Novel high performing fuel cell membranes based on fluorinated polymers

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Polymer Electrolyte Fuel Cell (PEFC)

Anode (fuel electrode):

\[
\text{H}_2 \rightarrow 2 \text{H}^+ + 2e^- \\
\text{O}_2 + 2\text{H}^+ + 2e^- \rightarrow \text{H}_2\text{O}
\]

Cathode (air electrode):

\[
\text{H}_2\text{O} + \text{Pt} \rightarrow \text{H}_2 + \text{O}_2
\]

Catalyst Particle:
- highly dispersed Pt (Ø ~2 nm)
- carbon black ~500 m²/g

Viscoelastic Properties of Films and Membranes

Power-law behavior

\[
E_r(t) = E_r^0 t^n
\]

KWW 'stretched exponential' model

\[
E_r(t) = E_r^0 \exp \left( \frac{-t}{\tau} \right)^\beta
\]

Relaxation of membranes:
- Decrease in relaxation times upon increasing RH (rel. humidity)
- RH < 50%: Power-law behavior (n < 0.2)
- RH > 60%: Maxwell behavior (n = 1)

Structure-Property Relationships

Increase Membrane Performance
Enhance Membrane Durability

Improved Membrane Performance (30 cm² single cell)

Maximize proton flux from anode to cathode

Minimize ohmic resistance / losses:
- Membrane-Electrode interfacial resistance
- Membrane surface resistance
- Membrane bulk resistance

Dynamic Protocol:

Voltage degradation

<table>
<thead>
<tr>
<th>Membrane</th>
<th>MEA #</th>
<th>Failure [h]</th>
<th>Failure Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nafion® XL-100</td>
<td>MEA 1</td>
<td>1980 h</td>
<td>Excessive crossover</td>
</tr>
<tr>
<td>Nafion® XL-100</td>
<td>MEA 2</td>
<td>927 h</td>
<td>Excessive crossover</td>
</tr>
<tr>
<td>Nafion® XL-100</td>
<td>MEA 3</td>
<td>927 h</td>
<td>Excessive crossover</td>
</tr>
<tr>
<td>Nafion® XL-100</td>
<td>MEA 4</td>
<td>1363 h</td>
<td>Excessive crossover</td>
</tr>
<tr>
<td>PSI Gen2 Membrane</td>
<td>MEA 1</td>
<td>&gt; 2000 h</td>
<td>Not failed</td>
</tr>
<tr>
<td>PSI Gen2 Membrane</td>
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<tr>
<td>PSI Gen2 Membrane</td>
<td>MEA 3</td>
<td>564 h</td>
<td>Electrical short</td>
</tr>
</tbody>
</table>

State of the art commercial PFSA Membrane
(Mechanically reinforced + chemically stabilized)

FT-IR Analysis of PSI Membranes after 2416 h of dynamic operation:
- Less than 10% loss in ionic functionality
- No brittleness, cracks, material loss, pinholes or thinning observed.

 failure of last Nafion XL-100

BL : DuPont Nafion® NR212 (Commercial Benchmark)
A : Standard Gen2 Membrane
B : Improved Membrane-Electrode interface (Optimized MEA bonding conditions)
C : Improved membrane surface (Reduced process related loss of surface functionality)
D : Improved base substrate (Increased flexibility of backbone)
E : Improved membrane bulk (Reduced restrictions in chain mobility and water content)
F : Reduced membrane thickness (25 -> 12 um)