Control of the Balance between Vapor and Heat Transfer for the Reduction of Oxygen Transport Resistance in High Current Density PEFC Operation

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Introduction

Objective

To improve cell performance by reducing oxygen transport resistance

1) To clarify the increase in oxygen transport resistance
2) Control of the balance between Vapor and Heat Transfer to reduce oxygen transport resistance
3) Effect of channel and flow rate

Background

Flooding (the blockage of the gas supply by the accumulation of water) ⇒ Oxygen transport resistance increases

However, we confirmed the increase in oxygen transport resistance not by flooding
### Experimental Methods and Conditions

#### IV curve and oxygen transport resistance measurements

![IV curve graph](image)

- **Oxygen transport resistance**: 
  \[ R_T = 4F \frac{C_0}{I_{lim}} \]
  
  - \( F \): Faraday’s constant
  - \( C_0 \): Oxygen concentration
  - \( I_{lim} \): Limiting current density (V=0.1V)

#### Conditions

- **Active area**: 1.8cm² (2cm × 0.9cm)
- **Rib channel width**: 0.3mm
- **GDL with MPL**: CB-MPL, 28BC, 38BC

<table>
<thead>
<tr>
<th>Cell Temperature</th>
<th>Cathode</th>
<th>Anode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td>Mixed Gas (O₂+N₂)</td>
<td>H₂</td>
</tr>
<tr>
<td><strong>Flow Rate</strong></td>
<td>4000sccm</td>
<td>100sccm</td>
</tr>
<tr>
<td><strong>O₂</strong>: 1~24%</td>
<td>100kPa</td>
<td>100kPa</td>
</tr>
<tr>
<td><strong>H₂</strong>: 100%</td>
<td>81%RH</td>
<td>81%RH</td>
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Causes of Increase in $R_T$ (CB-MPL)

The RH of the gas increases
The increase in the $R_T$ shifts to **lower $I_{Lim}$**

**Flooding**

The RH of the gas increases
The increase in the $R_T$ shifts to **higher $I_{Lim}$**

**Drying**
Causes of Increase in $R_T$ (CB-MPL)

- At 80°C
- The RH of the gas increases
- The increase in $R_T$ shifts to higher $I_{Lim}$

- The cell resistance is kept similar
- The voltage drops suddenly
  ⇒ Not by the dry-out of PEM

- The RH of the gas increases
- The increase in the $R_T$ shifts to higher $I_{Lim}$
Cryo-SEM Observation

**Freezing Method**

Observation method of the water distribution in the cell by freezing and immobilizing the water in ice form


**Freezing method**

Operation → Cooling (-40 °C) → Making samples in liquid nitrogen → Cryo-SEM observation (-150 °C)
Cryo-SEM Observation Results

Flooding condition
(50°C, 81%RH, 220kPa)

A large amount of ice in MPL and CL

High temperature condition
(80°C, 81%RH, 100kPa)

No ice in MPL and CL
One-dimensional Analysis

Vapor diffusion and Heat conduction model

\[ \begin{align*}
T_{CL} &= \frac{Z_H (E - V)i}{k} (h_{GDL} + h_{MPL}) + T_s \\
T_{CL} &= \frac{7.5}{237.5 + T_{CL}} \\
P_{W,CL} &= 6.11 \times 10^{237.5 + T_{CL}} \\
P_{W,CL} &= Z_W \frac{iR}{2FD_{eff}} \left\{ \frac{Z_H (E - V)i}{k} (h_{GDL} + h_{MPL})^2}{2} + T_s (h_{GDL} + h_{MPL}) \right\} + P_{W,Ch}
\end{align*} \]
Estimation of RH in the CL

Vapor diffusion and Heat conduction model

\[ \text{RH}_{\text{CL}} \% \text{RH} \]

- 53%RH
- 66%RH
- 81%RH

\[ R_T \] increases at around 40%RH

\[ I_{\text{Lim}} \text{ [A/cm}^2\text{]} \]

80°C

Cause: Drying in the CL

Decrease in water content of the ionomer

⇒ Poor oxygen permeability

Estimation of RH in the CL

Vapor diffusion and Heat conduction model

\[ R_{T} \text{ increases at around 40\%RH} \]
Cause of Drying in the CL

RH in the CL decreases as $I_{\text{Lim}}$ increases

Low thermal conduction of the CB-MPL

$\rightarrow$ Temperature in the CL ($T_{\text{CL}}$) increases

$\rightarrow$ Saturated vapor pressure ($P_{S,\text{CL}}$) increases

<table>
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<th>28BC</th>
<th>38BC</th>
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<tr>
<td>Thermal Conduction $k$ [W/m·K]</td>
<td>0.116</td>
<td>0.500</td>
<td>0.350</td>
</tr>
<tr>
<td>Diffusivity $D$ / Effective Diffusivity $D_{\text{eff}}$</td>
<td>4.10</td>
<td>4.50</td>
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Controlling the balance between vapor and heat transfer (RH is constant)

To reduce the oxygen transport resistance

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<th>Material</th>
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Results (81%RH, 100kPa)

**CB-MPL**

- Voltage [V] vs. Current Density [A/cm²]
- Curves for 35°C, 50°C, and 80°C temperatures.

**28BC**

- Voltage [V] vs. Current Density [A/cm²]
- Curves for 40°C, 64°C, and 80°C temperatures.

**38BC**

- Voltage [V] vs. Current Density [A/cm²]
- Curves for 40°C and 80°C temperatures.

**Additional Diagrams**

- Resistance $R_T$ [Ω] vs. $I_{Lim}$ [A/cm²]
  - CB-MPL: Curves for 35°C, 50°C, and 80°C temperatures.
  - 28BC: Curves for 40°C and 80°C temperatures.
  - 38BC: Curves for 40°C and 80°C temperatures.
• **Cathode Gas Flow Rate : 4000sccm**

⇒ To prevent water from staying in the channel

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**Graph:**
- Voltage [V] vs. Current Density [A/cm²]
- Conditions: 80°C, 81%RH, 100kPa, 28BC
- Lines:
  - 4000sccm
  - 2000sccm

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**Images:**
- Channel size: 0.3mm
- Channel size: 1.0mm
Unrealistic Operating Conditions (1)

- **Rib channel width**: 0.3mm → 1.0mm

80°C, 81%RH, 100kPa, 28BC

Voltage [V] vs. Current Density [A/cm²]

- **0.3mm**
- **1.0mm**

Channel structure diagram with regions labeled MPL, GDL, MPL, CL, and PEM.

Microscope images showing MPL, CL, and an ice layer at 0.3mm and 1.0mm channel widths.
Conclusions

• Under high temperature conditions where water is less likely to stay in the GDL and channel, the increase in oxygen transport resistance can be due to the drying of the ionomer in the CL.

• It was confirmed that the increase in oxygen transport resistance could be suppressed by controlling the balance between vapor diffusion and heat conduction. This is considered to be useful knowledge for designing GDL / MPL structure.

• In this research, the liquid water is less likely to stay inside the cell (narrow channel, high gas flow rate). It is necessary to design the cell structure so that the increase in oxygen transport resistance can be suppressed even under conditions closer to actual operation.