

D5.2– Report on cell performance and durability test results

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1. Content

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2. Executive summary

This deliverable reports the electrochemical test results of the cells that have been manufactured in the project. In total seven batches of more than 20 cell tests have been conducted, including initial performance characterization and long-term durability evaluation. For testing, current-voltage curves (iV) and electrochemical impedance spectra (EIS) were measured for the initial characterization and cell voltages and EIS were recorded under current during durability tests. The durability test condition was focused on 700 °C with 10% H₂ + 90% H₂O supplied to the fuel electrode compartment and under current densities of -0.5 – -1 A/cm². Low degradation rates with <1%/1000 hours at -0.85A/cm² were obtained on some of the selected cells tested for durability, which fulfilled the target of the project.

3. Cell information

In the PilotSOEL project, seven different batches of cells have been manufactured by ELCAS and DTU. The cells produced by ELCAS include fuel electrode optimized cells, ALD (deposited by BENEQ) and PVD (deposited by NACO) interdiffusion barrier layer cells. Cells produced by DTU are manufactured by water-based tape co-casting. Tabel 1 lists the selected cells tested in the project by DTU. Detailed information on the cell manufacture processes have been reported in D2.1, D2.2, D2.3 and D2.4 respectively.

Tabel 1: Type of cells manufactured in the PilotSOEL project

Batch No.	Cell type	Manufacture	Comments
1	Ni/YSZ-YSZ-CGO-LSC	ELCAS	400um support
2	Ni/YSZ-YSZ-CGO-LSC	ELCAS	300um support
3	Ni/YSZ-YSZ-CGO-LSC	ELCAS	Fuel electrode optimized microstructure
4	Ni-Me/YSZ-YSZ-CGO-LSC	ELCAS	Doped fuel electrode
5	Ni/YSZ-YSZ-CGO-LSC	ELCAS+ BENEQ	ALD interdiffusion barrier layer
6	Ni/YSZ-YSZ-CGO-LSC	ELCAS+ NACO	PVD interdiffusion barrier layer
7	Ni/YSZ-YSZ-CGO-LSC/CGO	DTU	Water based co-casting

4. Performance characterization

Cell performance investigation was carried out by measuring iV curves and electrochemical impedance spectra (EIS). Figure 1 presents the selected iV curves measured in both fuel cell and electrolysis mode at 700 °C with 24L/h 50% H₂ + 50% H₂O supplied to the fuel electrode and 100L/h air supplied to the oxygen electrode. The iV curves show rather linear for all the cells except B4. Cells with B1, B2, B3, B5 show rather similar performance. Lower performances were observed on cell B4 and B7.

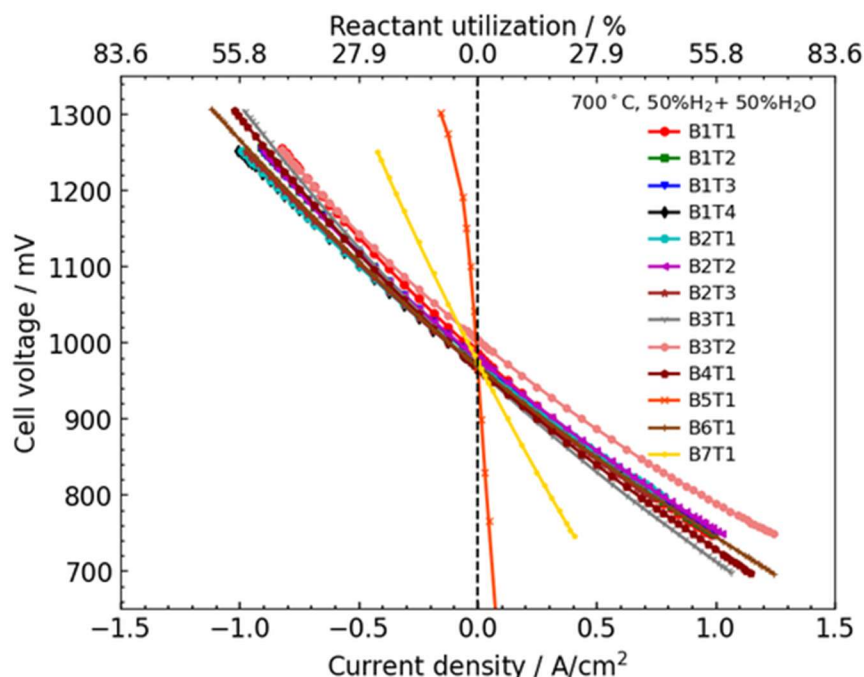


Figure 1: iV characterization of the cells in SOFC and SOEC mode with 50% H₂ + 50% vH₂O supplied to the fuel electrode and air supplied to the oxygen electrode at 700 °C.

Area specific resistances (ASR) at $\pm 0.25 \text{ A/cm}^2$ have been calculated from the measured iV data and presented in Table 1. In general, the ASR calculated in SOFC mode are slightly lower than SOEC mode. Slight scattering of ASR values are also observed on the same type of cells, which may be due to small variation in mounting of the tests and different cell test rigs. The ASR values confirmed that the initial performance of the manufactured cells has very similar performance at the measurement condition. Except for B5 and B7.

Table 1: Area specific resistance calculated based on the iV curve at $\pm 0.25 \text{ A/cm}^2$

Cell test number	ASR @ $\pm 0.25 \text{ A/cm}^2$, $\Omega \cdot \text{cm}^2$	
	SOFC mode	SOEC mode
B1T1	0.242	0.285
B1T2	0.229	0.265
B1T3	0.231	0.264
B1T4	0.222	0.250
B2T1	0.221	0.245

B2T2	0.225	0.225
B2T3	0.234	0.259
B3T1	0.251	0.294
B3T2	0.205	0.262
B4T1	0.235	0.276
B5T1	4.245	2.114
B6T1	0.219	0.255
B7T1	0.562	0.604

Figure 2 present the typical iV curves of the seven batches of cells characterized in SOEC mode with 13.4/h 10% H_2 + 90% H_2O supplied to the fuel electrode compartment and 100L/h air supplied to the oxygen electrode compartment at 700 °C and the corresponding ASR at -0.25A/cm² calculated based on the iV curve can be seen in Table 2. Cells except B4 and B7 were all reached 1.2A/cm² at voltage below thermoneutral voltage of 1.3V with similar calculated ASR value, and the iV curves show linear increase of voltage with current, no starvation was observed even at more than 80% of steam utilization, indicated the good gas diffusion path of those manufactured cells.

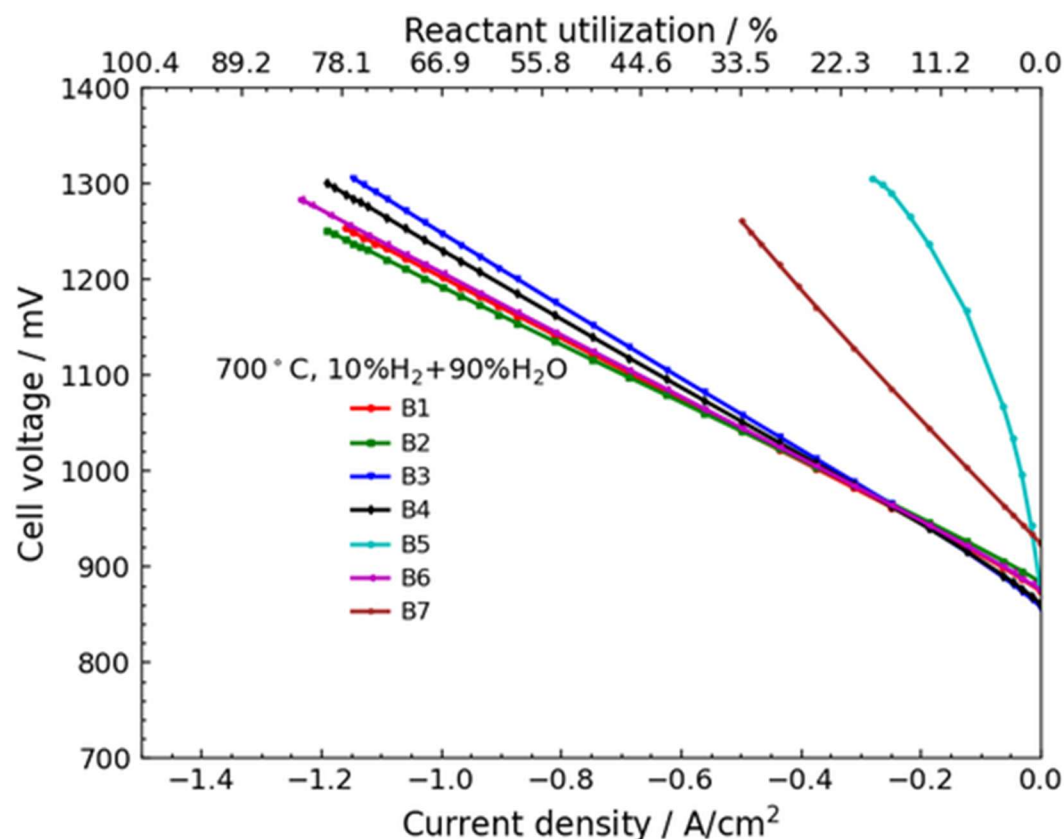


Figure 2: iV characterization of the cells in SOEC mode with 10% H_2 +90% H_2O supplied to the fuel electrode and air supplied to the oxygen electrode at 700 °C

Table 2: Area specific resistance calculated based on the iV curve at -0.25 A/cm^2

Cell batch	ASR @ -0.25 A/cm^2 , $\Omega \cdot \text{cm}^2$
B1	0.327
B2	0.308
B3	0.391
B4	0.320
B5	1.526
B6	0.330
B7	0.638

To further investigate the performance of the cells, EIS of the cells were measured with 50% H_2 + 50% H_2O supplied to the fuel electrode and air supplied to the oxygen electrode at 700°C , and the results were presented in Figure 3. The EIS characterization agrees well with the iV measurement results. Cell B1, B2, B3 and B4, B6 showed similar performance with ASR values $0.25\text{--}0.3 \Omega \cdot \text{cm}^2$. Larger ASR can be seen on B5 and B7 cells. However, B5 cell exhibits the lowest ohmic resistance, R_s value, indicate the beneficial of thin barrier layer deposited by ALD, the polarization, R_p on the other hand is exceptionally large and the distribution of relaxation time (DRT) analysis results revealed a large peak associates with a summit frequency of ca. 200 Hz, which might be correlated to the oxygen electrode process. It is speculated that the surface property of the ALD barrier layer may cause bad adhesion with the oxygen electrode. Further investigation will be undertaken to investigate the interface between the oxygen electrode and the ALD interdiffusion barrier layer.

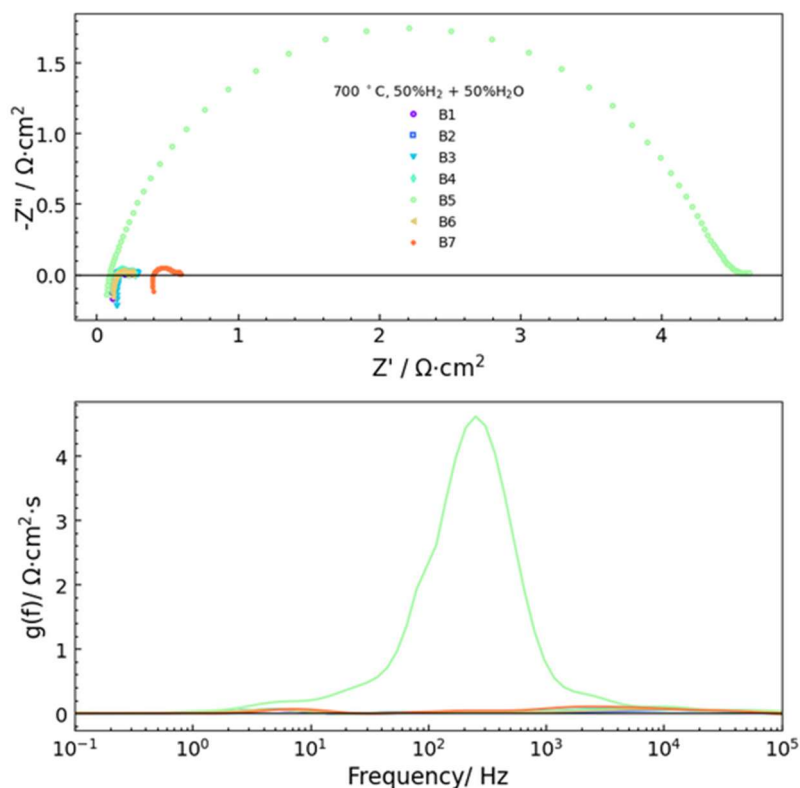


Figure 3: EIS of the cells measured with 50%H₂+50%H₂O supplied to the fuel electrode and air supplied to the oxygen electrode at 700 °C.

A better overview of the cell performance can be seen in Figure 4 after excluding the EIS of B5 cell. It can be seen that the major difference between Cell B7 and the other cells are the ohmic resistance R_s , this is as expected since cell B7 was manufactured by water-based co-casting of the half-cell, which has ca. 2-4 times thick electrolyte and interdiffusion barrier layer, lower resistance can be achieved by reducing the electrolyte and interdiffusion barrier layer thickness. Also compared with the other cells, B7 also exhibits a slightly higher R_p . Based on the DRT analysis results, both fuel electrode and oxygen electrode can be further optimized to reduce the polarization resistance.

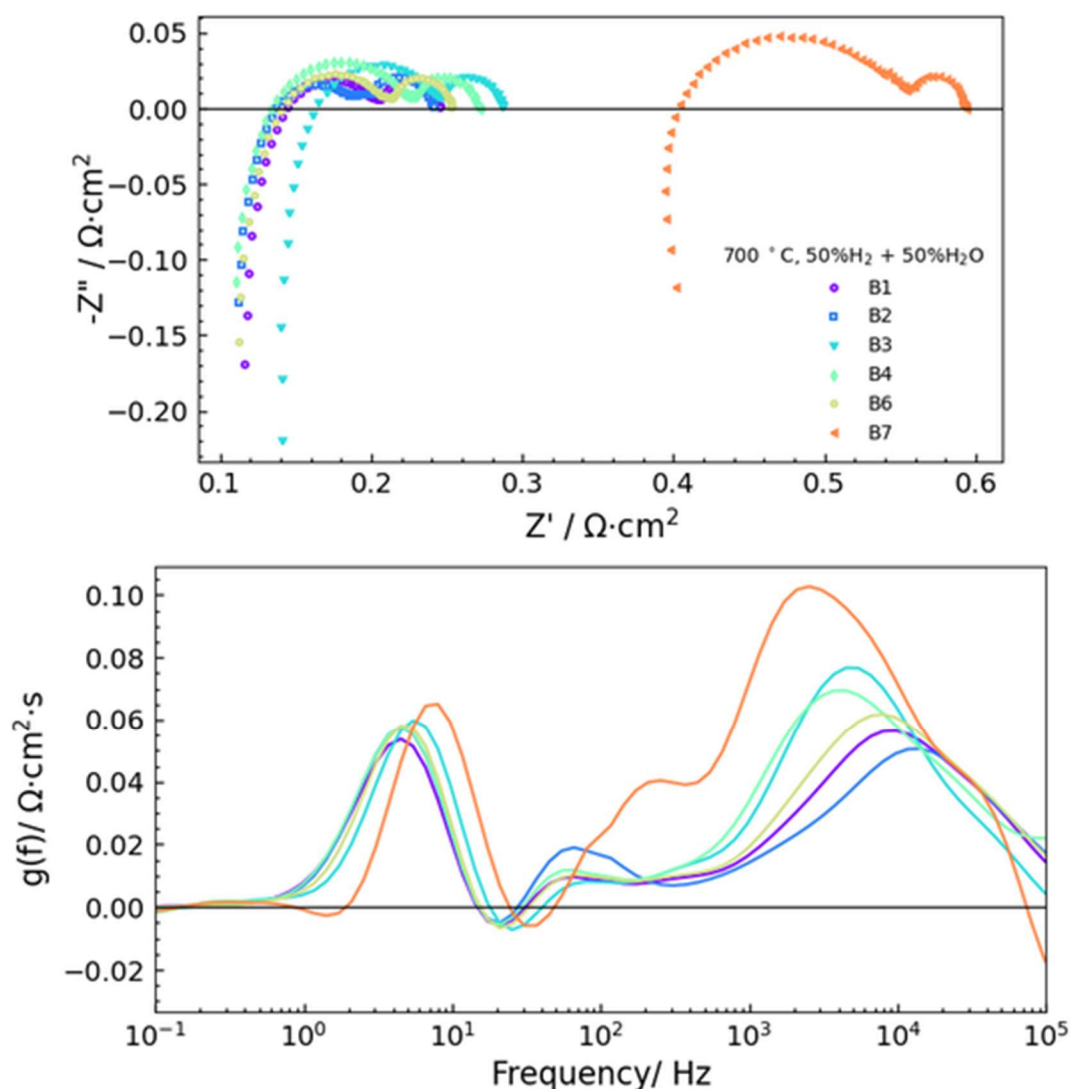


Figure 4: EIS of the cells measured with 50%H₂+50%H₂O supplied to the fuel electrode and air supplied to the oxygen electrode at 700 °C, without B5.

5. Durability test

Promising cells were selected for durability test at different current densities and steam conversion. The test condition was focused with 10% H_2 +90% H_2O supplied to the fuel electrode compartment and air supplied to the oxygen electrode compartment at 700 °C. Cells tested under $-0.85A/cm^2$ are selected to present in Figure 5. In which B3 and B6 are still in operation and the zoom in voltages can be seen in Figure 6, therefore long-term degradation will not be evaluated here. Compared with the tests that run over 1000 hours, Cell B1 showed higher degradation than B2 and B4. The degradation rates of B2 and B4 after the first 500 hours initial degradation are $-1.4\%/1000h$ and $0.7\%/1000h$, respectively, which is lower than the project targeted value of $1\%/1000$ hours.

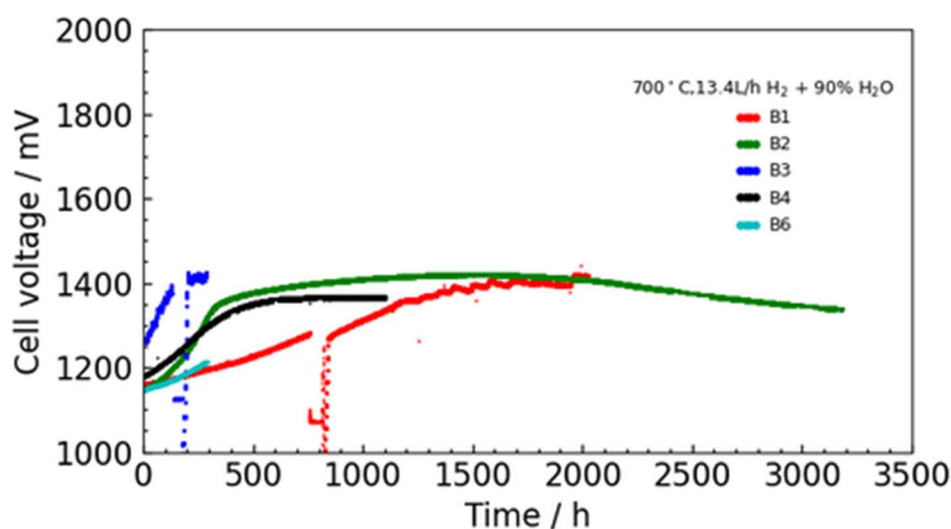


Figure 5: Durability characterization of the cells under $-0.85A/cm^2$ with 10% H_2 +90% H_2O supplied to the fuel electrode and air supplied to the oxygen electrode at 700 °C.

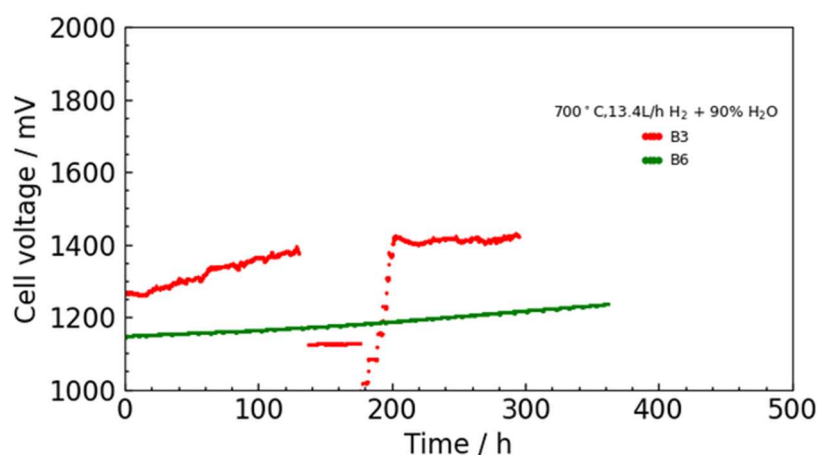


Figure 6: Durability characterization of B3 and B6 under $-0.85A/cm^2$ with 10% H_2 + 90% H_2O supplied to the fuel electrode and air supplied to the oxygen electrode at 700 °C.

To further understand the degradation behaviors, EIS were recorded during the durability test under current. The EIS evolution during the test of cell B2 and B4 are presented in **Error! Reference source not found.** Both ohmic and polarization resistance increased during the initial degradation period. After that, the ohmic resistance stabilized and the polarization resistance kept decreasing during the rest of the test period, indicating an activation process. On the other hand, B4 shows a very low ohmic degradation, and polarization resistance degradation stopped after the initial 500 hours operation. From the characteristic frequency analyzed by DRT of the peak change, both cells degradation can be attributed to the fuel electrode.

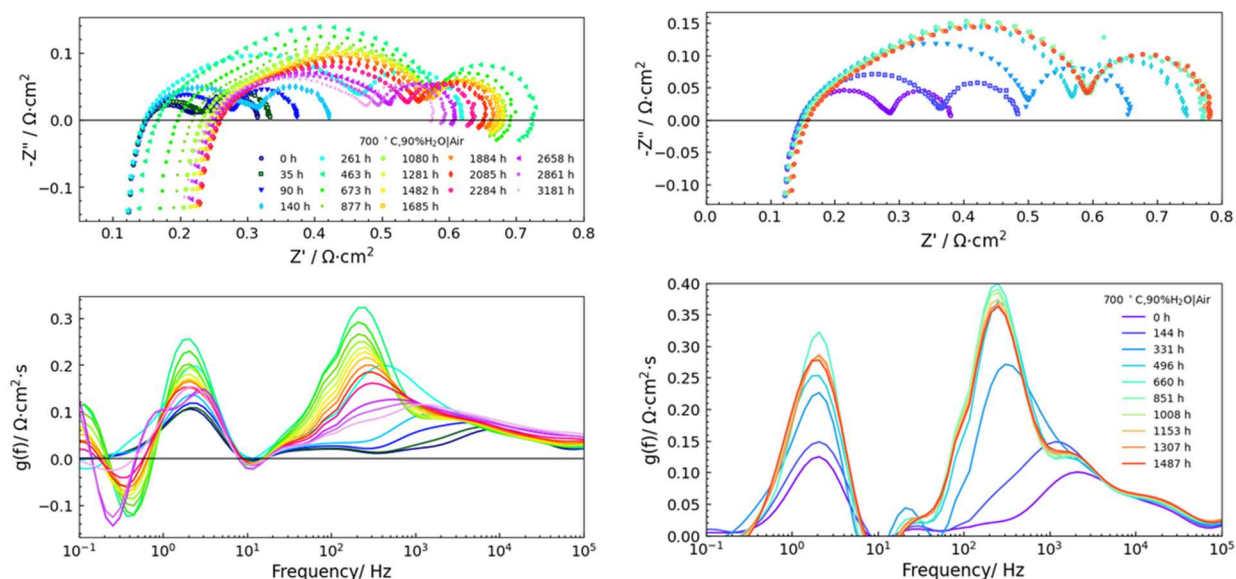


Figure 7: EIS recorded during the durability test under current. left: B2, right: B4.

6. Conclusion

In this report, the electrochemical test results of seven batches of cells are presented. Cells manufactured in the project showed very promising results. From performance characterization, all the cells except B5 and B7, show very similar performance. Cell B5 with ALD interdiffusion barrier layer exhibited the lowest ohmic resistance, but high polarization resistance which may be due to the not optimized interface between the ALD layer and the oxygen electrode. On the other hand, cell B7 showed similar R_p as other cells, but higher R_s due to the thick electrolyte and interdiffusion barrier layers. Further optimization of the cells is ongoing. Long term durability tests show that after the initial degradation, both cell B2 and B4 presented a very low degradation rate of $<1\%/1000$ hours, and the degradation can mainly be attributed to the fuel electrode process.