst Support	Catalyst	PTFE
70wt.%	20wt.%	10wt.%

Doctor Blading

Diameter	Thickness
50mm	1mm

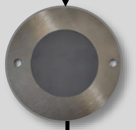
Pressing on mesh

Force	Mesh
7 MPa (1.4t)	d = 250-500µm

Heat Treatment

Melting PTFE
1h @ 340°C

GDEs @ DLR-TT-ECE-Bat – Dry Pressing

Manufacturing Step		Parameters		
	Milling	Catalyst Support: 70wt.%	Catalyst: 20wt.%	PTFE: 10wt.%
	Doctor Blading	Diameter: 50mm	Thickness: 1mm	
	Pressing on mesh	Force: 7 MPa (1.4t)	Mesh: d = 250-500µm	
	Heat Treatment	Melting PTFE: 1h @ 340°C		

PTFE
- Fibrillate during milling
- Binds particles together
- Hydrophobic

Catalyst support
- Provides conductivity
- Substrate for catalyst
- Hydrophilic

Advantages
- Flexible, small scale GDE production
- Easy to learn & reproduceable
- Solvent free
- Upscaling: rolling process

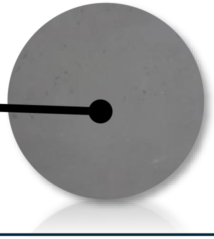
GDE

Porosity	Thickness	Pore size
≈ 50%	≈ 250-500µm	≈1-10µm

GDEs @ DLR-TT-ECE-Bat: Electrolyte study

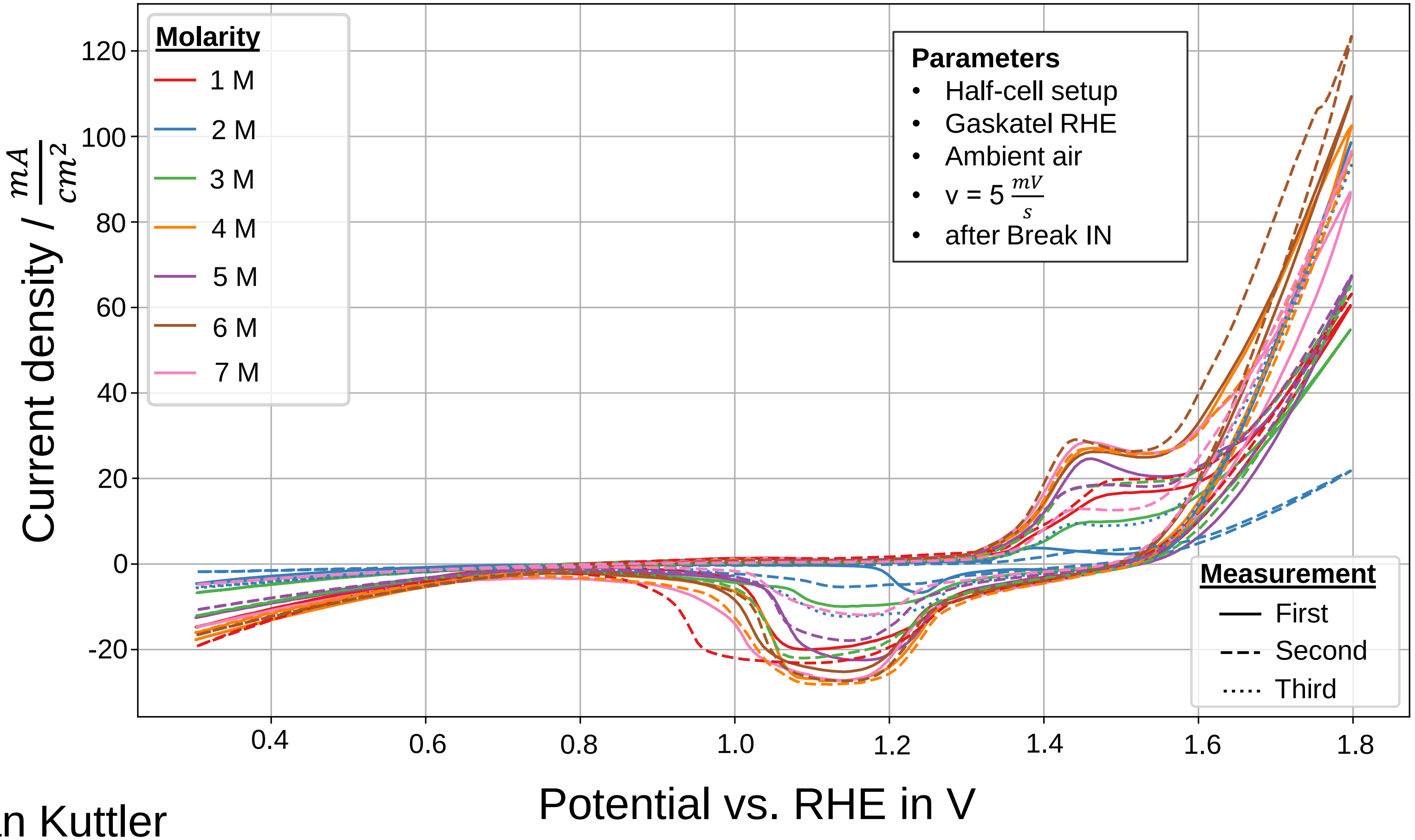
90 wt.% Ni
10 wt.% PTFE

Catalyst
NiFeOOH



GDE

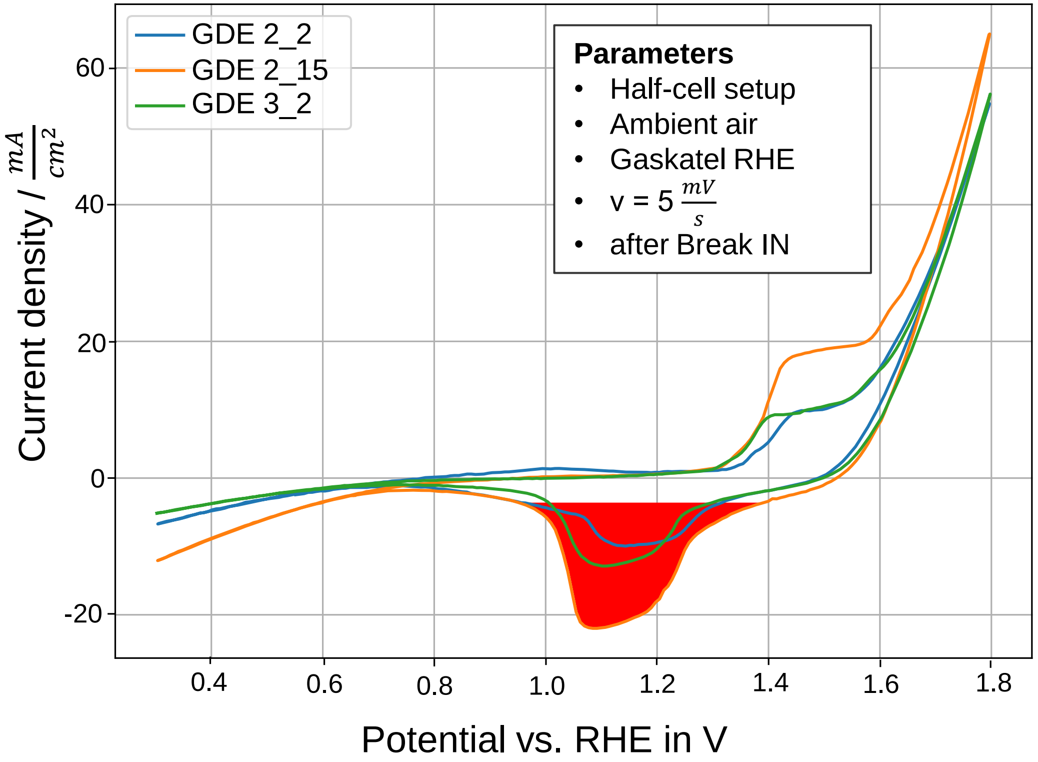
Porosity	Thickness	Pore size
≈ 48%	≈ 500µm	≈10µm

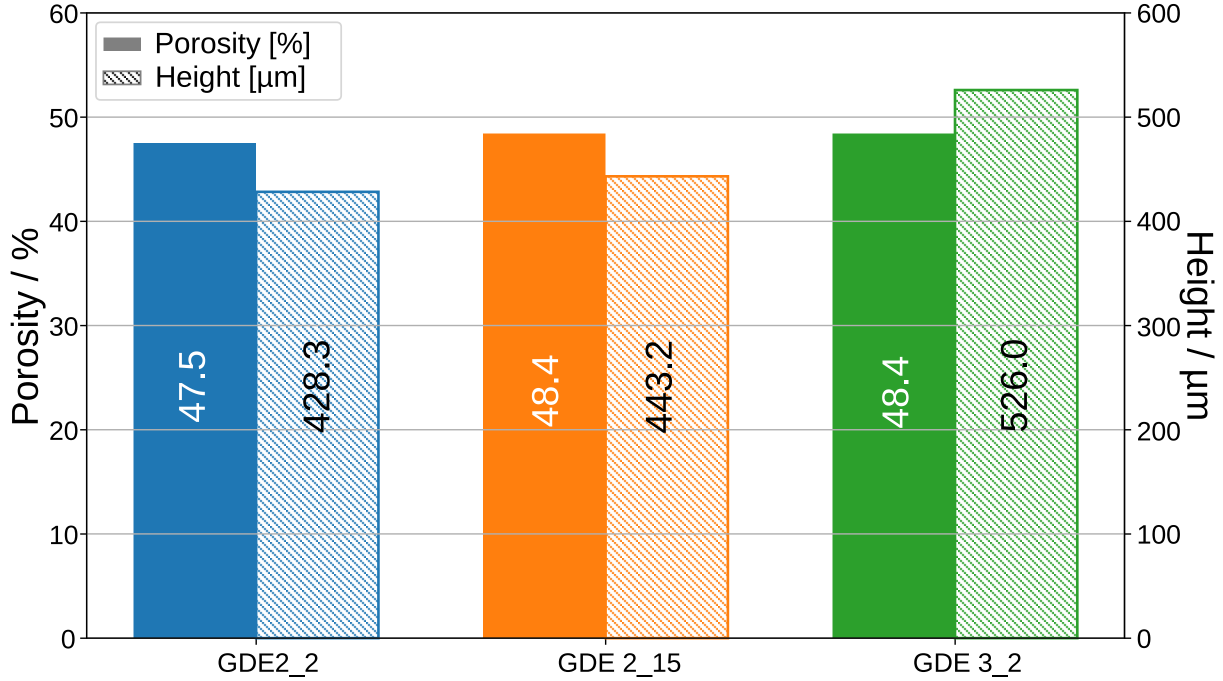


Master Thesis Jan Kuttler

Electrolyte study
Parameter influence Porosity/Height

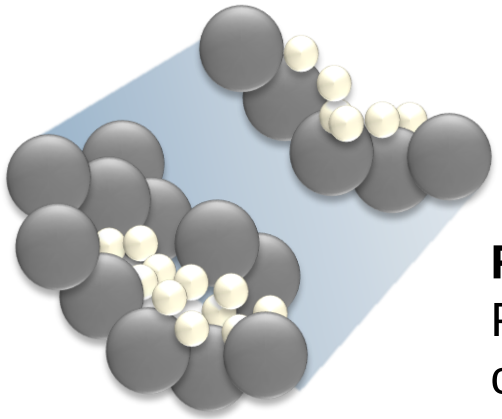
3 mol measurement series

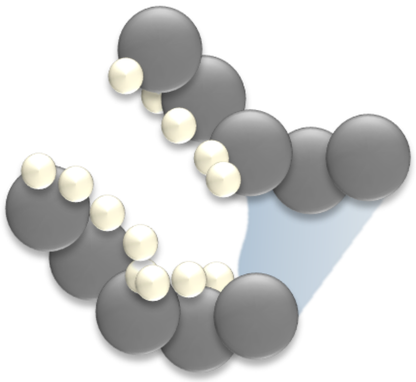




Wettability differs:
- PTFE pore wall content not controlled

Why we need to change the fabrication method!





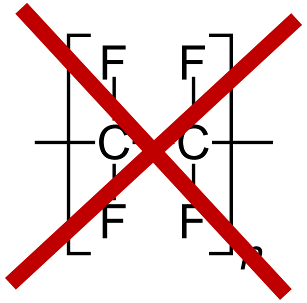
Reproducibility
PTFE overall content vs. pore wall content:

- Same mass percentages
- Different wettability

Finetune wettability

Decouple Wettability and Mechanical Stability

➢ Easier to finetune Wettability



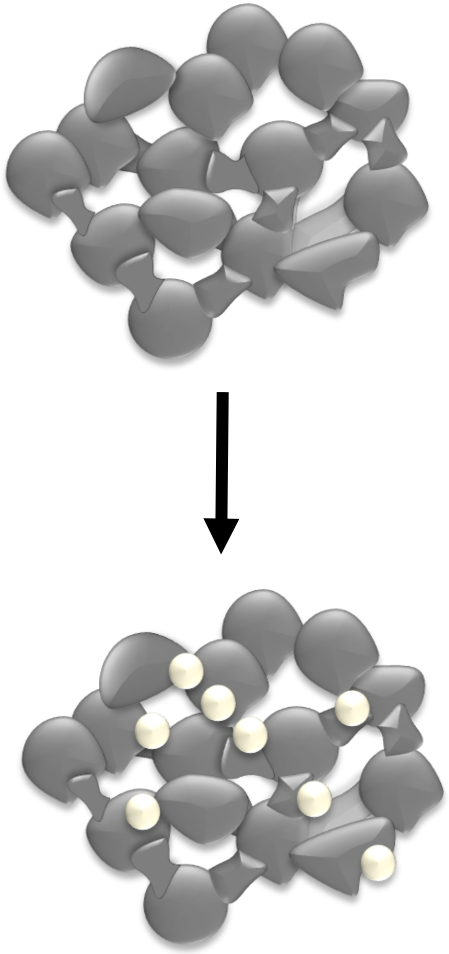
Possible PFAS ban
e.g. 3M already doesn’t provide powders anymore
➢PTFE is easier to replace, when it is only impacting hydrophobicity

New manufacturing concept

Requirements
- Flexible, small scale GDE production
- Easy to learn & reproduceable
- New GDEs close to the “old” GDEs
- Upscaling: ?

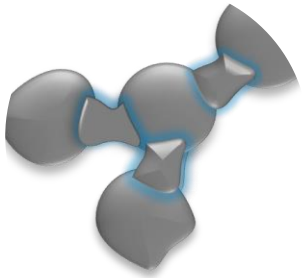
Approach

1. Generate stable, conductive, porous metal structure
2. Change wettability



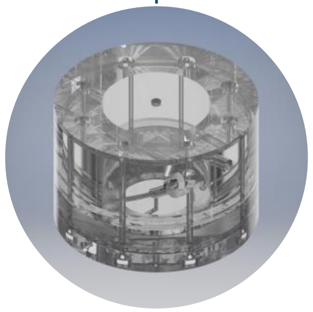
Approach

Pure metal powder



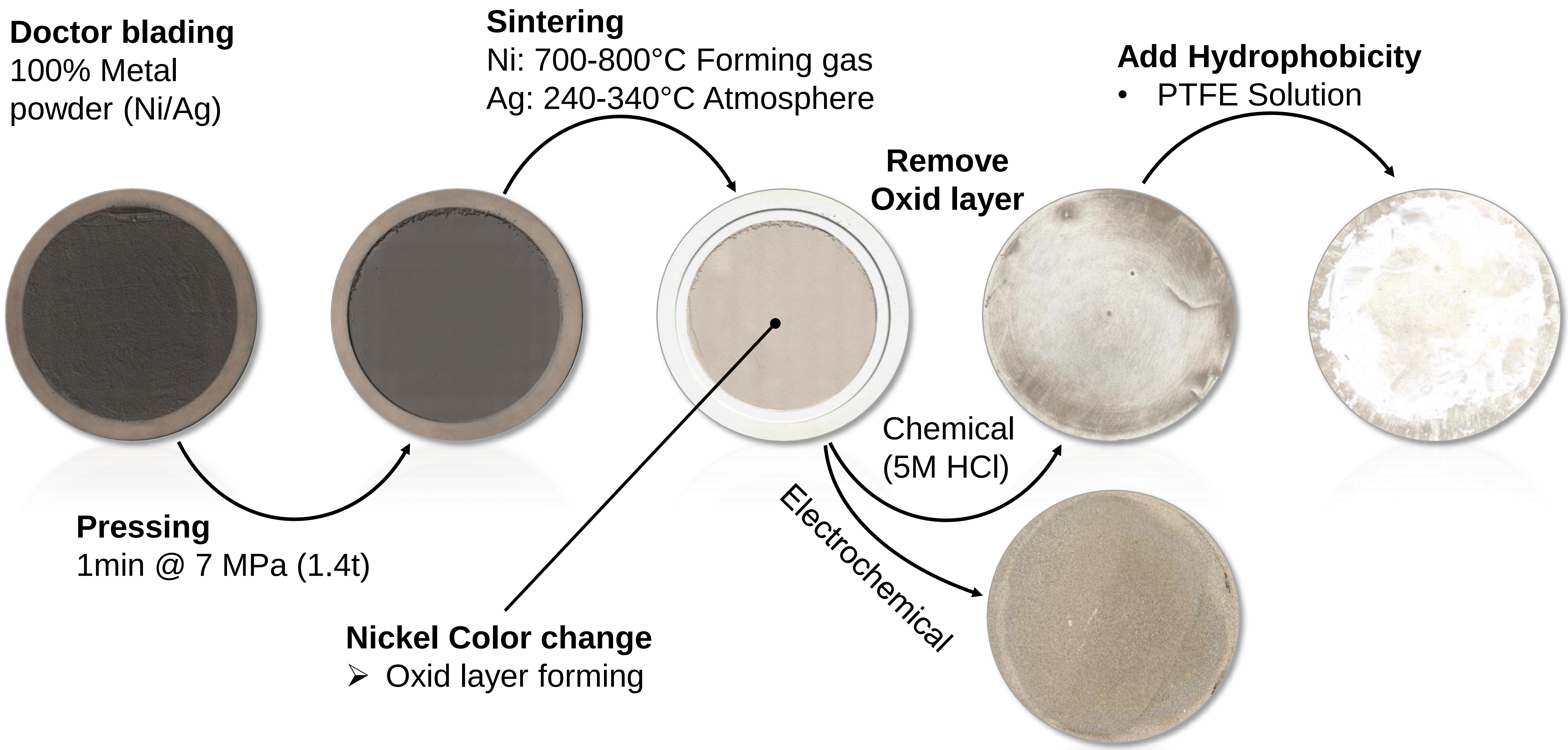
Sintering

Thermal



Electrochemical
Depositing

Method
Thermal sintering process



Results
Ni based sintered electrodes

Electrochemical activated

Porosity	Thickness	Stability
54%	≈ 600µm	✓

Result
Ni based sintered electrodes

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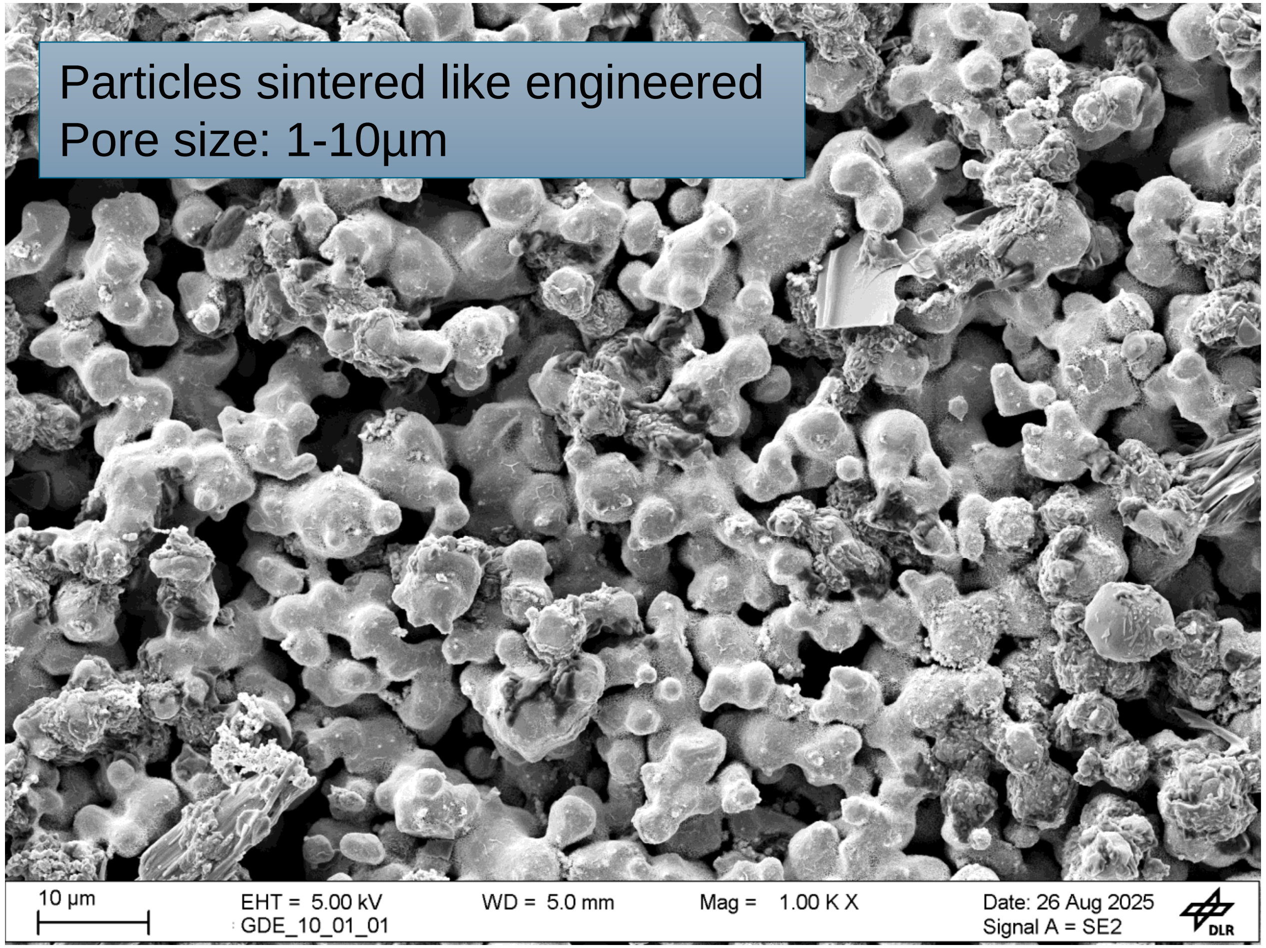

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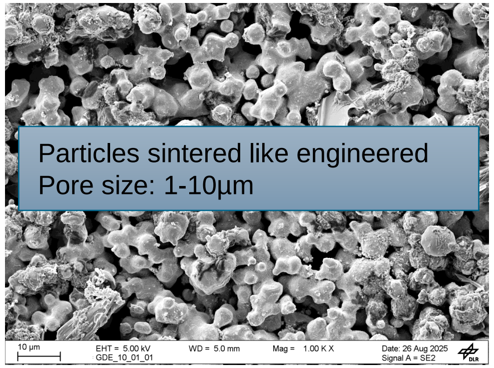

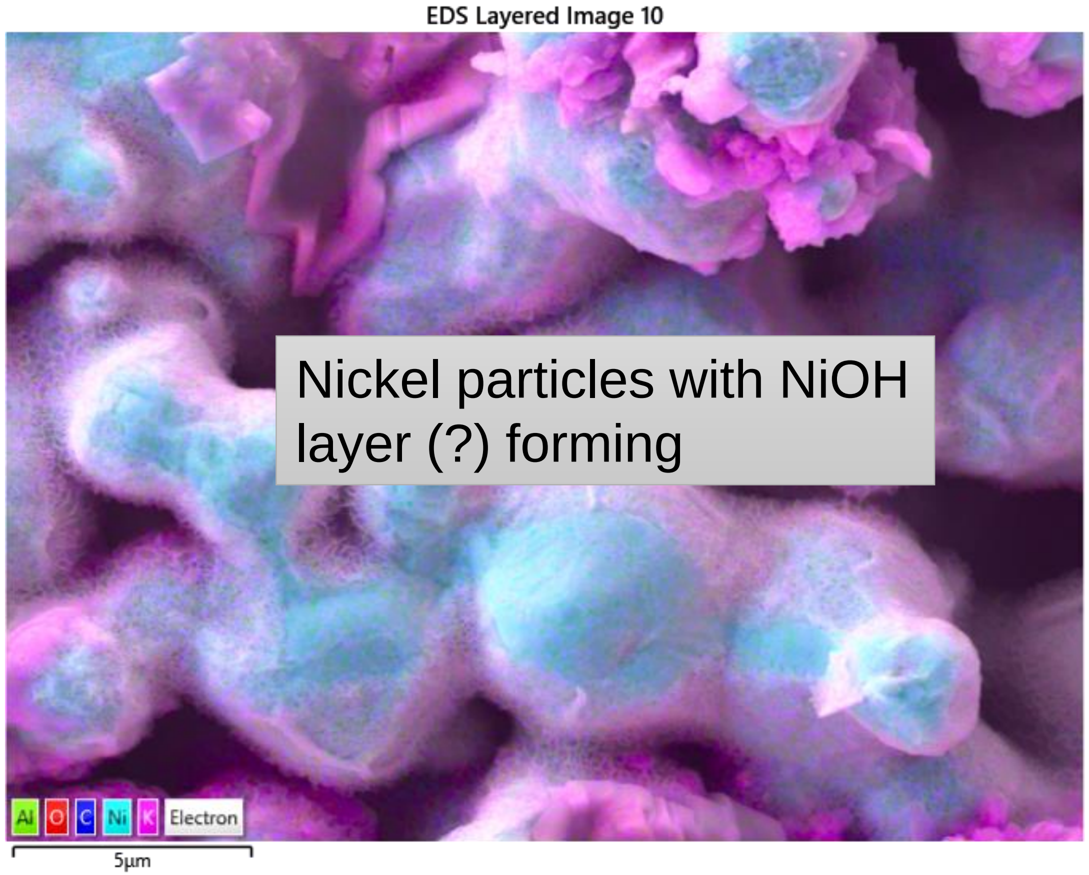

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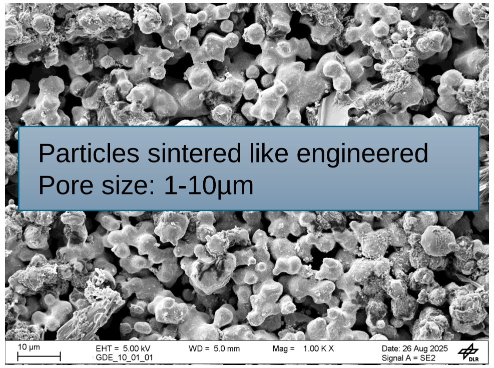
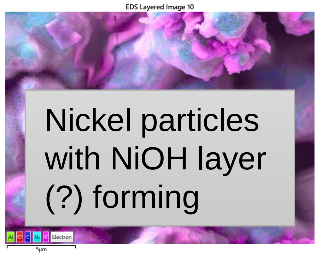
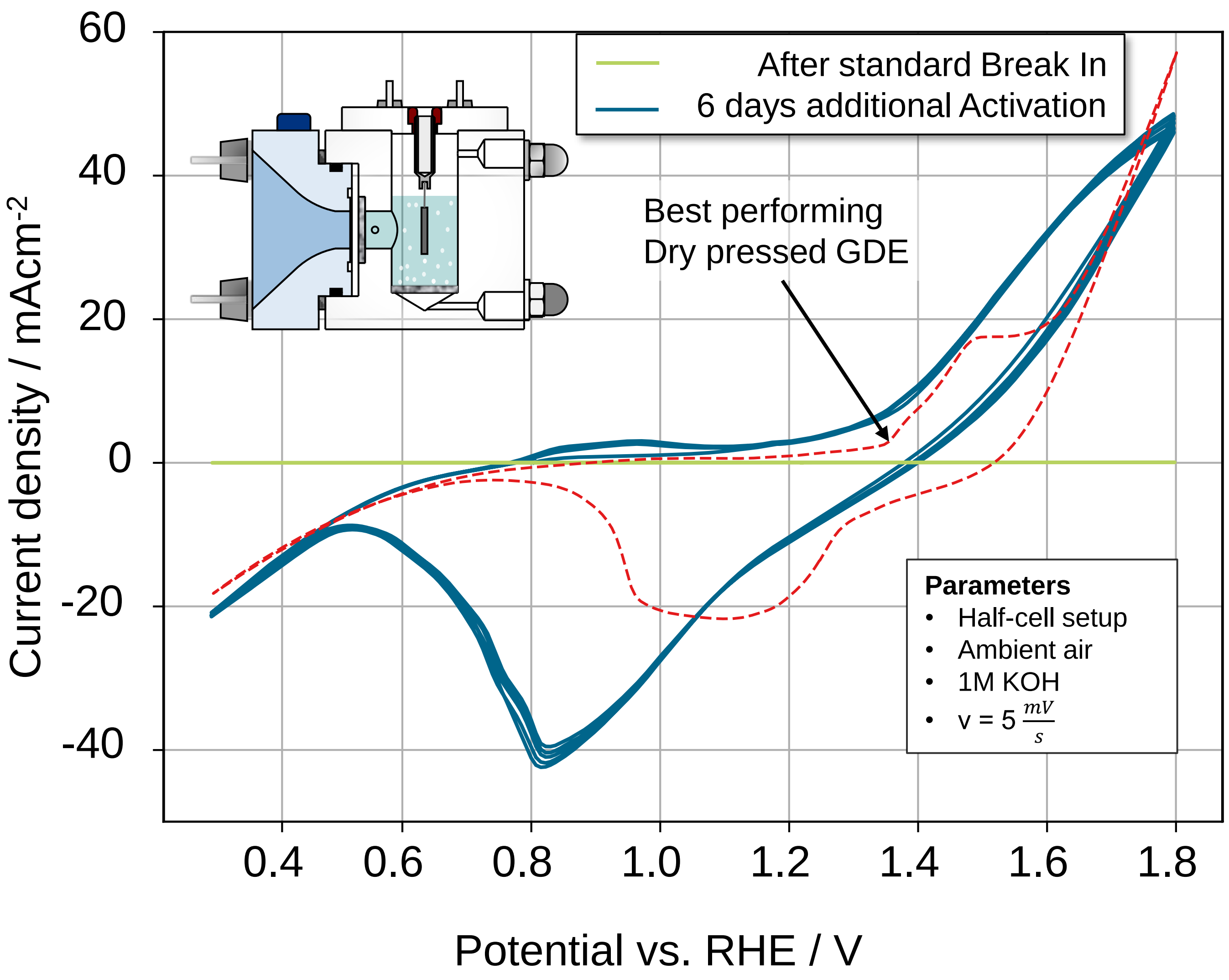
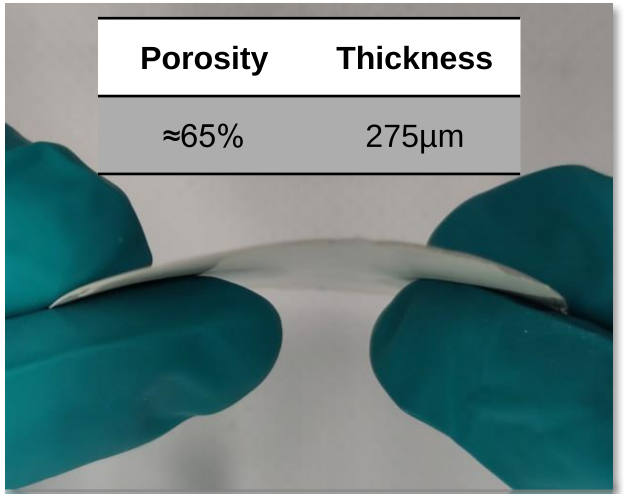






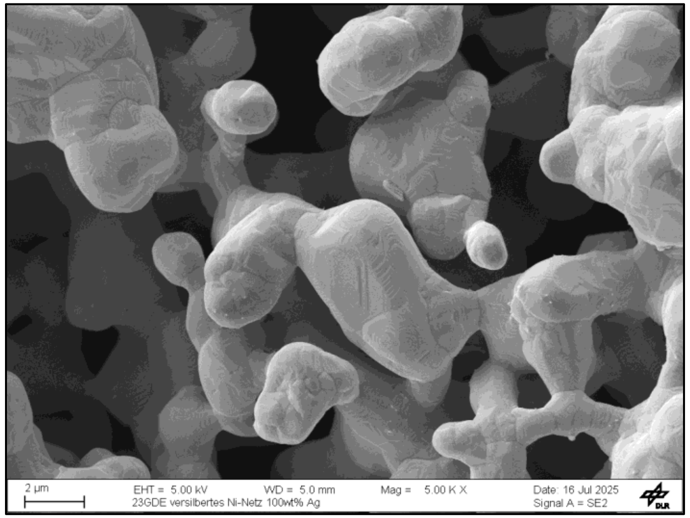
Results
Silver based sintered electrodes

- Easy to sinter (with and without mesh)
- No oxidation
- Strong, flexible base structure
- PTFE study in the making

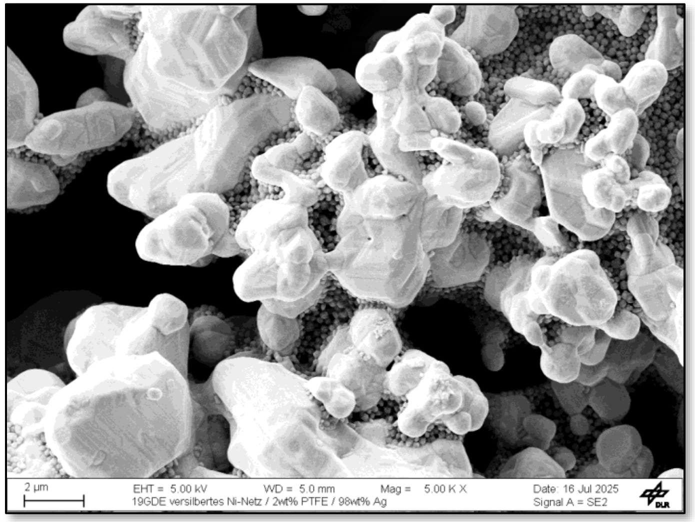


Porosity	Thickness
≈65%	275µm

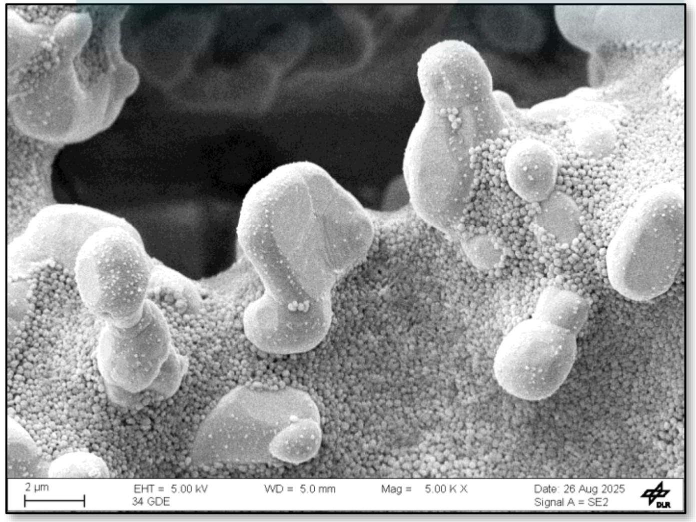
@ Jule Burmeister



0 wt.% PTFE



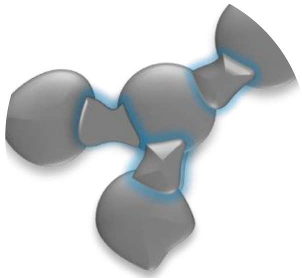
2 wt.% PTFE



16 wt.% PTFE

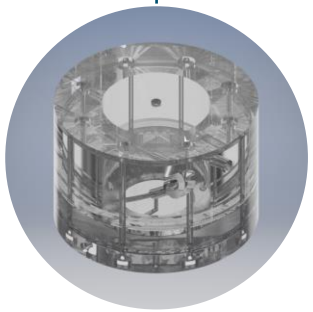
Approach

Pure metal powder



Sintering

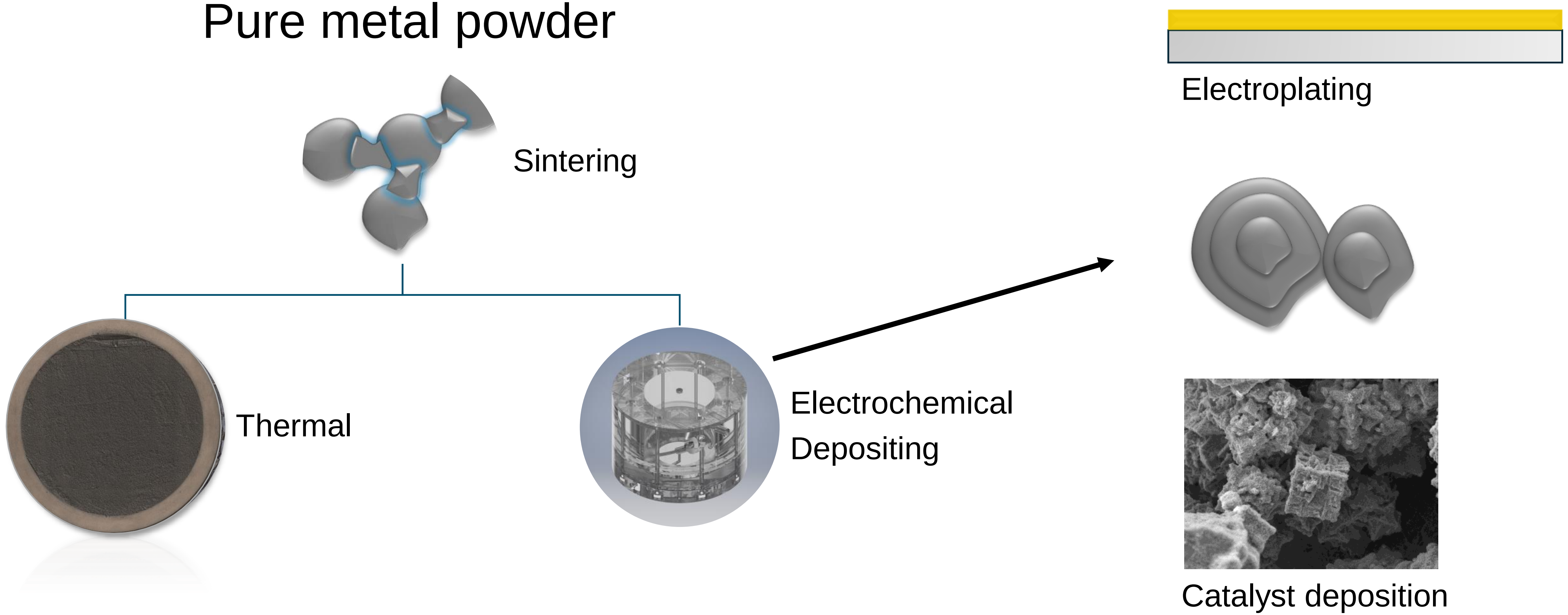
Thermal



Electrochemical
Depositing

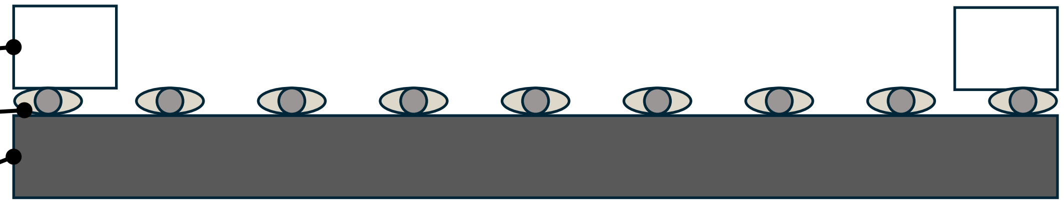
Approach

Pure metal powder



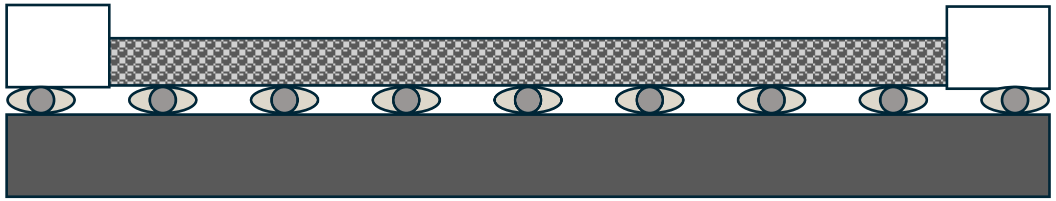
Electrodeposition process

Prepare Form
- d= 50mm / 60mm
- PTFE Sealing ring 1mm
- Nickel Mesh coated with PTFE / surface grinded
- Graphite base 1mm



Electrodeposition process

Distribute powder
Nickel powder distributed on top of mesh



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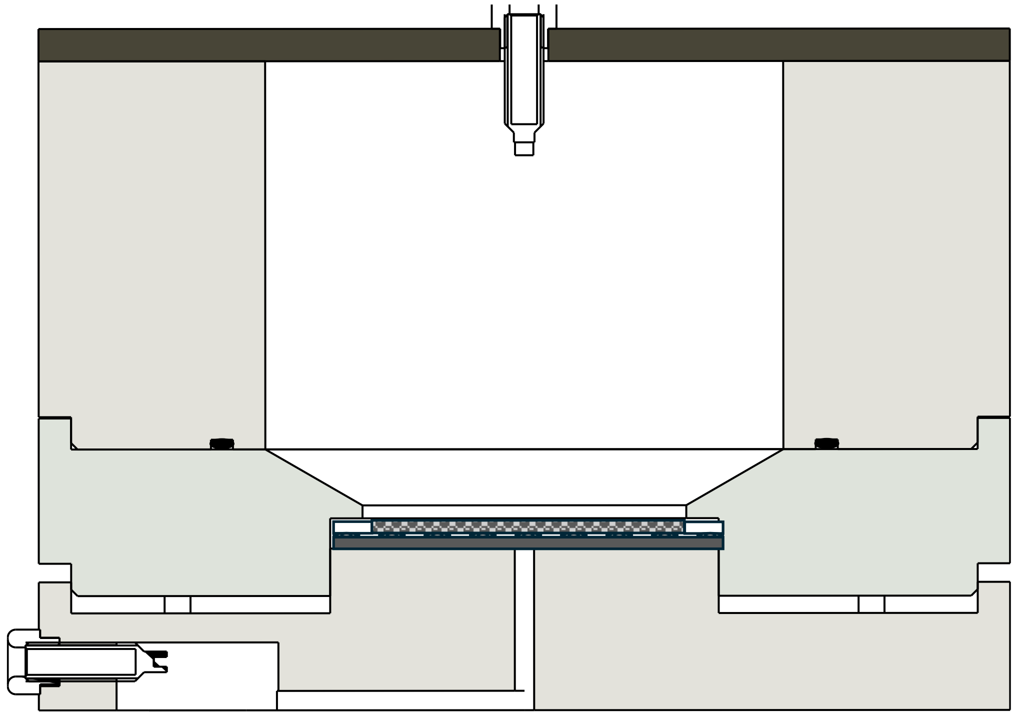
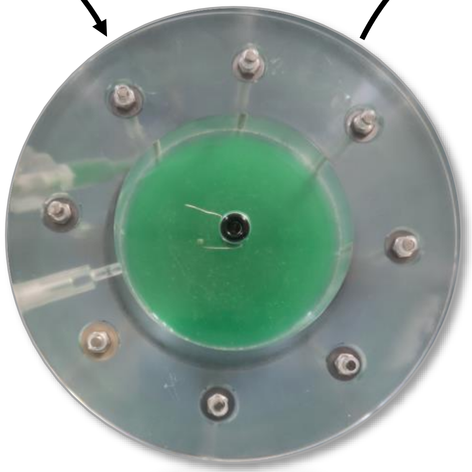


Electrodeposition process

Cleaning



Prepare Form
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Distribute powder
Nickel powder distributed on top of mesh

Electrodeposition
All Chloride Solution
- 250 g/l $NiCl_2$ x 6 H_2O
- 30 g/l Boric Acid

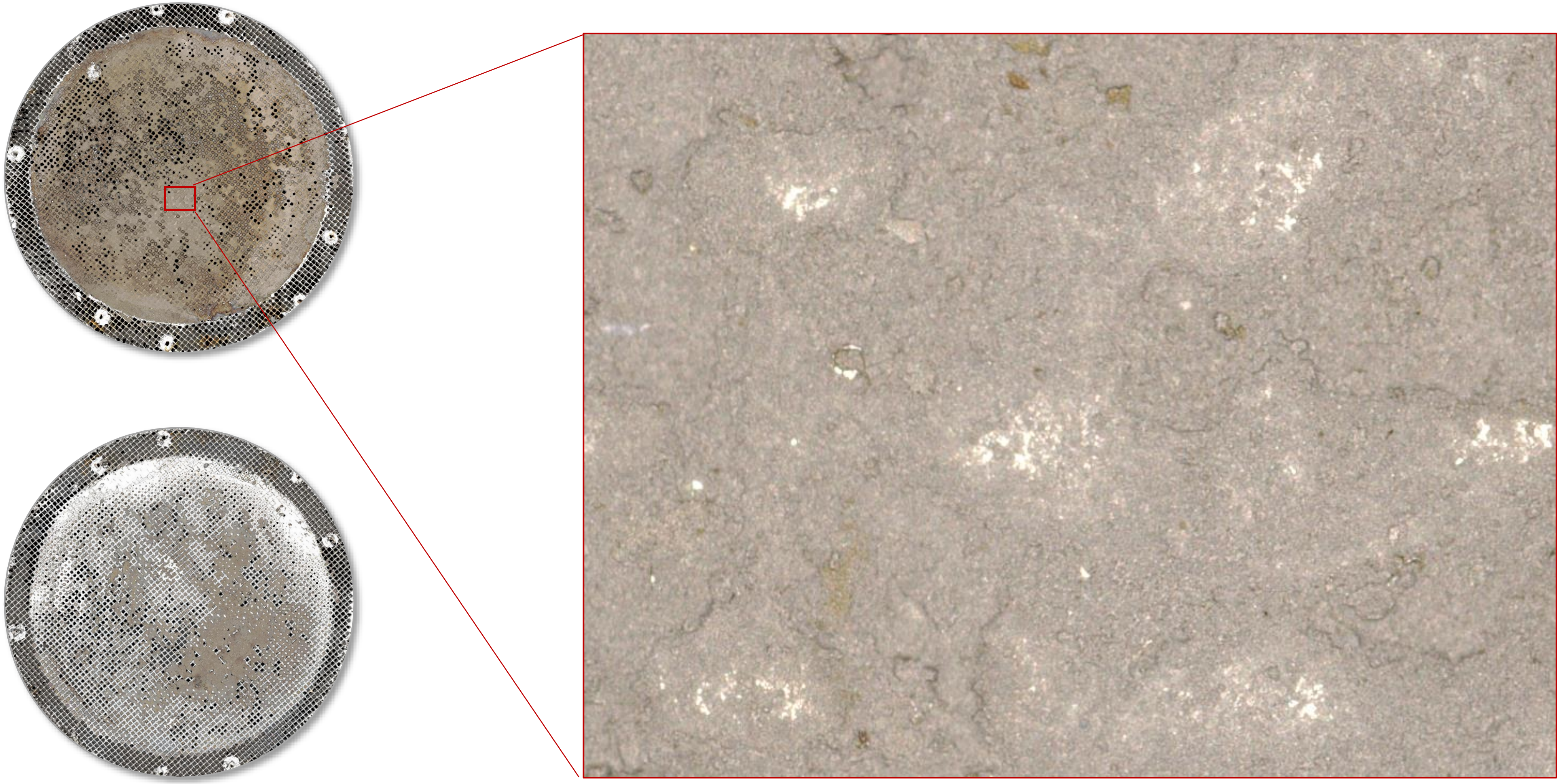
Pulsed (4h):
- 10s @ 10 $mAcm^{-2}$
- 50s @ 0 mA

Results
Ni based Electrodeposited Electrodes

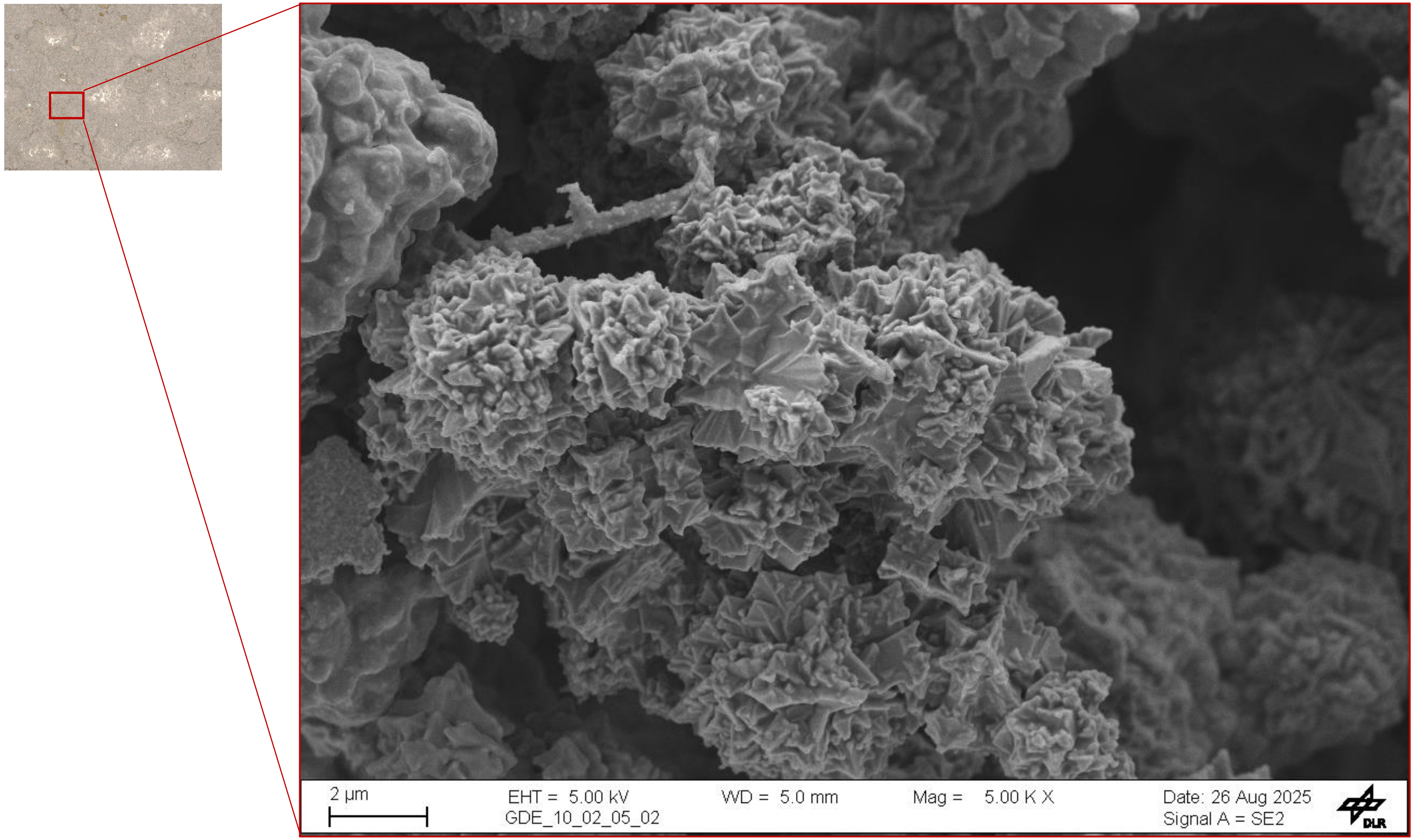
Front

Back

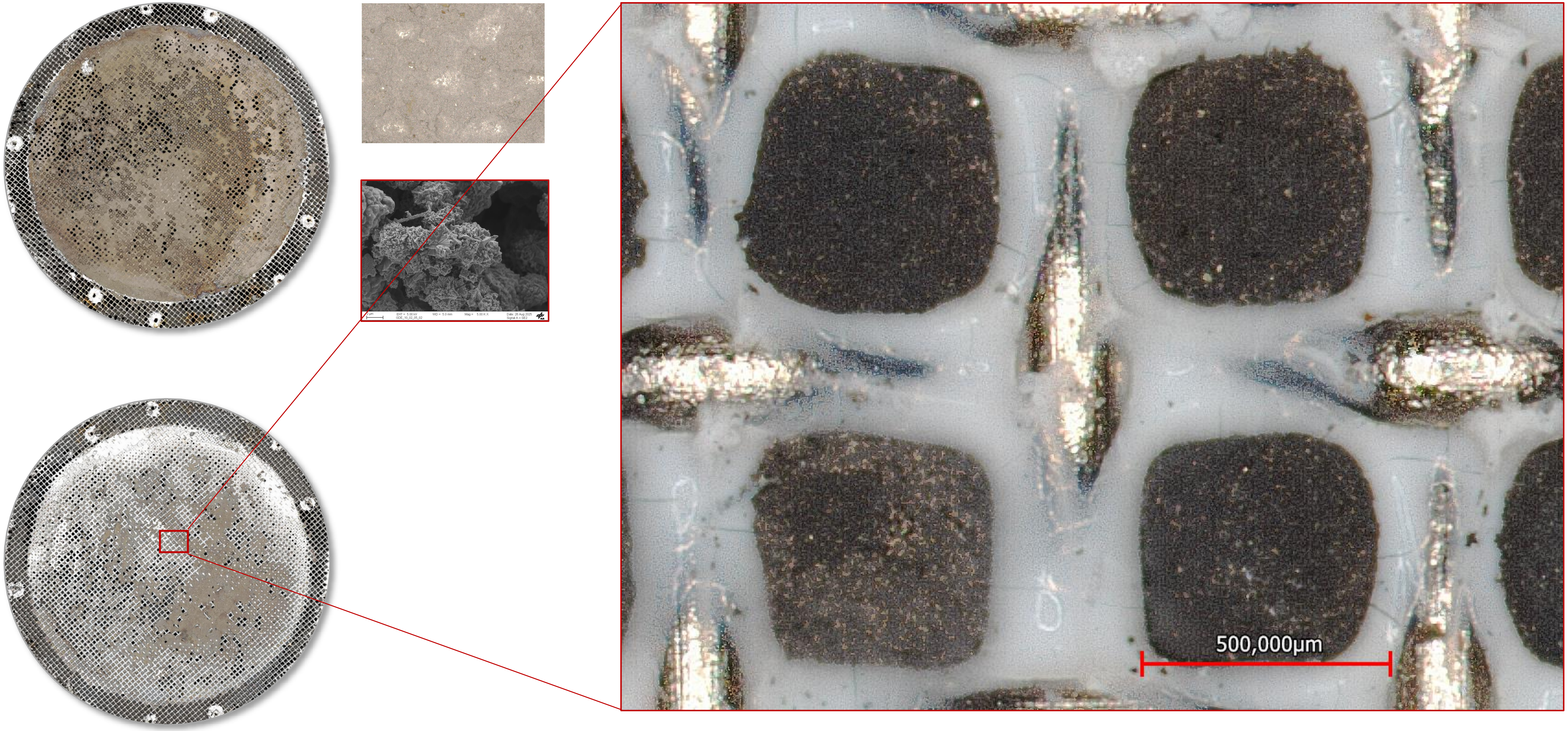
Results
Ni based Electrodeposited Electrodes



Results
Ni based Electrodeposited Electrodes



Results
Ni based Electrodeposited Electrodes



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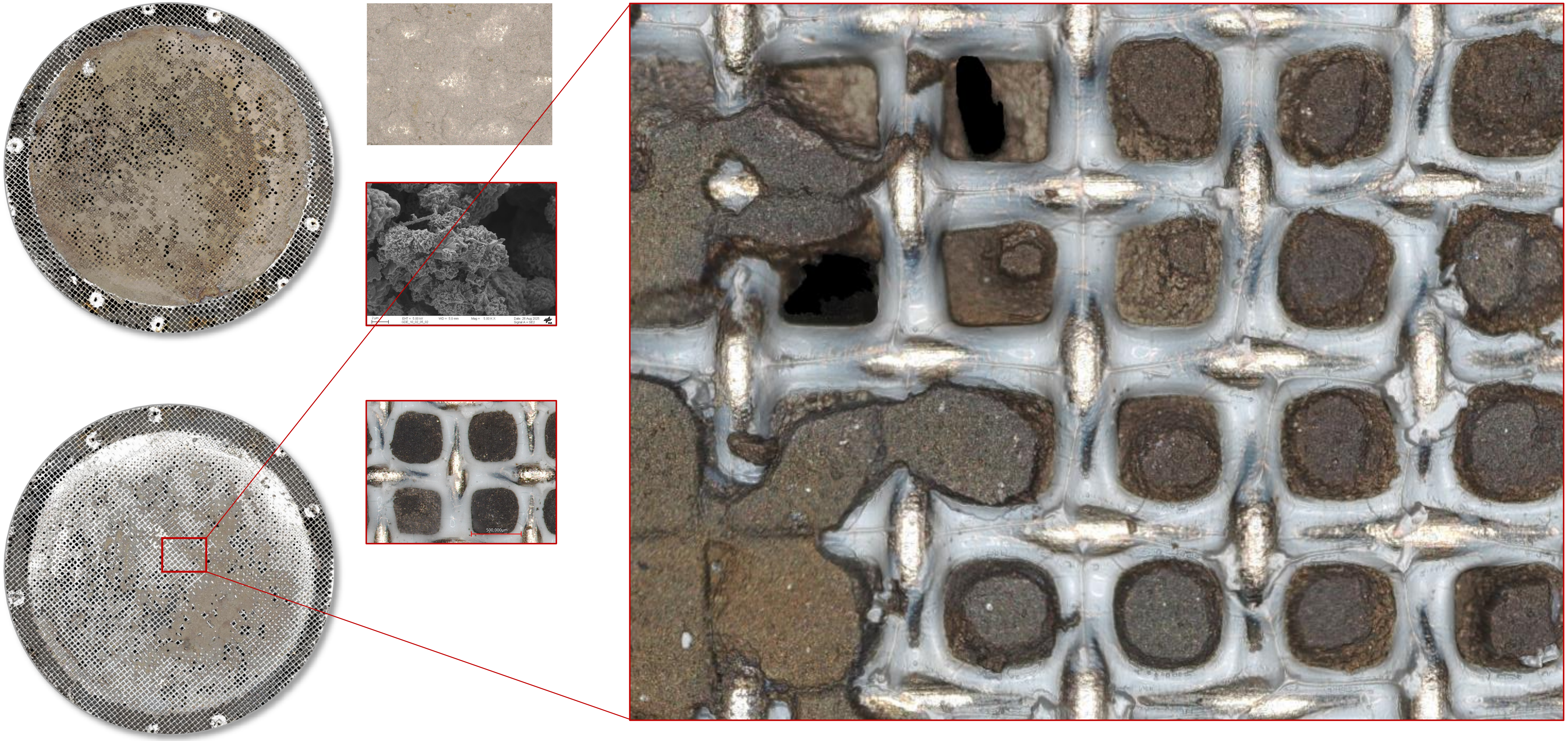

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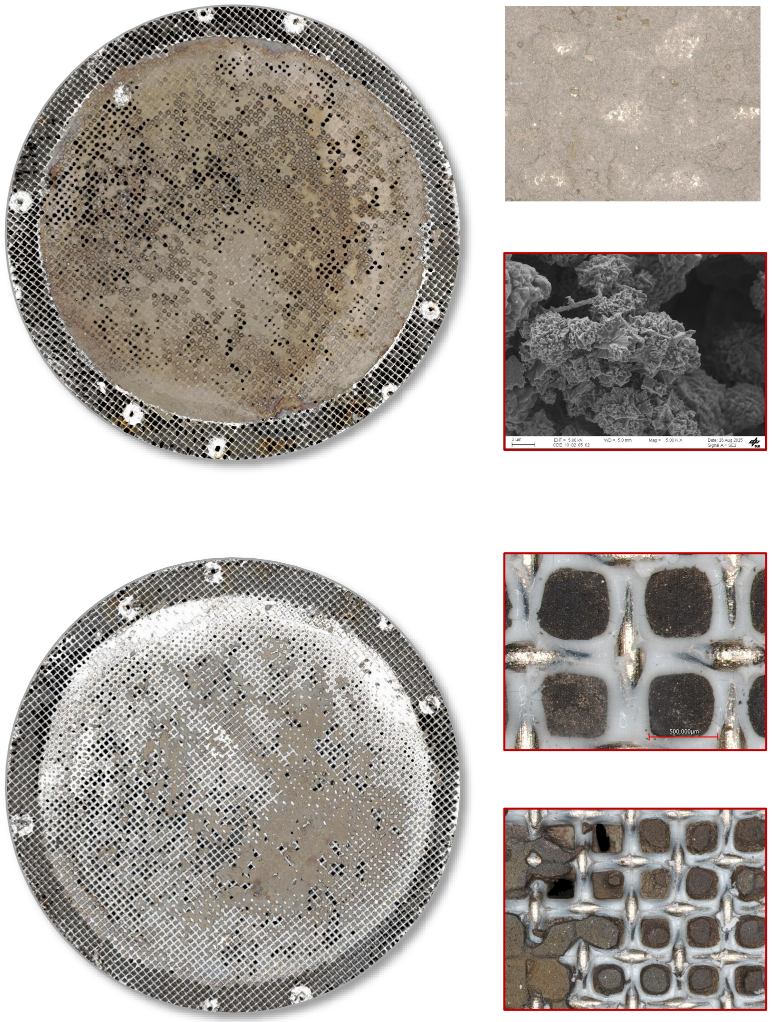
Ni based Electrodeposited Electrodes

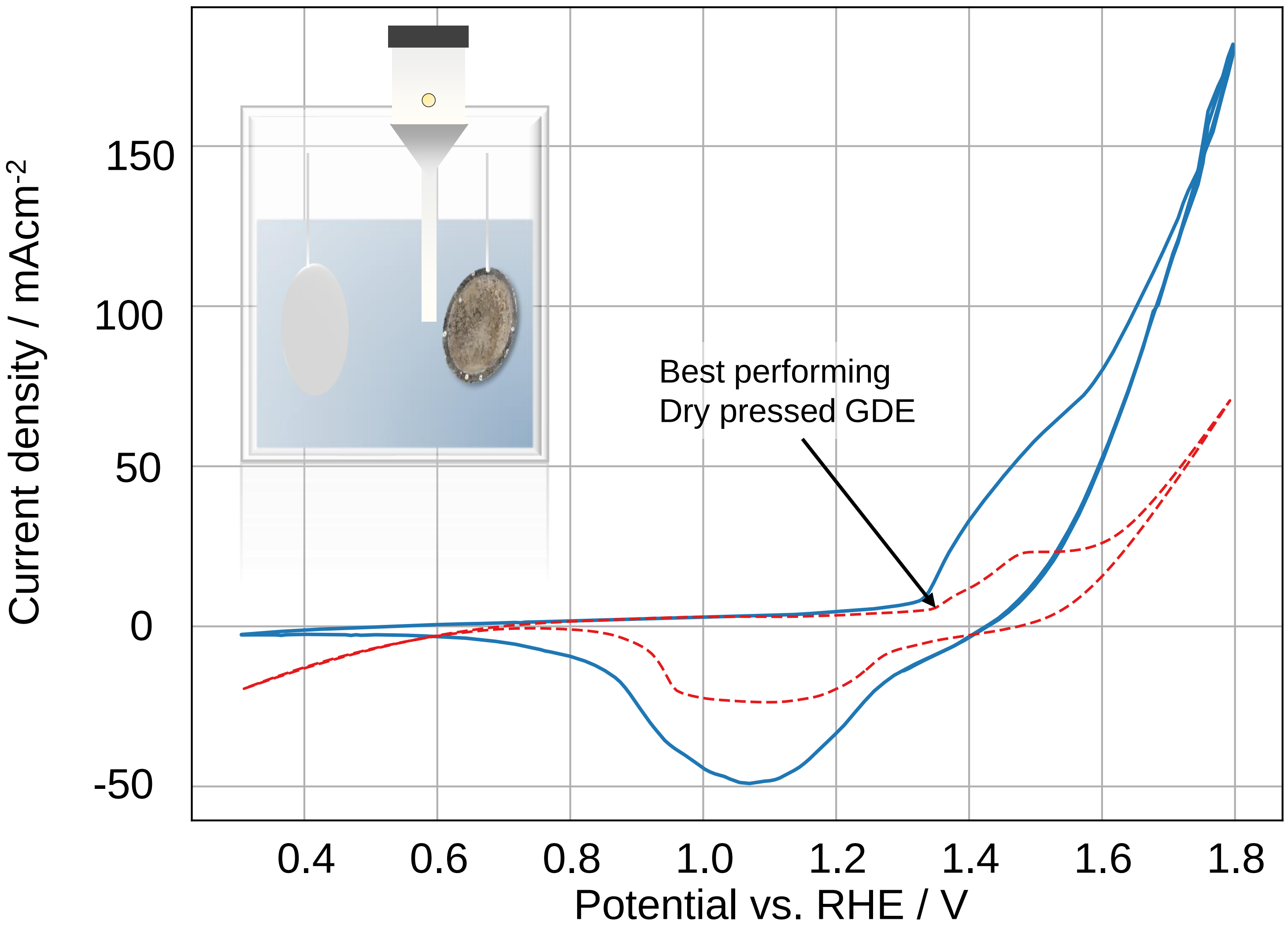


Conclusion for Electrodeposition

- Electrodeposition provides „sintered“ Nickel structures
- SEM shows highly structures Ni Particles
- Mesh backing needs improvement
  - ➢Stop Ni „Breakthrough“

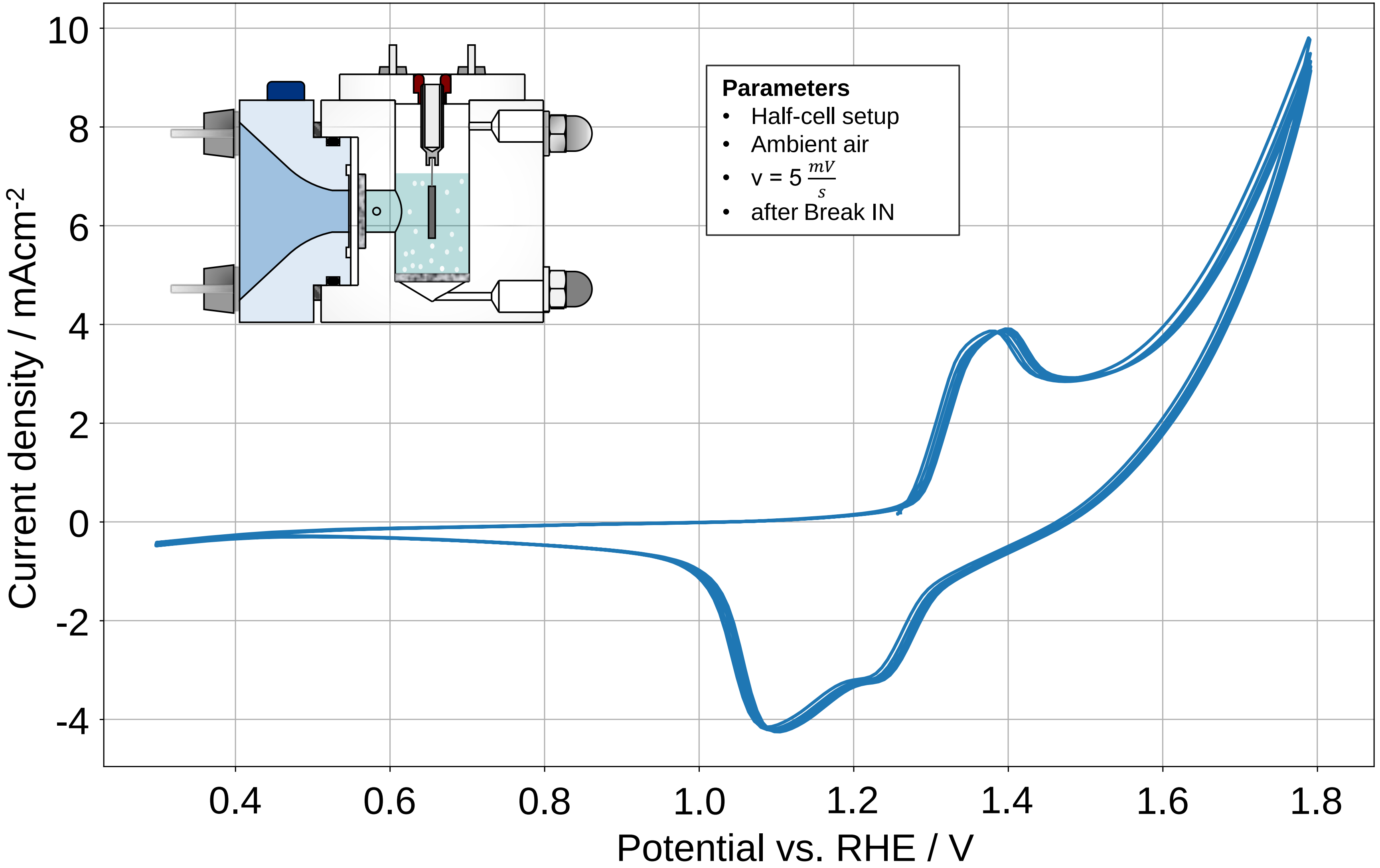
Pretests
Electrodeposited Electrodes

Test in beaker
Electrode submerged
1M KOH



Half cell performance
Performance of Electrodeposited GDEs

Hydrophobization



Conclusion

Proof-of-concept

- Thermal
- Electrodeposition

Improve process

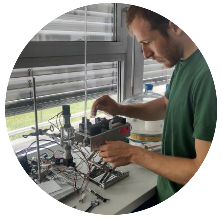
- Oxidation
- ED process:
  - Form
  - Current profile
  - Electrolyte
- Hydrophobization

Reproducibility

- Show reproducible results

Use full potential of approaches

- Direct catalyst deposition
- ED as sintering + coating
- Mix both approaches



Thank you for your attention!

Special thanks to Tobias Morrawitz for the great support with SEM/EDX pictures!

Acknowledgements:
This project has received funding from the European Union´s Horizon Research and Innovation Programme under grant agreement No 101115421. Views and opinions expressed are however those of the author(s) only and no not necessarily reflect those of the European Union nor the granting authority can be held responsible for them.

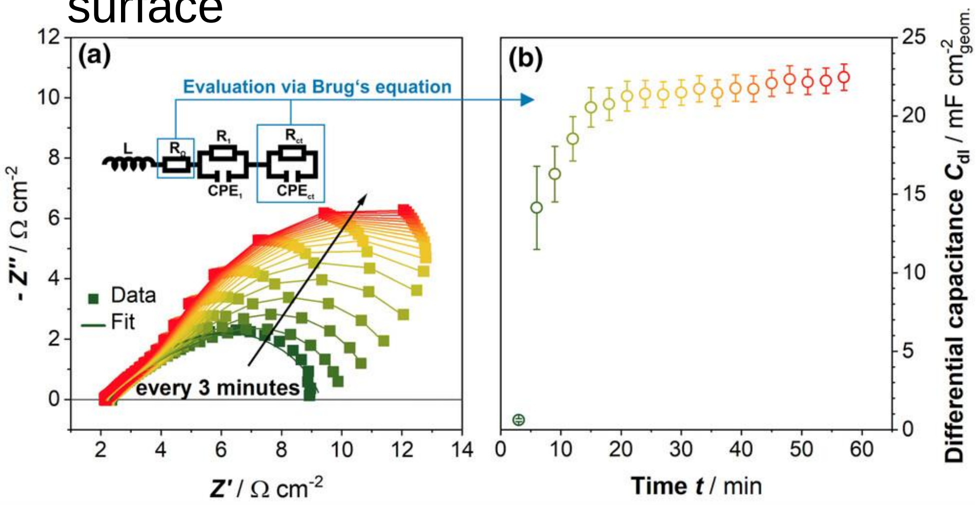
European Innovation Council

HIPERZAB

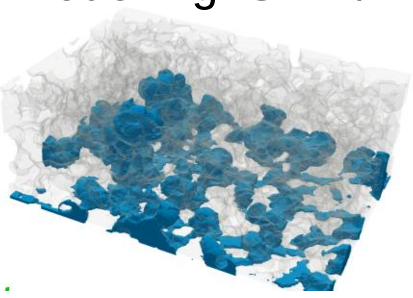
Next steps: Wettability characterization

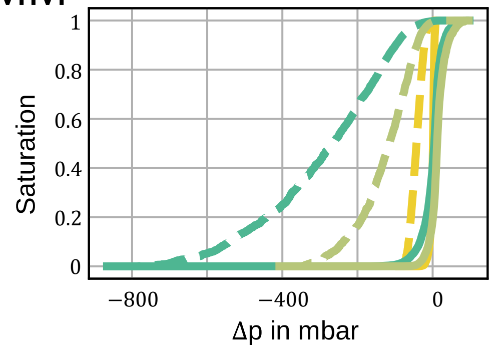
Established methods

Electrochemical analysis for wetted internal surface



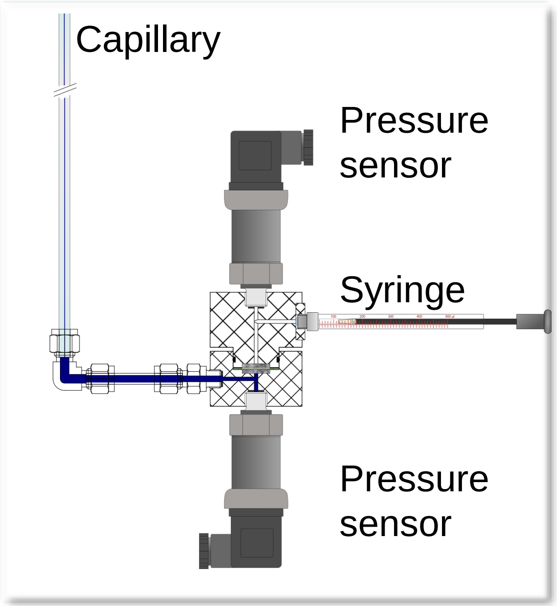
Modelling: SPH / PMM

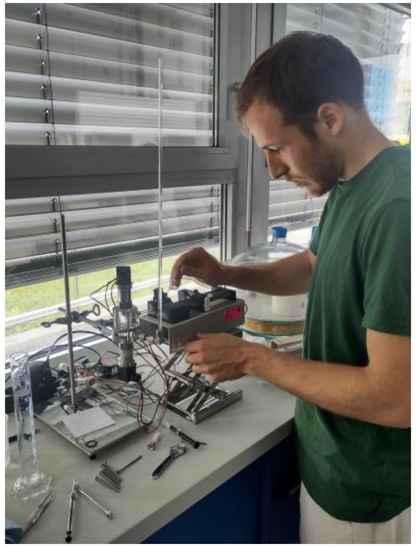




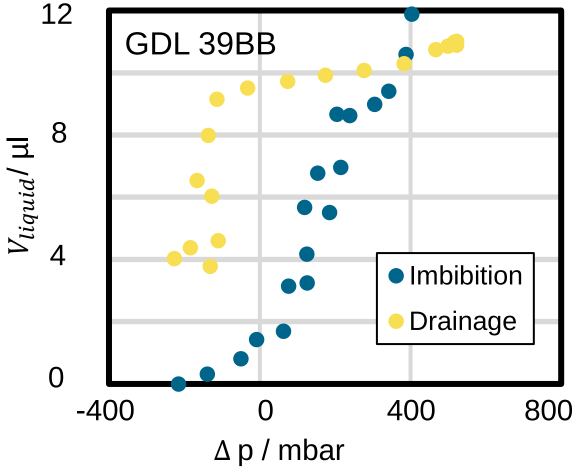
F. Bienen et al. Electrochem Sci Adv. 2023, 3, e2100158. https://doi.org/10.1002/elsa.202100158
Collaboration with University of Stuttgart (ICVT)

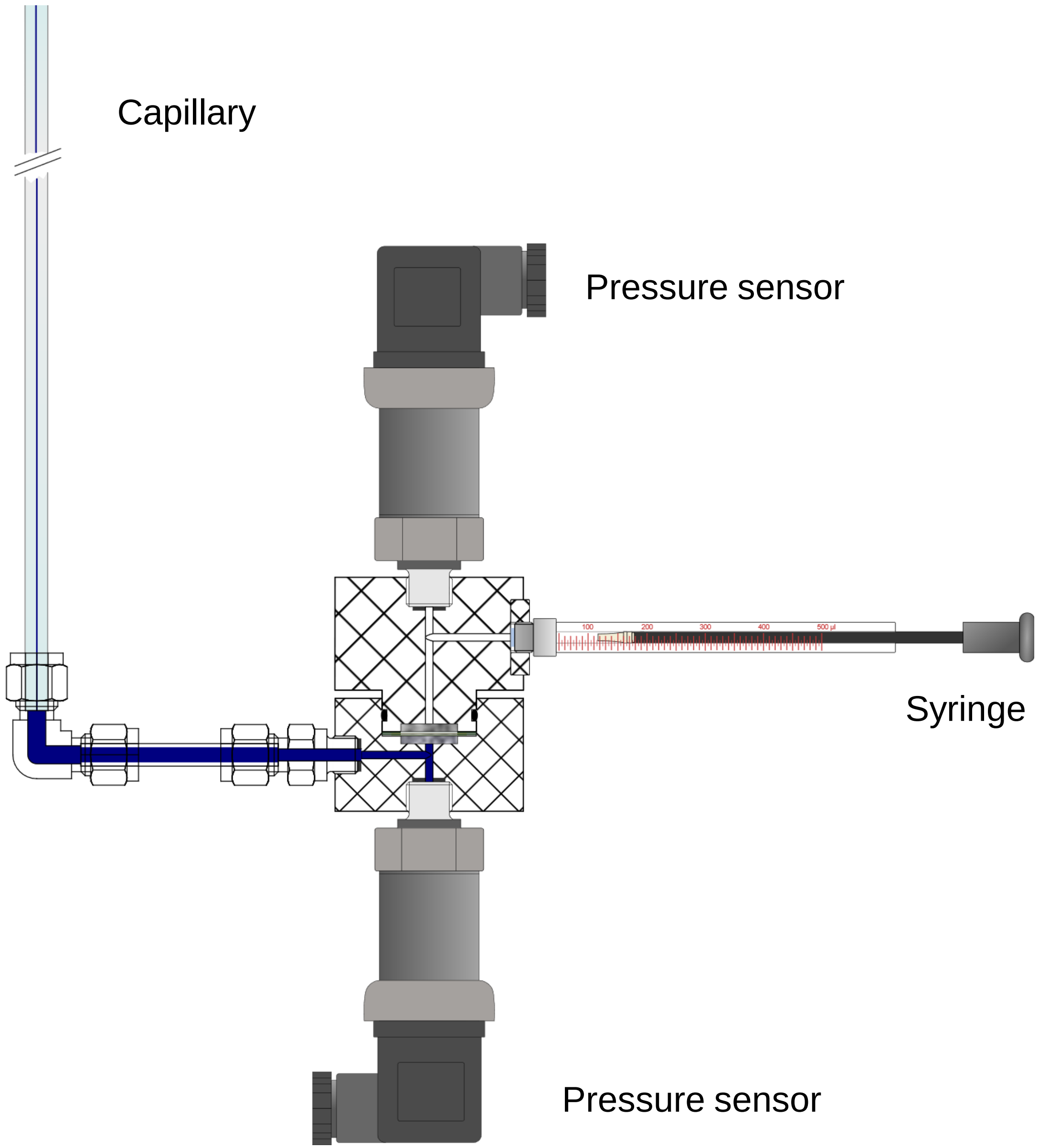
New pressure saturation setup





Hannes Minzenmay (HiWi)
Made the concept work




Capillary
Pressure sensor
Syringe
Pressure sensor