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GreenPower RTD 2010

FNSNF

Novel high performing fuel cell membranes based on fluorinated polymers

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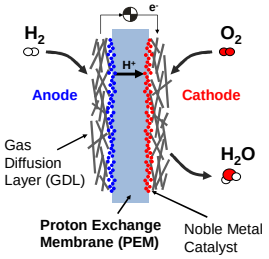
BELENOS Clean Power Holding Ltd

csem centre suisse d'électronique et de microtechnique

Polymer Electrolyte Fuel Cell (PEFC)

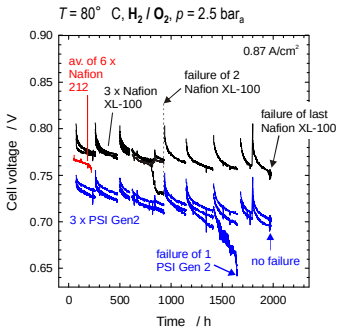


Anode (fuel electrode):
$H_2 \longrightarrow 2\,H^+ + 2\,e^-$

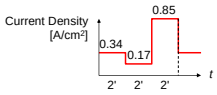
Cathode (air electrode):
$1/2\,O_2 + 2\,H^+ + 2\,e^- \longrightarrow H_2O$

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

Enhanced Membrane Durability (60 cm^2 stack)



Dynamic Protocol:



Voltage Degradation	0.17 A/cm^2	0.85 A/cm^2
XL-100	5 µV/h	10 µV/h
PSI Gen2	3 µV/h	16 µV/h

Benchmark used under dynamic protocol : DuPont Nafion® XL-100

State of the art commercial PFSA Membrane

(Mechanically reinforced + chemically stabilized)

Membrane	MEA #	Failure [h]	Failure Criteria
DuPont Nafion® XL-100	MEA 1	1980 h	Excessive crossover
	MEA 2	927 h	Excessive crossover
	MEA 3	927 h	Excessive crossover
	MEA 4	1161 h	Excessive crossover
PSI Gen2 Membrane	MEA 1	> 2000 h	Not failed
	MEA 2	> 2000 h	Not failed
	MEA 3	1648	Electrical short

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.

Structure-Property Relationships

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- Membrane synthesis
- In-situ fuel cell testing
- Ex-situ characterization
- Small-angle X-ray studies

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- Dynamic Mechanical Thermal Analysis (DMTA)
- Gas permeation properties

Structure-Property Relationships

Increase **Membrane Performance**

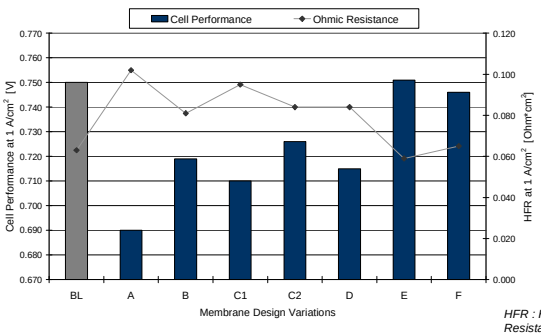
Enhance **Membrane Durability**

Improved Membrane Performance (30 cm^2 single cell)

Maximize proton flux from anode to cathode

Minimize ohmic resistance / losses :

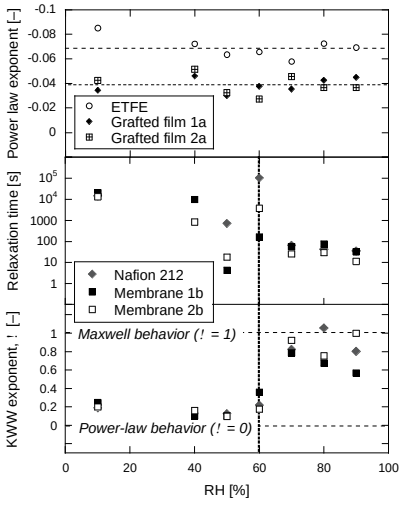
- Membrane-Electrode interfacial resistance
- Membrane surface resistance
- Membrane bulk resistance



HFR : High Frequency Resistance at 1 kHz

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)

Viscoelastic Properties of Films and Membranes



Power-law behavior $E_r(t) = E_r^0\, t^{\kappa}$

KWW 'stretched exponential' model

τ relaxation time

$0 < \beta < 1$ width of relaxation time spectrum

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

Relaxation of membranes :

Decrease in relaxation times upon increasing RH (rel. humidity)

RH < 50% : Power-law behavior (b < 0.2)
RH > 60% : Maxwell behavior (b ~ 1)