In situ observation of water distribution and behavior in a polymer electrolyte fuel cell by synchrotron X-ray imaging


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1. Introduction

PEFC (Polymer electrolyte fuel cell) or PEMFC (Proton exchange membrane fuel cell)

- Low temperature fuel cells
- High energy conversion efficiency
- High energy density
- Environmental friendly emission
1. Introduction

- Membrane dry out
- Destabilizes power generation

Water management

- Flooding
- Inhibits power generation

DISTRIBUTION AND BEHAVIOR OF WATER
1. Introduction

- Can measure the removal of water droplets from the GDL
- Superior in terms of spatial and temporal resolution
  - cannot detect the water distribution within the PEFC.
  - Difficult to quantify the water content.

- Excellent penetration
- Sensitive to light element compounds such as water
- Low spatial resolution (>150 um).

- Non-destructive imaging technique
  - the cross section for Water is not sufficient in the case of hard X-rays.

Phase-shift effect

\[ n = 1 - \delta - i\beta \]
1. Introduction

**Synchrotron X-ray imaging**

High brilliance, coherent Synchrotron X-ray permit real time observation of refraction enhanced images of water in the fuel cell.

- Refraction enhanced imaging
- Contains edge-enhanced effects by objects
- The visibility of water droplet in a PEFC is expected to be improved
2. Experimental

Spring-8 in Hyōgo Prefecture, Japan
Beamline: BL19B2 and BL20B2

BL19B2
- Tunable energy range: 5~72 keV
- Horizontal beam divergence: 1.4 mrad
- Photon flux: \( \sim 10^9 \) photons/s
- Energy resolution: \( \Delta E/E \sim 10^{-4} \)
- Higher harmonics rejection ratio: \( \sim 10^{-4} \)

BL20B2
- Energy range:
  - Si 311: 8.4-72.5 keV
  - Si 111: 5.0-37.5 keV
  - Si 511: 13.5-113.3 keV
- Beam divergence:
  - 1.5 mrad (Horizontal)
  - 0.06 mrad (Vertical)
2. Experimental

Experimental hutches were placed at 111 m (BL19B2) and 206 m (BL20B2) from the light source.
A monochromatic rectangle X-ray beam was irradiated on the PEFC and the transmitted X-ray beam was recorded using a two-dimensional X-ray detector as an image. Images were measured continuously before and during power generation.
The PEFC was placed in two directions on the sample stage: either the layers were parallel to the incident X-rays for observing the distribution of water in the depth direction of each layer, or the layers were perpendicular to the incident X-rays for observing the in-plane distribution of water of the layers.
3. Results and discussion

This measurement was performed at **BL19B2**.

Beer–Lambert’s law,

\[ I = I_0 A \exp(-\mu \Delta l) \]

(a) Photograph of the PEFC.
(b) Raw image of the PEFC before power generation.
(c) Analysed images during measurement of the polarization curve at current density: 7 mA/cm²
(d) 105 mA/cm²
(e) 190 mA/cm²
(f) An analysed image after flooding.

When layers were perpendicular to incident X-rays

**Polarization curve**
3. Results and discussion

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(a) Photograph of the PEFC.
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When layers were perpendicular to incident X-rays
When layers were parallel to incident X-rays
3. Results and discussion

This measurement was performed at BL20B2.

Cross-section images of water distribution of two PEFCs.

normal carbon paper was used as the cathode GDL.
120 mA/cm² (g), 242 mA/cm² (h) and 346 mA/cm² (i).

modified GDL contained carbon paper and had a pinhole array perpendicular to the GDL.
91 mA/cm² (b), 152 mA/cm² (c), 242 mA/cm² (d) and 373 mA/cm² (e)
4. Conclusion

- A synchrotron X-ray imaging technique was used to observe the water distribution and behaviour in PEFCs during power generation. Using this technique, the water distribution and behaviour were clarified with high spatial resolution in the components of the PEFC such as GDL or foam metal at the same time.

- This technique is very powerful for verifying the mechanism of water flow in PEFC under several conditions such as component materials of the PEFC or power generation. The technique is also useful for comparing numerous models of water distribution with actual distributions with high spatial resolution.
Thank You!