Electronic Supplementary Information

Electronic Structure Modulation of MnO₂ by Ru and F Incorporation for Efficient Proton Exchange Membrane Water Electrolysis

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<tr>
<td>References</td>
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</table>
Fig. S1 SEM images of (a and b) α-MnO$_2$, (c and d) (Mn$_{0.94}$Ru$_{0.06}$)O$_2$, (e and f) (Mn$_{0.96}$Ru$_{0.04}$)O$_2$:2.5F, (g and h) (Mn$_{0.93}$Ru$_{0.07}$)O$_2$:2.5F, and (i and j) (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:2.5F. (k and l) EDS analysis of (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:2.5F. (m) Inverse FFT image of (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:2.5F regarding (310) plane.
**Fig. S2** (a) Mn K-edge XANES spectra of the reference materials and as-prepared samples (MnO, Mn$_2$O$_3$, α-MnO$_2$, (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:1.3F, (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:2.5F), (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:5F and (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:10F. (b) Radial distribution functions of the $k^3$-weighted EXAFS. (c) Linear regression of the edge energy in the XANES spectra and the Mn valence state. (d) Phase composition determined with LCF of the XANES spectra.
Fig. S3 EDS elemental mapping images of (Mn$_{0.93}$Ru$_{0.07}$)O$_2$:2.5F; (a) overall, (b) Mn, (c) Ru and (d) O.
Fig. S4 (a) XRD patterns of the standard materials and as-prepared samples α-MnO$_2$, (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:1.3F, (Mn$_{0.93}$Ru$_{0.07}$)O$_2$:2.5F, (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:5F and (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:10F. (b) Enlarged XRD patterns in the 2θ range of 27.5°–38.5°.
Fig. S5 (a) Mn 3s XPS spectra of \((\text{Mn}_{0.94}\text{Ru}_{0.06})\text{O}_2\cdot 2.5\text{F}\). (b) F 1s and (c) Ru 3p XPS spectra of the as-prepared samples.
Fig. S6 LSV curves of $\alpha$-MnO$_2$, (Mn$_{0.94}$Ru$_{0.06}$)O$_2$, (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:1.3F, (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:2.5F, (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:5F and (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:10F.
Fig. S7 (a) Equivalent circuit used for EIS fitting. (b) Nyquist plots of the as-prepared samples.
Fig. S8  The CV curves of the as-prepared samples; (a) (Mn$_{0.94}$Ru$_{0.06}$)O$_2$:2.5F, (b) (Mn$_{0.96}$Ru$_{0.04}$)O$_2$:2.5F, (c) (Mn$_{0.94}$Ru$_{0.06}$)O$_2$, (d) RuO$_2$, (e) (Mn$_{0.93}$Ru$_{0.07}$)O$_2$:2.5F and (f) α-MnO$_2$. 
Fig. S9 Stability test of \((\text{Mn}_{0.94}\text{Ru}_{0.06})\text{O}_2\cdot2.5\text{F}\) at 10 mA cm\(^{-2}\) for 15 hours.
Fig. S10 The performance of the PEMWE single-cell. (a) Polarization curves of the PEMWE with \((\text{Mn}_{0.94}\text{Ru}_{0.06})\text{O}_2:2.5\text{F}\) anode. (b) Stability test of the PEMWE with \((\text{Mn}_{0.94}\text{Ru}_{0.06})\text{O}_2:2.5\text{F}\) anode at 100 mA cm\(^{-2}\) for 20 hours. (c) Polarization curves of \((\text{Mn}_{0.94}\text{Ru}_{0.06})\text{O}_2:2.5\text{F}\) with and without iR-correction. (d) Nyquist plots of the PEMWE before and after the stability test.
Fig. S11 Cross-section image of pristine MEA. (a) Cathode-adjacent, (b) middle and (c) anode-adjacent images of the MEA. The EDS results of the (d) Fig. S11a, (e) Fig. S11b and (f) Fig. S11c.
**Fig. S12** (a) The cross-section image of MEA after steady-state test at 10 mA·cm⁻² for 200 hours. The specific image of the (b) cathode-adjacent, (c) middle and (d) anode-adjacent image of MEA. The EDS results of the (e) Fig. S12b, (f) Fig. S12c and (g) Fig. S12d. (h) The image of MEA after steady-state test at 100 mA·cm⁻² for 20 hours. The specific image of the (i) cathode-adjacent, (j) middle and (k) anode-adjacent image of MEA. The EDS results of the (l) Fig. S12i, (m) Fig. S12j and (n) Fig. S12k.
Fig. S13 Surface SEM/EDS analyses of the pristine (Mn_{0.94}Ru_{0.06})O_2:2.5F on membrane.

Fig. S14 Surface SEM/EDS analyses of the (Mn_{0.94}Ru_{0.06})O_2:2.5F after steady-state test at 10 mA·cm^{-2} for 200 hours.
Table S1. Contents of Mn and Ru determined by the quantitative EDS analysis.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Atomic percentage</th>
<th>Weight percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mn (at %)</td>
<td>Ru (at %)</td>
</tr>
<tr>
<td>(Mn$<em>{0.94}$Ru$</em>{0.06}$)O$_2$</td>
<td>30.97</td>
<td>2.38</td>
</tr>
<tr>
<td>(Mn$<em>{0.96}$Ru$</em>{0.04}$)O$_2$:2.5F</td>
<td>32.29</td>
<td>1.53</td>
</tr>
<tr>
<td>(Mn$<em>{0.94}$Ru$</em>{0.06}$)O$_2$:2.5F</td>
<td>31.52</td>
<td>2.29</td>
</tr>
<tr>
<td>(Mn$<em>{0.93}$Ru$</em>{0.07}$)O$_2$:2.5F</td>
<td>30.76</td>
<td>3.71</td>
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</table>
Table S2  Edge energies and oxidation states determined by the Mn K-edge XANES spectra.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Edge energy (eV)</th>
<th>Oxidation state</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnO</td>
<td>6544.51</td>
<td>2+</td>
</tr>
<tr>
<td>Mn$_2$O$_3$</td>
<td>6548.53</td>
<td>3+</td>
</tr>
<tr>
<td>α-MnO$_2$</td>
<td>6553.38</td>
<td>4+</td>
</tr>
<tr>
<td>(Mn$<em>{0.96}$Ru$</em>{0.04}$)O$_2$:2.5F</td>
<td>6552.85</td>
<td>3.89+</td>
</tr>
<tr>
<td>(Mn$<em>{0.94}$Ru$</em>{0.06}$)O$_2$:2.5F</td>
<td>6552.68</td>
<td>3.85+</td>
</tr>
<tr>
<td>(Mn$<em>{0.93}$Ru$</em>{0.07}$)O$_2$:2.5F</td>
<td>6553.01</td>
<td>3.92+</td>
</tr>
<tr>
<td>(Mn$<em>{0.94}$Ru$</em>{0.06}$)O$_2$</td>
<td>6553.31</td>
<td>3.99+</td>
</tr>
<tr>
<td>(Mn$<em>{0.94}$Ru$</em>{0.06}$)O$_2$:1.3F</td>
<td>6552.46</td>
<td>3.80+</td>
</tr>
<tr>
<td>(Mn$<em>{0.94}$Ru$</em>{0.06}$)O$_2$:5F</td>
<td>6550.40</td>
<td>3.34+</td>
</tr>
<tr>
<td>(Mn$<em>{0.94}$Ru$</em>{0.06}$)O$_2$:10F</td>
<td>6550.73</td>
<td>3.41+</td>
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Table S3 Phase composition determined by the LCF of the Mn K-edge XANES spectra.

<table>
<thead>
<tr>
<th>Samples</th>
<th>MnO</th>
<th>Mn₂O₃</th>
<th>MnO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mn₀.⁹₆Ru₀.⁰₄)O₂:2.5F</td>
<td>0.000</td>
<td>0.042</td>
<td>0.958</td>
</tr>
<tr>
<td>(Mn₀.⁹₄Ru₀.⁰₆)O₂:2.5F</td>
<td>0.000</td>
<td>0.089</td>
<td>0.911</td>
</tr>
<tr>
<td>(Mn₀.⁹₃Ru₀.⁰₇)O₂:2.5F</td>
<td>0.000</td>
<td>0.030</td>
<td>0.970</td>
</tr>
<tr>
<td>(Mn₀.⁹₄Ru₀.⁰₆)O₂</td>
<td>0.000</td>
<td>0.004</td>
<td>0.996</td>
</tr>
<tr>
<td>(Mn₀.⁹₄Ru₀.⁰₆)O₂:1.3F</td>
<td>0.000</td>
<td>0.052</td>
<td>0.948</td>
</tr>
<tr>
<td>(Mn₀.⁹₄Ru₀.⁰₆)O₂:5F</td>
<td>0.000</td>
<td>0.382</td>
<td>0.618</td>
</tr>
<tr>
<td>(Mn₀.⁹₄Ru₀.⁰₆)O₂:10F</td>
<td>0.000</td>
<td>0.280</td>
<td>0.720</td>
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Table S4 Shifts in the XRD peak positions for (310) and (121) planes from those of the α-MnO₂.

<table>
<thead>
<tr>
<th>Sample</th>
<th>2θ for (310) (degrees)</th>
<th>Δ2θ (degrees)</th>
<th>2θ for (121) (degrees)</th>
<th>Δ2θ (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-MnO₂</td>
<td>28.70</td>
<td>0</td>
<td>37.76</td>
<td>0</td>
</tr>
<tr>
<td>(Mn₀.⁹₄Ru₀.⁰₆)O₂</td>
<td>28.57</td>
<td>−0.13</td>
<td>37.59</td>
<td>−0.17</td>
</tr>
<tr>
<td>(Mn₀.⁹₆Ru₀.⁰₄)O₂:2.5F</td>
<td>28.52</td>
<td>−0.18</td>
<td>37.44</td>
<td>−0.32</td>
</tr>
<tr>
<td>(Mn₀.⁹₄Ru₀.⁰₆)O₂:2.5F</td>
<td>28.40</td>
<td>−0.3</td>
<td>37.28</td>
<td>−0.48</td>
</tr>
<tr>
<td>(Mn₀.⁹₃Ru₀.⁰₇)O₂:2.5F</td>
<td>28.38</td>
<td>−0.32</td>
<td>37.37</td>
<td>−0.39</td>
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Table S5 XRD peak positions, FWHMs, crystallite sizes and d-spacing values for the (121) plane, determined by Scherrer analysis.

<table>
<thead>
<tr>
<th>Sample</th>
<th>2θ for (121) (degrees)</th>
<th>θ (degrees)</th>
<th>FWHM</th>
<th>Crystallite size (nm)</th>
<th>d-spacing (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-MnO₂</td>
<td>37.75</td>
<td>18.87</td>
<td>0.522</td>
<td>16</td>
<td>0.238</td>
</tr>
<tr>
<td>(Mn₀.⁹₄Ru₀.₀₆)O₂</td>
<td>37.59</td>
<td>18.79</td>
<td>0.517</td>
<td>16</td>
<td>0.239</td>
</tr>
<tr>
<td>(Mn₀.⁹₆Ru₀.₀₄)O₂:2.₅F</td>
<td>37.44</td>
<td>18.72</td>
<td>0.510</td>
<td>16</td>
<td>0.240</td>
</tr>
<tr>
<td>(Mn₀.⁹₄Ru₀.₀₆)O₂:2.₅F</td>
<td>37.28</td>
<td>18.64</td>
<td>0.513</td>
<td>16</td>
<td>0.241</td>
</tr>
<tr>
<td>(Mn₀.⁹₃Ru₀.₀₇)O₂:2.₅F</td>
<td>37.37</td>
<td>18.68</td>
<td>0.513</td>
<td>16</td>
<td>0.241</td>
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Table S6 XPS peak position determined from deconvolution of Mn 2p XPS spectra.

<table>
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<th>Samples</th>
<th>Peak position</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mn 2p\textsubscript{3/2} (eV)</td>
<td>Mn 2p\textsubscript{1/2} (eV)</td>
<td>Mn 2p\textsubscript{3/2} (eV)</td>
</tr>
<tr>
<td>α-MnO\textsubscript{2}</td>
<td>642.8</td>
<td>654.5</td>
<td>641.6</td>
</tr>
<tr>
<td>(Mn\textsubscript{0.94}Ru\textsubscript{0.06})O\textsubscript{2}</td>
<td>642.8</td>
<td>653.6</td>
<td>640.9</td>
</tr>
<tr>
<td>(Mn\textsubscript{0.96}Ru\textsubscript{0.04})O\textsubscript{2}:2.5F</td>
<td>642.6</td>
<td>653.9</td>
<td>641.3</td>
</tr>
<tr>
<td>(Mn\textsubscript{0.94} Ru\textsubscript{0.06})O\textsubscript{2}:2.5F</td>
<td>642.6</td>
<td>653.9</td>
<td>641.3</td>
</tr>
<tr>
<td>(Mn\textsubscript{0.93}Ru\textsubscript{0.07})O\textsubscript{2}:2.5F</td>
<td>642.4</td>
<td>653.7</td>
<td>641.1</td>
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Table S7 XPS peak position determined from the deconvolution of O 1s XPS spectra.

<table>
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<th>Samples</th>
<th>O 1s (eV)</th>
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<tbody>
<tr>
<td></td>
<td>Lattice oxygen</td>
<td>Oxygen vacancy</td>
<td>Adsorbed water</td>
</tr>
<tr>
<td>α-MnO₂</td>
<td>529.7</td>
<td>531.3</td>
<td>533.0</td>
</tr>
<tr>
<td>(Mn₉₄Ru₀₆)O₂</td>
<td>529.0</td>
<td>530.5</td>
<td>531.9</td>
</tr>
<tr>
<td>(Mn₉₆Ru₀₄)O₂:2.5F</td>
<td>529.2</td>
<td>530.8</td>
<td>532.8</td>
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<tr>
<td>(Mn₉₄Ru₀₆)O₂:2.5F</td>
<td>529.0</td>
<td>530.6</td>
<td>532.6</td>
</tr>
<tr>
<td>(Mn₉₃Ru₀₇)O₂:2.5F</td>
<td>529.0</td>
<td>530.7</td>
<td>532.6</td>
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Table S8 XPS peak area ratio of Mn³⁺/Mn⁴⁺ and Oᵥ/Oₐ determined by the deconvolution of XPS spectra.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Mn³⁺/Mn⁴⁺</th>
<th>Oᵥ/Oₐ</th>
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<tr>
<td>α-MnO₂</td>
<td>0.586</td>
<td>0.558</td>
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<tr>
<td>(Mn₉₄Ru₀₆)O₂</td>
<td>0.529</td>
<td>0.472</td>
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<tr>
<td>(Mn₉₆Ru₀₄)O₂:2.5F</td>
<td>0.819</td>
<td>0.706</td>
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<tr>
<td>(Mn₉₄Ru₀₆)O₂:2.5F</td>
<td>0.936</td>
<td>0.806</td>
</tr>
<tr>
<td>(Mn₉₃Ru₀₇)O₂:2.5F</td>
<td>0.919</td>
<td>0.730</td>
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Table S9 XPS peak positions for F 1s and Ru 3p XPS spectra.

<table>
<thead>
<tr>
<th>Samples</th>
<th>F 1s (eV)</th>
<th>Ru(^{4+})</th>
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<th>Ru(^{0})</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ru 3p(_{3/2}) (eV)</td>
<td>Ru 3p(_{1/2}) (eV)</td>
<td>Ru 3p(_{3/2}) (eV)</td>
</tr>
<tr>
<td>(Mn(<em>{0.94})Ru(</em>{0.06}))O(_2)</td>
<td>-</td>
<td>463.7</td>
<td>485.9</td>
<td>461.9</td>
</tr>
<tr>
<td>(Mn(<em>{0.96})Ru(</em>{0.04}))O(_2):2.5F</td>
<td>685.4</td>
<td>463.7</td>
<td>485.9</td>
<td>461.9</td>
</tr>
<tr>
<td>(Mn(<em>{0.94})Ru(</em>{0.06}))O(_2):2.5F</td>
<td>685.0</td>
<td>463.7</td>
<td>485.9</td>
<td>461.9</td>
</tr>
<tr>
<td>(Mn(<em>{0.93})Ru(</em>{0.07}))O(_2):2.5F</td>
<td>684.6</td>
<td>463.7</td>
<td>485.9</td>
<td>461.9</td>
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Table S10 Series and charge transfer resistances obtained from the EIS analysis.

<table>
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<th>Samples</th>
<th>Rs (Ω)</th>
<th>R(_{ct}) (Ω)</th>
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<tbody>
<tr>
<td>α-MnO(_2)</td>
<td>23.7</td>
<td>10126</td>
</tr>
<tr>
<td>(Mn(<em>{0.94})Ru(</em>{0.06}))O(_2)</td>
<td>31.9</td>
<td>346</td>
</tr>
<tr>
<td>(Mn(<em>{0.96})Ru(</em>{0.04}))O(_2):2.5F</td>
<td>22.7</td>
<td>7799</td>
</tr>
<tr>
<td>(Mn(<em>{0.94})Ru(</em>{0.06}))O(_2):2.5F</td>
<td>30.0</td>
<td>86</td>
</tr>
<tr>
<td>(Mn(<em>{0.93})Ru(</em>{0.07}))O(_2):2.5F</td>
<td>22.5</td>
<td>460</td>
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Table S11 OER activity in terms of overpotential at 10 mA·cm$^{-2}$, Tafel slopes, $C_{dl}$, and ECSA.

<table>
<thead>
<tr>
<th>Samples</th>
<th>$\eta$ at 10 mA cm$^{-2}$ (mV)</th>
<th>Tafel slope (mV dec$^{-1}$)</th>
<th>$C_{dl}$ (mF)</th>
<th>ECSA (cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$-MnO$_2$</td>
<td>n.a.</td>
<td>364</td>
<td>0.07</td>
<td>2.0</td>
</tr>
<tr>
<td>(Mn$<em>{0.94}$Ru$</em>{0.06}$)O$_2$</td>
<td>421</td>
<td>97</td>
<td>0.65</td>
<td>18.6</td>
</tr>
<tr>
<td>(Mn$<em>{0.96}$Ru$</em>{0.04}$)O$_2$:2.5F</td>
<td>766</td>
<td>133</td>
<td>0.10</td>
<td>2.9</td>
</tr>
<tr>
<td>(Mn$<em>{0.94}$Ru$</em>{0.06}$)O$_2$:2.5F</td>
<td>257</td>
<td>62</td>
<td>0.66</td>
<td>18.9</td>
</tr>
<tr>
<td>(Mn$<em>{0.93}$Ru$</em>{0.07}$)O$_2$:2.5F</td>
<td>642</td>
<td>99</td>
<td>0.19</td>
<td>5.4</td>
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Table S12 OER activity comparison of Mn and noble-metal-based catalysts in terms of loading, overpotential at 10 mA·cm$^{-2}$ and mass activity.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Loading (mg cm$^{-2}$)</th>
<th>Noble metal loading (mg cm$^{-2}$)</th>
<th>$\eta$ (mV)</th>
<th>Mass activity (mA mg$^{-1}$)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mn$<em>{0.7}$Ir$</em>{0.3}$)O$_2$:10F</td>
<td>0.3</td>
<td>0.135</td>
<td>245</td>
<td>74.06</td>
<td>[S1]</td>
</tr>
<tr>
<td>(Mn$<em>{0.8}$Ir$</em>{0.2}$)O$_2$:10F</td>
<td>0.3</td>
<td>0.101</td>
<td>200</td>
<td>99.18</td>
<td>[S1]</td>
</tr>
<tr>
<td>(Mn$<em>{0.8}$Nb$</em>{0.2}$)O$_2$:10F</td>
<td>0.3</td>
<td>0.059</td>
<td>680</td>
<td>169.60</td>
<td>[S2]</td>
</tr>
<tr>
<td>Ir$<em>{0.4}$/Mn$</em>{0.6}$</td>
<td>0.2</td>
<td>0.108</td>
<td>237</td>
<td>92.24</td>
<td>[S3]</td>
</tr>
<tr>
<td>RuO$_2$/(Co,Mn)$_3$O$_4$</td>
<td>n.a.</td>
<td>0.06</td>
<td>270</td>
<td>166.67</td>
<td>[S4]</td>
</tr>
<tr>
<td>Ir-MnO$_2$</td>
<td>4</td>
<td>0.205</td>
<td>218</td>
<td>48.73</td>
<td>[S5]</td>
</tr>
<tr>
<td>Mn-RuO$_2$</td>
<td>0.275</td>
<td>0.196</td>
<td>158</td>
<td>50.93</td>
<td>[S6]</td>
</tr>
<tr>
<td>12Ru/MnO$_2$</td>
<td>0.2</td>
<td>0.023</td>
<td>161</td>
<td>434.8</td>
<td>[S7]</td>
</tr>
<tr>
<td>This work</td>
<td>0.216</td>
<td>0.017</td>
<td>250</td>
<td>588.24</td>
<td>This work</td>
</tr>
</tbody>
</table>
**Table S13** Contents of Mn and Ru in electrolyte after stability test, determined by the ICP-MS analysis.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mn (ppm)</th>
<th>Ru (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mn_{0.94}Ru_{0.06})O_{2.5}F</td>
<td>3.157</td>
<td>0.053</td>
</tr>
</tbody>
</table>

**Table S14** Contents of Mn, Ru and F in membrane after stability test at 10 mA cm\(^{-2}\) and 100 mA cm\(^{-2}\).

<table>
<thead>
<tr>
<th>MEA sector</th>
<th>10 mA cm(^{-2})</th>
<th>100 mA cm(^{-2})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mn (at%)</td>
<td>Ru (at%)</td>
</tr>
<tr>
<td>Cathode-adjacent</td>
<td>3.61</td>
<td>0.03</td>
</tr>
<tr>
<td>Middle</td>
<td>3.40</td>
<td>0.16</td>
</tr>
<tr>
<td>Anode-adjacent</td>
<td>2.36</td>
<td>0.28</td>
</tr>
</tbody>
</table>
**Table S15** Relative contents of Mn, Ru and F in catalyst layer before the stability test at 10 mA cm$^{-2}$ (normalized data considering only Mn, Ru and F).

<table>
<thead>
<tr>
<th>MEA sector</th>
<th>10 mA cm$^{-2}$</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mn (at%)</td>
<td>Ru (at%)</td>
<td>F (at%)</td>
</tr>
<tr>
<td>Point 1</td>
<td>66.3</td>
<td>7.9</td>
<td>25.8</td>
</tr>
<tr>
<td>Point 2</td>
<td>62.9</td>
<td>7.8</td>
<td>29.3</td>
</tr>
<tr>
<td>Point 3</td>
<td>67.5</td>
<td>8.1</td>
<td>24.4</td>
</tr>
<tr>
<td>Average</td>
<td>65.6</td>
<td>7.8</td>
<td>26.5</td>
</tr>
</tbody>
</table>

**Table S16** Relative contents of Mn, Ru and F in catalyst layer after stability test at 10 mA cm$^{-2}$ (normalized data considering only Mn, Ru and F).

<table>
<thead>
<tr>
<th>MEA sector</th>
<th>10 mA cm$^{-2}$</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mn (at%)</td>
<td>Ru (at%)</td>
<td>F (at%)</td>
</tr>
<tr>
<td>Point 1</td>
<td>2.0</td>
<td>17.2</td>
<td>80.7</td>
</tr>
<tr>
<td>Point 2</td>
<td>2.0</td>
<td>15.4</td>
<td>82.6</td>
</tr>
<tr>
<td>Point 3</td>
<td>2.0</td>
<td>17.6</td>
<td>80.4</td>
</tr>
<tr>
<td>Average</td>
<td>2.0</td>
<td>16.7</td>
<td>81.2</td>
</tr>
</tbody>
</table>
References


