WP7: Polymer Electrolyte Fuel Cells

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Rational design of fuel cell components

CORE: Efficient utilisation of reactants
CORE: Corrosion of catalyst support
Plus: Reduced platinum loading

Performance
Longevity
Cost
Challenges

• What level of fidelity is required in models
• How to efficiently distribute reactants throughout a fuel cell

Approaches

• Ex-situ imaging of reactant transport in fuel cells

Ambition

• Rational design of flow fields and materials
• Validation of computational approaches
CORE – “A NEW REACTIVE GAS FLUX IMAGING METHOD BASED ON CHEMILUMINESCENCE”

T. Lopes, B Kakati, M Ho, A Kucernak, J. Power Sources, submitted
Different geometries of flow fields

Many flow field designs are propriety

- Square contact
- Parallel
- Interdigitated
- Serpentine
- Meander
Different types of material for reactant transport layers
How are reactants distributed within the PEFC?

Measure reactant concentration in catalyst layer under a range of operating conditions.
Modelling studies of reactant distribution in channels/transport media


Can We Image the Gas partial pressure at the Catalyst Layer Interface?
How To Image the Flux of “Oxygen” at the Catalyst Layer Interface

Ozone as a Proxy gas to Bi molecular Oxygen (Similar Binary Diffusion Coefficients in \( N_2 \), 0.175 \( \text{cm}^2 \text{s}^{-1} \) and 0.16 \( \text{cm}^2 \text{s}^{-1} \))\(^a,b\)

Taking Advantage of the Instantaneous Chemiluminescent Reaction of \( \text{O}_3 \) with a Dye – HIGHER SPATIAL and TEMPORAL Resolutions\(^c\)

Temporal and spatial resolution: 0.040 sec and 0.055 mm

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Experimental Set-Up – Ex-situ “fuel cell”

Flow field 27x27 mm
0.8mm channels, 1.6mm land
Effect of flow rate on reactant transport
Effect of flow rate on reactant transport
Effect of flow rate on reactant transport
Effect of flow rate on reactant transport
Effect of flow rate on reactant transport
Effect of flow rate on reactant transport
Light intensity varies with reactant flow rate

$R_e = 245$

$R_e = 551$

Augmenting The Flux $(\text{mL min}^{-1})$
Transport in the “GDL” – not just diffusion


NOT gas diffusion layers – “Reactant transport layers”
Asymmetry at higher flow rates

Gas Outlet

200 ccm

Gas Inlet

450 ccm

Gas Inlet
Convective Flow In the Gas Transport Media

Arrows Are Illustrative Only

Change in Momentum Upon U-Turns

Turbulent Gas Flow?
Convective Flow In the Gas Transport Media

Fixed 150 sccm of air
Variation in $P_{O_3}$

Light $\propto -d[O_3]/dt = k[O_3]$

$J = A k^0 [O_2] a_{H^+} \exp(\alpha \eta RT/F)$
Sensitivity to properties of Reactant Transport layer

Microporous Layer

Hydrophobic Agent (PTFE™)

Carbon Paper
The Constituents of a Gas Transport Medium and the Partial Pressure of the Reactive Gas at the Catalyst Layer Interface

350 mL min\(^{-1}\) Air

\(R_e = 429\)

"Generated upon Reaction"

Teflonated Carbon Layer with Microporous Layer

\(~ 6.5\% \text{ Loss in } P_{O_3}\)

Teflonated Carbon Layer

\(~ 3.0\% \text{ Loss in } P_{O_3}\)
Challenges

- Transient events lead to local voltage spikes
- These lead to degradation of systems
- Testing takes a long time (hundreds of start/stop cycles)

Approaches

- Development of *in situ* reference electrode

Ambition

- Measure effect and dependence on important parameters
- Devise and test mitigation strategies
CORE – IN SITU REFERENCE ELECTRODES FOR MEASURING LOCAL POTENTIALS

Transient effects during startup of fuel cells

- Formation of corrosion cell at moving boundary
- Transient high potentials
Transient effects during startup of fuel cells

Anode flow field

How to measure local electrochemical potential

Solid state reference electrode

Solid polymer electrolyte

Reference electrode attached to 10 μm thick porous polycarbonate conductor

31 μm

8 μm

54 μm

3 mm

30 mm
Stable reference potential

- Stable potential with time
- Measure local pH
- Important for Alkaline PEFC
Transient potential variation during startup

- Transient production of 1.4 V
- Corrosion correlated to position in cell
- Mitigation strategies being examined

Challenges

• What would the ideal electrode structure be?
• What is the ultimate performance

Approaches

• Develop a fuel cell with new electrode structure

Ambition

• Characterise limits of performance
• Bottom up approach for electrode design
FLEXIBLE: BUILDING THE “PERFECT” PEFC FUEL CELL ELECTRODE
**Platinum all over again...**

**Advances in performance of polymer electrolyte fuel cells**

![Graph showing the performance of fuel cells over time]

W.L. Gore and Associates, GORE® PRIMEA® MEAs for Transportation (2003).

From Michael Eikerling
SFU, Canada
What would an ideal structure look like?

Substrate: thin (< 10 μm), high electrical conductivity

Condensed phase

Pore: Fast diffusion of reactants with no condensation

Pt/C agglomerate: 0.5 μm

Gas phase

Fast access of protons
Use any catalyst

- E.g. 0.16 µg cm\(^{-2}\) Pt (60wt% JM HiSPEC 9100)

10 µm thick GDL

400 nm diameter hydrophobic pores

Tortuosity = 1
Catalyst Loadings
Uniform homogeneous layer across the macro and micro scale

60% Pt/C catalyst, Alfa Aesar, HiSPEC 9100

2.5 $\mu g_{Pt} \text{ cm}^{-2}$

1 $\mu g_{Pt} \text{ cm}^{-2}$

0.5 $\mu g_{Pt} \text{ cm}^{-2}$

0.16 $\mu g_{Pt} \text{ cm}^{-2}$

**ORR: Gaseous diffusion test**

P\[^{2}\_O/O_{total}\] = 0.21

Carrier gas:
- Nitrogen
- Helium

Catalyst: 60% Pt/C catalyst, Alfa Aesar, HiSPEC 9100, 4.0 mol dm\(^{-3}\) HClO\(_4\), \(O_2\), 298 K, 10 mV s\(^{-1}\), 4.9 μg\(_{Pt}\) cm\(^{-2}\)

220 \(O_2\) molecules/Pt/s
HOR/HER on Low Pt Loading Electrodes

0.55 A cm\(^{-2}\)

\(\approx 1300\) H\(_2\) molecules s\(^{-1}\)/Pt site

8 A cm\(^{-2}\)\(\approx 19,000\) H\(_2\) molecules s\(^{-1}\)/Pt site

Catalyst: 60% Pt/C catalyst, Alfa Aesar, HiSPEC 9100, 4.0 mol dm\(^{-3}\) HClO\(_4\), O\(_2\), 298 K, 10 mV s\(^{-1}\), 2.2 µg\(_{Pt}\) cm\(^{-2}\)

\(\Rightarrow\) Limiting current due to adsorption rate limitation

\[ k_{ad} > 4.9\ \text{cm s}^{-1} \ (c.f.\ k_{MT} > 50\ \text{cm s}^{-1}) \]
Platinum all over again...

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From Michael Eikerling
SFU, Canada
Making a fuel cell using these new electrodes
Making a fuel cell using these new electrodes

Nafion Membrane

50 µm

25 µm
3-electrode solid state electrochemical cell

Key benefits:
- More representative of a fuel cell MEA
- Variable water activity studies
- Larger temperature range of operation
Conclusions

- Flow is not fully laminar in a single serpentine flow field
- Convective flow is observed in reactant transport media
- The term “gas diffusion layer” is incorrect – convection is important
- Electrokinetic functions for the \textit{orr} and \textit{hor} reactions have been generated
- A solid state three-electrode cell has been produced
- The full fuel cell system is being constructed at the moment
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