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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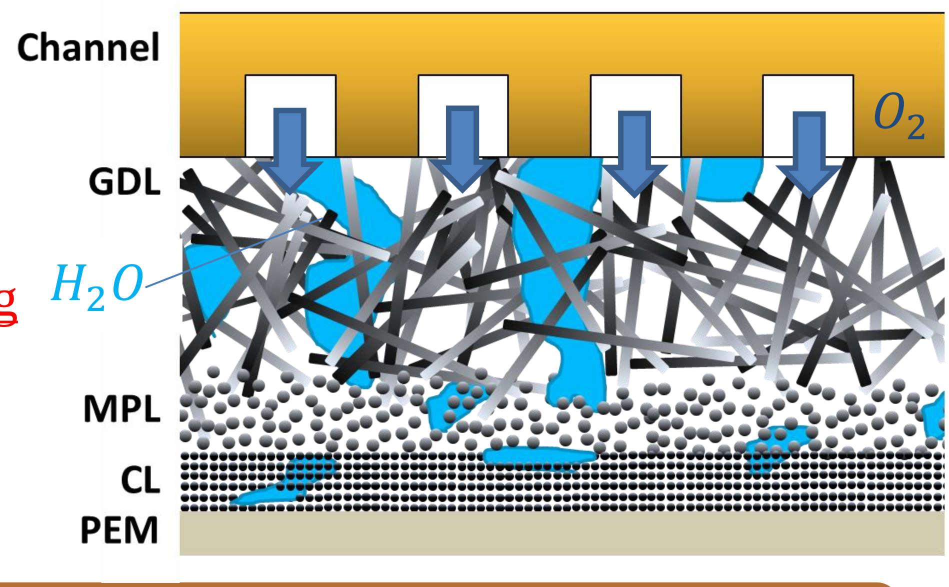
Introduction

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



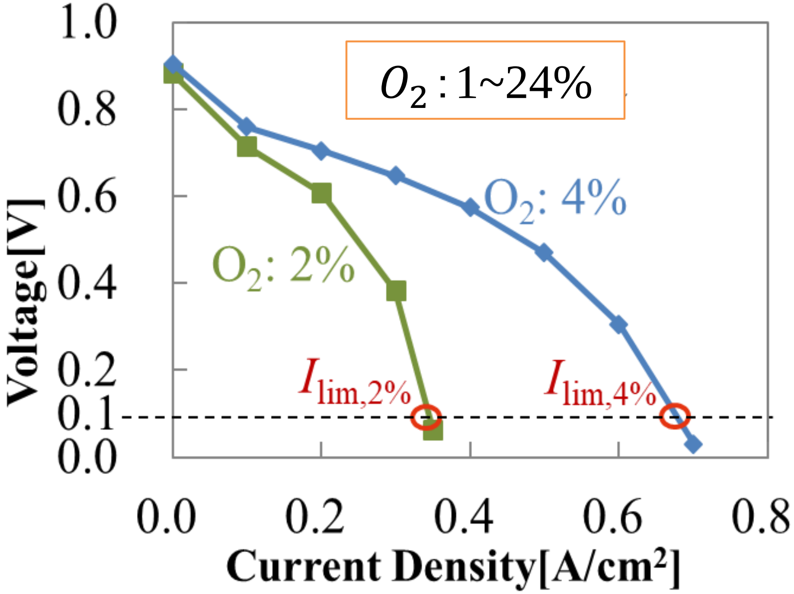
Objective

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

Experimental Methods and Conditions

IV curve and oxygen transport resistance measurements



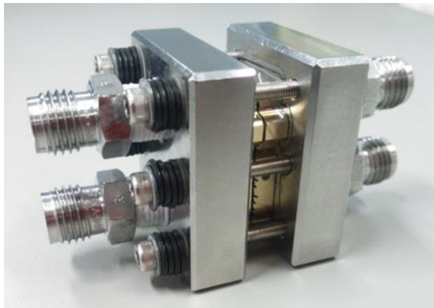
Limiting Current Method

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

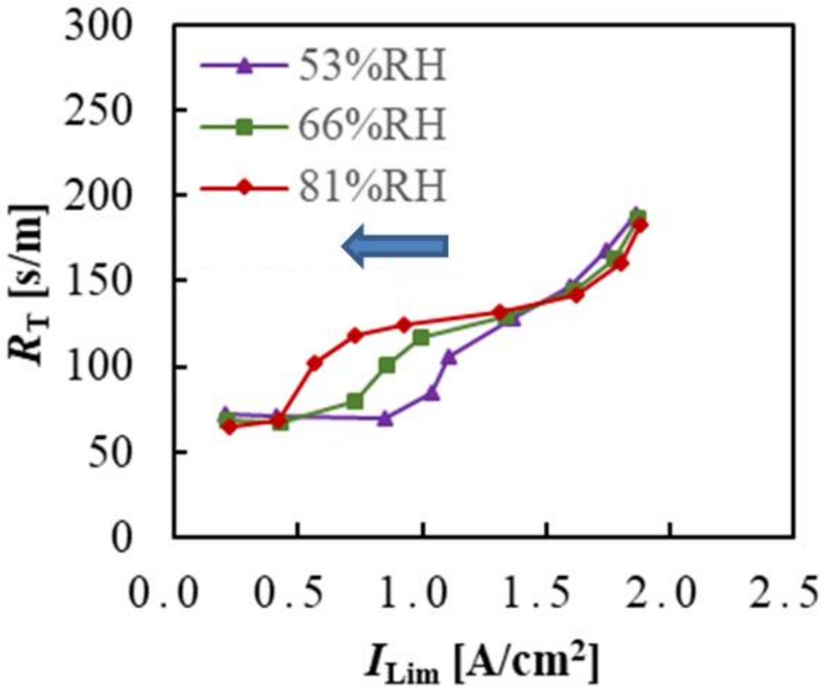


・Active area : 1.8cm² (2cm × 0.9cm)
・Rib channel width : 0.3mm
・GDL with MPL : CB-MPL, 28BC, 38BC

	Cathode	Anode
Cell Temperature	35~80°C	
Gas	Mixed Gas (O_2+N_2)	H_2
Flow Rate	4000sccm	100sccm
	O_2: 1~24%	H_2: 100%
Pressure	100kPa	100kPa
Humidity	81%RH	81%RH

Causes of Increase in R_T (CB-MPL)

35°C

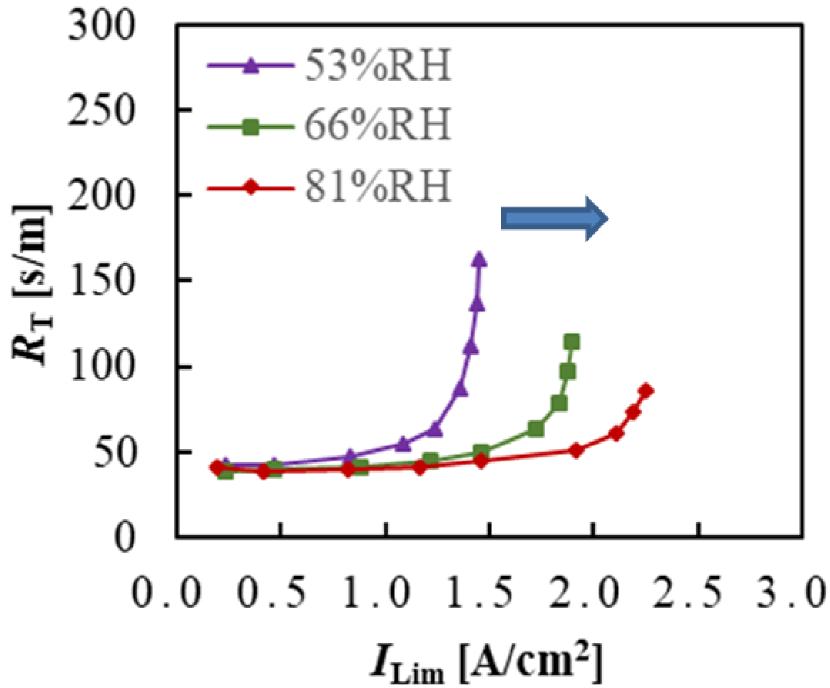


The RH of the gas increases

The increase in the R_T shifts to lower I_{Lim}

Flooding

80°C



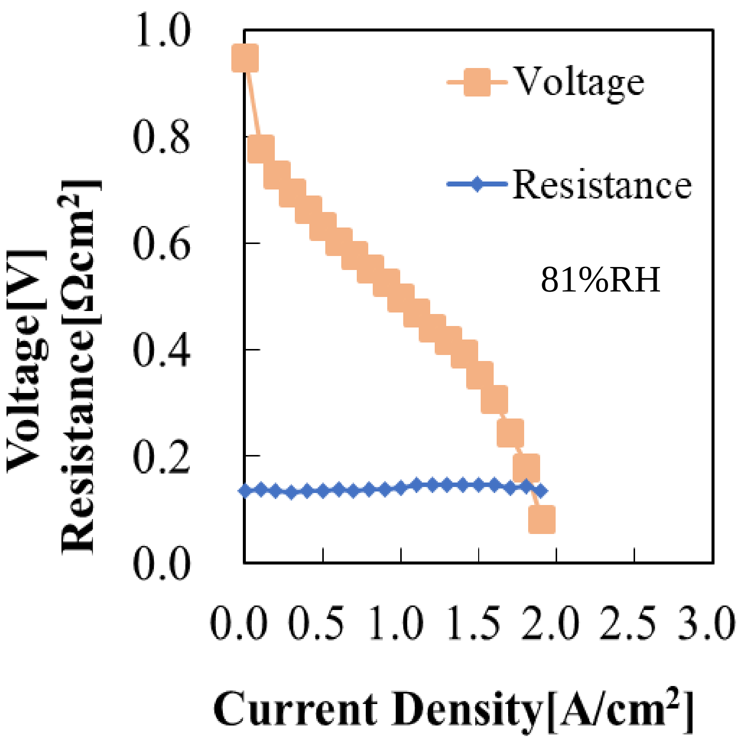
The RH of the gas increases

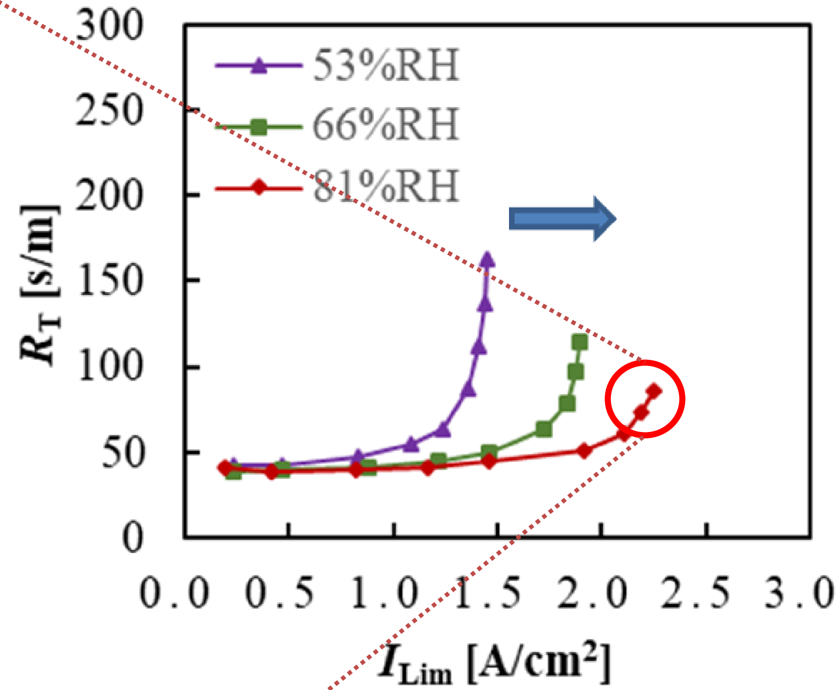
The increase in the R_T shifts to higher I_{Lim}

Drying

Causes of Increase in R_T (CB-MPL)

80°C





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}

Drying

Cryo-SEM Observation

Freezing Method

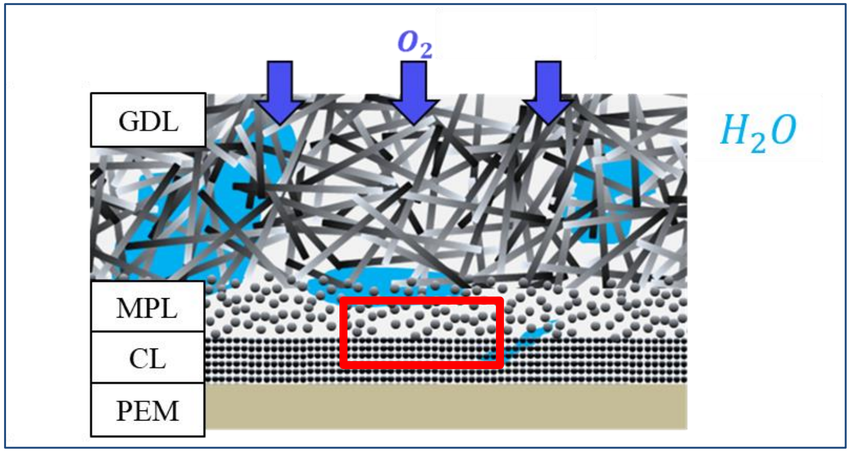
Observation method of the water distribution in the cell by freezing and immobilizing the water in ice form

[1] Y. Aoyama, K. Suzuki, Y. Tabe, and T. Chikahisa, *Electrochem. Commun.*, **41**, 72 (2014).

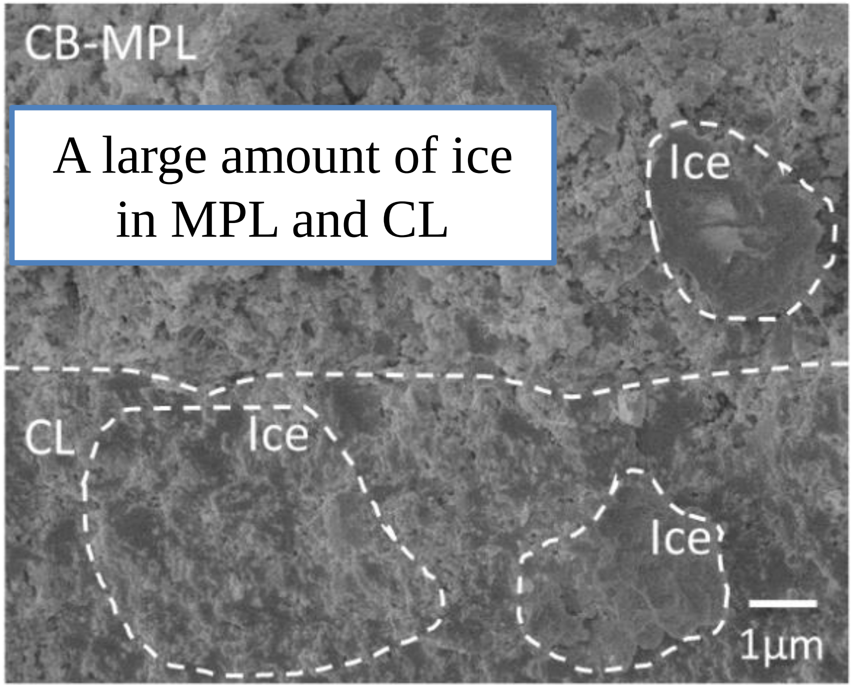
Freezing method

Operation → Cooling (-40 ºC) → Making samples in liquid nitrogen → Cryo-SEM observation (- 150 ºC)

Cryo-SEM Observation Results

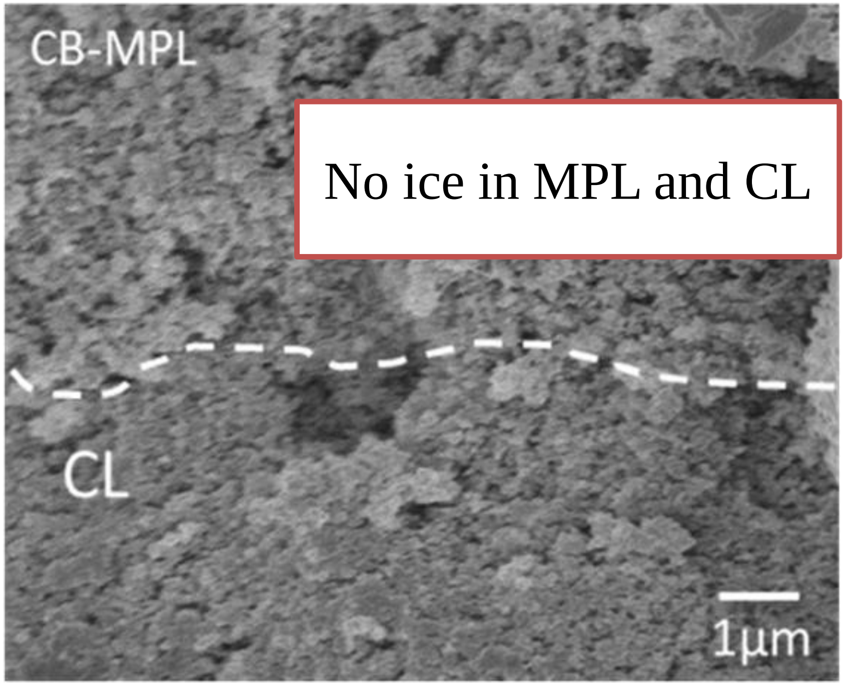


Flooding condition (50°C, 81%RH, 220kPa)



A large amount of ice in MPL and CL

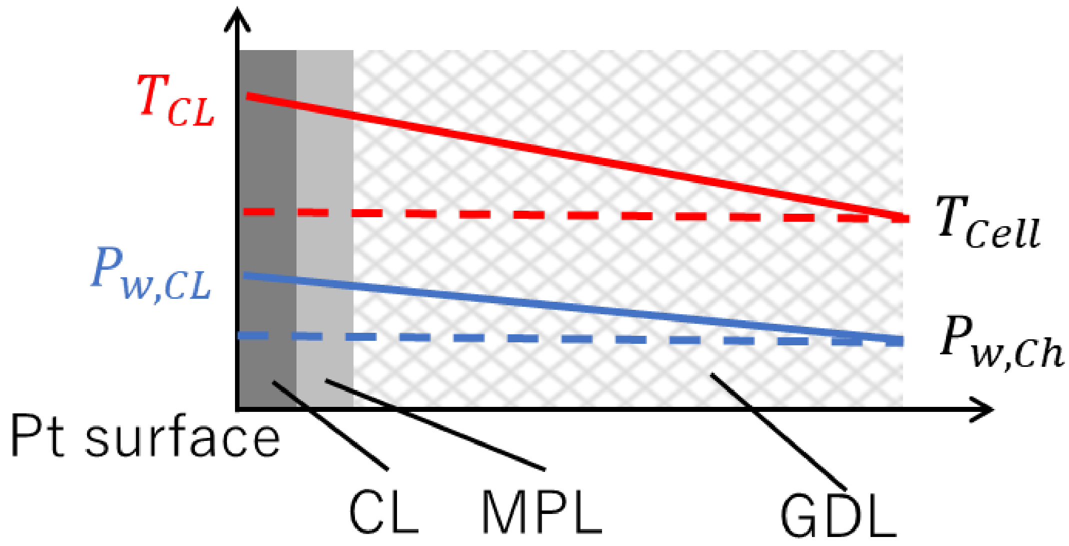
High temperature condition (80°C,81%RH, 100kPa)



No ice in MPL and CL

One-dimensional Analysis

Vapor diffusion and Heat conduction model



$$\boldsymbol{RH_{CL}} = \frac{\boldsymbol{P_{W,CL}}}{\boldsymbol{P_{S,CL}(T_{CL})}}$$

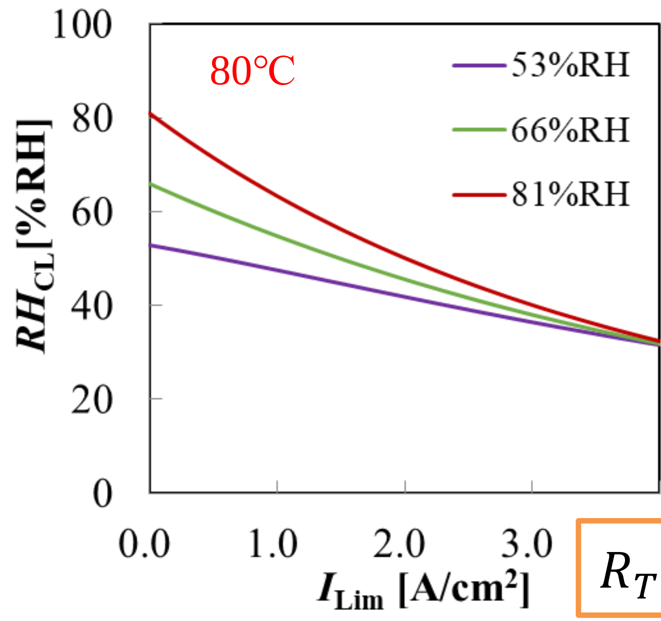
$$T_{CL} = \frac{Z_H(E-V)i}{k}(h_{GDL} + h_{MPL}) + T_s$$

$$P_{s,CL} = 6.11 \times 10^{\frac{7.5T_{CL}}{237.5+T_{CL}}}$$

$$P_{W,CL} = Z_W \frac{iR}{2FD_{eff}} \left\{ \frac{Z_H(E-V)i}{k} \frac{(h_{GDL} + h_{MPL})^2}{2} + T_s(h_{GDL} + h_{MPL}) \right\} + P_{W,Ch}$$

Estimation of RH in the CL

Vapor diffusion and Heat conduction model



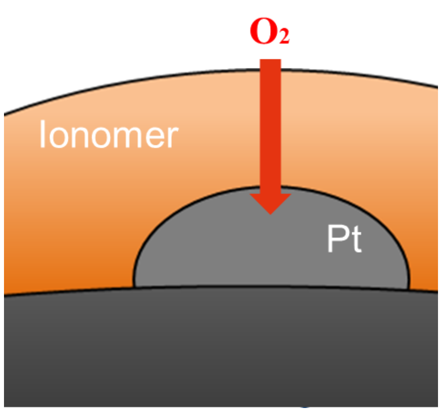
R_T increases at around 40%RH

300

300

Cause : Drying in the CL

Decrease in water content of the ionomer
⇒Poor oxygen permeability



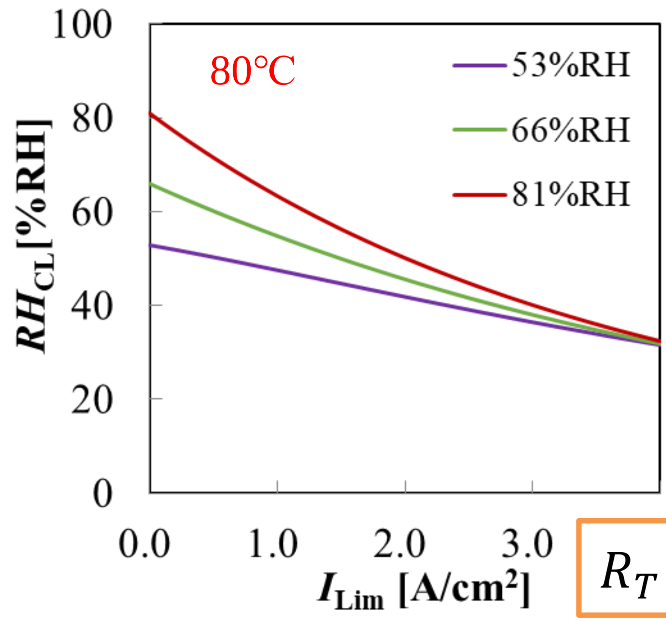
[7] H. F. M. Mohamed, et al, *Polymer*., 40 (2008), 3091.

I_{Lim} [A/cm²]

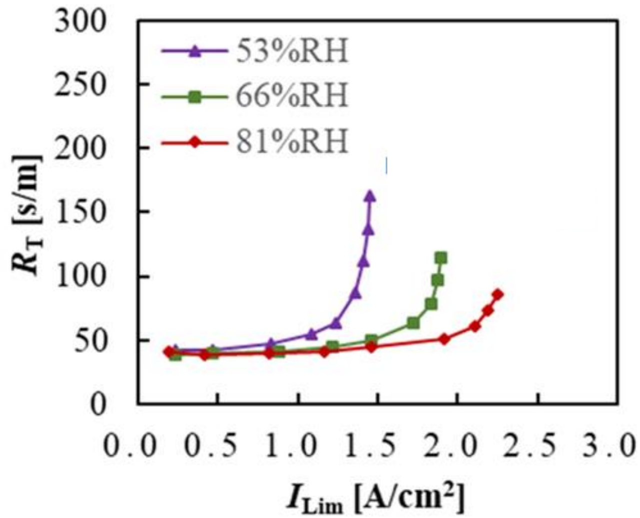
RH_{CL} [%RH]

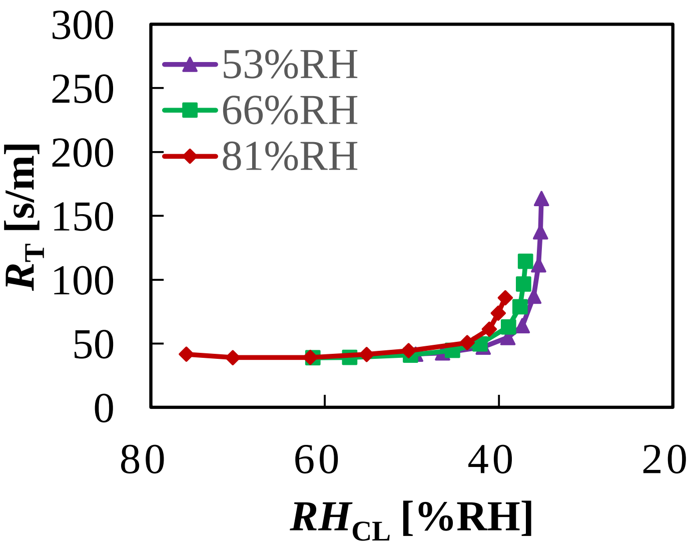
Estimation of RH in the CL

Vapor diffusion and Heat conduction model

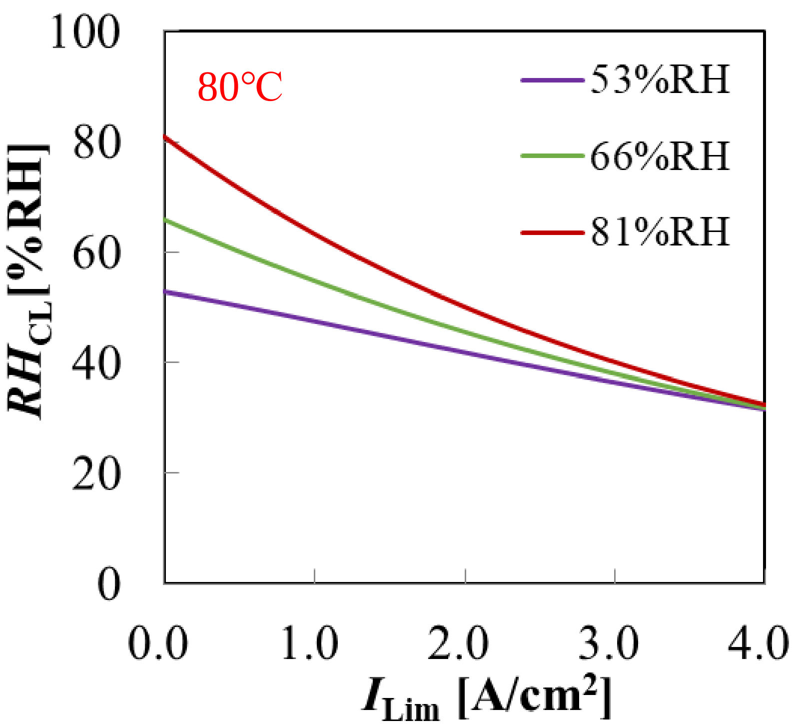


R_T increases at around 40%RH





Cause of Drying in the CL

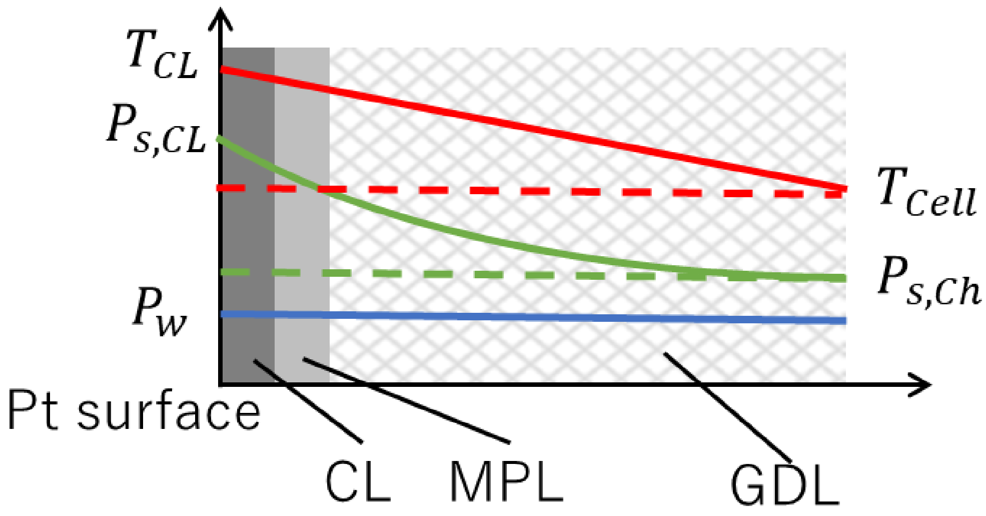


RH in the CL decreases as I_{Lim} increases

<u>Low thermal conduction of the CB-MPL</u>

→Temrperature in the CL (T_{CL}) increases

→Saturated vapor pressure ($P_{s,CL}$) increases



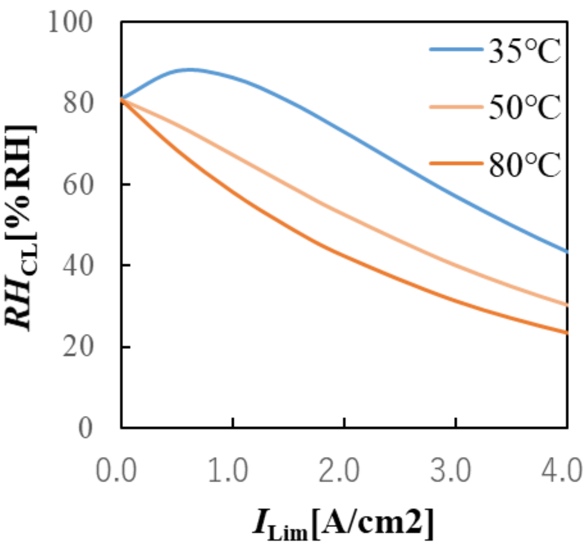
	CB-MPL	28BC	38BC
Thermal Conduction k [W/m·K]	0.116	0.500	0.350
Diffusivity D / Effective Diffusivity D_{eff}	4.10	4.50	4.50

Vapor Diffusion and Heat Conduction

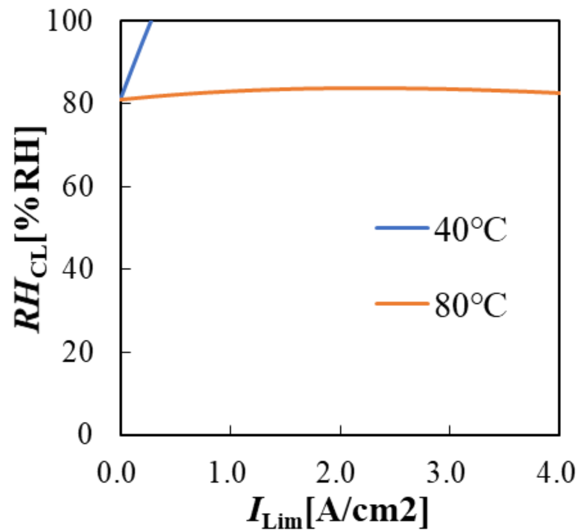
Controlling the balance between vapor and heat transfer
(RH is constant)

To reduce the oxygen transport resistance

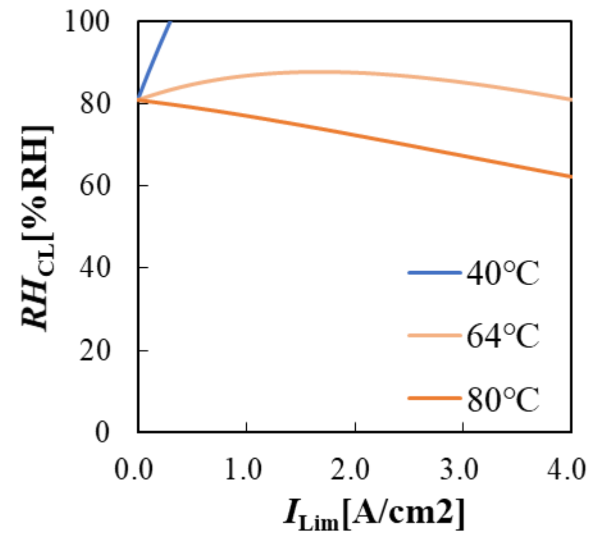
CB-MPL



28BC



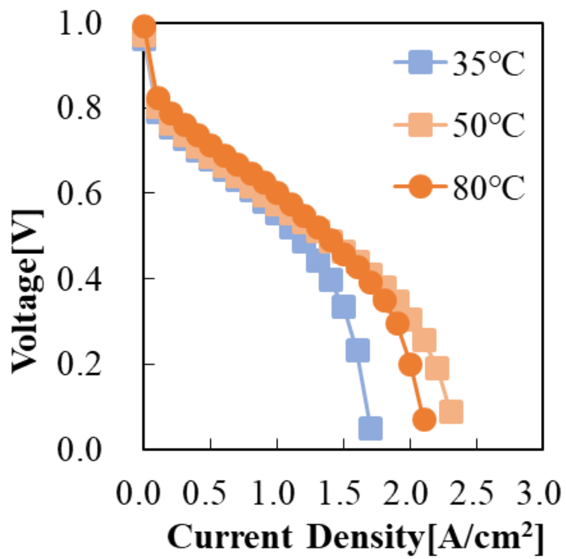
38BC

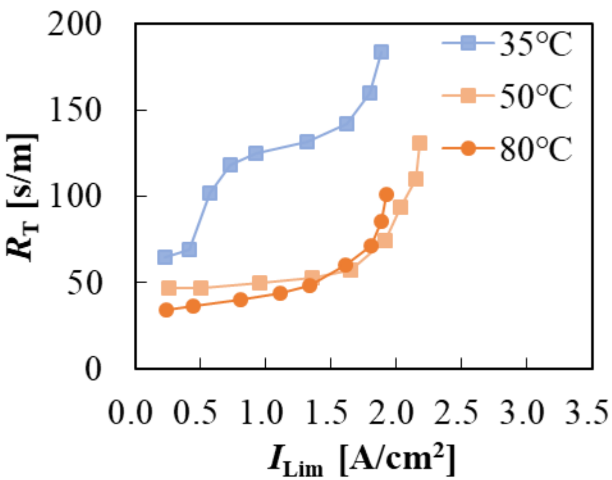


	CB-MPL	28BC	38BC
Thermal Conduction k [W/m·K]	0.116	0.500	0.350
Diffusivity D / Effective Diffusivity D_{eff}	4.10	4.50	4.50

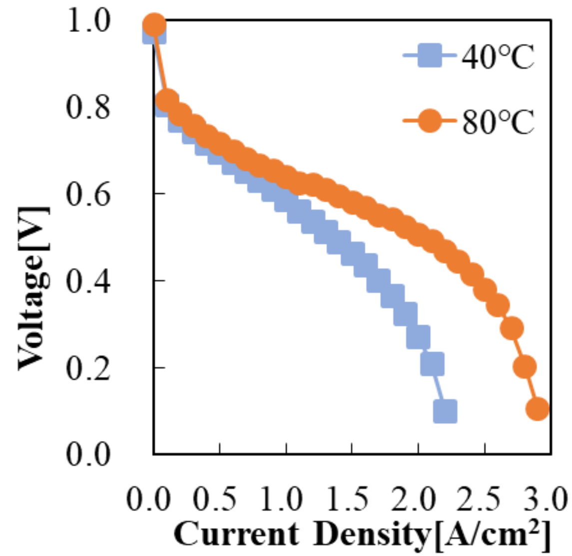
Results (81%RH,100kPa)

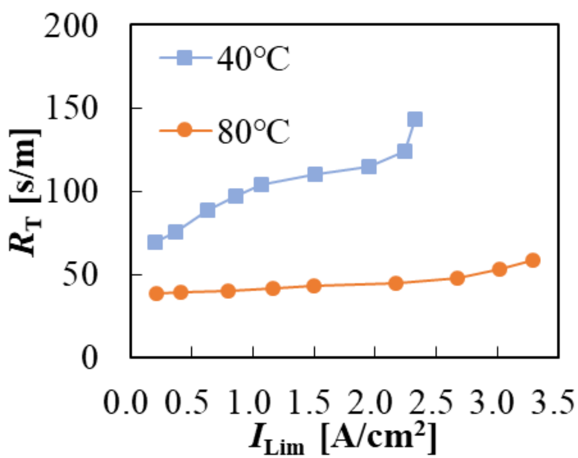
CB-MPL



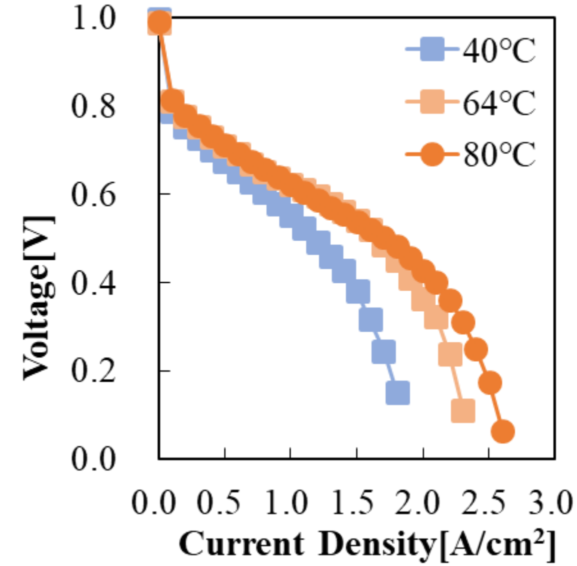


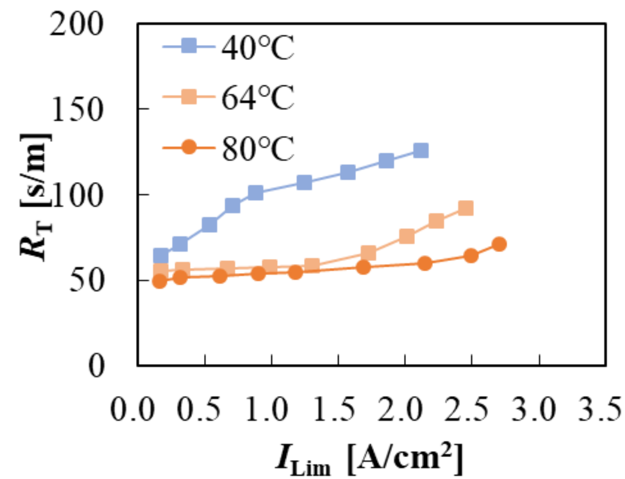
28BC





38BC



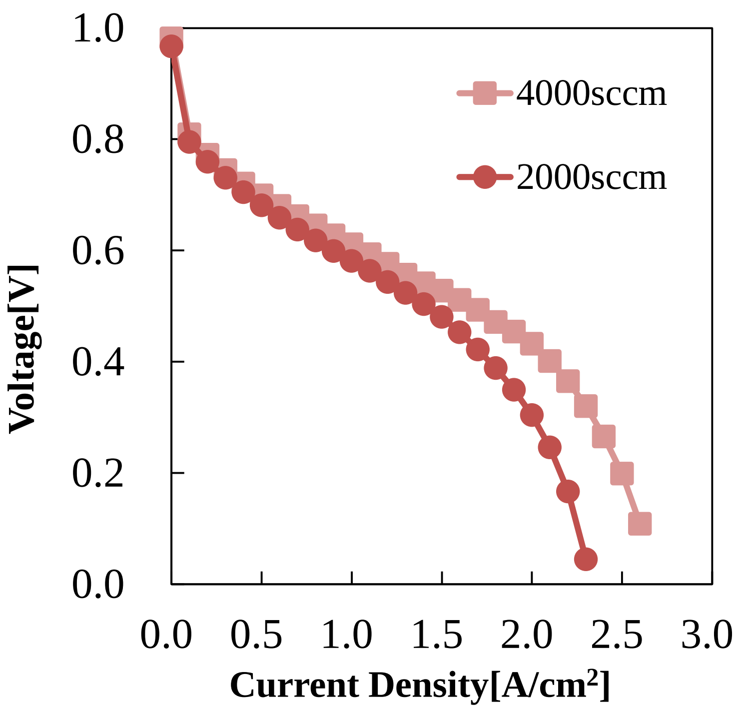


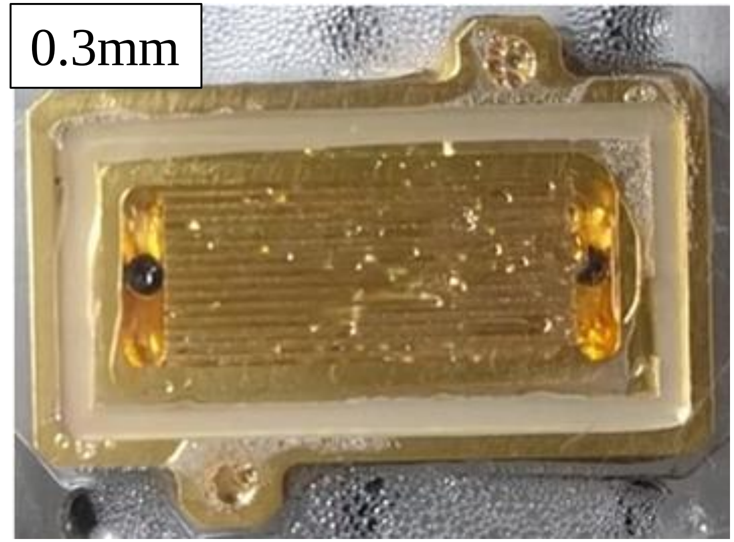
Unrealistic Operating Conditions (2)

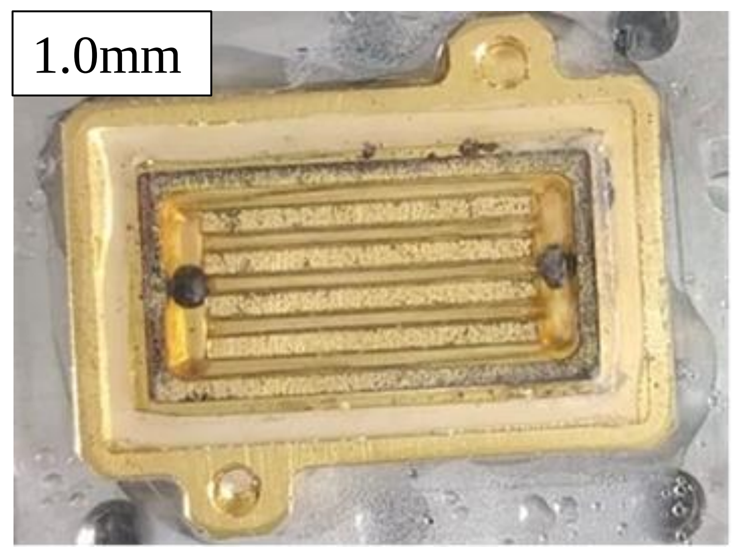
- **Cathode Gas Flow Rate : 4000sccm**

⇒ To prevent water from staying in the channel

80°C, 81%RH, 100kPa, 28BC



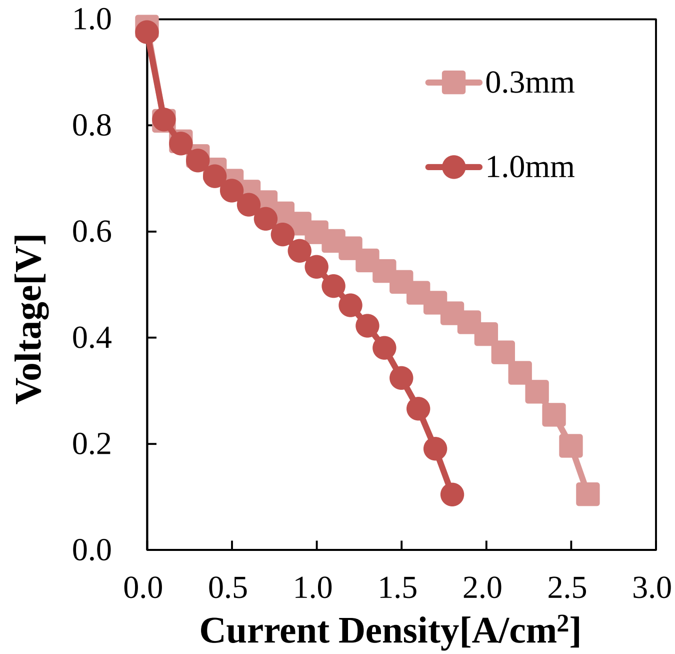


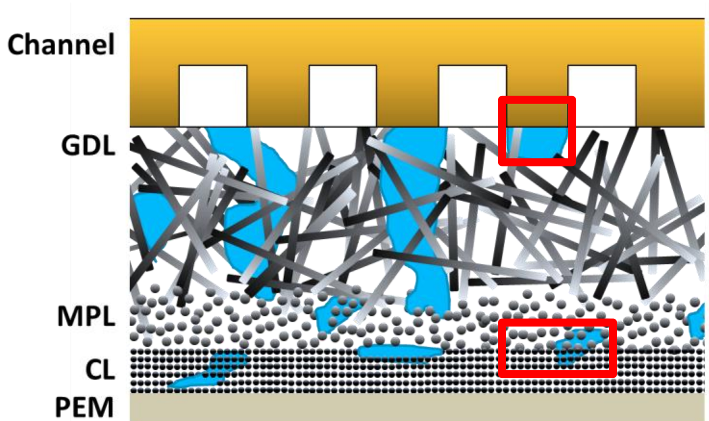


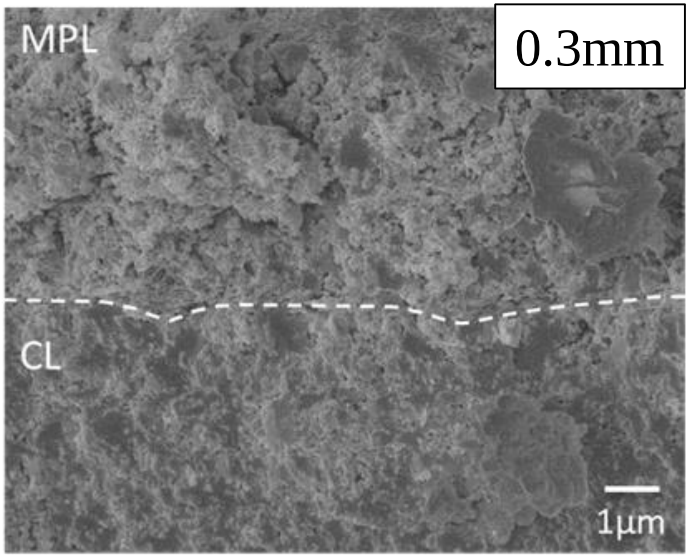
Unrealistic Operating Conditions (1)

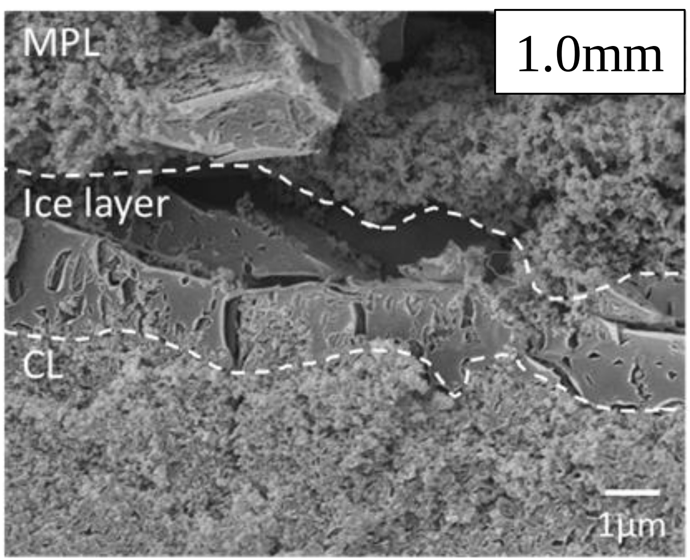
- **Rib channel width : 0.3mm → 1.0mm**

80°C, 81%RH, 100kPa, 28BC









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.