Multiscale water visualization inside polymer electrolyte fuel cells

The effective use of hydrogen, which is produced from renewable energy sources, is key to achieving sustainable development goals. Polymer electrolyte fuel cells (PEFCs) are used as a power source for automobiles because they generate electricity from hydrogen and air and discharge only the produced water as a byproduct. To realize a carbon-neutral society by 2050, PEFCs are expected to be used in a wide range of applications, including trucks, ships, railways, and smart cities. To satisfy the demand for heavy-duty applications, PEFCs must be improved not only to in terms of their catalytic activities but also their water management. If the produced water remains inside a PEFC, then the supply of reactant gases to the electrodes is inhibited. However, excessively dry conditions significantly reduce proton conductivity. Therefore, water management is critical in the development of PEFC materials and operating protocols. We established a multiprobe technique for multiscale water visualization inside PEFCs using *operando* neutron and synchrotron X-ray radiography at J-PARC BL22 and SPring-8 **BL33XU**, respectively [1,2]. Figure 1 illustrates the concept of the multiscale water-visualization technique for PEFCs. Wide-field observations of water distribution in the planar direction of the PEFCs are evaluated using neutron radiography. Furthermore, high-resolution observations of the water dynamics in the stacking direction of the PEFCs are achieved using synchrotron X-ray radiography. The complementary use of multiprobe radiography can reveal the three-dimensional water distribution inside PEFCs.

Figure 2 shows the PEFC setup used for the water-visualization experiments. For *operando* neutron radiography, we used a single cell comprising a membrane electrode assembly (MEA) assembled using separators with gas channels (Fig. 2(a)). The single cell was sandwiched between cooling pads under Fluorinert flow to control the cell temperature (Fig. 2(b)). The RADEN instrument at the J-PARC can acquire one image per second with a spatial resolution of 0.3 mm, where the image encompasses the entire MEA area with a width of approximately 25 cm [1]. For *operando* synchrotron X-ray radiography, we can use the same MEA as that used for neutron radiography and in-house carbon separators with three gas channels (Fig. 2(c)) [2]. The Toyota beamline instrument can output one image of the in-house cell per second over an area of 1.59 × 2.65 mm^2 with a spatial resolution of 1.3 μm (Fig. 2(d)).

Figure 3 shows an example of water-visualization images for the planar and cross-sectional directions of a PEFC operating at a constant current density of 1.47 A·cm^{-2} and a cell temperature of 60°C. Figure 3(a) shows the inhomogeneous water distribution in the planar direction of the PEFC. If water generated at the cathode flows toward the air outlet, then the accumulated water should be observed on the right side of Fig. 3(a), which corresponds to the air outlet. However, *operando* measurements showed nonuniform accumulation of water in the PEFC center. This suggests that some of the produced water was transported toward the anode outlet owing to water back-diffusion. Figure 3(b) shows the water distribution in the cross-sectional direction of the PEFC. Water accumulation was observed at the cathodes. Similarly, water accumulation was observed at the anode, thus indicating that water back-diffusion occurred from the cathode to the anode. Water movement due to back-diffusion was clearly observed in the video (data not shown). These results suggest that back-diffusion discharges excess

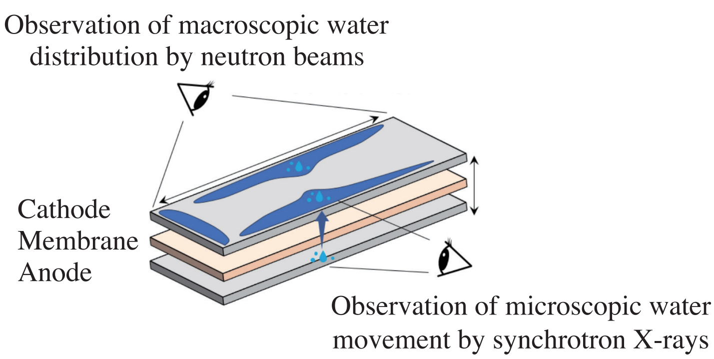

Fig. 1. Concept of multiscale water visualization inside PEFCs.

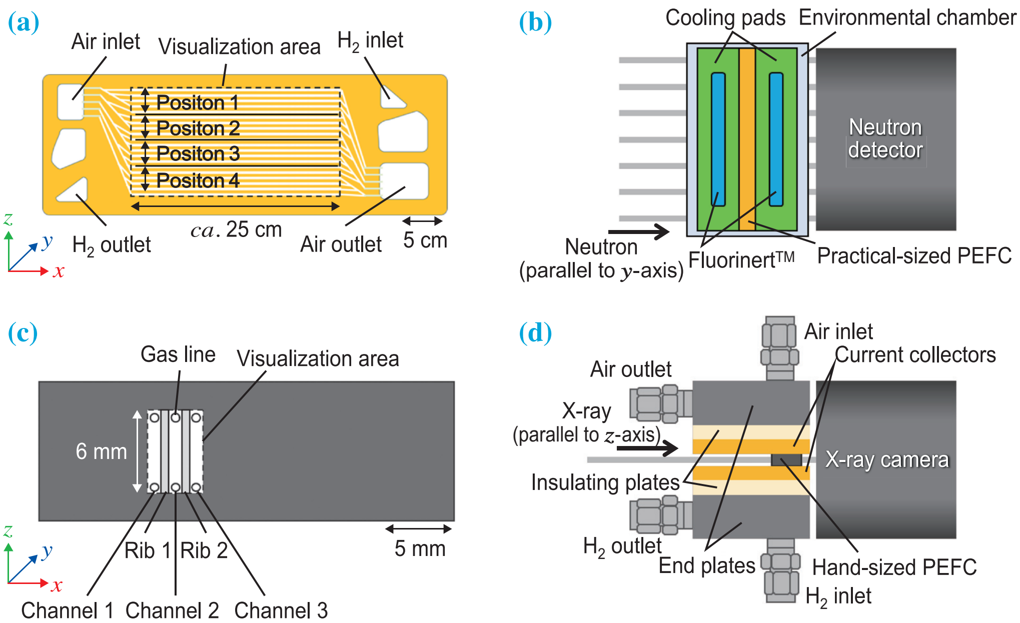

Fig. 2. Experimental setups for *operando* **(a,b)** neutron and **(c,d)** synchrotron X-ray radiography. [1]

water from PEFCs. Furthermore, they indicate that thin MEAs (<10 μm) for automotive applications not only reduce proton transport resistance but also facilitate water back-diffusion.

In conclusion, we established a multiscale water-visualization technique to achieve rational water management for PEFCs. The present results suggest for the first time that not only water discharge at the cathode, which has been improved by engineers, but also water discharge by back-diffusion to the anode is an effective method for the water management of PEFCs. This established technique for material and protocol development shall be utilized in the near future.

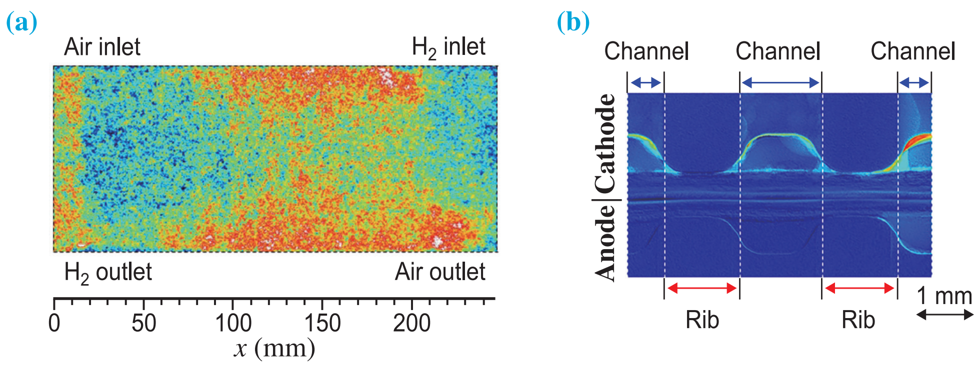

Fig. 3. Water distribution in **(a)** planar and **(b)** cross-sectional direction of PEFC. Blue and red indicate low and high water contents, respectively. [1]

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References

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[2] A. Kato *et al.*: J. Power Sources **521** (2022) 230951.