High-Performing and Durable Electrodes for PEMFCs

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**Introduction**

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**Flow and Mass Transport for PEM Electrolyzers**

**High-Performing and Durable Electrodes for PEMFCs**
#1: Next Generation Electrode Structures for PEMFC

Motivation: challenges for conventional electrodes
- Random mixture of Pt/C, ionomer, and pore
- Tortuous and inefficient H⁺/O₂ transport pathways

Approach
- Partition H⁺/O₂ transport pathways via **groovy electrodes**

Two main features
1) High I/C electrode ridges for H⁺
2) Grooves for O₂

Groovy Electrodes Enable Facile $\text{H}^+$/O$_2$ Transport

- Increase in I/C ratio reduced sheet resistance.
- Similar trend was observed after the addition of grooves.
- 60% decrease (groovy I/C 1.2 vs. flat I/C 0.9)

- Increase in I/C ratio increased oxygen transport resistance.
- $R_{O_2}$ of groovy (I/C 1.2) became comparable to that of flat (I/C 0.9).

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Closer Grooves Enhance Performance

- Closer grooves led to shorter $O_2$ diffusion path.
  - Reduction in groove spacing leads to reduced distance from electrode interior to surface
  - 8-fold from flat to 1.8 µm/3 µm

• Improved performance across a wide range of operating conditions
• Groovy electrodes are particularly advantageous under dry conditions.
  - $H^+$ transport-limited under dry conditions, and higher I/C enhances $H^+$ transport.

Cell: 0.3 mgPt/cm², I/C 0.9, TEC10E40E, N211, SGL 22BB
Testing: 5 cm² differential, 1000/3000 sccm H₂/Air, 150 kPa, 80°C

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Motivation: challenges of crack investigation

- Difficulty in controlling crack width, depth, density, and orientation
- Unclear effects of cracks on electrode durability

Approach

- Using lithography-based approach to engineer cracks with prescribed morphology

After support AST, denser cracks enhance the performance of PEMFCs.

Negligible difference in carbon loss (measured via NDIR), MA, ECSA, and HFR.
Electrode Cracks Reduce O\textsubscript{2} Transport Resistance

- After support AST, R\textsubscript{O2} is significantly lower with cracks.
  - Electrode collapses, leading to R\textsubscript{O2}-limited structure
  - Cracks provide shorter O\textsubscript{2} path
- Cracks are getting wider with carbon corrosion.
  - Preferential corrosion near cracks?

• No preferential corrosion was observed.

• Two hypotheses:
  1. Cracks mainly act as O\textsubscript{2} pathway rather than H\textsubscript{2}O
  2. Support AST conditions do not flood the cracks
#3: Cobalt Contamination in PEMFC Electrodes

Motivation: challenges of understanding Co^{2+} effects
• Deconvoluting physical loss of Co and effect of Co^{2+} contamination in ionomer/membrane

Approach
• Electrode decal-based MEAs tested under various % Co^{2+}

M2FCT Year 1 Milestone (Q3):
Acceptable transition metal loss from alloy catalysts (% of sulfonyl acid sites in ionomer layer) defined with respect to electrode layer losses. (LBNL, LANL, ORNL, ANL, NREL)

• **$R_{MT}$ increased** with increasing Co$^{2+}$ doping.  
  ➢ Water uptake in the ionomer decreases with increasing Co$^{2+}$ doping.

• **$R_{sheet}$ increased** with increasing Co$^{2+}$ doping.  
  ➢ Co$^{2+}$ ion-exchanging with sulfonic acid sites lead to poor proton transport.

• Membrane resistance, and kinetic resistance remained relatively unchanged.

Cell: 0.25 mgPt/cm$^2$, I/C 0.9, TEC10E40E, N211, SGL 22BB, I/C 0.9
Testing: 5 cm$^2$ differential, 1000/3000 sccm H$_2$/Air, 150 kPa, 80°C
Summary and Future Work

#1: Groovy Electrode Enhances Performance.
- Enhanced H$^+$ and effective O$_2$ transport led to improved performance, particularly under dry conditions.
- **Future work** will couple experimental results with computational tools to further optimize structure for enhanced performance.

#2: Electrode cracks lead to improved performance after support AST.
- After electrode collapses, cracks act as a short-cut for O$_2$ to diffuse to reaction sites.
- **Future work** will examine the effect of electrode cracks on membrane durability during RH cycling.

#3: ~44% Co$^{2+}$ exchange can be tolerated in electrode ionomers.
- Co$^{2+}$ exchange results in higher $R_M$ and $R_{sheet}$.
- **Future work** will explore operating strategies/electrode designs to suppress Co$^{2+}$ effects.

Aspirations: develop my own research group centered around hydrogen and fuel cell technology, to (1) advance the science and technology and (2) train next generation scientists and engineers.
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