Rare-earth Information Center

Insight

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Solid Oxide Fuel Cells

Over the last few years, we have been hearing quite a lot about fuel cells, as there is an increasing need to find a clean alternative for the burning of fossil fuels. Recently, the *Journal of Materials Science* published a special section entitled "The Materials Science of Fuel Cells." Fuel cells are not new, they were first demonstrated in 1839 when William R. Grove, an English physicist, demonstrated that combining hydrogen and oxygen could produce water, and an electric current, reverse electrolysis. Unlike batteries, fuel cells operate off a continuous stream of air, as a source of oxygen and a source of hydrogen fuel. If pure H_2 is available, the fuel cell is relatively simple, however, the transportation of pure H_2 is a complex problem. Thus, many of the fuel cell concepts, which are being developed, involve the reforming of hydrocarbons. Unfortunately, a certain level of CO impurities are associated with this process. These impurities tend to poison the catalysts used in simple fuel cells. Thus, the development of a fuel cell for wide spread applications requires a rather complex systems approach.

While many types of fuel cells use no rare earth materials, the solid oxide fuel cell (SOFC) relies on the ionic conduction properties of a rare earth based solid electrolyte. The role of the electrolyte is to conduct ions while not conducting electrons. The electrolyte separates the anode where H_2 is split into $2H^+$ and 2 electrons, and the cathode where O_2 is split into $2O^{2-}$ consuming four electrons. The $2H^+$s then recombine with an O^{2-}, and it is the heat of formation for the H_2O that provides the energy. The trick is to cause the electrons to take the long way around through an electric circuit, while ions are conducted through the electrolyte. It makes no difference to the basic chemistry if the H^+ is conducted thorough the electrolyte, in which case water is formed at the cathode or O^{2-} is conducted, and water is formed at the anode. In most SOFCs, ions are conducted through the electrolyte and, thus, rare earth based ionic conductors are of interest. There are also rare earth based proton (H^+) conductors. In SOFCs, both the anode and cathode are porous to allow the gas reactions to take place at the interface with the electrolyte. Thus, the electrolyte must provide a gas tight barrier between the H_2 and O_2. Unfortunately, significant ion conduction does not take place until the cell is heated to a relatively high temperature so that the cell must withstand repeated thermal cycling. Thus, there are significant requirements for both electrical and mechanical performance. Since the anode and cathode must be in intimate contact with the electrolyte, they are frequently rare earth based conductors.

Twelve of the papers, included in the *Journal of Materials Science* section, deal with fuel cells using rare earth based materials. Of most general interest is the introductory article by the section editor, B. C. H. Steel {*J. Mater. Sci.,* **36**, 1053-68 (2001)}. This article has extensive sections on each of the fuel cell technologies so that one can compare the rare earth based technologies with the competition. One of the major advantages of the SOFC is that hydrocarbon fuels may be reformed into H_2 within the cell simplifying the system. SOFCs are divided into two classes, high temperature cells (HT-SOFC), which operate at about 1000°C, and intermediate temperature cells (IT-SOFC), which operate in the range between 500 and 750°C. The HT-SOFC cells place additional compatibility requirements between the anode, cathode and electrolyte, since the cells are processed at temperature up to 1300°C. If there is significant diffusion between the materials of the various components, the performance is significantly degraded. HT-SOFC are based on yttria stabilized zirconia (YSZ) as electrolyte and use a SrO doped $LaMnO_3$ cathode. The anode for these cells is NiO doped YSZ, and the cells employ $LaCr(Mg)O_3$ interconnects. One of the papers by A. Selcuk et al. {*J. Mater. Sci.*, **36**, 1173-82 (2001)} deals with the problem of residual stress in symmetric multiple electrode assemblies. Since the residual stresses in these materials are often relieved by cracking, this can be a major problem in obtaining a gas tight membrane. A major problem with these cells is actually the fabrication cost. In addition, due to the high temperature operation, the exhaust gas from HT-SOFC contains significant energy. Therefore to obtain high efficiencies, the units are combined with microturbines and are expected to deliver 70% efficiency. Clearly, this is only suitable for large-scale installations.

The high operating temperature requirement of YSZ based cells is dictated by the temperature dependence of the ionic conductivity of YSZ. In order to lower the temperature of operation, other ion conducting electrolytes have been investigated. $Ce_{0.9}Gd_{0.1}O_{1.95}$ has a number of problems, when used at high temperature due to a large lattice expansion that occurs when the Ce^{4+} is reduced to Ce^{3+} under fuel rich conditions. However, this problem does not occur at 500°C. Unfortunately, alternative cathode materials are needed for this low temperature operation. A driving force for the development of these cells is that they are considered to act as a direct methanol fuel cell. This would be ideal for electric vehicles. A number of other electrolytes are currently being investigated, such as doped $LaGaO_3$, $La_{10}Si(Ge)_6O_{27}$.

A complete discussion of the *Journal of Materials Science* section is beyond the scope of this newsletter, however, it would appear that IT-SOFC is a prime candidate for electric vehicle applications that would then be a very significant market for rare earth oxides.

GaN:RE Phosphors

Thin film electroluminescence (TFEL) phosphors are required for full color flat panel displays that are currently being developed for portable display and flat TC applications. Currently, the phosphors for these displays are based on II-VI semiconductors. Now, A. J. Steckl et al. {*Mater. Sci. Eng. B*, **81**, 97-101 (2001)} have reported advances in phosphors based on the III-V semiconductor GaN doped with RE. By using Eu, Er, or Tm dopants, red, green, or blue emission colors can be produced. Multiple color capability can be achieved in a single device by adjusting the bias voltage of a co-doped GaN:Er,Eu layer. The light emission from the phosphors is very good and reflects the fact that relatively high concentrations of RE may be doped into the GaN without degrading the host material or causing RE precipitation.

News:

Great Western Gold Corporation has reported that the initial assay results for their rare earth project in northern Saskatchewan show promising results. The company has also reported that it is proceeding with a non-brokered private placement for $750,000 to complete metallurgical work and infill drilling on the property. Details of their reports are available at http://www.greatwesterngold.com.

Magnequench International has filed patent infringement suits against 10 major electronic and computer firms. The basis for the suit appears to be the use of unlicensed magnets in spindle drive motors for CD and DVD-ROM drives, as well as the motors for camcorder zoom lenses. More information is available at
http://www.magnequench.com.

Sincerely,

R. W. McCallum
Director of RIC