Zirconia Electrolyte Based Fuel Cells

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INTRODUCTION

The high oxide ion conductivity over wide ranges of temperature and oxygen pressures in stabilized zirconia has led to its use as a solid oxide electrolyte in a variety of electrochemical applications. These include high temperature solid oxide fuel cells (SOFCs) which offer a clean, low-pollution technology to electrochemically generate electricity at high efficiencies. These fuel cells provide many advantages over traditional energy conversion systems including high efficiency, reliability, modularity, fuel adaptability, and very low levels of NO_x and SO_x emissions. Quite, vibration-free operation of SOFCs also eliminates noise usually associated with conventional power generation systems. Furthermore, because of their high temperature of operation (~800-1000^{o}C), natural gas fuel can be reformed within the cell stack eliminating the need for an expensive, external reformer system. Also, pressurized SOFCs can be integrated with gas turbines and such hybrid power systems are expected to reach efficiencies approaching 75%. This paper reviews the current status of the SOFC technology for power generation in various applications.

Among all designs of SOFCs, the most progress has been achieved with the tubular design (1). A 100 kW power generation system utilizing tubular SOFCs, fabricated by Siemens Westinghouse Power Corporation, operated very successfully for two years without any detectable performance change. However, the electrical resistance of tubular design cells is high, and specific power output (W/cm^2) and volumetric power density (W/cm^3) low (2). These low power densities make tubular SOFCs suitable only for stationary power generation and are unattractive for mobile applications. Planar SOFCs, in contrast, are capable of achieving very high power densities (3). Additionally, sizeable cost reductions are possible through a concept called “mass customization” that is being pursued in the U.S. Department of Energy’s Solid State Energy Conversion Alliance (SECA) (4). This concept involves the development of a 3 to 10 kW size core SOFC module, that can be mass produced and then combined for different size applications in stationary power generation, transportation, and military market sectors, thus eliminating the need to produce custom-designed and inherently more expensive fuel cell stacks to meet a specific power rating.

ANODE-SUPPORTED PLANAR SOFCs

Currently, electrolyte-supported, cathode-supported, and anode-supported SOFCs are under development. In electrolyte-supported cells, the thickness of the electrolyte, typically yttria-stabilized zirconia (YSZ), is 50 to 150 μm, making their ohmic resistance high, and such cells are suitable for operation at ~1000°C. In electrode-supported designs, the electrolyte thickness can be much lower, typically 5 to 20 μm, decreasing their ohmic resistance and making them better suited for operation at lower temperatures (~700-800°C). Lower temperature operation results in less degradation of cell and stack components, makes feasible use of inexpensive metallic interconnects, is less demanding on seals, and aids in faster heat up and cool down. The anode (Ni/YSZ cermet) is selected as the supporting electrode, because it provides superior thermal and electrical conductivity, superior mechanical strength, and minimal chemical interaction with the electrolyte. Kim et al (3) have reported power densities as high as 1.8 W/cm^2 at 800°C for such anode-supported SOFCs. Such high power densities make them very attractive for use in the core SOFC module. Cathode and interlayer materials and their microstructures for anode-supported cells are being optimized to achieve higher and stable performance.

SOFCs FOR AUXILIARY POWER UNITS (APUs)

The polymer electrolyte membrane (PEM) fuel cell is generally regarded as the fuel cell of choice for transportation applications. PEM fuel cells require pure H_2, with no CO, as fuel to operate successfully. However, presently no H_2 infrastructure exists, and on-board reformer systems to produce H_2 from existing fuel base (e. g. gasoline and diesel) are technically challenging, complex, and expensive. Furthermore, it is difficult to eliminate all the CO from the reformate stream. In contrast, SOFCs can use CO along with H_2 as fuel, and their higher operating temperature and availability of water on the anode side makes on-cell or in-stack reformation of hydrocarbon fuels feasible. Also, no noble metal catalysts are used reducing cost of the cells. The initial application of SOFCs in the transportation sector will be for on-board APUs. Such APUs, operating on existing fuel base, will supply the ever-increasing electrical power demands of luxury automobiles, recreational vehicles, and heavy-duty trucks.

Delphi Automotive Systems is engaged in the development of a 5 kW APU using anode-supported SOFCs. The building blocks of such an APU consist of a SOFC stack, fuel reformation system, waste energy recovery system, thermal management system, process air supply system, control system, and power electronics and energy storage (battery) system. An initial proof-of-concept unit has been developed and tested on gasoline by Delphi (5). APUs require fast heat up and ability to be thermally cycled; thermomechanical, thermal-fluids, and stress modeling is being conducted to aid in achieving stack designs with these properties.

SUMMARY

Anode-supported planar SOFCs are being developed for potential use in a core module of 3 to 10 kW size capable of being mass produced for use in stationary, transportation, and military applications. Current work is aimed at achieving higher stack power density, faster start up, thermal cyclability, hydrocarbon fuel reformation either on the cell or integrated with the cell stack, and lower cost.

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