Determination of the cathode catalyst layer limitations inside the PEM fuel cell

Tom Servais, Nathalie Job

NCE CHEMICAL ENGINEERING

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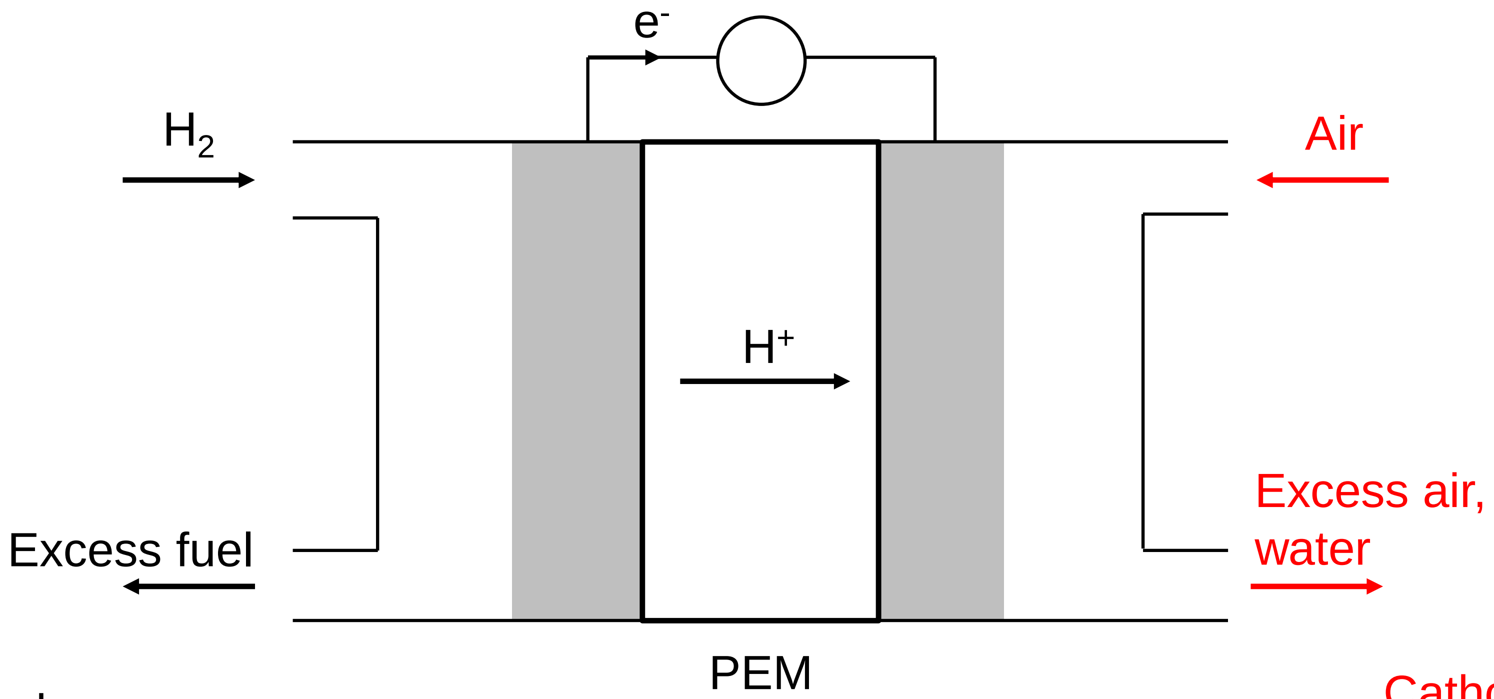
Introduction: PEM fuel cell



Anode:

$H_2 \rightarrow 2\ H^+ + 2\ e^-$

ϵ^0 *vs*. RHE = 0 V

Cathode:

$O_2 + 4\ H^+ + 4\ e^- \rightarrow 2\ H_2O$

ϵ^0 *vs*. RHE = 1.23 V

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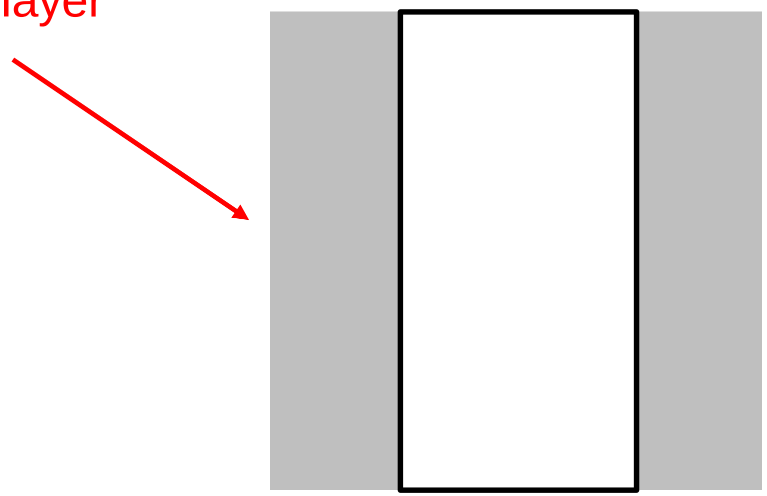

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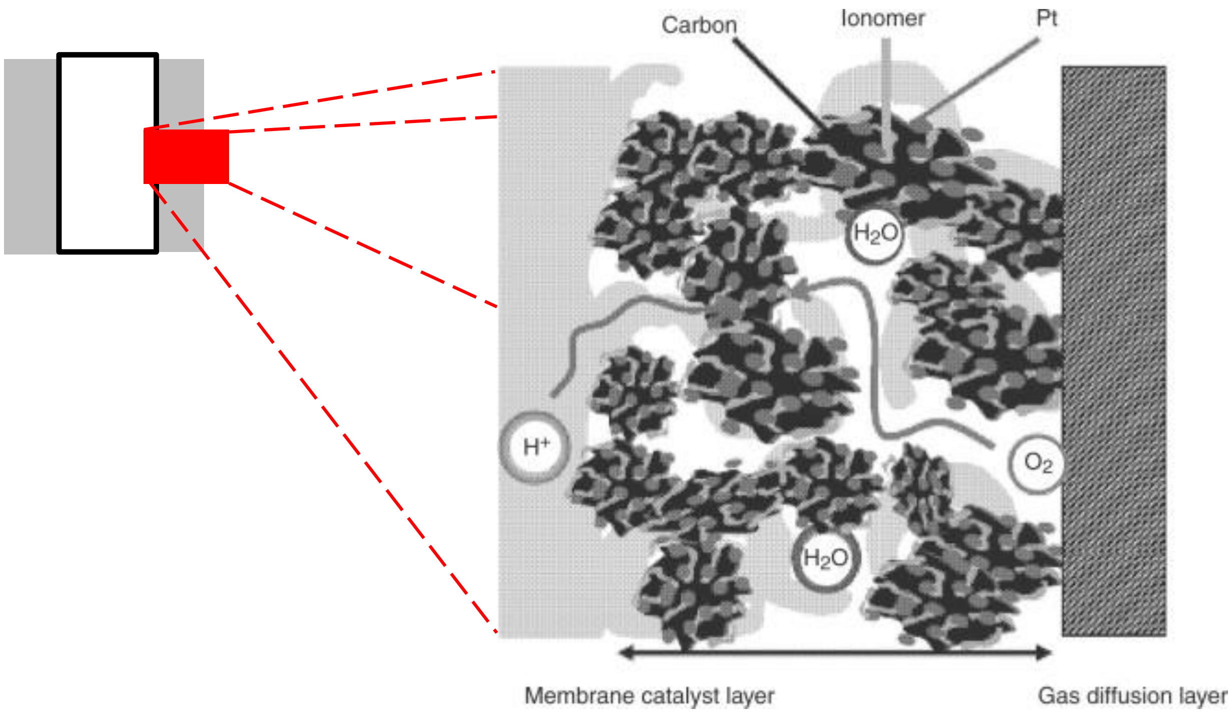
Introduction: Cathode catalyst layer (CL)



[1] K. Scott, Functional materials for sustainable energy applications, Woodhead, 2012.

Oxygen Reduction Reaction:

$$O_2 + 4\,H^+ + 4\,e^- \rightarrow 2\,H_2O$$

- Pt dispersed on a porous C support to maximize the active surface area

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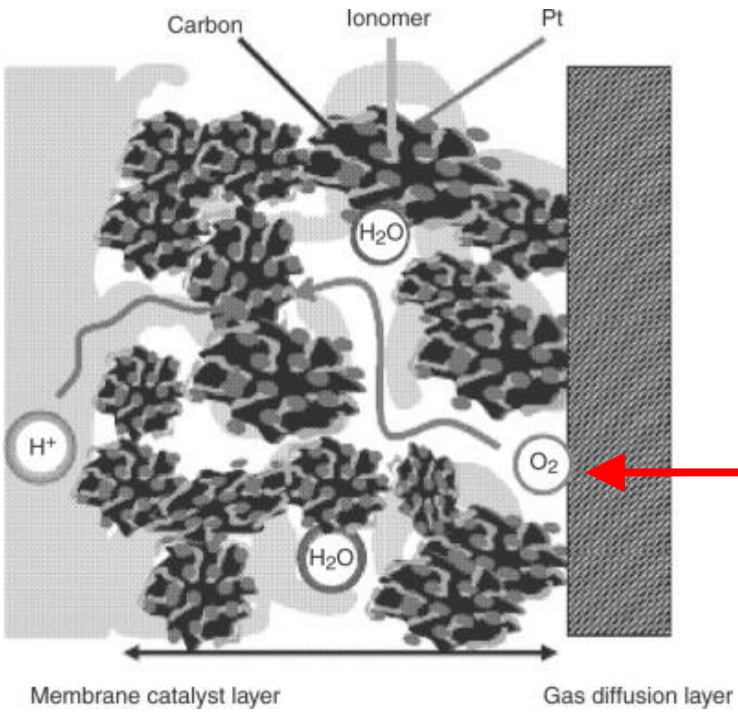

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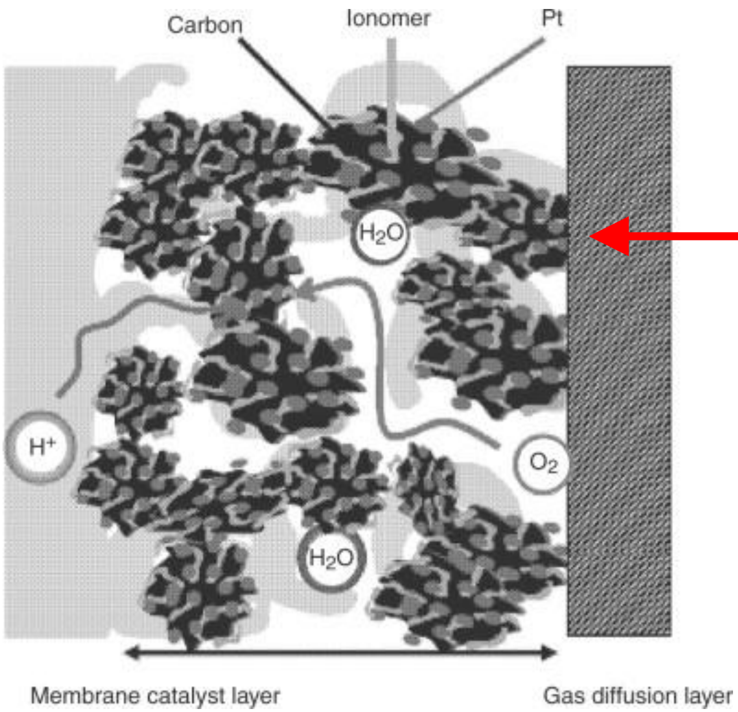

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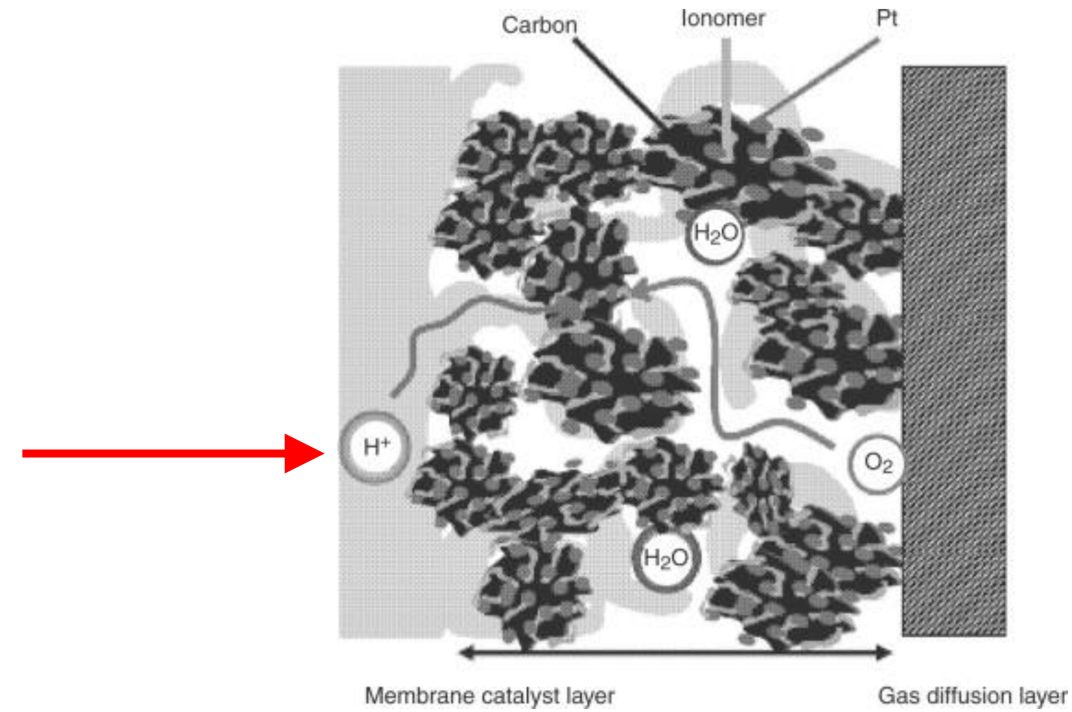

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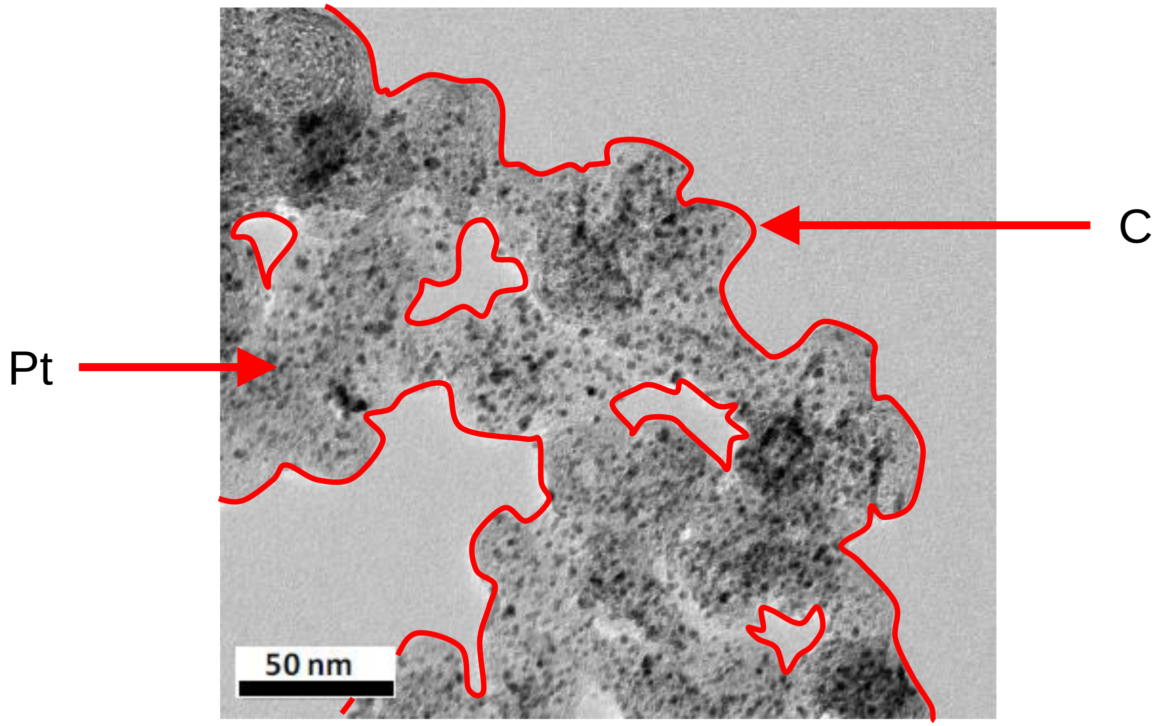
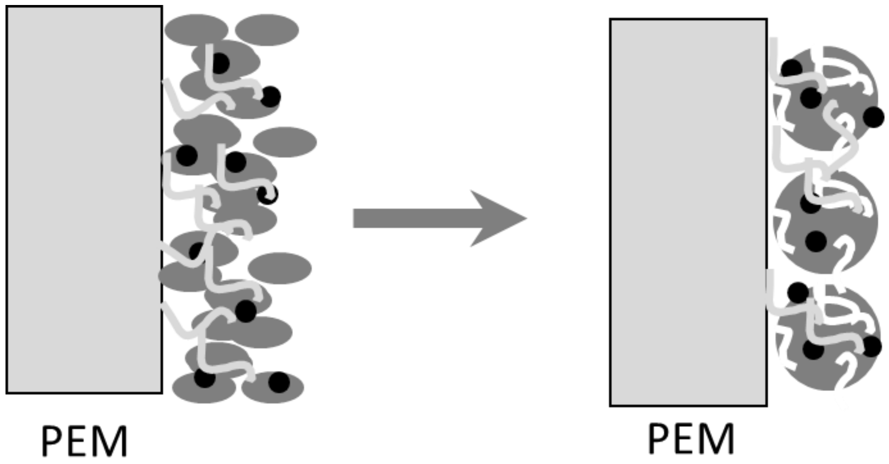
  (ii) e^- through C
  (iii) Ionomer added for H^+

Introduction: Catalyst



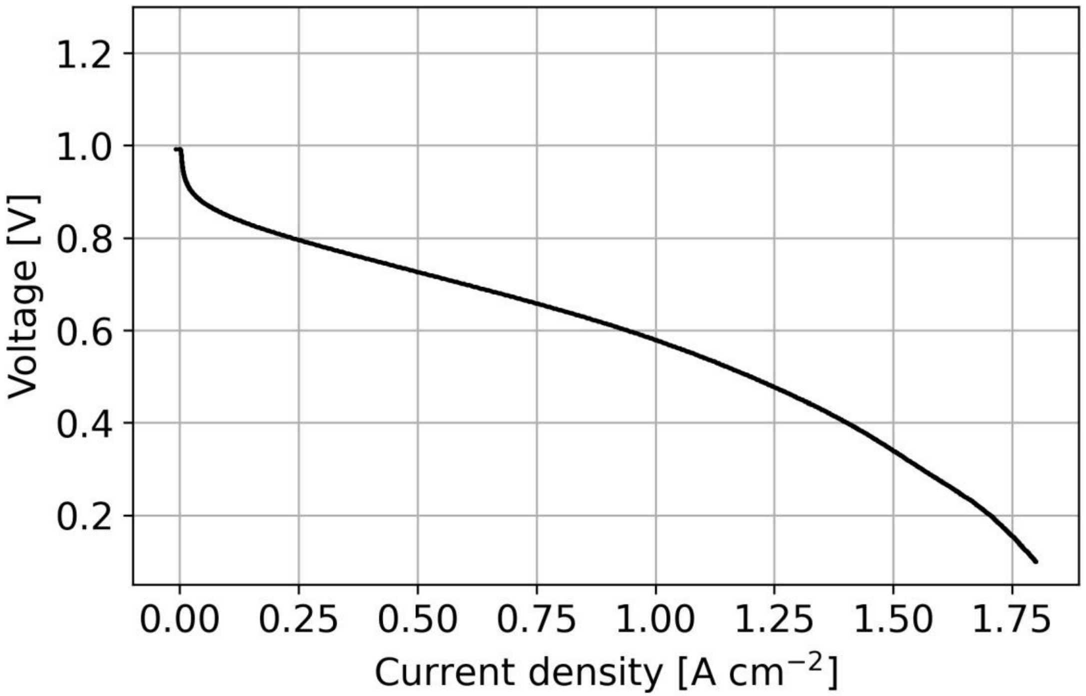
- Pt nanoparticles deposited on Carbon Black (TEM image)

Introduction: Catalyst



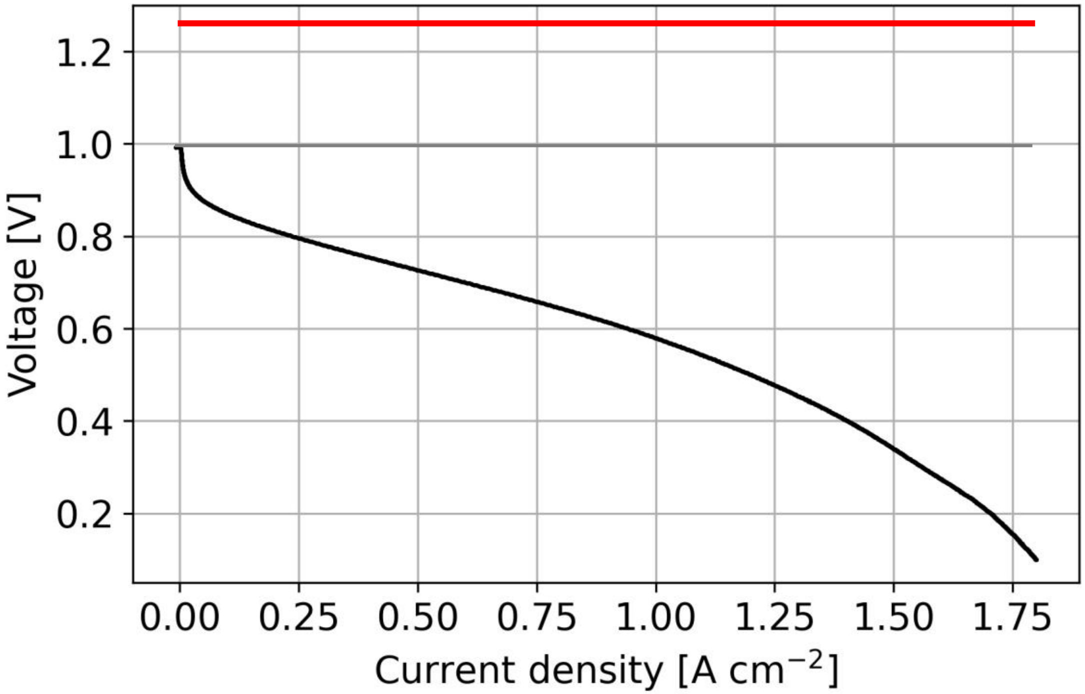
- **Goal**: Optimize the support for species transport (e.g. Carbon Xerogel)

Introduction: Performance



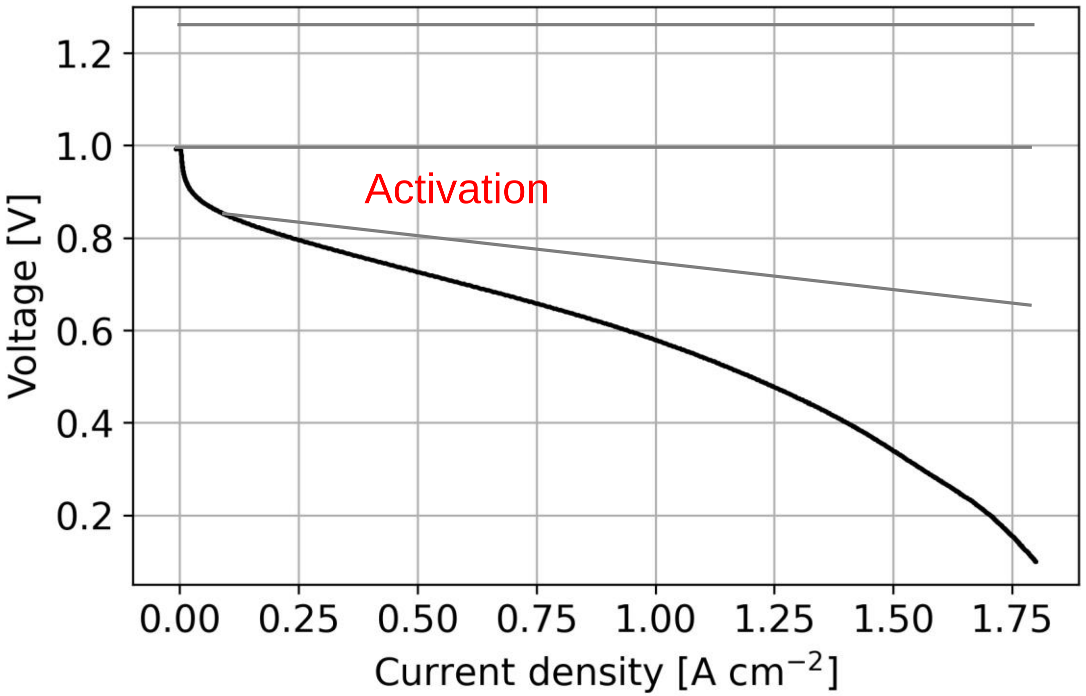
Polarization curve

Introduction: Performance



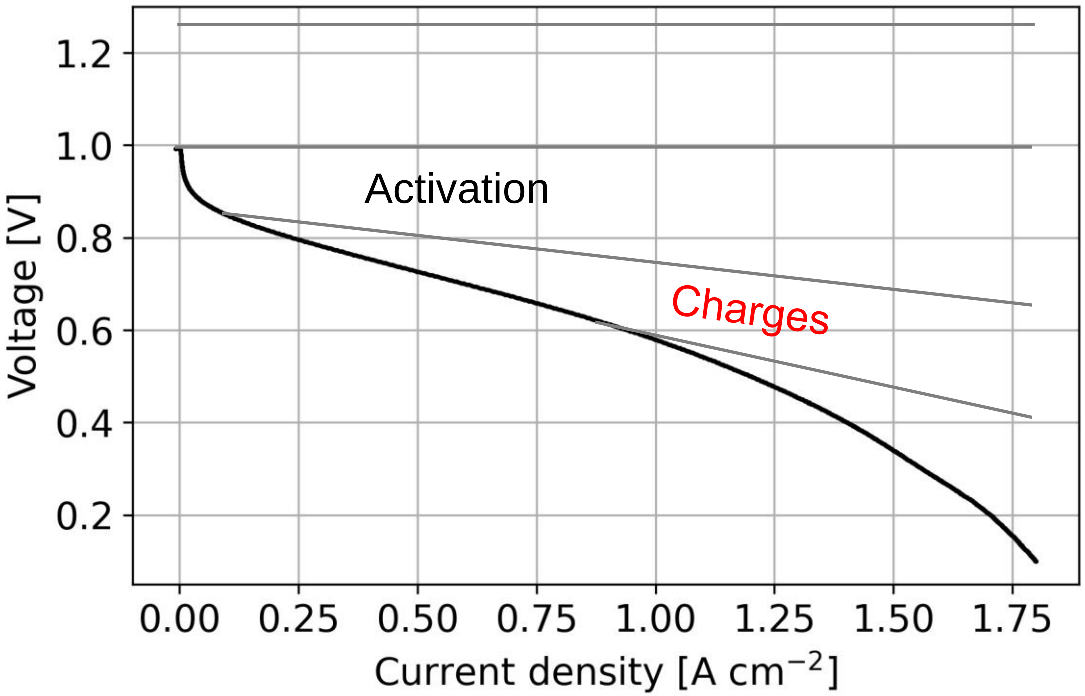
- Nernst equation

Introduction: Performance



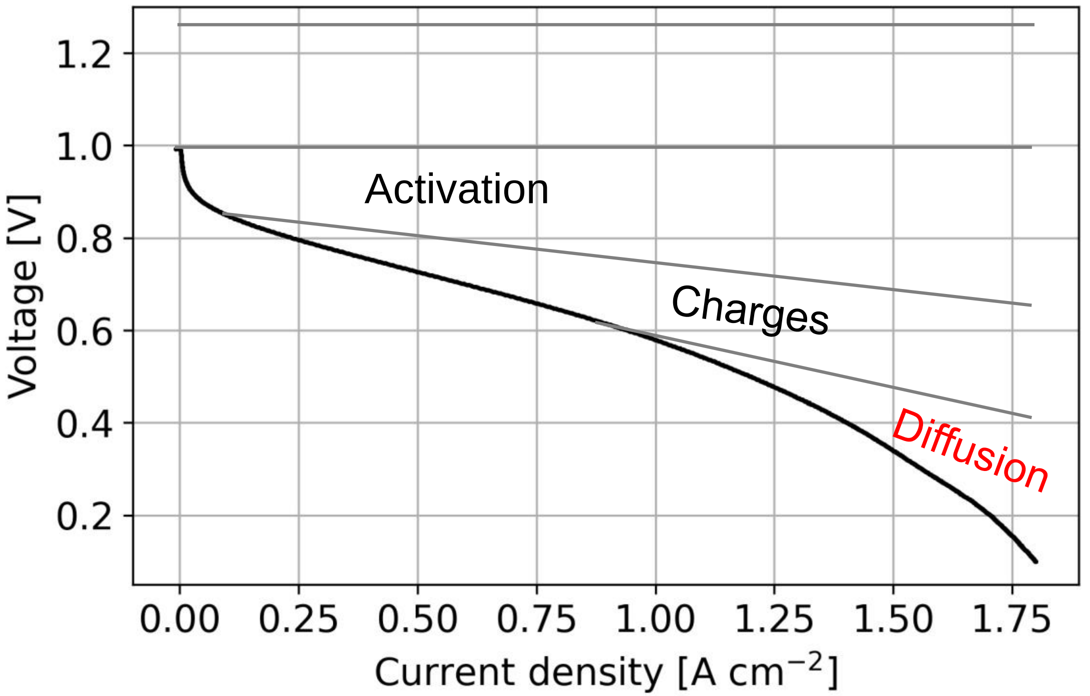
- Activation loss

Introduction: Performance



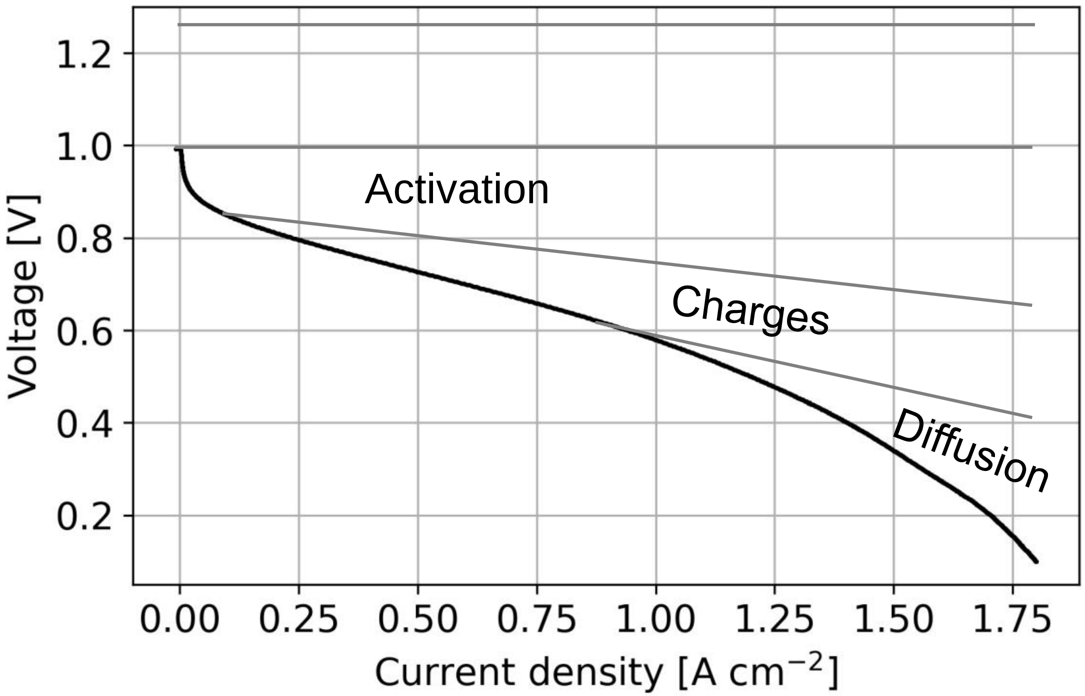
- Activation loss
- Charge transport loss

Introduction: Performance



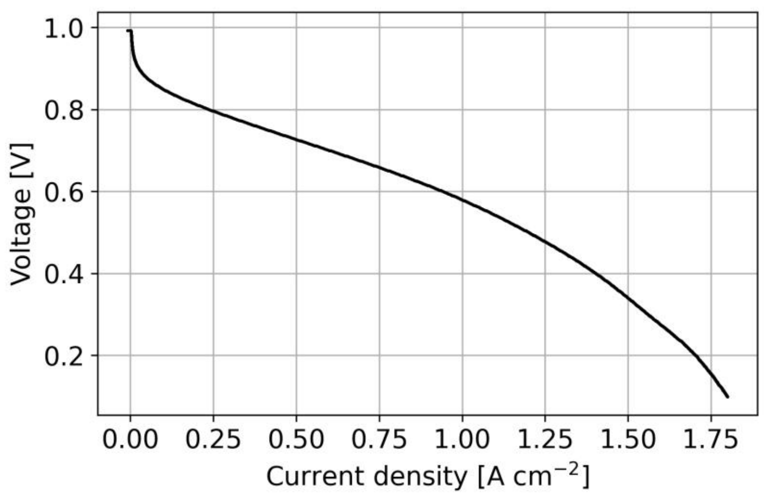
- Activation loss
- Charge transport loss
- Oxygen diffusion loss

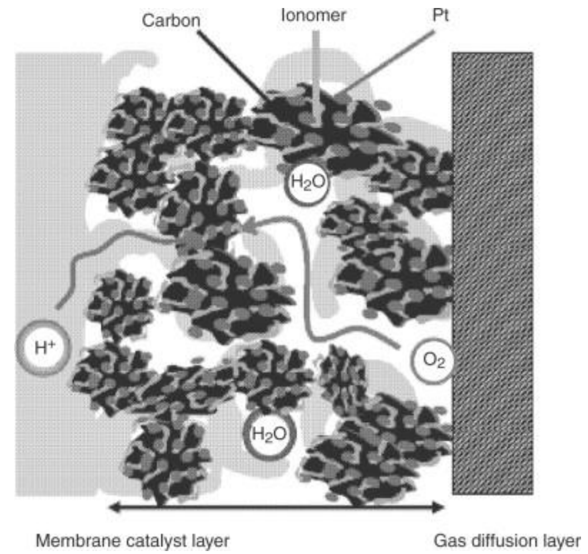
Introduction: Performance



- How to discriminate accurately ?
- How to predict the performance ?
- How to optimise ?

Problem





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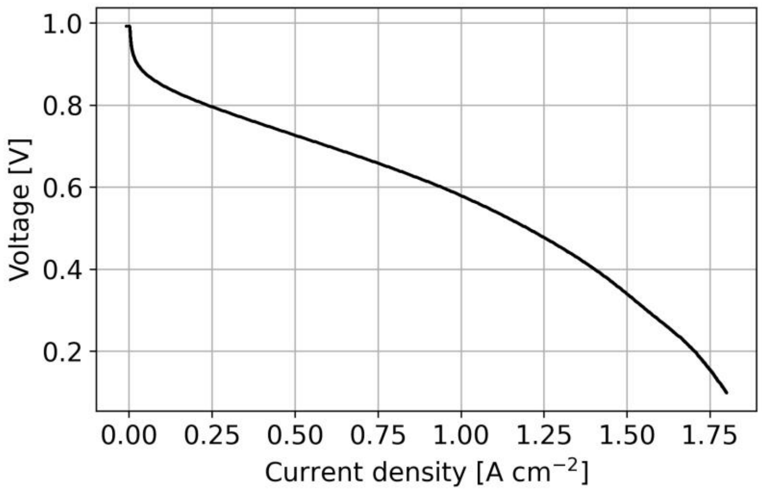
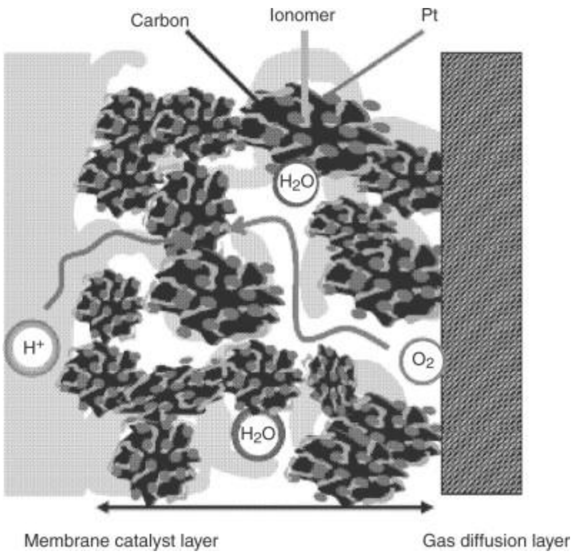
- How to link the performance and the cathode CL behavior ?
- How to obtain **diffusion** and **conductivity** properties ?

Problem





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1st study:

- Experimental strategy
- Numerical model

Experimental strategy

- Manufacture PEM fuel cells with different CL architectures
  - Pt located only on a portion of the cathode catalyst layer:

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    - Case a: Pt only close to the PEM

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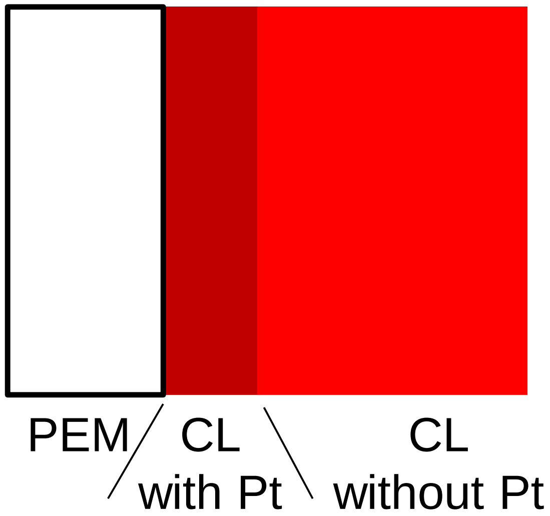

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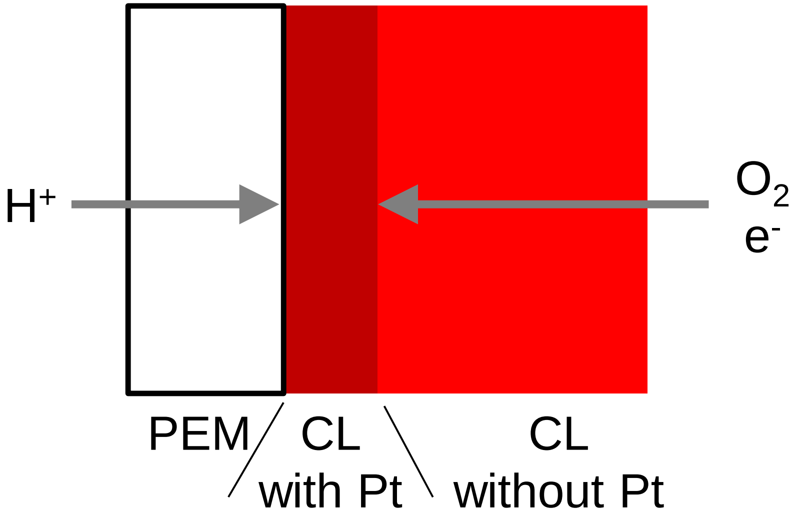

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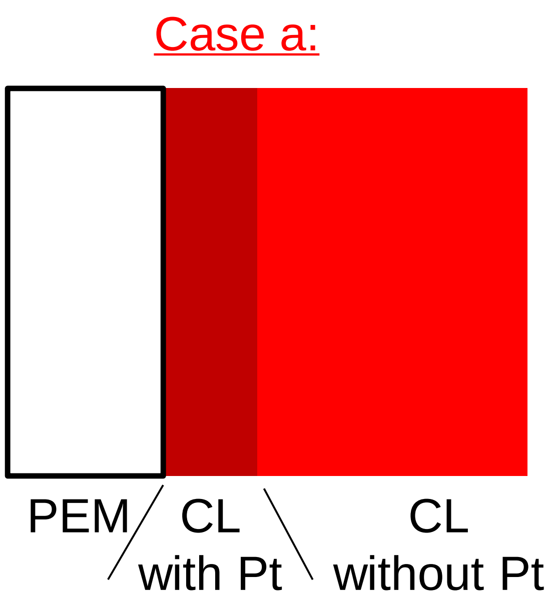

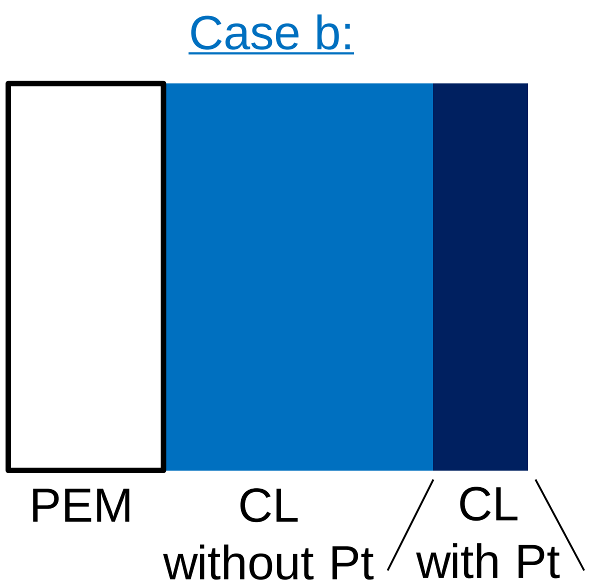

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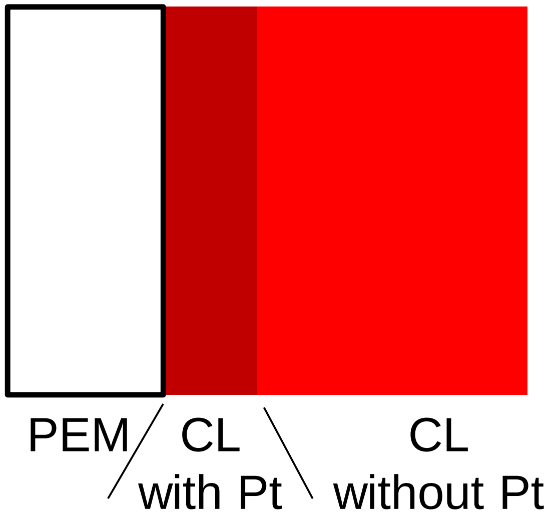
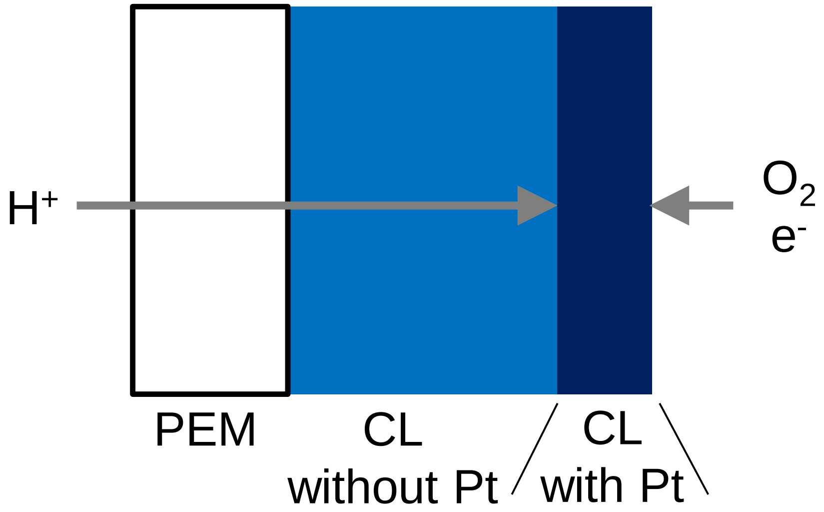
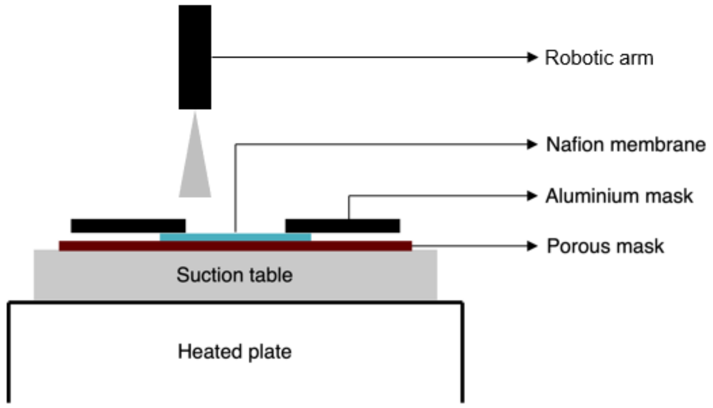




Manufacture & Characterization



CL manufacture:
Spray deposition on the PEM

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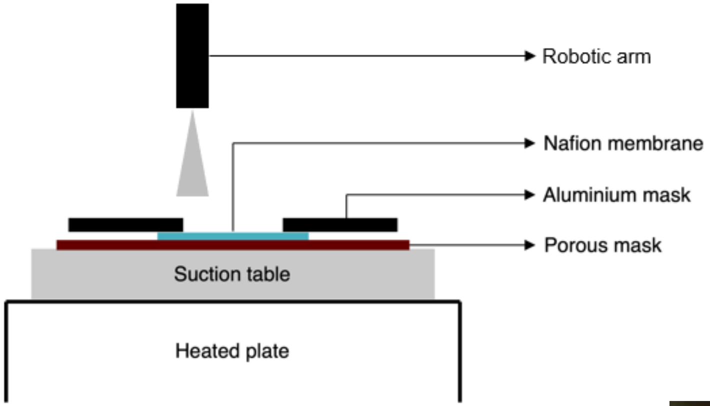
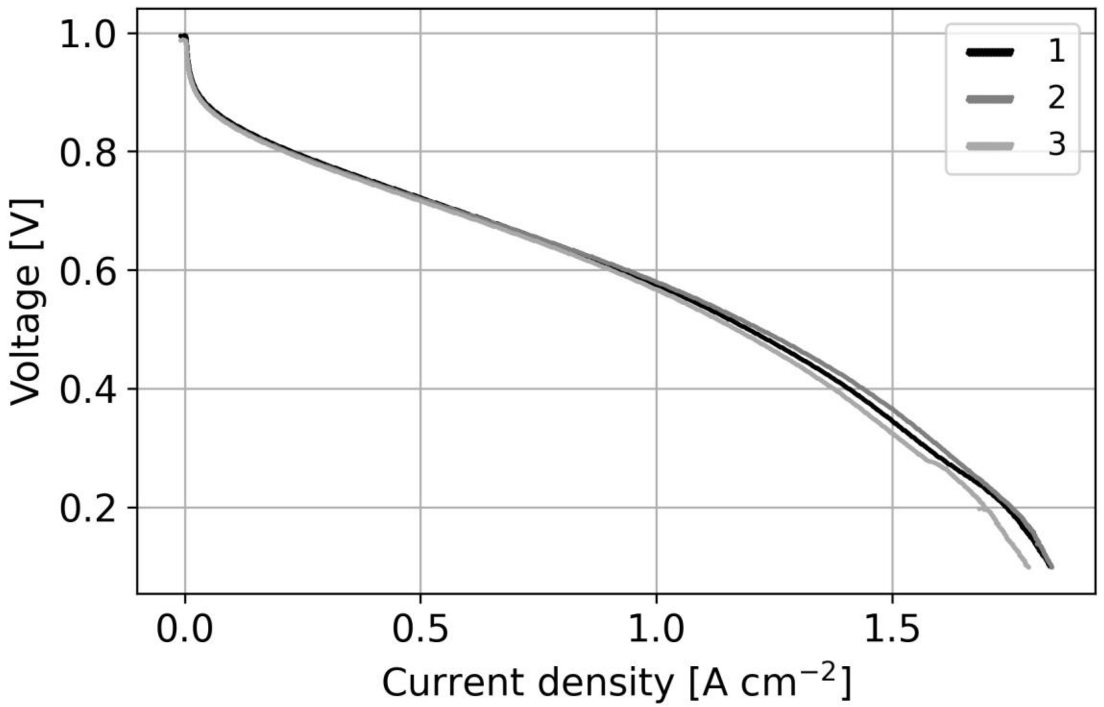


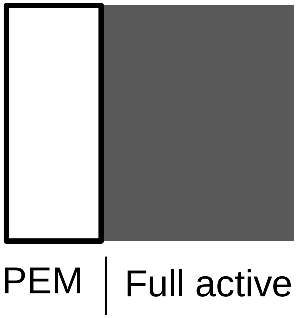
CL manufacture:
Spray deposition on the PEM

Characterization:
Assembly clamped in a cell

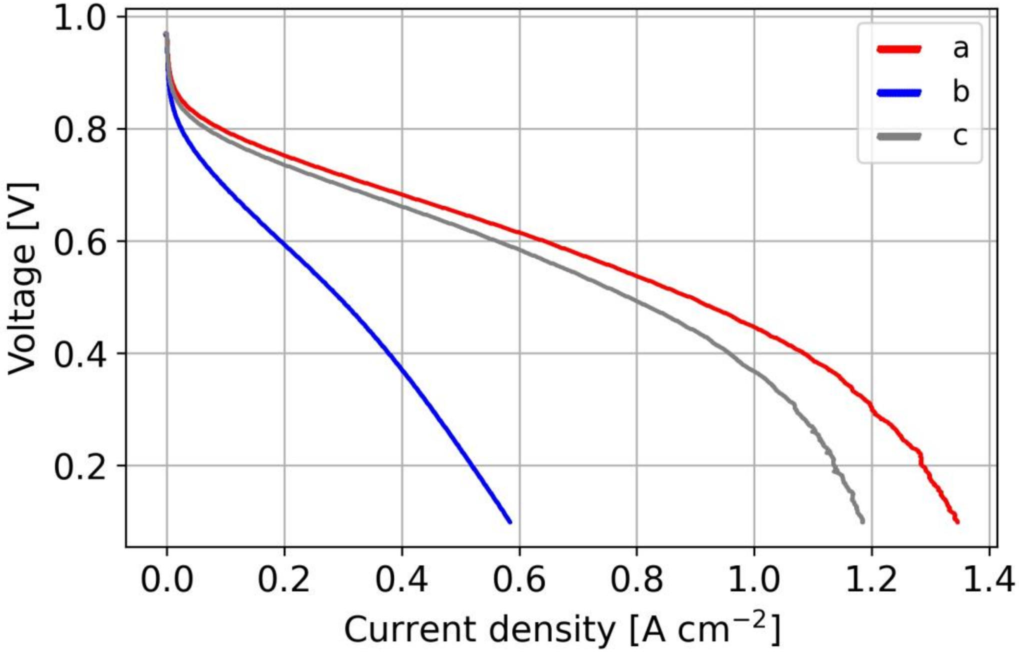
Reproducibility



- PEM fuel cells with 50% wt. Pt/C Black (Loading: 0.33 mg_{Pt} cm^{-2}, I/C=0.8)
- Nearly perfect reproducibility



Results 1



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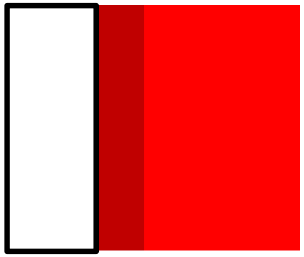
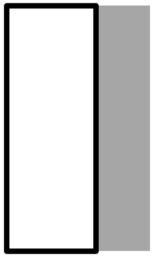


Case b:

Case c:



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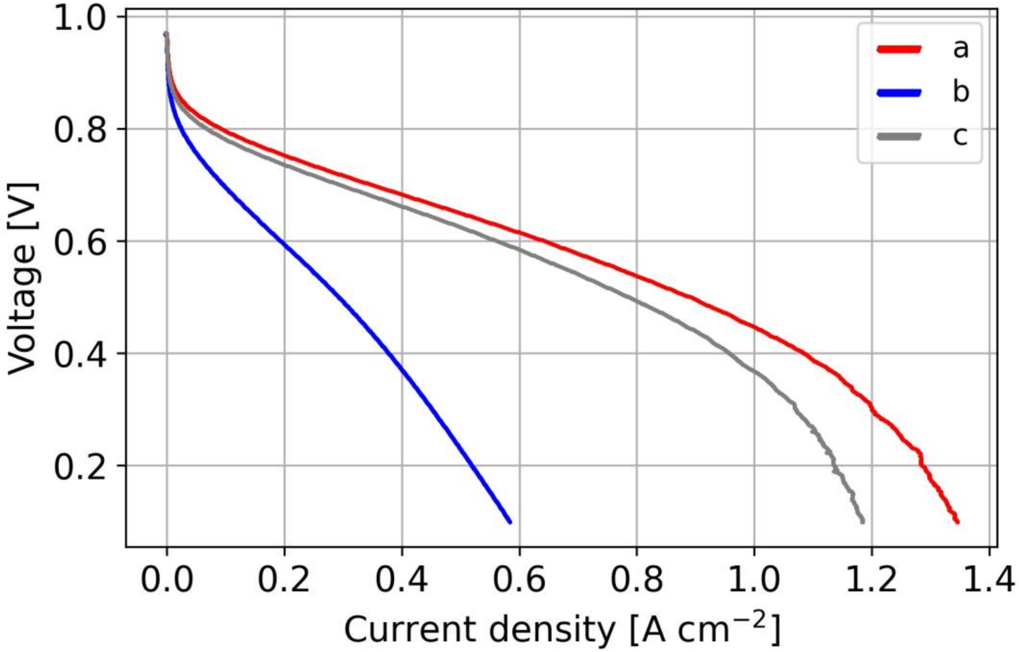

- Large impact of the CL ionic resistivity

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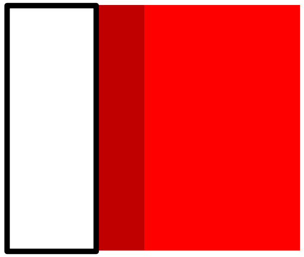

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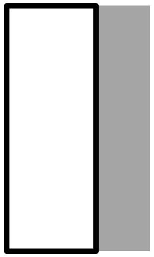
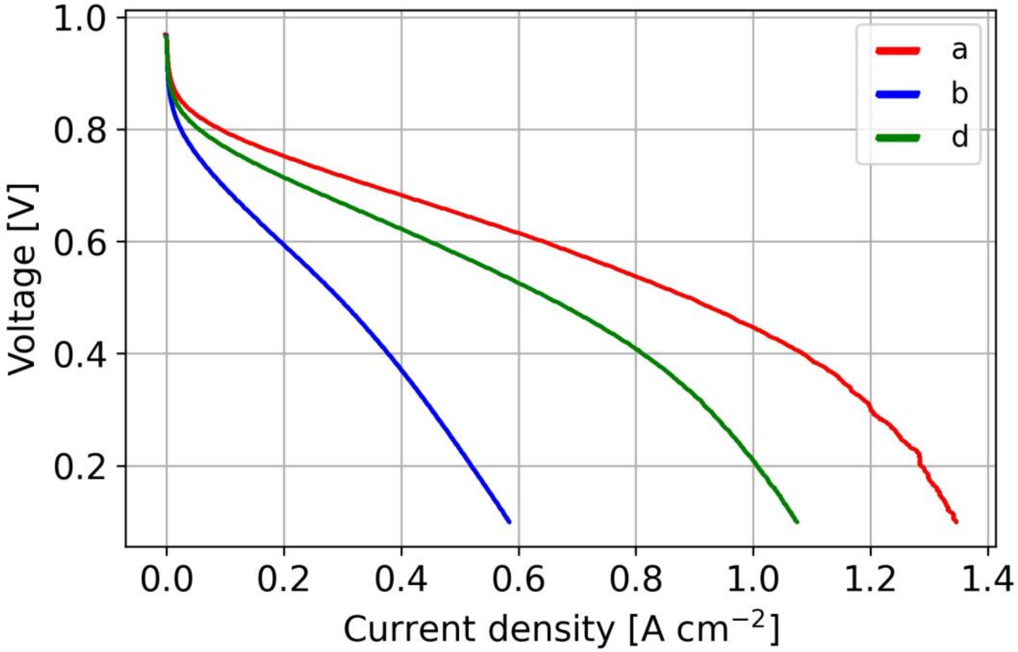


Results 2



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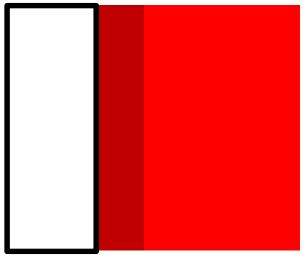
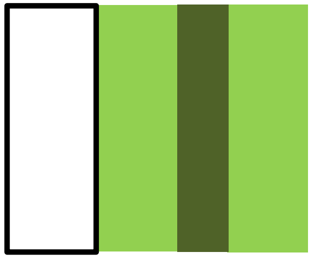


Case b:

Case d:



Experimental strategy

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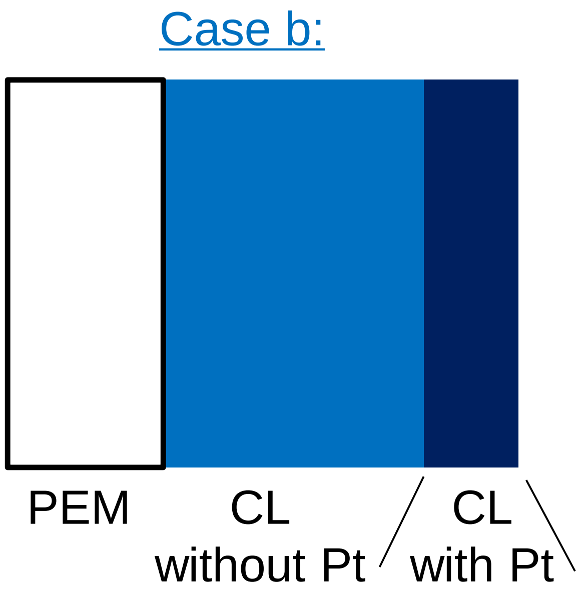

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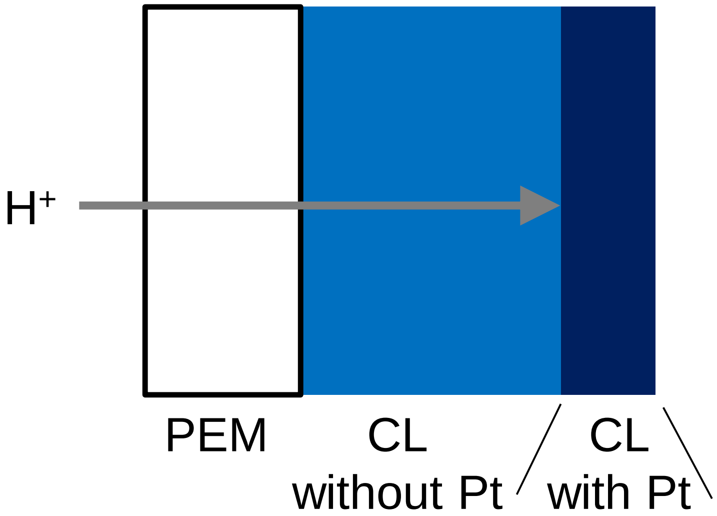

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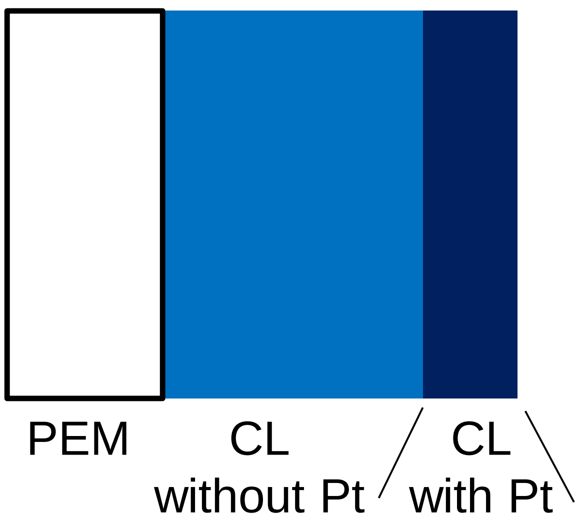
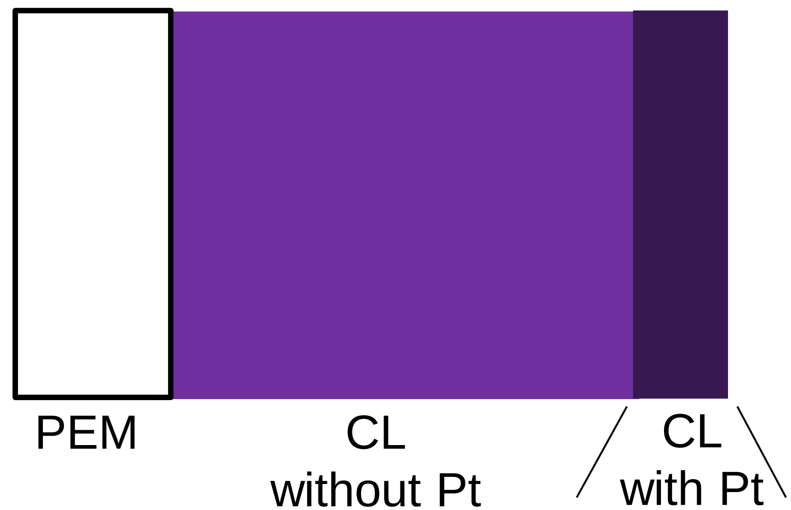
Case b:



Case b2:



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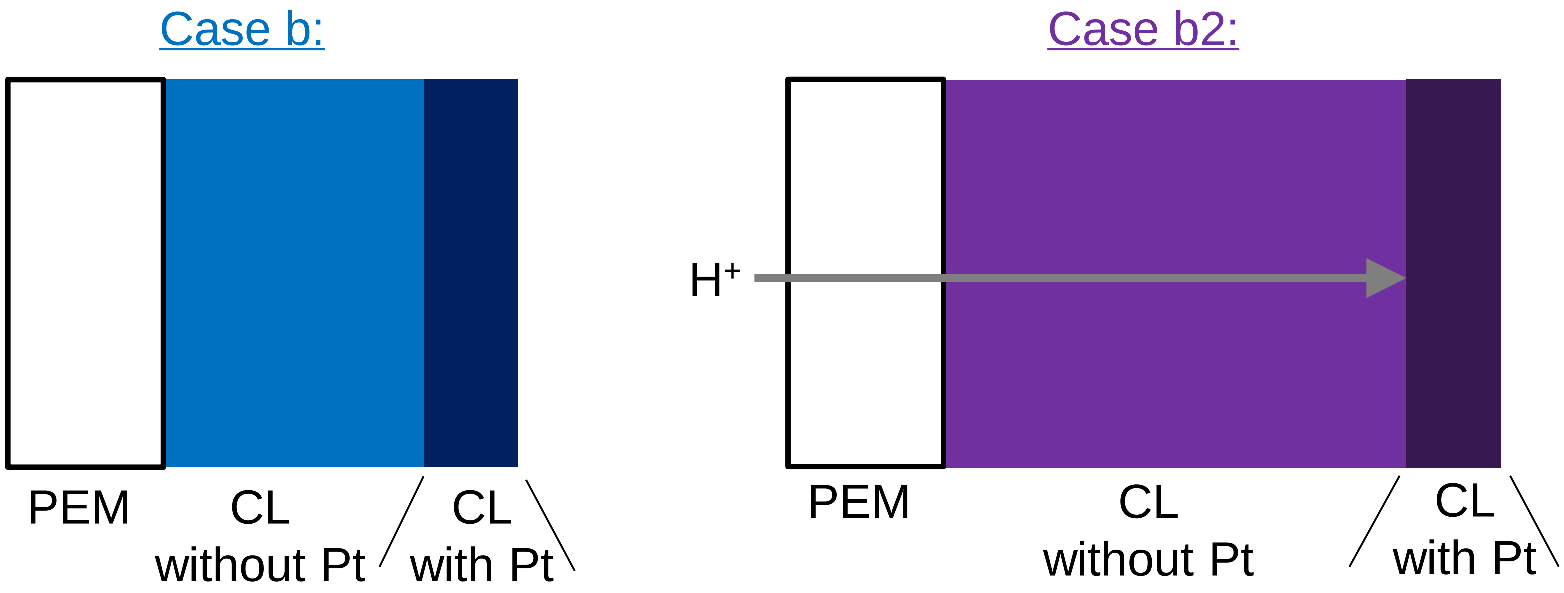
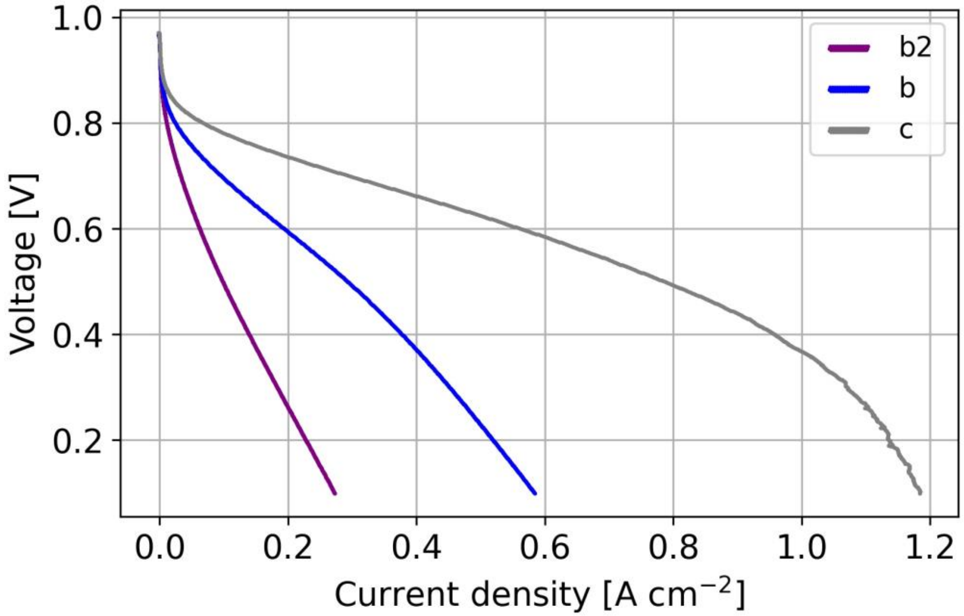


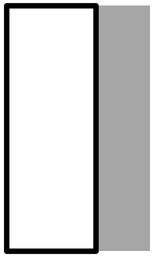
Results 3



Case b2:

Case b:

Case c:



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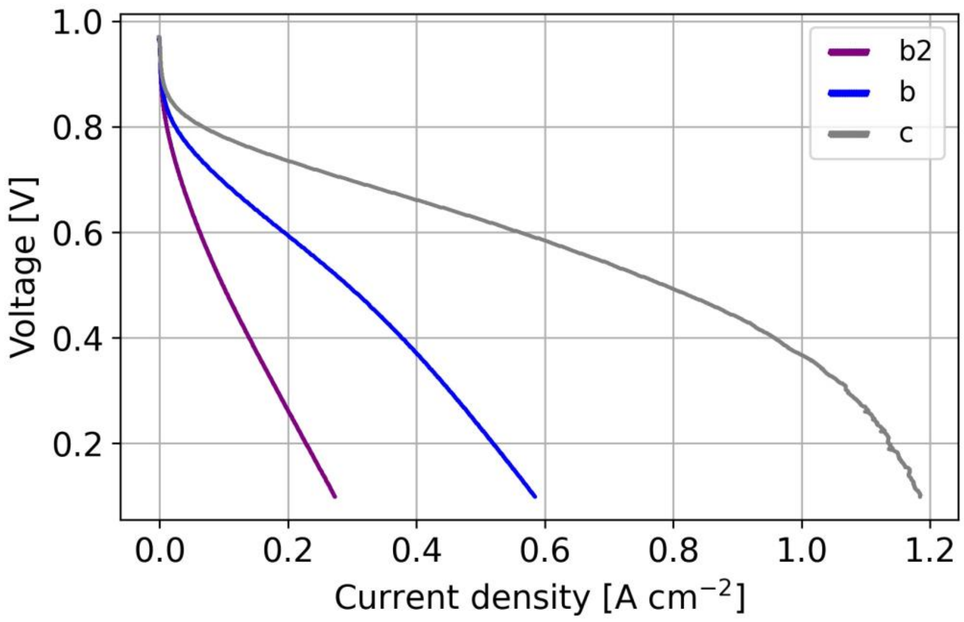
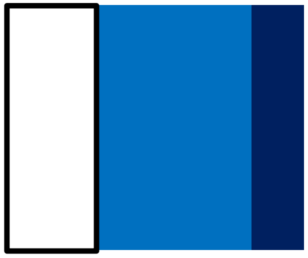


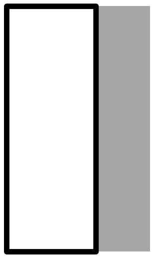
Resistivity:
525±25 Ω cm

Case b2:

Case b:



Case c:



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Numerical model

Assumptions:

- No electric loss (carbon black)
- No diffusion loss (at low current)

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- Proton conduction + kinetics :

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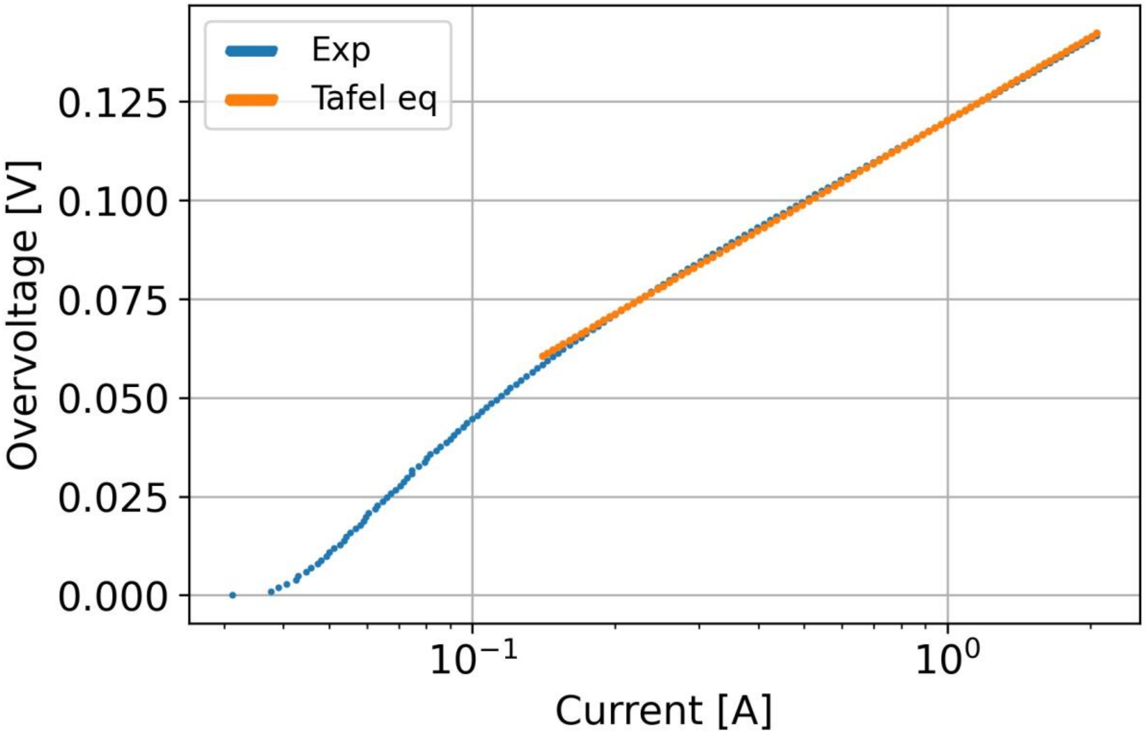
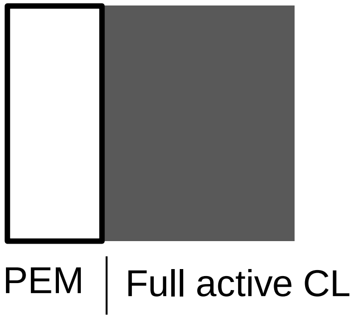
To find:

- i_0
- b
- Ionic resistivity

Kinetics parameters with O_2



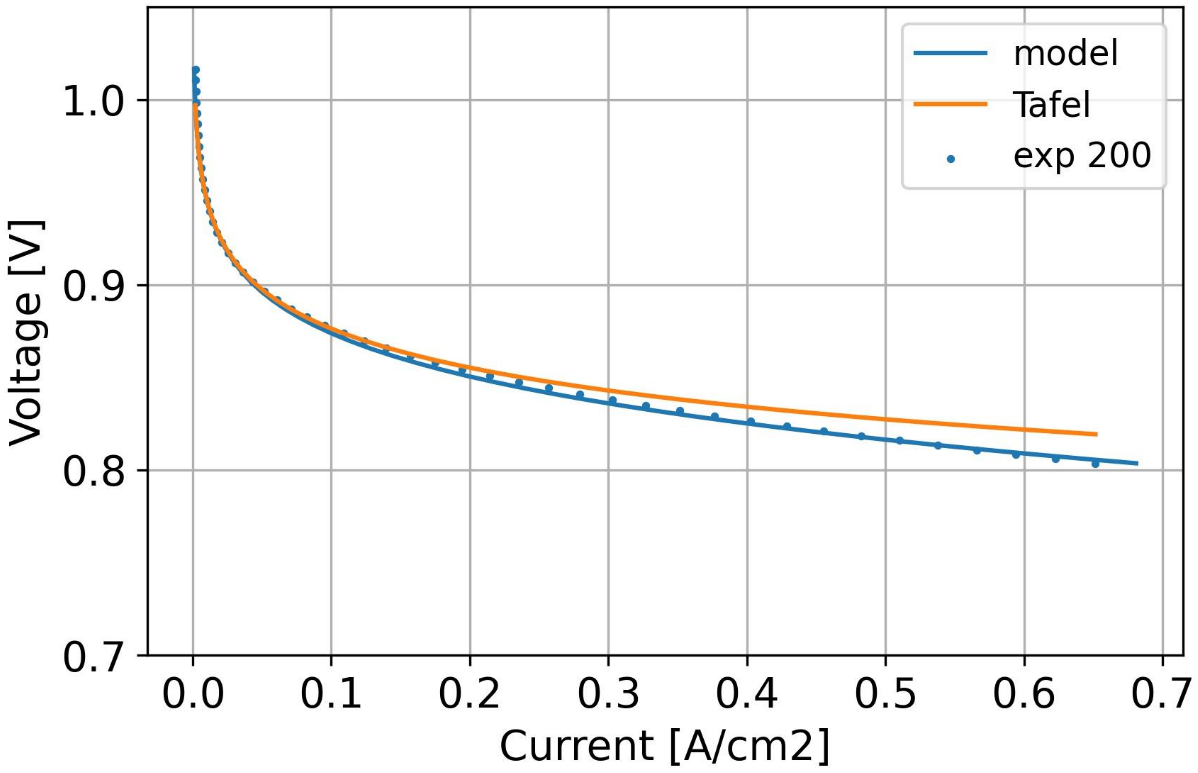


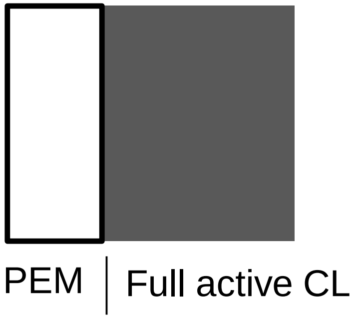
Tafel law at low current:

b = 0.0700 V/dec

i_0 = 0.0192 A

Resistivity 1



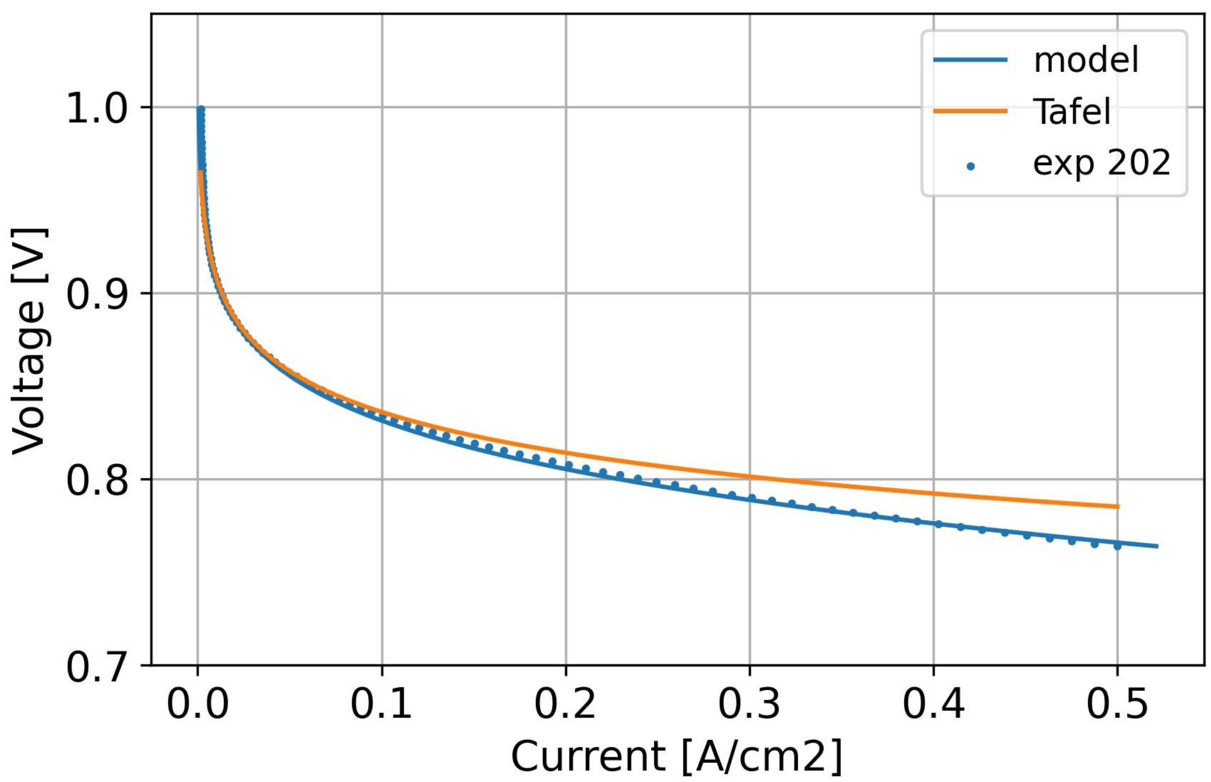


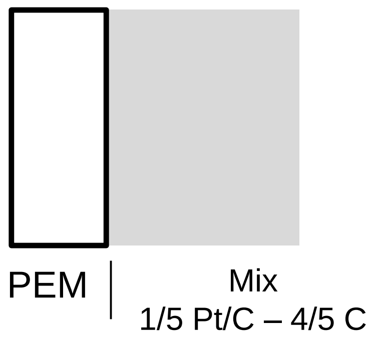
Resistivity:

73 Ω cm

(Experimentaly: 525 Ω cm)

Resistivity 2





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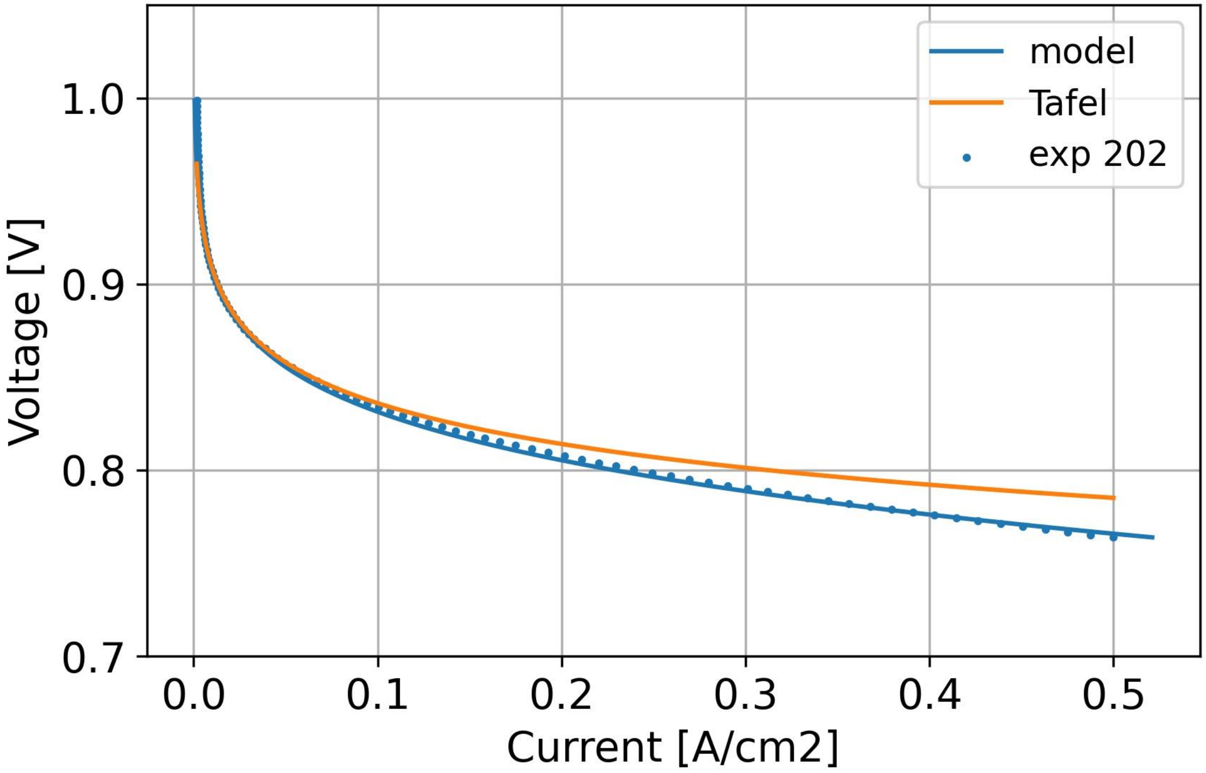

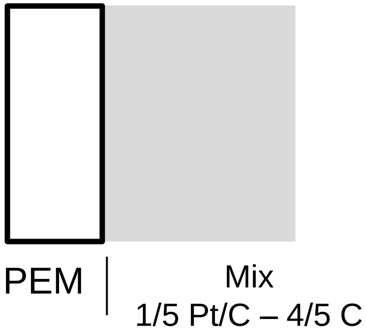

Resistivity:

139 Ω cm

Conclusion

Link the CL behavior and the performance of the PEM fuel cell

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→ Ionic R for inactive layer: 525 Ω cm

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→ Ionic R for inactive layer: 525 Ω cm

Numerical:

→ Ionic R for active layer: 73 Ω cm

Ionic R for partially active layer: 139 Ω cm

Perspectives

Model homemade catalyst on Carbon Black

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Change the support material: Carbon Xerogel

- Synthesis
- Layer deposition
- Fuel cell characterization

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Change the support material: Carbon Xerogel

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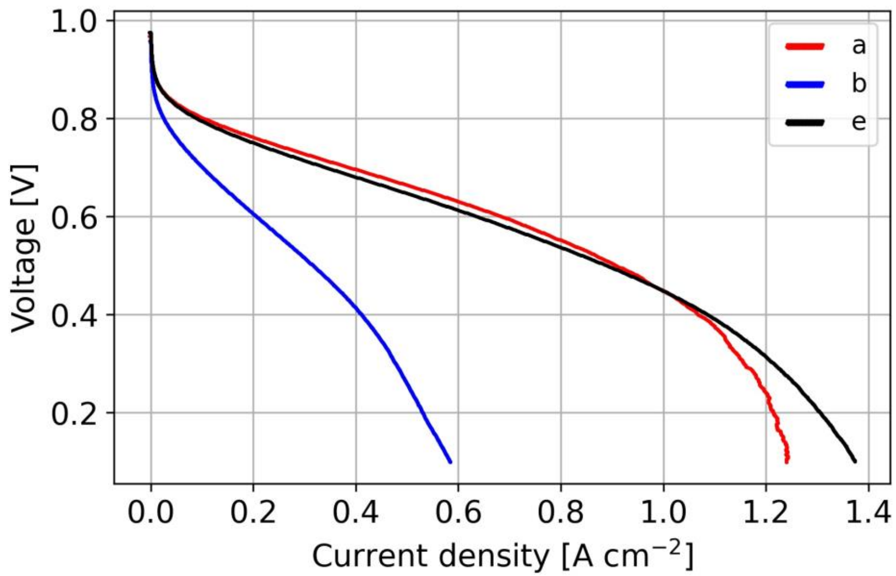
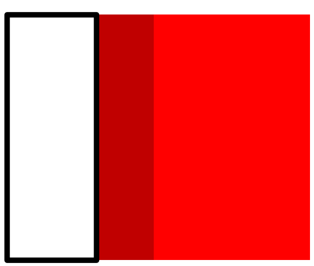
Improve the model: diffusion, electric resistivity and EIS

Thank you !

Annexe

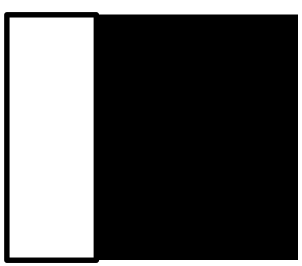


Case a:

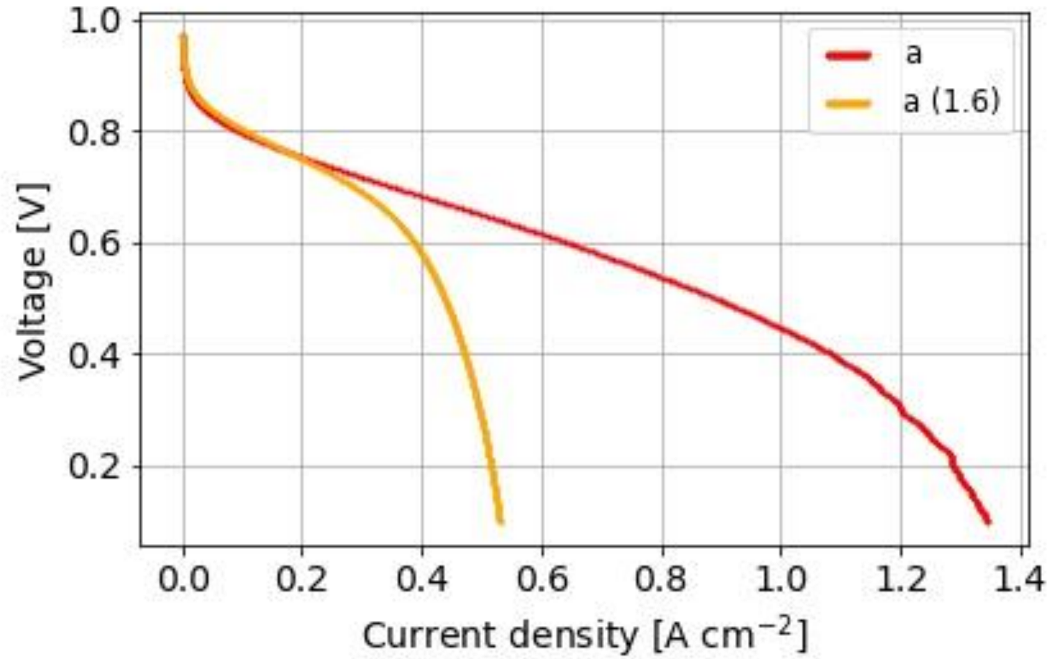


Case b:

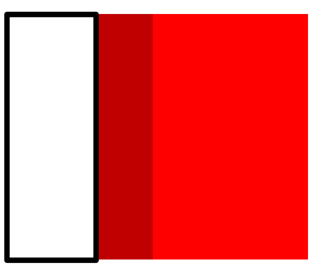
Case e:



Annexe

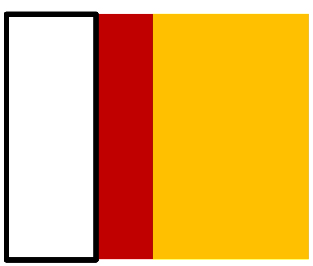


Case a:



N/C = 0.8

Case a(1.6):



N/C = 1.6

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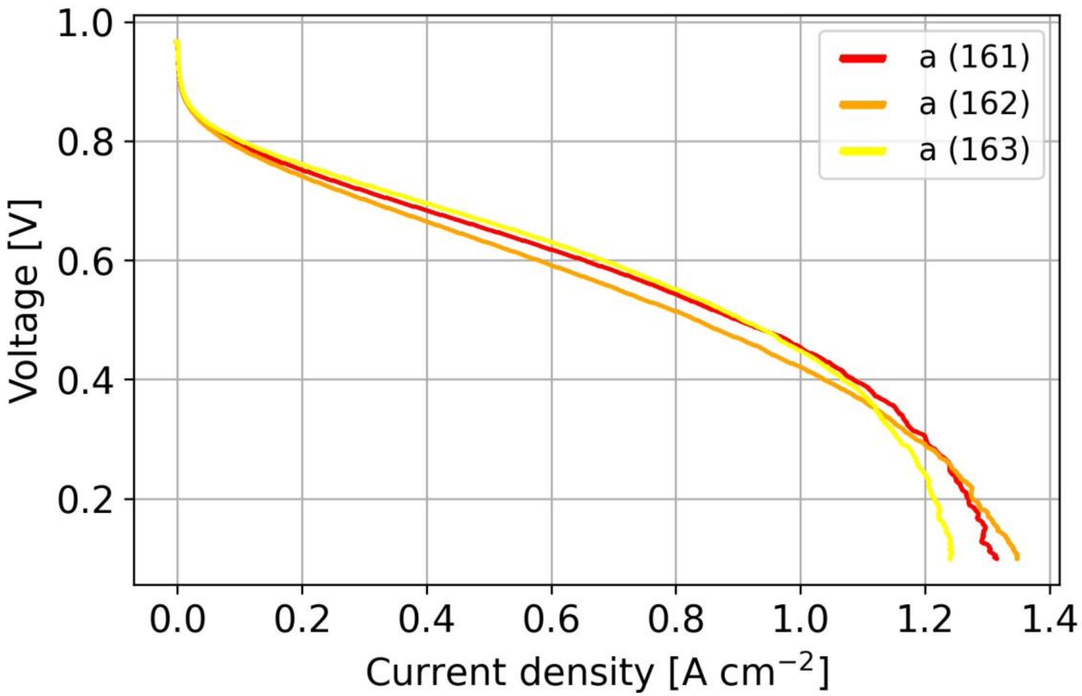
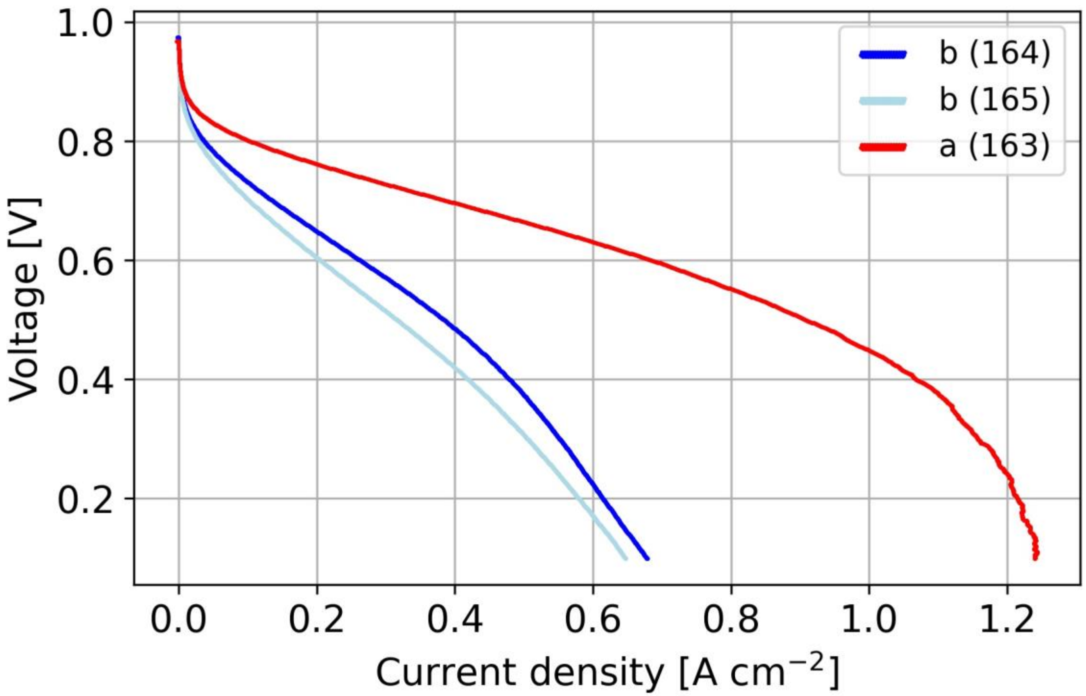
Annexe



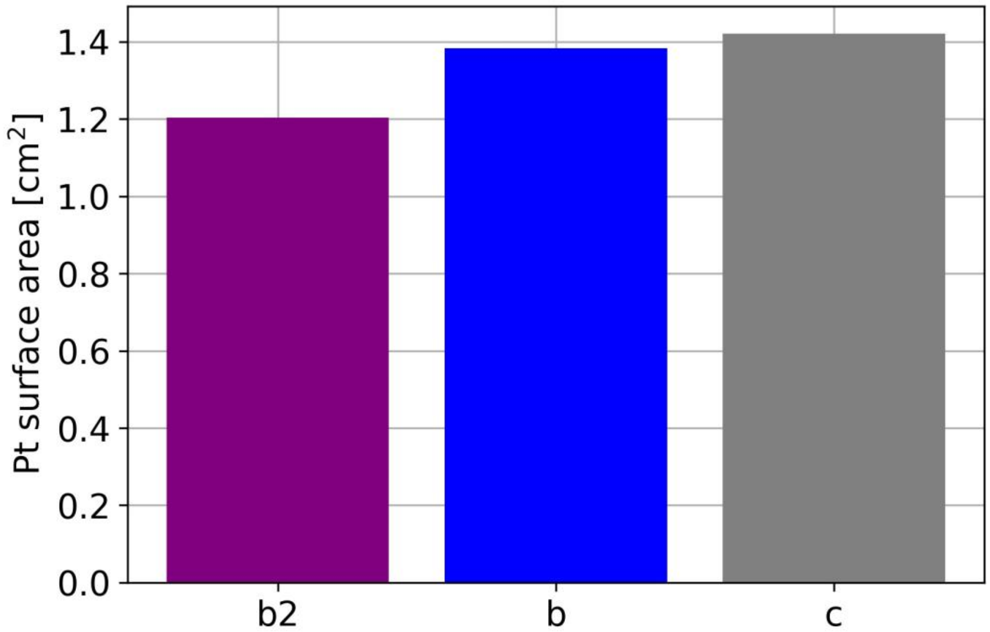
1.0
0.8
0.6
0.4
0.2
Voltage [V]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Current density [A cm−2]
a (161)
a (162)
a (163)

Annexe



1.0
0.8
0.6
0.4
0.2
Voltage [V]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Current density [A cm^{-2}]
b (164)
b (165)
a (163)

Annexe: CL active surface area



Case b2:

Case b:

Case c: