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Undergraduate

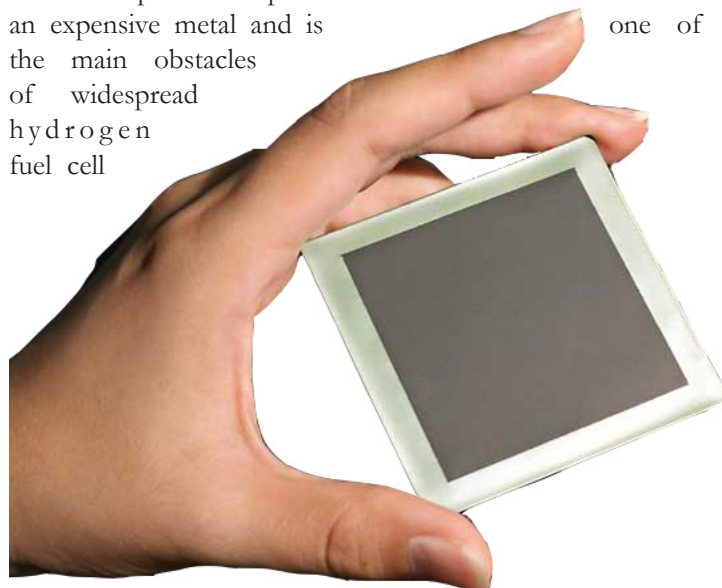
SOMETHING FOR NOTHING: SOLID-OXIDE FUEL CELLS

Karthik Gururangan

B S J

Fuel cells have been a popular contender for the gateway to the hydrogen economy for some time. Indeed, today we can see zero-emission buses and cars powered by a hydrogen fuel cell. Generally speaking, a fuel cell is an electrochemical system that drives the transferred electron occurring in redox reactions through an external circuit to power something. It is really the most straightforward way to convert chemical energy into electrical energy, and provided that the reactants remain in a steady supply, a fuel cell can indefinitely supply a steady current.

By referring to Figure 1 we can understand the setup of a hydrogen fuel cell. At the blue side (anode), hydrogen loses electrons and the resultant protons migrate into a reaction chamber. The green side (cathode) is very often an opening or simple air reservoir. The electrons flow through the circuit and reach the oxygen, completing the chemical reaction to produce water. Using the hydration electrochemical reaction is the basis of our intended hydrogen economy. In reality, one cell of this type hardly produces 1 volt so we combine single cells in series into what is called a fuel cell stack for applications. The main drawback of classical gas or liquid hydrogen fuel cells is that they require a platinum catalyst to speed up the reaction process to usable values (Minh, 2004). In Figure 1, the middle plate is the platinum – this is an expensive metal and is one of the main obstacles of widespread hydrogen fuel cell



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usage. Recently, scientists have proposed using solid-state diffusion of hydrogen and oxygen ions through an oxide electrolyte to make the hydration reaction (Park, 2000). These fuel cells are called solid-oxide fuel cells, or SOFCs. At high enough temperatures, SOFC diffusion can quickly outpace regular chemical kinetics, give us greater fuel choice flexibility, and eliminate harmful carbon monoxide by-products of common liquid fuel cells (Park, 2000).

Diffusion is a temperature-controlled exponential law based on two things: the diffusivity of a particular electrolyte and the activation energy of diffusion for that particular solute. The activation energy can be decomposed into the energy

needed to move around through the solid and the energy associated with moving around through holes called vacancies in the solid. Figure 2 gives an intuitive idea of what this means.

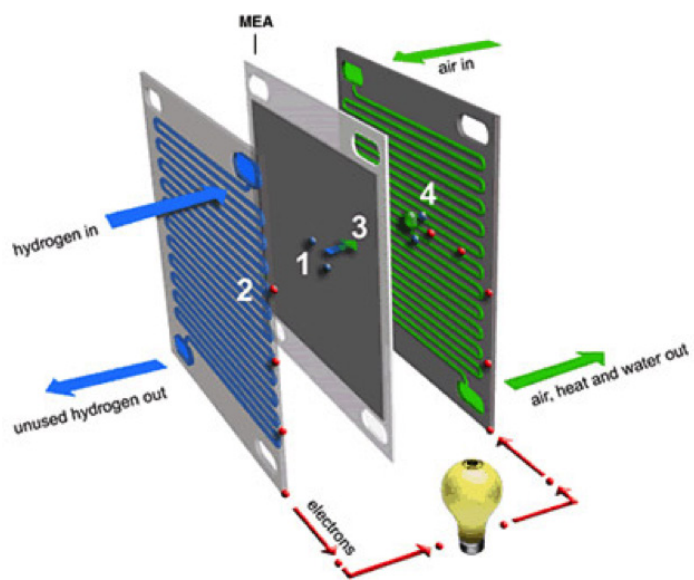


Figure 1. : Simple schematic of a single hydrogen fuel cell

An atom can either push its way past two others to move to another position or it can move through the existing gap defects. By choosing a solid oxide electrolyte, the much larger oxygen ions have an easier time migrating through the lattice, making the overall diffusion rate much faster than it

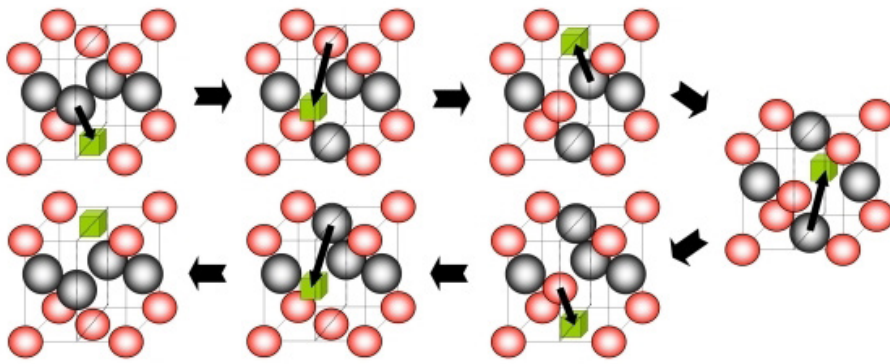


Figure 2. : Diagram of solid-state diffusion by vacancy mechanism with Arrhenius Law equation

would be using other solid electrolytes.

Figure 3 gives us a way to understand the electrochemical system that a SOFC operates on. The hydrogen-containing fuel is oxidized at the anode; the electrons provide power through an external circuit and reach the cathode where it reduces the oxygen atoms via exposure to air (Park 2000, & Hibino 2000). The oxygen ions now migrate through the electrolyte to combine with hydrogen ions at the anode to create water. The important research in SOFC research concerns the materials used for anode, cathode, and electrolyte (Shao & Halle, 2004). The selected electrolyte should be porous to oxygen ions but not oxygen molecules, have high ionic conductivity, resist oxidation, and act as a thermal barrier to combustion (Shao & Halle, 2004). Zirconia (ZrO_2) is a popular oxide ceramic electrolyte because it primarily satisfies these four conditions. Scientists have also found that doping zirconia with yttria (Yr_2O_3) will increase the number of vacancies (gaps) in the crystal, making the diffusion rate of oxygen ions through the electrolyte much

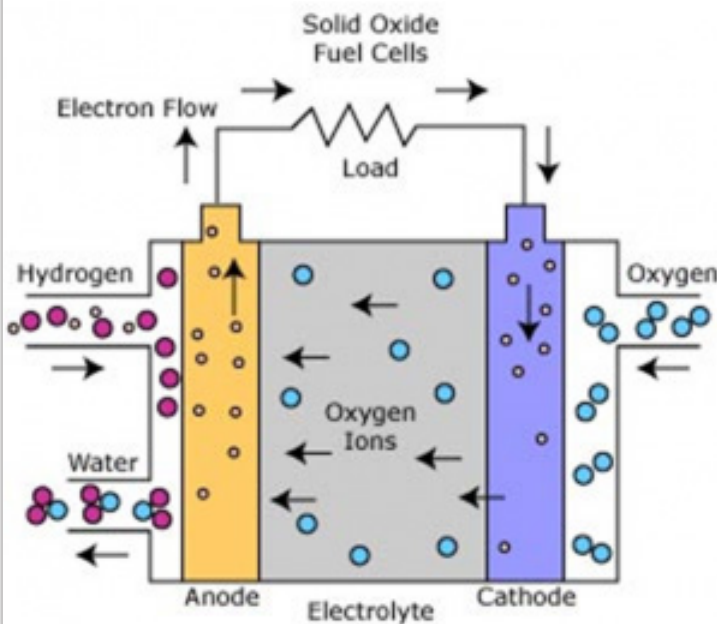


Figure 3. : Schematic of single SOFC operation. The anode, cathode, and electrolyte are solid and the rate of oxygen anion diffusion through the electrolyte is equal to the rate of electron flow (current generated)

faster. This particular electrolyte is called yttria-stabilized zirconia (YSZ) and is currently the most widespread contender for an electrolyte material. The major drawback of this diffusion mechanism is that SOFCs using YSZ must be operated between 600 – 1000 C (Singhal, 2000 & Steele, 2001). Other experiments have confirmed that samaria-doped ceria (SDC) can potentially yield an even greater oxygen diffusion rate at lower temperatures (Hibino, 2000). The key property of anode and cathode materials is a low area-specific resistivity (ASR)

(Steele, 2001). This value is inversely correlated to the fuel cell's energy density: the higher the energy density, the more power that can be produced (Steele, 2001). Common electrode materials are nickel for the anode and an alloy of lanthanum, strontium, and manganite called LSM (Steele, 2001). When these electrodes are combined with an SDC electrolyte, engineers have managed to produce sufficient output power at 50 – 60% efficiency at 500 C (Steele, 2001).

The final step in SOFC design is its implementation. Currently, engineers have employed a tubular design:

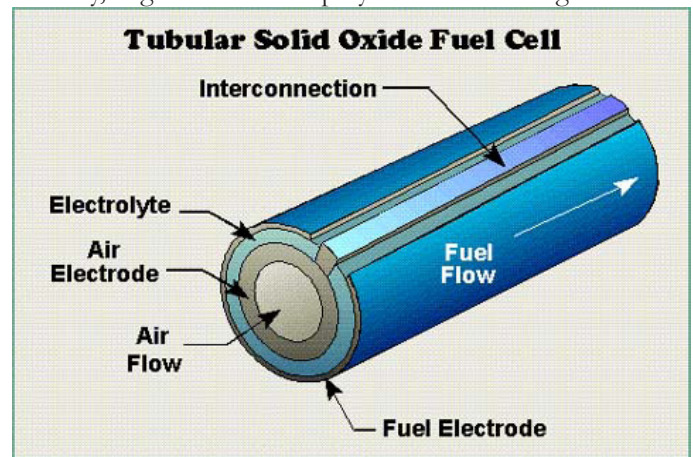


Figure 4. : Hollow SOFC tube. One side is exposed to air (oxygen) and the other is exposed to the hydrocarbon fuel. The electrons flow from fuel electrode to the inner electrode and oxygen ions diffuse outward

This popular layout is compact and amenable to the way these ceramic components are processed (Singhal, 2000). In addition, this design and others are flexible and scientists have managed to alter myriad power plant systems for fuel cell operation. The only barrier to widespread SOFC usage is its unfortunately high operation temperature (Hibino, 2000). While operation at room temperature or even common fuel cell temperatures is unlikely given how thermally-dependent diffusion is, SOFCs provide a zero-emission, innovative gateway to the hydrogen economy. Many power plants and generation schemes accommodate high-temperature operation and with advances in materials chemistry, we are developing components that can sustain high power output at lower and lower temperatures (Singhal, 2000).

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