Interesting New Electrochemical Energy Conversion Devices

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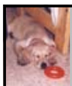

Outline

Johnson Thermo-Electrochemical Converter

TEFC 1: FC having separated exhaust for water

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

Summary

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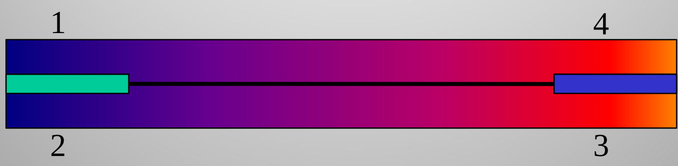
JTEC

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.

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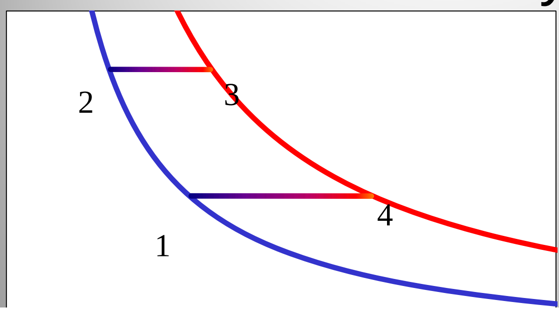
Ericsson Cycle



Shown here in P-V plane. Its theoretical efficiency equals the Carnot limit. How come? Regeneration of heat.

$$\left|Q_{out}\right| = \left|\int_1^2 PdV\right| = nRT_L \ln\frac{V_1}{V_2} = nRT_L \ln\frac{P_2}{P_1}$$

$$Q_{in} = nRT_H \ln\frac{P_3}{P_4} \Rightarrow \eta = 1 - \frac{nRT_L \ln\frac{P_2}{P_1}}{nRT_H \ln\frac{P_3}{P_4}} = 1 - \frac{T_L}{T_H}$$

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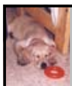

Tandem-Electrolyte FC – planar design

Figure

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

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Planar design

Figure

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.

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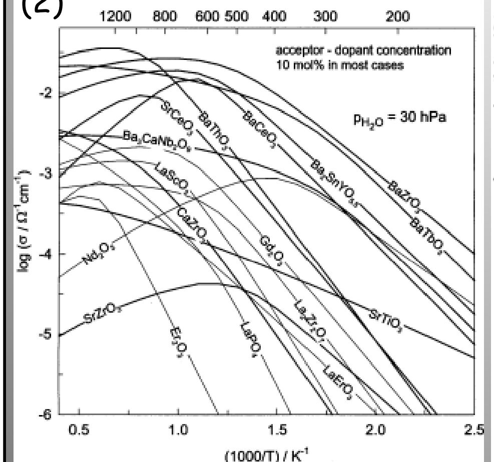
Proton Conductors

(2)



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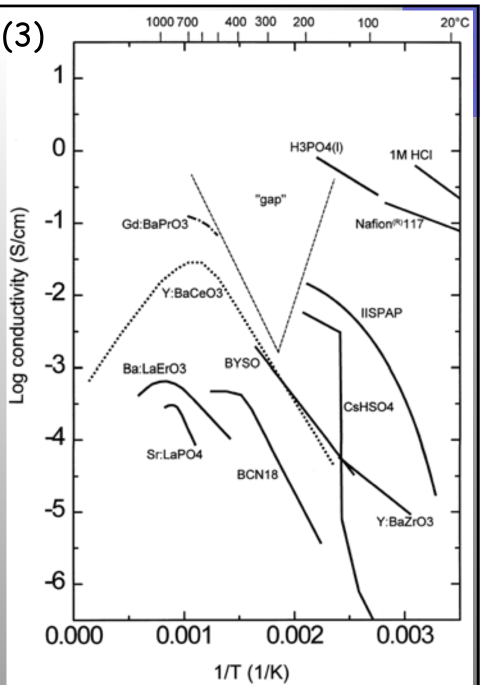


(2) K. D. Kreuer, Annu. Rev. Mater. Res. 2003. 33:333-59 (3) T. Norby, Solid State Ionics 125 (1999) 1-11

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

Acceptor-doped Proton Conductors

- Doping perovskites with acceptors results in enhancement of the oxygen vacancies concentration by means of self compensation.

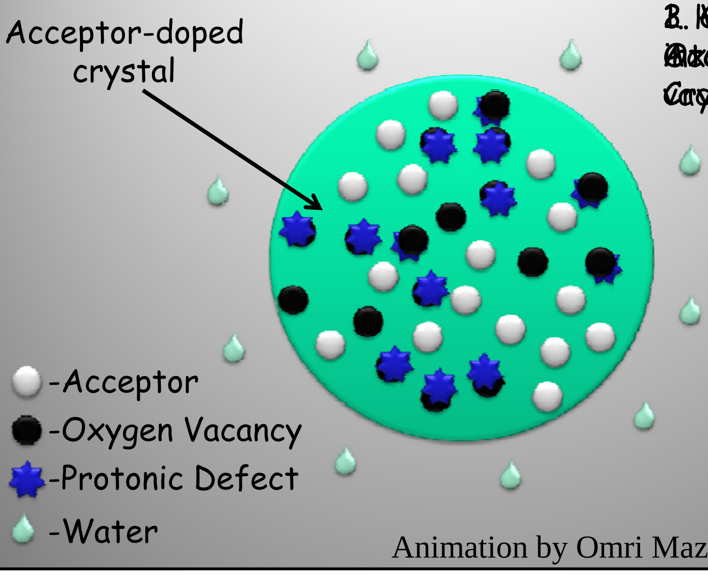
$$2Ce_{Ce}^{x} + O_{O}^{x} + Y_2O_3 \rightarrow 2Y_{Ce}' + V_{O}^{\bullet\bullet} + 2CeO_2$$

Acceptor-doped Proton Conductors

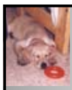
- Exposure of the doped crystal to water vapor results in the creation of protonic defects with the following reaction:

$$H_2O + O_O^x + V_O^{\bullet\bullet} \rightarrow 2OH_O^{\bullet}$$

Acceptor-doped Proton Conductors



Animation by Omri Mazar



Proton Transport

- Protons usually migrates in one of two mechanisms:

1. **Vehicle Mechanism**:

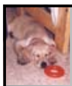
High $\mu(H_2)$

OH^- OH^- OH^- OH^- OH^- OH^-

Low $\mu(H_2)$

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

High $\mu(H_2)$ H^+ HOH^+ HOH^+ HOH^+ HOH^+ Low $\mu(H_2)$



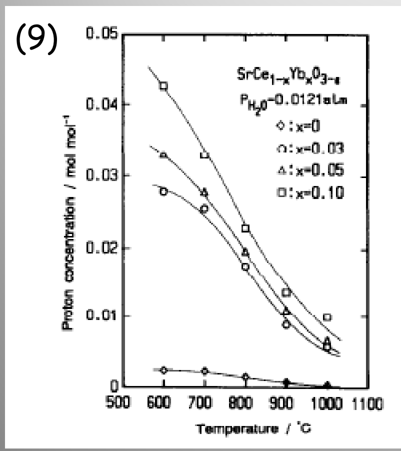
Proton Transport

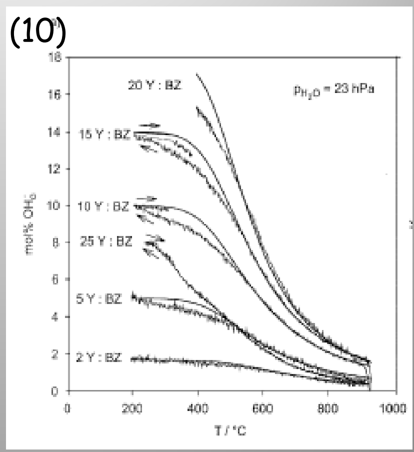
- The prevailing proton transport mechanism in perovskites is proton hopping.

- T. Norby and Y. Larring, Curr. Opi. on Solid State & Mat. Sci. 1997, 2:593-599
- A. S. Nowick and Y. Du, Solid State Ionics 77 (1995) 137-146

Acceptor-doped Proton Conductors

- Water uptake Vs. Temperature & Doping level





(9) H. Iwahara, Solid State Ionics 86-88 (1996) 9-15

(10) K. D. Kreuer et al., Solid State Ionics 145 (2001) 295-306

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Train design

Figure

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.

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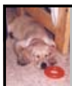

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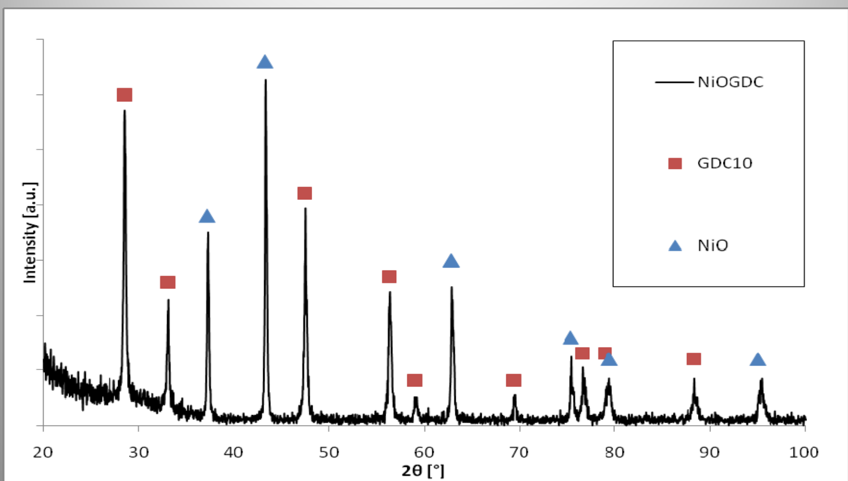
Anode material



CerMet: nanometric powder - single step GNP

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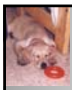

Summary

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.