

Electrochemical Evaluation of Bipolar Plate for Polymer Electrolyte Fuel Cell

1. Introduction

With heightened concern about environmental problems in recent years, higher expectations have also been placed on fuel cells as an alternative energy source for petroleum. The features of fuel cells include high power generating efficiency and low environmental impacts, as fuel cells do not emit atmospheric pollutants (sulfur oxides, nitrogen oxides, etc.) during cell operation. As shown in **Table 1**, the features and applications of fuel cells differ depending on the type of electrolyte used¹⁾. Among these, polymer electrolyte fuel cells (PEFCs) operate at a low temperature and display high power generating efficiency, and therefore are considered a promising source of clean electric power for automotive drive systems. The unit cell of a PEFC consists of one membrane electrode assembly (MEA) between two bipolar plates. Because the voltage output of a unit cell is on the order of 0.7 V, unit cells are actually used in fuel-cell stacks consisting of a large number of stacked cells. For example, the MIRAI, which was first marketed by Toyota Motor Corporation in 2014, is equipped with a stack consisting of 370 unit cells (maximum output: 114 kW)²⁾. Since the bipolar plates occupy a large percentage of the total weight and volume of the stack, it is important to reduce the thickness and cost of the plates. From this viewpoint, high expectations are placed on stainless steel as a promising candidate material for bipolar plates, as stainless steel is relatively inexpensive and can be press-formed. However, the corrosion resistance of the stainless steel becomes an issue for practical appli-

cation because the sulfate ions (SO_4^{2-}) and fluoride ions (F^-) separated by deterioration of the perfluoro-sulfonic acid polymer membrane used as the proton conductive membrane of the MEA in the PEFC concentrate on the bipolar plate/gas diffusion layer (GDL), creating an acidic environment containing F^- ^{3, 4)}. Therefore, in addition to the cell operation tests performed in evaluations of candidate bipolar plate materials, polarization tests in a simulated PEFC environment are also conducted. One distinctive feature of the corrosion resistance test in a simulated PEFC environment is evaluation of the corrosion resistance of the stainless steel bipolar plate in a short period of time.

2. Electrochemical Evaluation of Bipolar Plates for PEFC

2.1 Cell for Evaluation of Corrosion Resistance of PEFC Bipolar Plates

Acidic solutions with different concentrations of F^- and pH values are used as aqueous solutions simulating the bipolar plate/GDL⁵⁾. A glass cell is generally used in evaluations of corrosion resistance under a simulated PEFC environment. However, the silicon (Si) which is the main component of the glass cell used in the test dissolves into the test solution as a contaminant owing to the high test-temperature of 353 K and F^- content of the solution, and this Si contamination can have harmful effects on the quantitative analysis of the metals dissolved from the bipolar plate in subsequent measurements of the interfacial contact resistance (ICR) and analysis by inductively coupled plasma-mass spectrometry (ICP-MS). To avoid this problem, JFE Techno-Research Corporation developed an electrochemical cell to evaluate corrosion resistance of PEFC bipolar plate, as shown in **Fig. 1**, as a substitute for the conventional glass cell to reduce Si contamination.

2.2 Dissolution Test of Glass Components

Referring to a paper by Kumagai et al.⁴⁾, a dissolution test of the developed cell and a comparison glass cell was carried out for a period of 1 week in H_2SO_4 + 2 ppm F^- solution which had been adjusted to pH 3 and heated to 353 K. After the dissolution test, the Si

Table 1 Comparison of fuel cells

	PEFC	PAFC	MCFC	SOFC
Temperature (K)	~373	453-478	903-943	~1 273
Electrolyte	Polymer electrolyte membrane	H_3PO_4	Molten carbonate	Ceramics
Efficiency (%)	32-40	36-45	45-55	45-50

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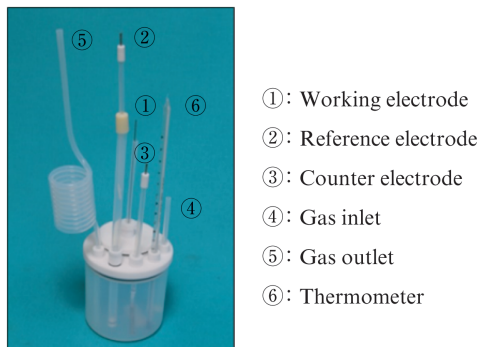


Fig.1 Appearance of polarization experiment setup

dissolved from the respective cells was determined by an analysis by inductively coupled plasma-atomic emission spectrometry (ICP-AES). The amount of Si dissolved from the developed cell was approximately 1/10 of that dissolved from the glass cell, clearly showing that dissolution of Si can be suppressed by using the developed cell.

2.3 Evaluation of Stainless Steel Bipolar Plates for PEFC

2.3.1 Electrochemical measurements of candidate bipolar plate materials

As candidate materials for bipolar plates, as-polished type 304 stainless steel and Au plated type 304 stainless steel were selected, and the potentiostatic polarization test was conducted for 100 h $\text{H}_2\text{SO}_4 + 2 \text{ ppm F}^-$ solution adjusted to pH 3 and heated to 353 K, again referring to Kumagai et al. ⁴⁾. The constant potential polarization test was conducted in the developed cell by the three-electrode method using a silver-silver chloride electrode (SSE) as the reference electrode and platinum as the counter electrode. The polarization potential was 600 mV (vs. SSE). **Figure 2** shows the results of the potentiostatic polarization test. The current density of both test pieces decreased rapidly after the start of polarization and then stabilized, indicating that the steel surface was not corroded. After the potentiostatic test, a quantitative analysis of the chromium (Cr), iron (Fe), nickel (Ni) and gold (Au) dissolved from the as-polished and Au plated type 304 stainless steel specimens was performed by ICP-MS. For comparison, the solution before the potentiostatic polarization test was also analyzed in the same manner. **Table 2** shows the results of the quantitative analysis. In comparison with the as-polished specimen, the results clarified the fact that dissolution of the metals can be suppressed by Au plated type 304 stainless steel.

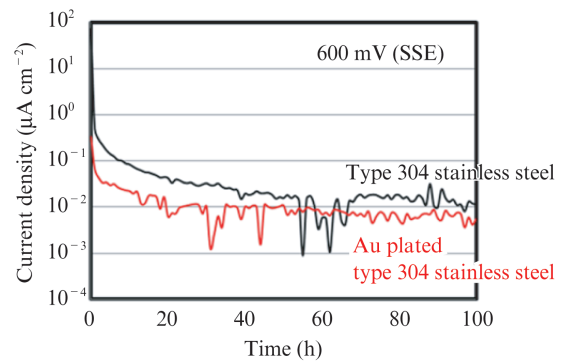


Fig. 2 $i-t$ curves of as-polished type 304 and Au plated type 304 stainless steels in $\text{H}_2\text{SO}_4 + 2 \text{ ppm F}^- @353 \text{ K}$

Table 2 Results of quantitative analysis of dissolved metals by ICP-MS ($\mu\text{g L}^{-1}$)

Element	Cr	Fe	Ni	Au
Before polarization	< 1	< 1	< 1	< 1
Type 304 stainless steel	14	130	27	—
Au plated type 304 stainless steel	1	28	< 1	< 1

2.3.2 Measurement of contact resistance of candidate bipolar plate materials

Measurement of the ICR with the GDL is one important evaluation item in the development of bipolar plates. Referring to the method proposed by Davies et al. ⁶⁾, the ICR between the as-polished and Au plated type 304 stainless steel specimens and the GDL (TGP-H-060) was measured before and after the potentiostatic polarization test shown in Fig. 2. Resin-impregnated carbon (IKC-433S) was used as a comparison material, and the load during the ICR measurement was 1 MPa. **Figure 3** shows the measurement results. The ICR of the as-polished type 304 stainless steel after the polarization test increased by approximately 5 times in comparison with before the test, but on the contrary, the ICR of the Au plated type 304 stainless steel was virtually unchanged before and after the test and was similar level to that of the resin-impregnated carbon.

3. Conclusion

As techniques for evaluating the applicability of PEFC bipolar plates, this article has introduced evaluation of corrosion resistance by electrochemical measurement, quantitative analysis of the dissolved metals by ICP-MS, and a technology for measurement of the ICR with the GDL, which functions as the electrode substrate, before and after electrochemical measurement.

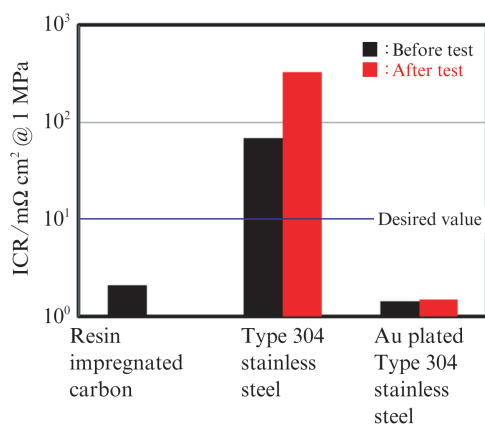


Fig. 3 ICR between as-polished type 304 and Au plated type 304 stainless steels and carbon paper before and after the polarization

In addition to these techniques, JFE Techno-Research Corporation has also created a complete system which is capable of conducting various types of evaluations of PEFCs, including observation of bipolar plates by ultra-low accelerating voltage-scanning electron microscopy (ULV-SEM) and transmission electron microscopy (TEM), evaluation of the oxidation state of the substrate material or the surface-treated layer and the composition distribution in the depth direction by X-ray photoelectron spectroscopy (XPS), evaluation

of wettability of the bipolar plate surface by the measurement of contact angle, etc. Utilizing these technologies, we hope to provide even stronger support for PEFC development in the future.

References

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