In situ Liquid Water Visualization in Polymer Electrolyte Membrane Fuel Cells with High Resolution Synchrotron X-ray Radiography

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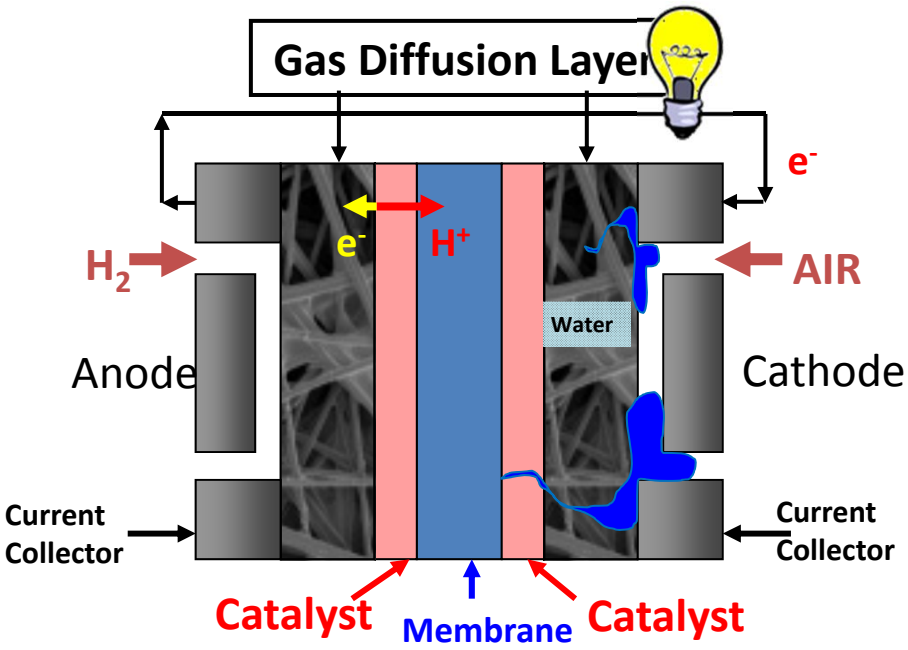
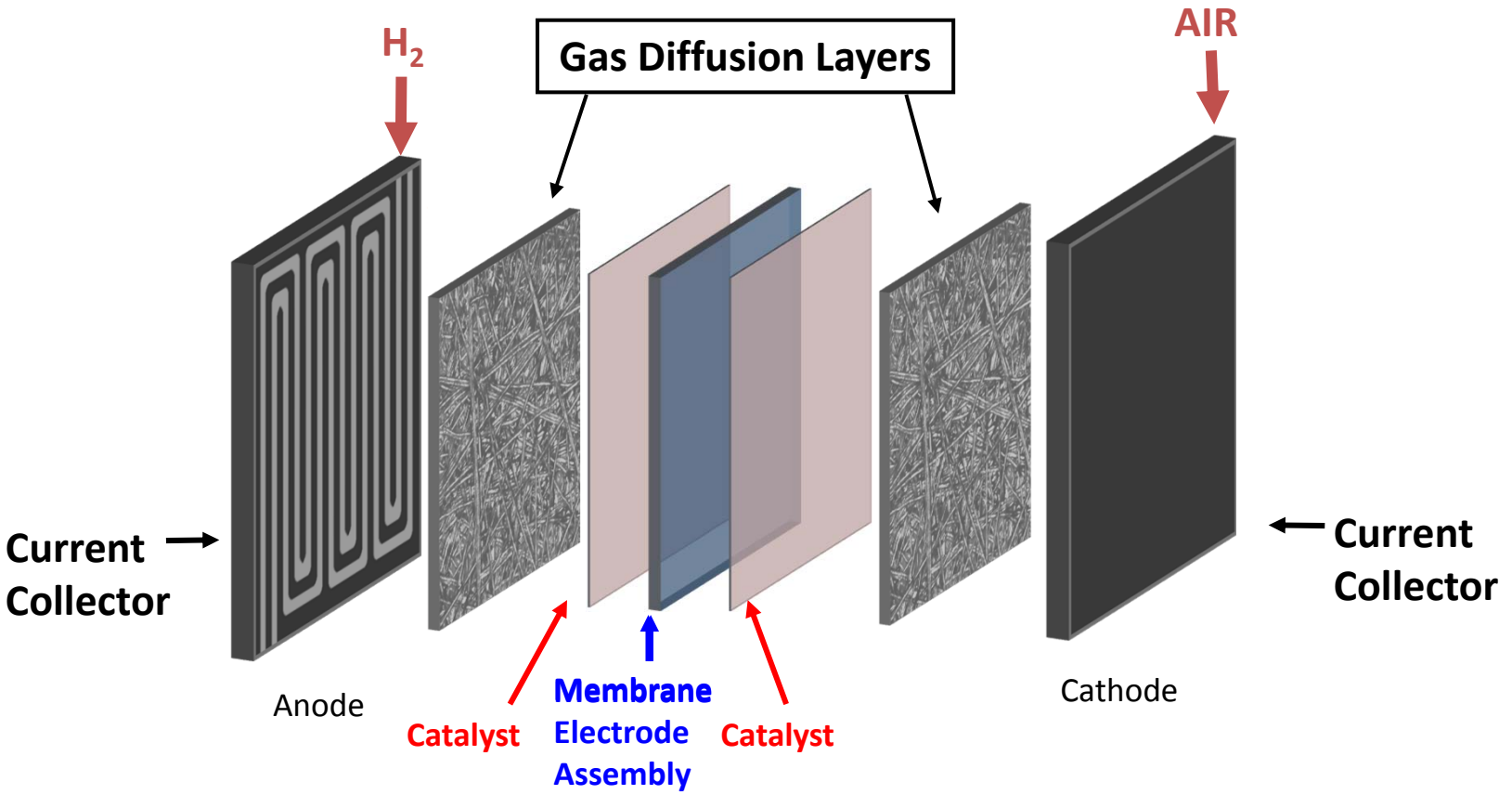
What is a Polymer Electrolyte Membrane Fuel Cell (PEMFC)?

- A fuel cell is an electrochemical energy conversion device.
- Use Hydrogen and Oxygen to produce electricity
- Water is the only by-product
- Chemical reactions
  - Anode: H_2 -> $2H^+ + 2e^-$
  - Cathode: ½.O_2 + $2H^+ + 2e^-$ -> H_2O
  - Overall: H_2 + ½.O_2 -> H_2O



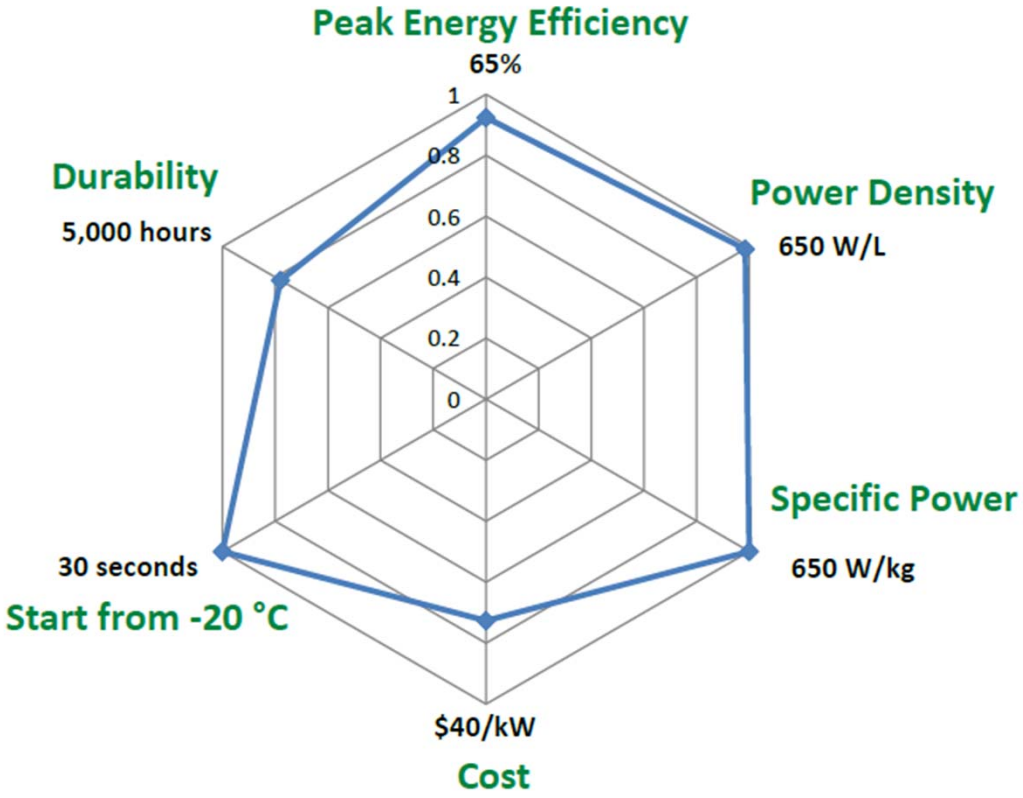
PEMFC Schematic

Proton Exchange Membrane Fuel Cell (PEMFC) Components



Thicknesses of the layers: between 20 – 200 µm.

DoE targets by 2020 for the commercial viability of PEMFC



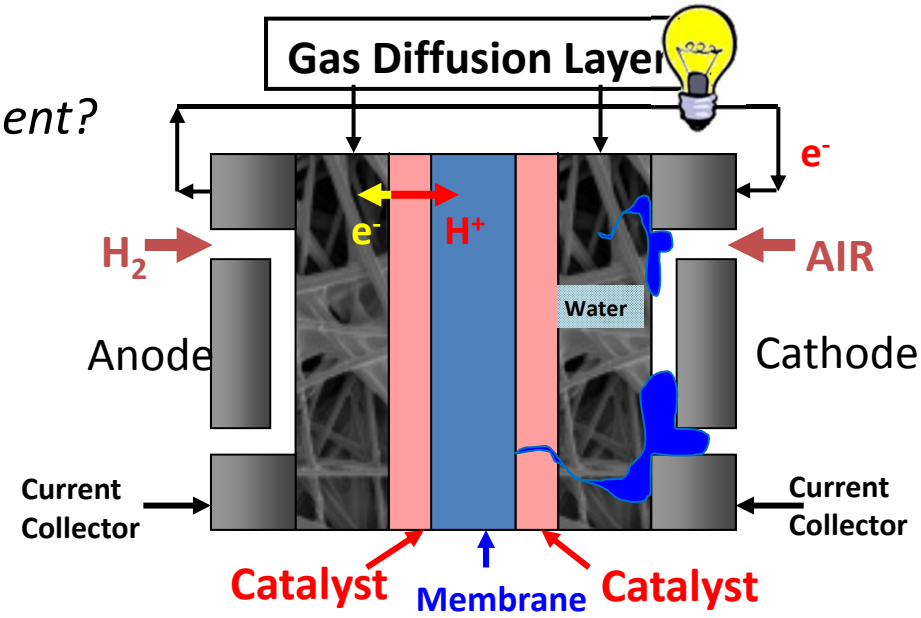
In particular, fuel cell performance and reliability are hindered by non-optimal liquid water management

Figure from *2015 Annual Merit Review and Peer Evaluation Meeting June 8 -12, 2015*

Fuel cell water management

What is the optimal fuel cell water management?

- Let enough liquid water in the fuel cell to hydrate the membrane
- Remove all the liquid water from the GDL



How to improve it?

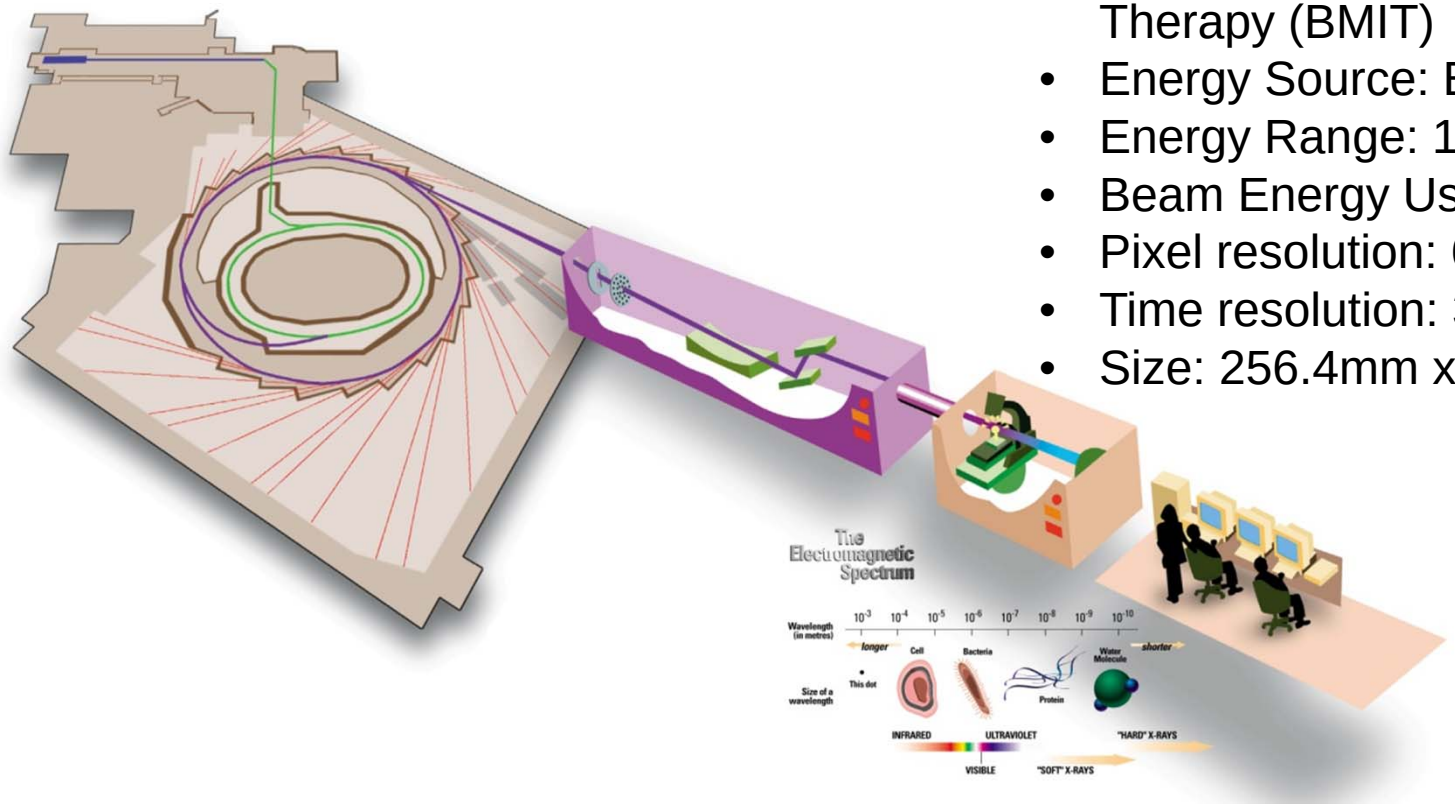
- By obtaining a better understanding of the liquid water transport
- By optimizing the structure of the GDL

➔ These challenges can be tackled by visualizing the liquid water in the GDL of an operating fuel cell

➔ High intensity X-ray radiography can fulfill this requirement.

Fuel cell imaging at the Canadian light source (CLS)

Employing high intensity, monochromatic, and collimated X-rays to facilitate imaging at with high spatial and temporal resolutions.



<u>Canadian Light Source Inc.</u>

- Beamline: BioMedical Imaging & Therapy (BMIT)
- Energy Source: Bending Magnet
- Energy Range: 15-40 keV
- Beam Energy Used: 24 keV
- Pixel resolution: 6.5 µm/pixel
- Time resolution: 3 s/image
- Size: 256.4mm x 8.7 mm @ 26m

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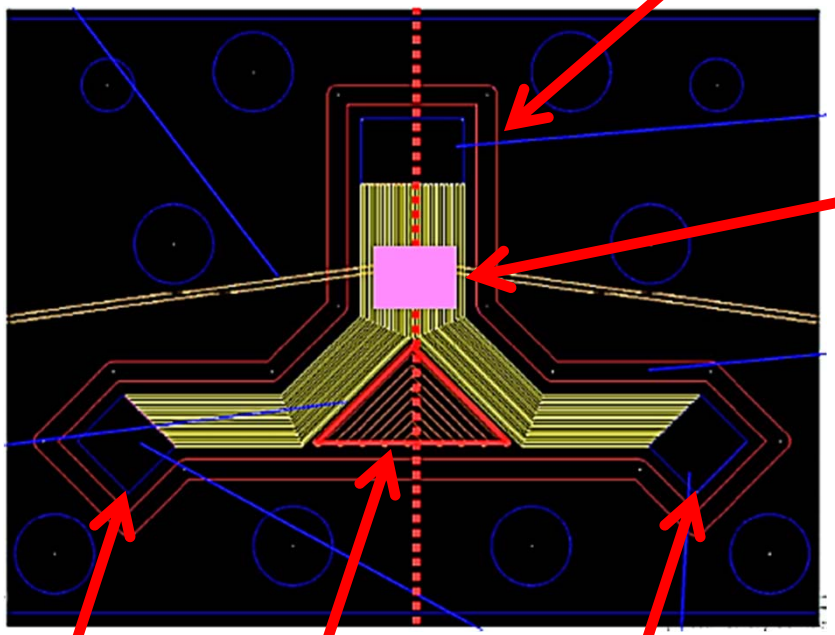
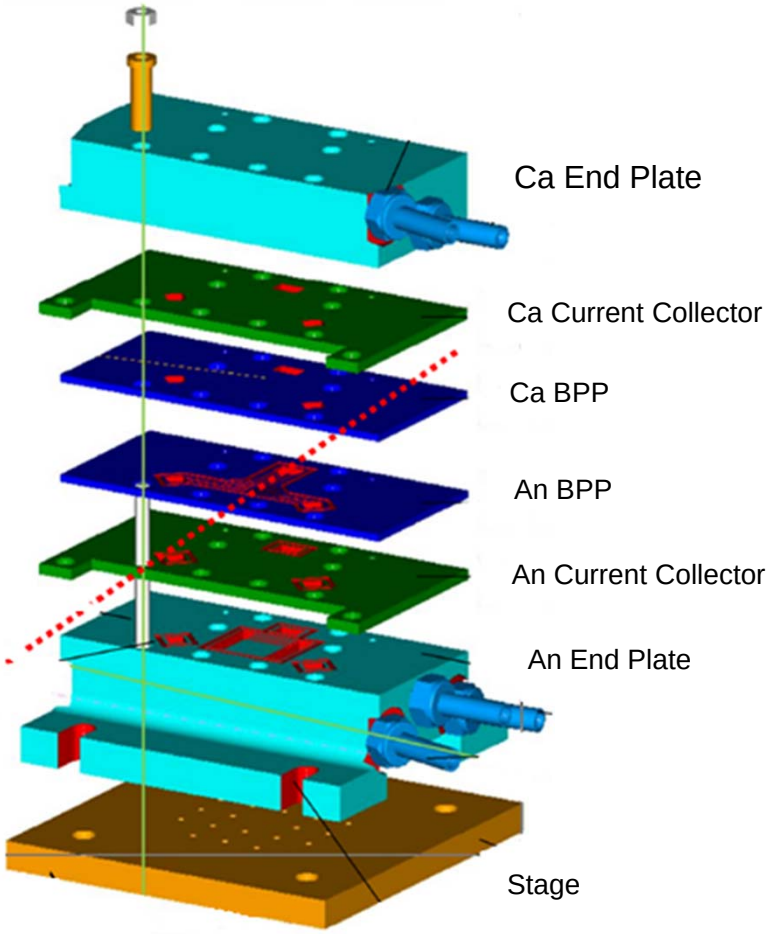
Miniature fuel cell was specifically designed for synchrotron X-ray radiography

Bipolar Plate Configuration
(In-plane View)

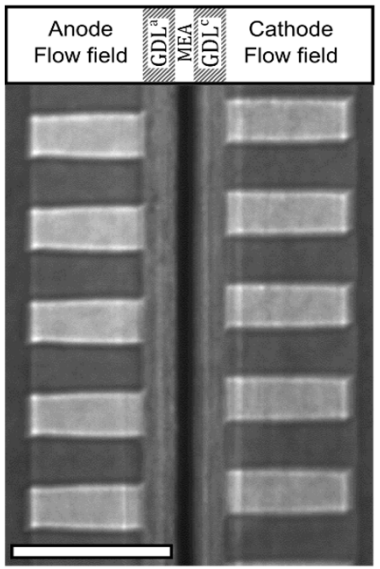


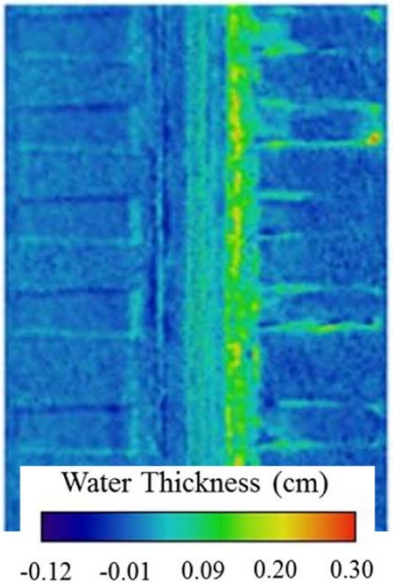


This fuel cell was designed in collaboration with Nissan Motor, Japan

Experimental setup

Image processing





1. Subtract dark image from stack (eliminates stationary artifacts in detector)
2. Compensate for intensity decrease over time
3. Correct images micro-movements
4. Apply Beer-Lambert Law

Liquid water thickness

$$X_w = \frac{1}{\mu_w} \cdot \ln\left(\frac{I_d}{I_w}\right)$$

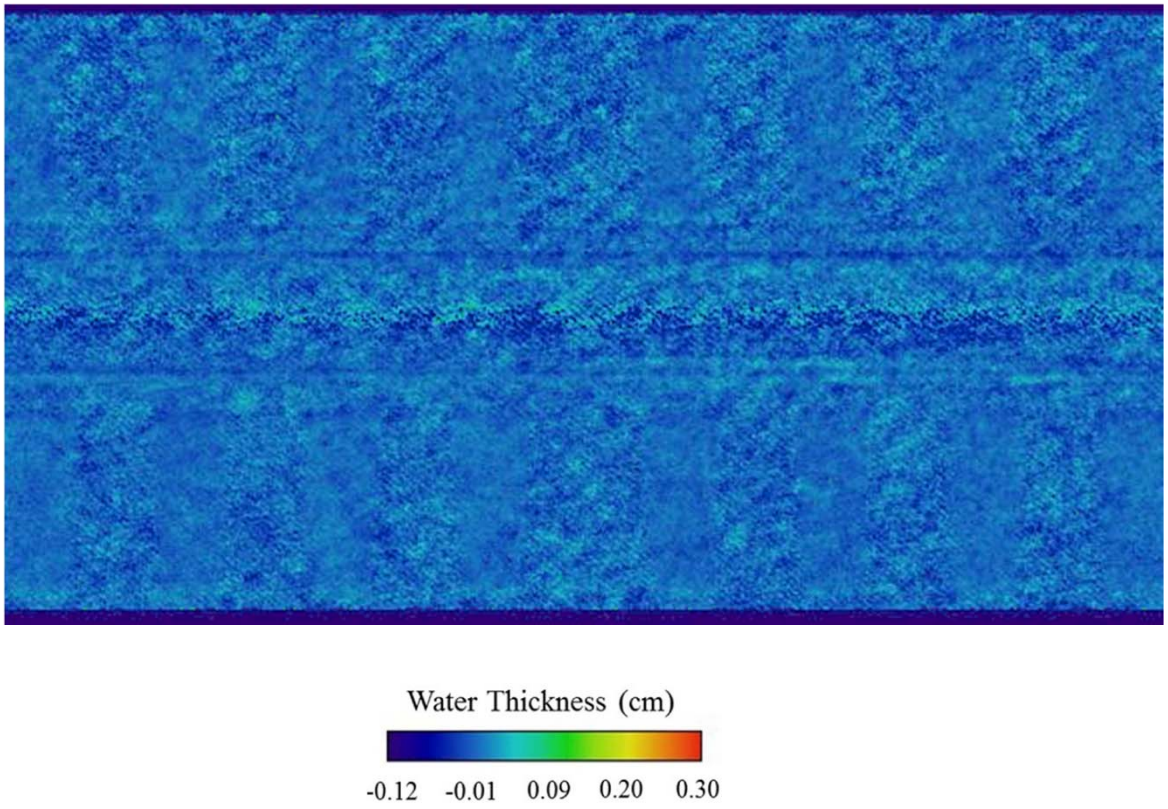
Dry image: fuel cell without liquid water

X-ray attenuation coefficient of water

Wet image: when liquid water has accumulated in the cell

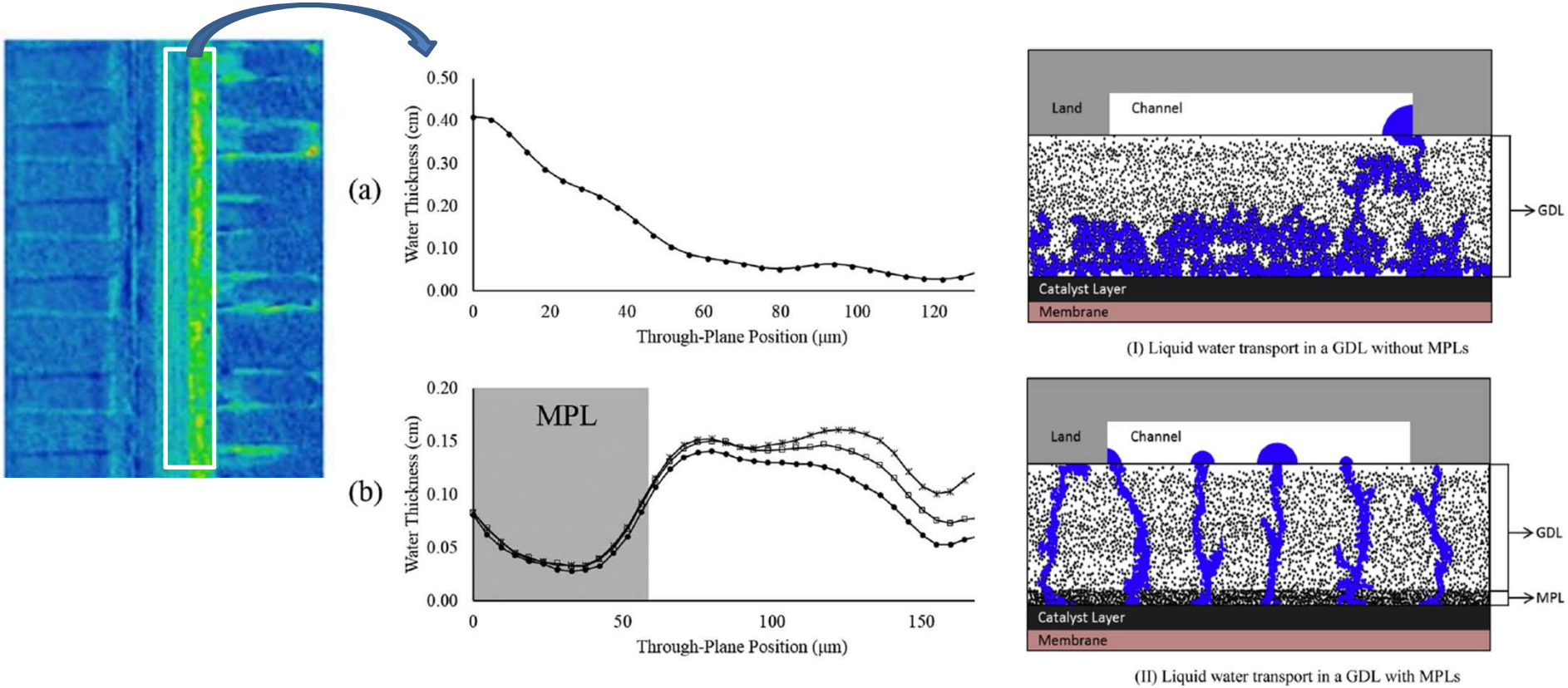
Results

Liquid water in an operating fuel cell



Impact of the GDL structure on the liquid water

Averaged profile in the cathode GDL

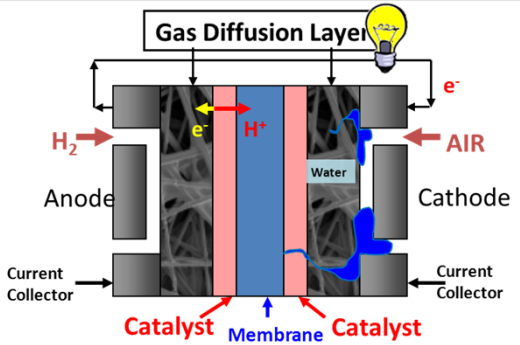


The addition of the micro-porous layer decrease the amount of liquid water accumulated in the fuel cell

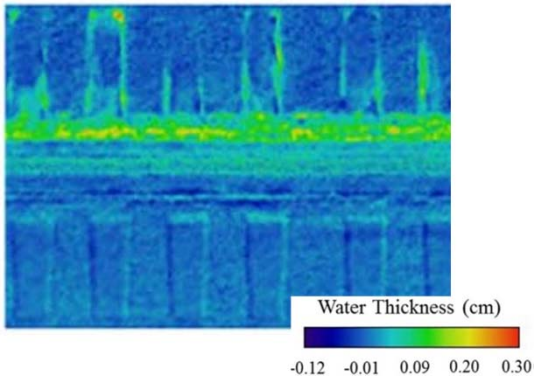
J. Lee et al., J. Power Sources. 227 (2013) 123–130.

Summary

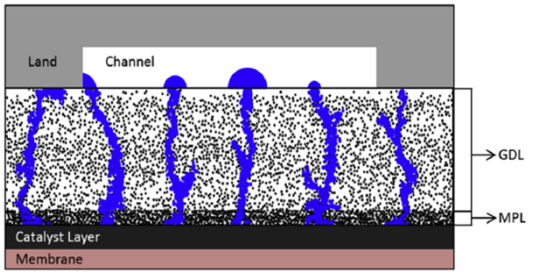
1. Fuel cell performance can be increased by optimizing the liquid water management



2. The liquid water was measured in an operating fuel cell using X-ray synchrotron radiography



3. The structure of the GDL can be used to control the fuel cell water management.



(II) Liquid water transport in a GDL with MPLs

Thank You.

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Canada Foundation for Innovation
Fondation canadienne pour l'innovation

Canadian Light Source
Centre canadien de rayonnement synchrotron

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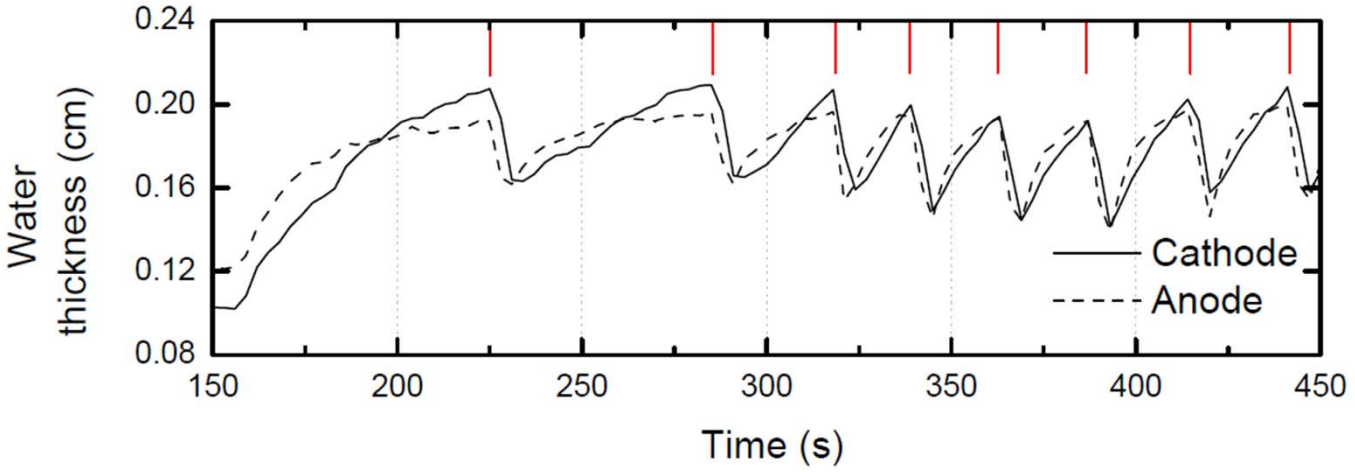
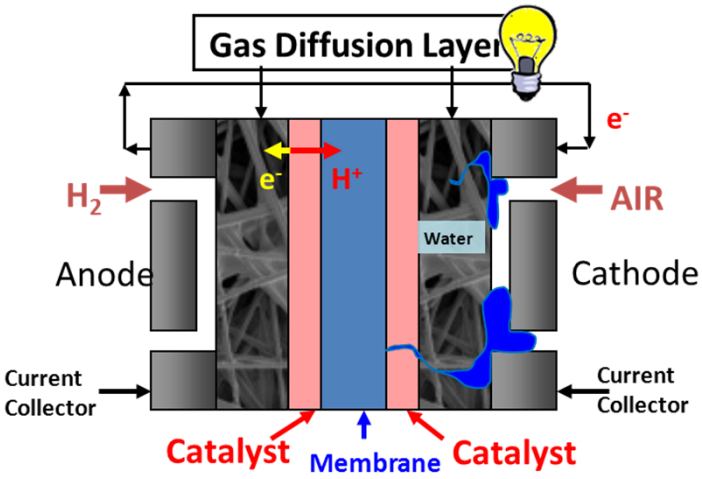
Impact of the fuel cell operating conditions on the liquid water

Fuel cell operating in real automotive conditions





➔ Strong transfer of liquid water from the anode to the cathode, and conversely.

➔ The membrane structure may help to control this transfer

S. Chevalier et al., Electrochem. Commun. (2015), in press.