Interesting New Electrochemical Energy Conversion Devices

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Outline

Johnson Thermo-Electrochemical Converter

TEFC 1: FC having separated exhaust for water

TEFC 2: Parallel conduction of different ions: train design.

Summary
The Johnson Thermo-Electrochemical Converter uses two membrane electrode assembly (MEA) stacks, coupled to two different temperatures.

The MEA at the cold end is used to pump hydrogen from the upper to the lower side. The MEA at the hot end uses the pressure difference.

This is a heat engine following Ericsson Cycle.

Ericsson Cycle


\[ Q_{\text{out}} = \int_{1}^{2} P \, dV = nRT_L \ln \frac{V_1}{V_2} = nRT_H \ln \frac{P_2}{P_1} \]

\[ Q_{\text{in}} = nRT_H \ln \frac{P_1}{P_3} \Rightarrow \eta = 1 - \frac{nRT_L \ln \frac{P_2}{P_1} \frac{P_2}{P_3}}{nRT_H \ln \frac{P_1}{P_3}} = 1 - \frac{T_2}{T_H} \]
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Tandem-Electrolyte FC – planar design

the reaction water formed neither at the anode nor at the cathode interfaces, but rather in an intermediate porous layer between the two ion conductors

Figure
Planar design

Third electrode (option): influence of an electrode on the catalysis of water reaction, and an additional degree of freedom through the bias potential of that electrode.

Proton Conductors

Advanced Energy Sources Seminar, Tel Aviv 5.2.09

Acceptor-doped Proton Conductors

- Protonic conductivity in acceptor-doped perovskites was initially discovered by Iwahara et al.\(^{(4)}\)
- Yb- and Mg-doped SrCeO\(_3\) were found to conduct protons under high hydrogen chemical potential gradients at high temperatures.

\(^{(4)}\) H. Iwahara et al., Solid State Ionics, 3-4 (1981), 359

\[
2\text{Ce}^\text{x}_{\text{Ce}} + \text{O}^\text{x}_{\text{O}} + \text{Y}_2\text{O}_3 \rightarrow 2\text{Y}^\text{++}_{\text{Ce}} + \text{V}^\text{--}_{\text{O}} + 2\text{CeO}_2
\]
Acceptor-doped Proton Conductors

- Exposure of the doped crystal to water vapor results in the creation of protonic defects with the following reaction:

$$H_2O + O_O^x + V_o^{..} \rightarrow 2OH_O^.$$
Proton Transport

• Protons usually migrate in one of two mechanisms:

1. **Vehicle Mechanism**:

   \[
   \text{High } \mu(H_2) \quad \begin{array}{c}
   \text{OH}^- \\
   \text{OH}^-
   \end{array}
   \quad \text{Low } \mu(H_2) \quad \begin{array}{c}
   \text{OH}^- \\
   \text{OH}^-
   \end{array}
   \]

2. **Hopping (Grotthuss) Mechanism**:

   \[
   \text{High } \mu(H_2) \quad \begin{array}{c}
   \text{H}^+ \\
   \text{HOH}^+ \\
   \text{HOH}^+
   \end{array}
   \quad \text{Low } \mu(H_2) \quad \begin{array}{c}
   \text{HOH}^+ \\
   \text{HOH}^+
   \end{array}
   \]

• The prevailing proton transport mechanism in perovskites is proton hopping.

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Acceptor-doped Proton Conductors

- Water uptake Vs. Temperature & Doping level


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Summary
Two TEFC cells having parallel conduction of different ions, connected in series. The fuel will be injected into the porous anode. Not shown in this figure: the sealing material that will cover the whole front except the anodes.

CerMet: nanometric powder - single step GNP
Summary

Two novel Energy conversion devices have been presented. The JTEC is a heat engine utilizing two MEAs conducting protons at two different temperatures. The TEFC is a fuel cell utilizing two types of electrolytes that conduct different ions in parallel. Demo systems will hopefully come soon.