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Anode aging in polymer electrolyte membrane fuel cells

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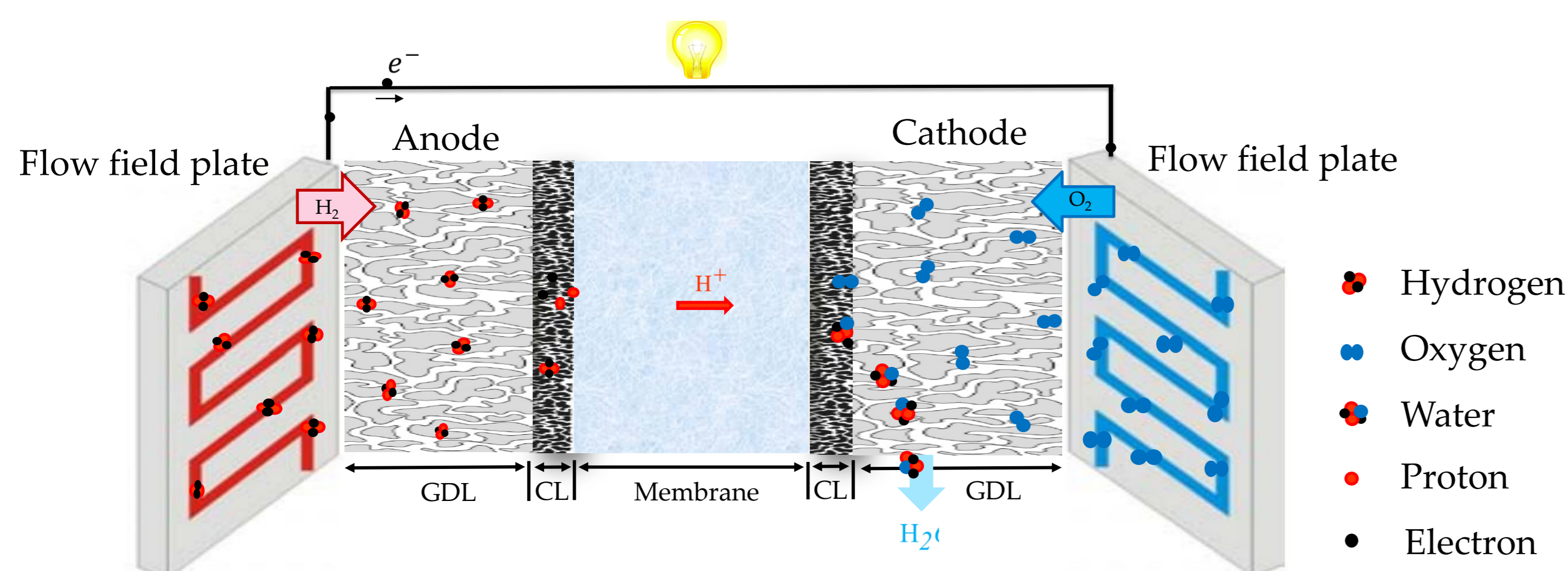
Motivation and purpose of the research

Considering the issues of global warming and depletion of fossil fuels, the urgent need for clean renewable energy sources is higher than ever. The development of zero-carbon emission electrochemical energy conversion technologies as promising alternatives to fossil fuels increased enormously in recent years. The proton exchange membrane fuel cells (PEMFC), which use hydrogen to generate electricity, has attracted widespread attention because of its high efficiency, high power density, low operating temperature and zero emissions. However, their low durability and life-span limit their large-scale application.

Therefore, this work aims at analyzing and understanding the aging mechanisms of the different components of fuel cells (FC), using an accelerated stress test based on complex operating conditions leading to accelerated fuel cell aging. The results obtained using in-situ and ex-situ characterization techniques show a strong degradation of the initial performances due to aging of the anode and cathode electrodes, especially the anode catalyst layer, which degradation has rarely been studied in the literature.

Proton Exchange Membrane Fuel Cells

Principle of operation

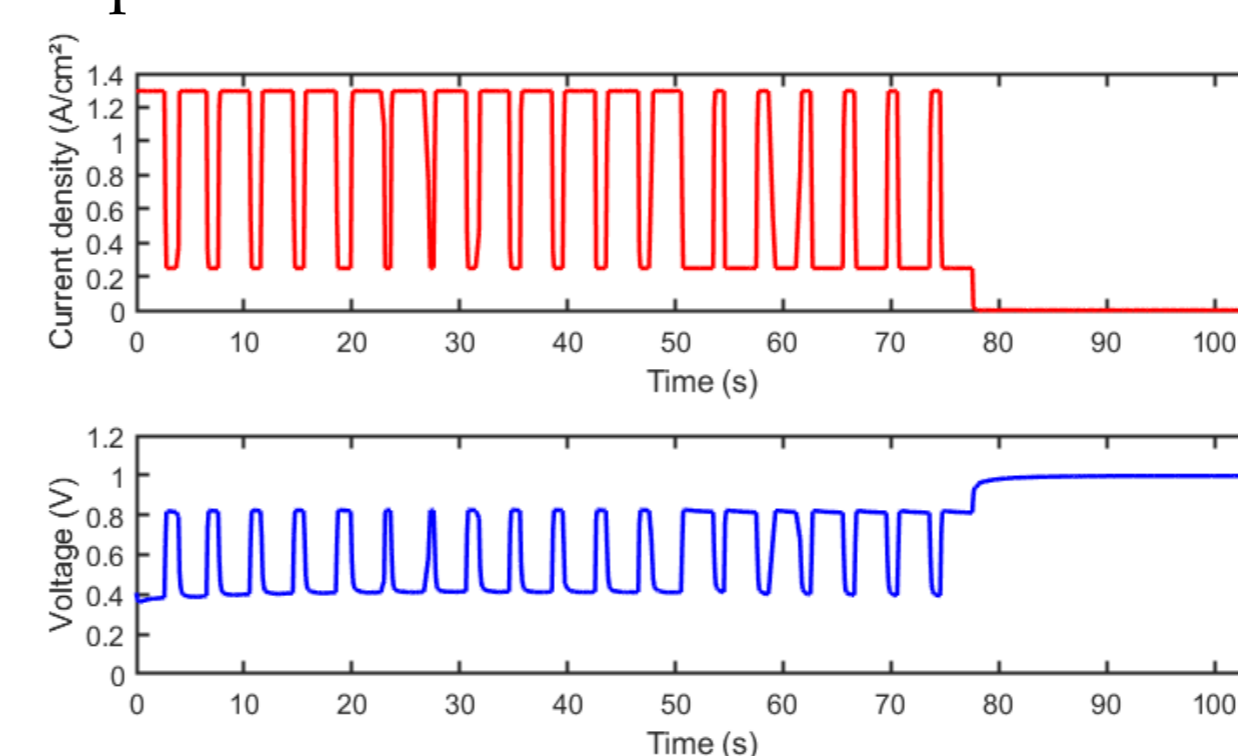


- Hydrogen oxidation reaction (anode): $\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$
- Oxygen reduction reaction (cathode): $\frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{O}$
- Global reaction: $\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$

Work carried out

Accelerated stress test (AST)

The FC is subjected to an AST capable of inducing degradations of the main components: electrodes and membrane.

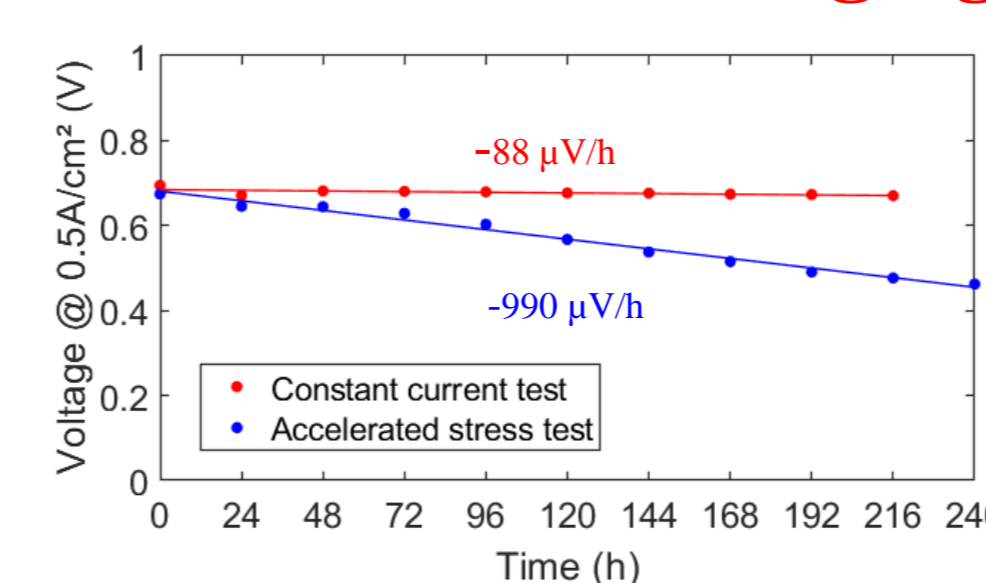


The AST is a combination of:

- Potential cycling
- Humidity cycling
- Open circuit voltage (OCV)

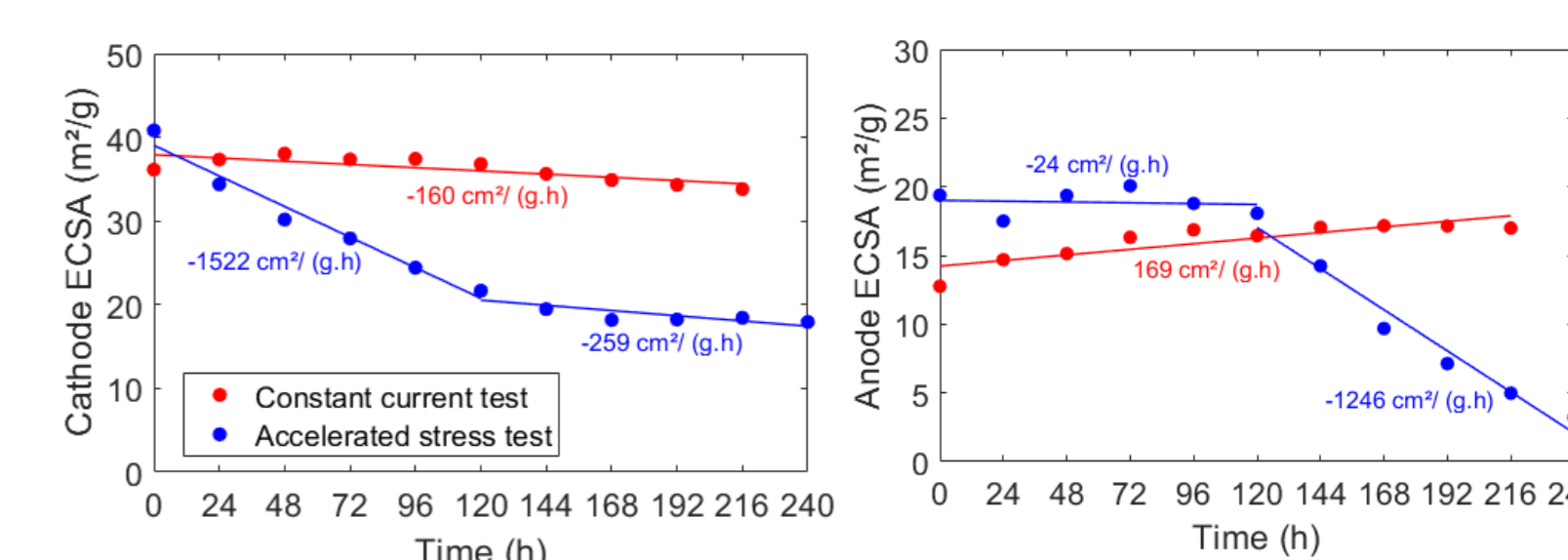
Humidity cycling is controlled by current cycling at constant gas flow rates.

Performance aging

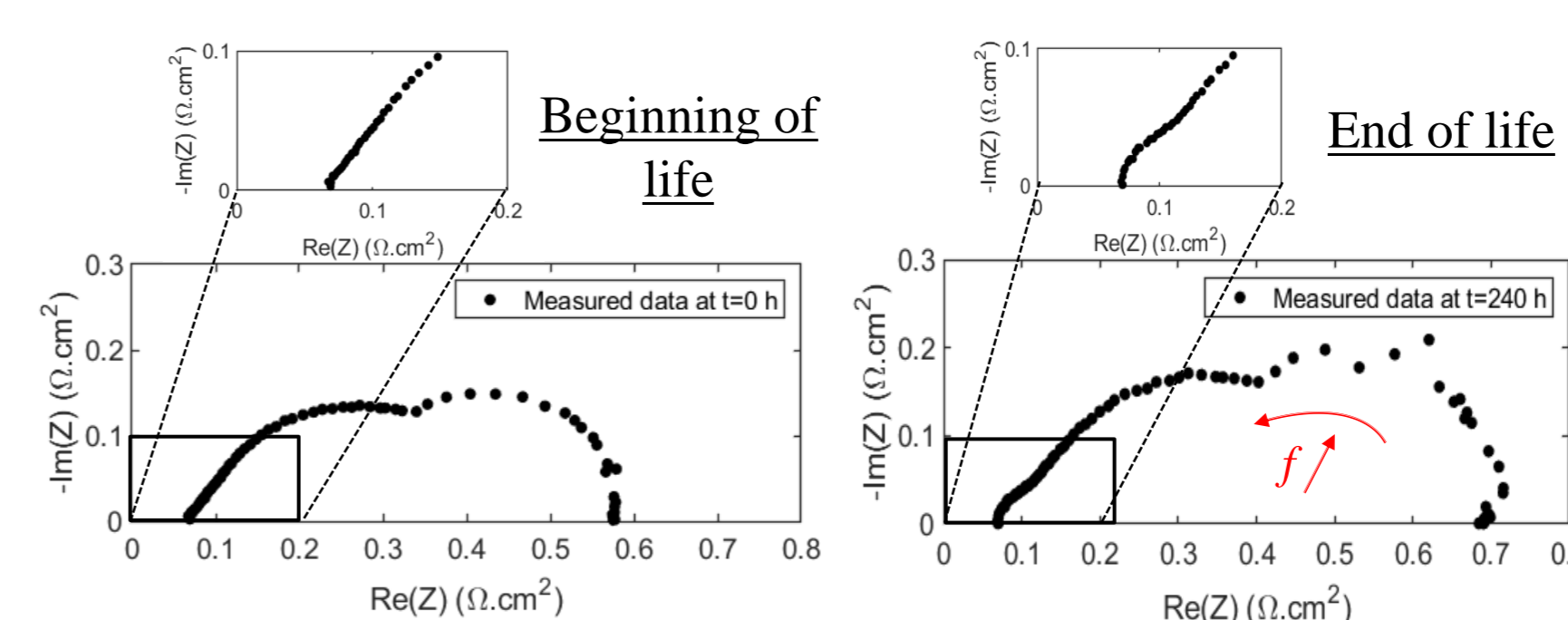


- Strong performance degradation in the case of AST compared to constant current test

- Strong degradation of the electrochemical surface area (ECSA) at the anode and cathode in the case of AST

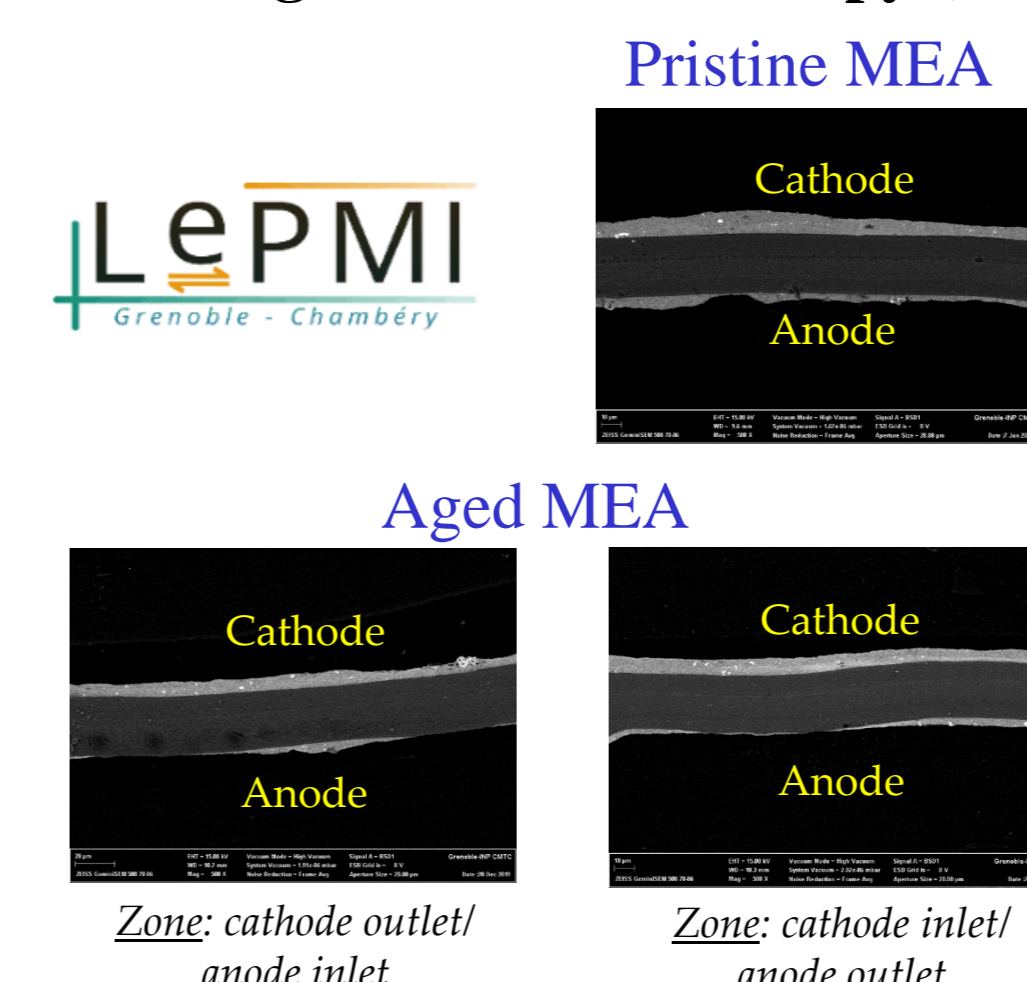


- Appearance of the anode half-loop on the impedance spectrum at very high frequencies at the end of the AST.

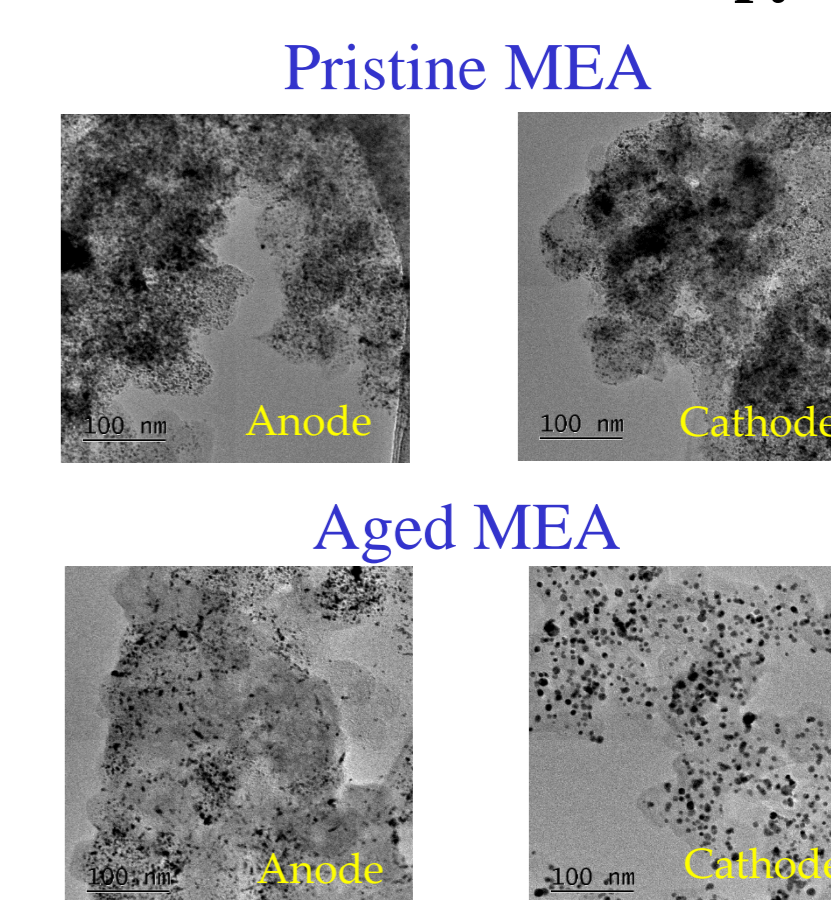


Postmortem analysis

Scanning Electron Microscopy (SEM)



Transmission Electron Microscopy (TEM)

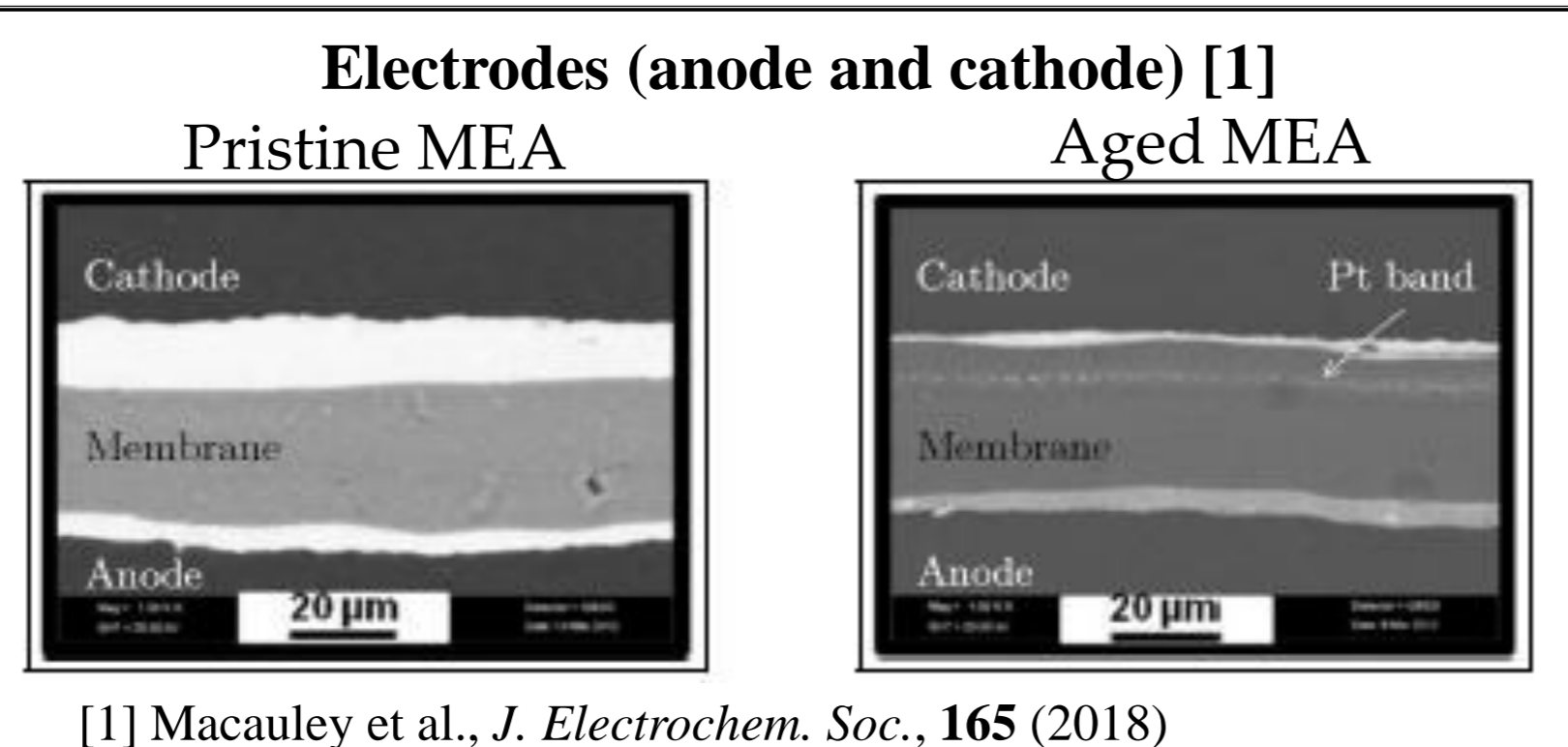


- Post-mortem analyzes showed a thinning of the catalytic layers, in addition to the dissolution and deposition of Pt at the anode and at the cathode

Context: aging of the Membrane-Electrode Assembly (MEA) and durability of Fuel cell (FC)

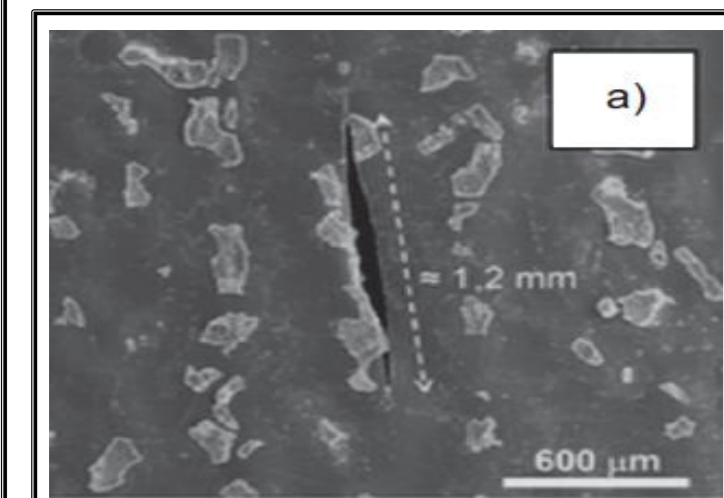
Degradation of MEA components

- Carbon corrosion and dissolution and deposition of Pt...



[1] Macauley et al., *J. Electrochem. Soc.*, 165 (2018)

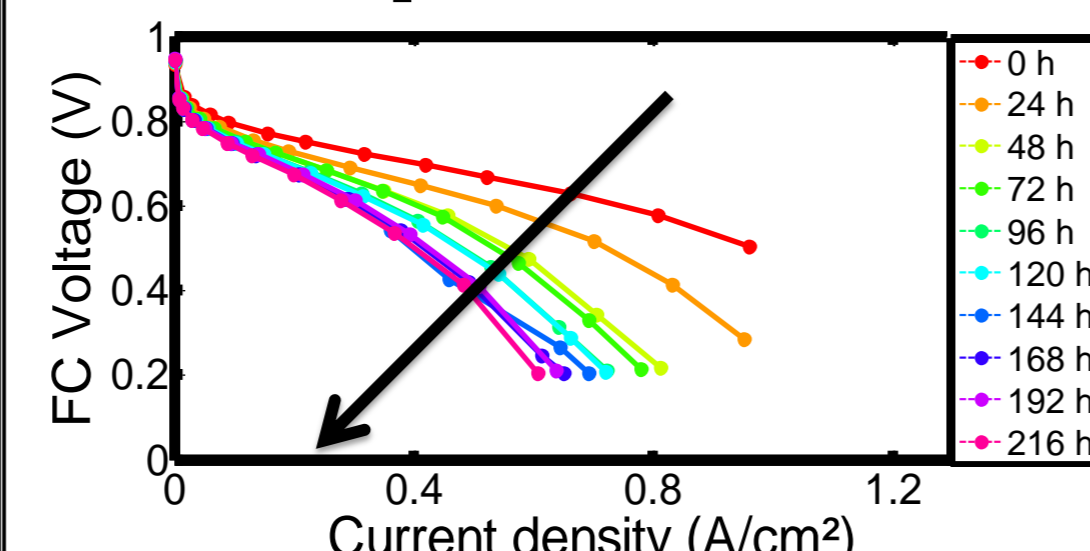
Membrane [2]



- Chemical and mechanical stresses...

[2] De Moor et al., *Fuel Cells*, (2012)

Fuel cell performance decrease [3]

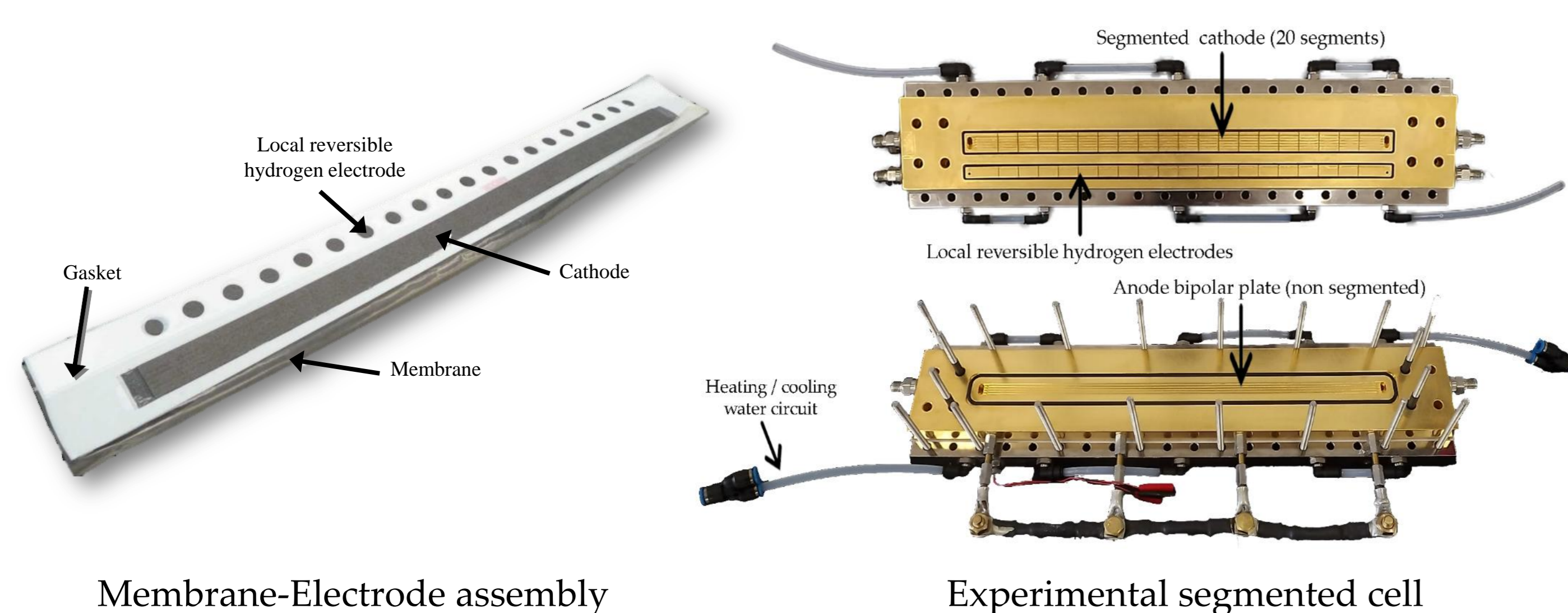


[3] S. Abbou, *Ph.D Thesis, UL* (2015)

Measurement on a segmented cell

Segmented cell with reference electrodes

A segmented cell is a single cell where one of the distributor plates is divided into several segments on which several electrochemical measurements can be performed: electric current, impedance, active electrochemical surface, etc.



Conclusions & Perspectives

- Degradation of polymer electrolyte membrane fuel cells (PEMFC) is investigated through an accelerated stress test (AST) consisting of load cycling, load-induced humidity cycling, and open circuit voltage sequences.
- The results showed a strong degradation of the performance due to the aging of the electrodes, which is confirmed by several characterization techniques such as ECSA, impedance spectroscopy and post mortem analysis.
- In the future, we are going to investigate the anode degradation mechanisms by introducing some modifications in the AST to clearly identify which conditions (RH cycling or load cycling, or both combined) are the most detrimental to the cell performances and damaging to its constitutive materials.