IV.J.3 Bipolar Plate-Supported Solid Oxide Fuel Cell

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Objectives

- Develop an improved solid oxide fuel cell (SOFC) for auxiliary power units (APUs)
- Improve mechanical properties (i.e., vibration and shock resistance)
- Improve cell power output by eliminating contact resistance between cell and interconnect layers
- Reduce materials costs
- Develop a low-cost fabrication method

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- O. Stack Material and Manufacturing Cost
- P. Durability
- Q. Electrode Performance
- R. Thermal and Water Management

Approach

- Support cell on metallic bipolar plate to improve durability, cyclability, and shock-resistance
- Minimize thickness of expensive ceramic-containing layers (anode, electrolyte, and cathode)
- Fabricate cell components using tapecasting and powder metallurgy techniques
- Eliminate manufacturing steps to reduce cost

Accomplishments

- Scaled single cell fabrication from 1" x 1" to 2" x 2"
- Designed and built stack test apparatus and developed internal manifolding procedure
- Fabricated two-cell TuffCell stack and ran initial test with hydrogen/air
- Improved single cell fabrication materials and procedure using dilatometer results. Current power density status: >260 mW/cm^2

Future Directions

- Continue to improve single cell and stack power densities to decrease size, weight, and cost
- Improve design and fabrication procedure
- Investigate improved materials for metallic support, anode, and cathode

- Demonstrate that TuffCell stacks can meet DOE Technical Performance Targets for APU application
- Test start-up time (goal: < 30 min.)
- Test temperature cycling (goal: > 500 cycles)
- Investigate durability (goal: > 5,000 operating hours)

Introduction

Solid oxide fuel cells are attractive power sources for auxiliary power applications because they exhibit high power densities and efficiencies, have simplified fuel reforming requirements, and are fuel flexible. However, the high operating temperature and brittle nature of the ceramic cell components have so far precluded their widespread use. SOFCs have traditionally been operated at ~1000°C because the cell support was a relatively thick, doped-zirconia electrolyte layer, which had too high a resistance at lower temperatures. Recently, the operating temperature has been lowered to 650–800°C by supporting the cell on a thick ceramic-metal (cermet) anode layer and decreasing the thickness of the electrolyte layer to <20 µm, thus decreasing its resistance. These lower operating temperatures have made SOFCs viable for auxiliary power, allowing better thermal integration with the fuel reformer (operating at ~700°C), the use of metallic flow fields and interconnects, and shorter start-up times.

Barriers to the use of SOFCs remain, however, including: (1) susceptibility to cracking due to vibration, impact, and thermal shock, (2) contact resistance between the cell components, and (3) high material and manufacturing costs. To build affordable SOFC stacks, it is necessary to reduce the weight fraction of expensive materials and cut manufacturing costs. The bulk of the materials cost of the anode-supported SOFC lies in the large amount of zirconia in the thick anode support and the cost of expensive alloys in the bipolar plate. The use of a cermet layer to support the cell in the anode-supported design also makes the cell fragile and susceptible to thermal shock.

Approach

A new SOFC design is being developed, dubbed the TuffCell, to address the issues facing the use of SOFCs in auxiliary power applications. The objective of the Argonne approach is to improve the mechanical properties, to eliminate contact resistance between the cell and interconnect layers, and to reduce materials and manufacturing costs. In the TuffCell concept, the brittle electrolyte and anode layers are co-sintered with the metallic gas flow fields and the bipolar plate, forming an integrated repeat unit for stacking. The metallic bipolar plate serves as the structural support that offers increased mechanical strength and improved thermal cyclability of the cell. The bulk of the bipolar plate can be made of inexpensive stainless steels with thin functionally passivating layers at the surfaces exposed to the corrosive fuel and oxidant atmospheres. Materials costs are reduced by using thin layers of electrolyte, anode, and metal alloys on an inexpensive metallic support. In contrast to state-of-the-art SOFC fabrication, which includes several sintering steps in air, the TuffCell approach uses a single-step powder metallurgy process carried out in a reducing atmosphere to preserve the reduced state of the metals. Eliminating high temperature processing steps reduces fabrication costs.

Each component layer of the cell is formed using tape-casting or slurry-coating methods. After drying, the layers are laminated together to form a monolithic stack unit. Laminates containing the electrolyte, anode, fuel flow field, bipolar plate, and air flow field are sintered in a controlled-atmosphere tube furnace. The cathode is applied and sintered *in situ* during the initial heating of the cell or stack. Figure 1 shows a schematic and photo of the TuffCell stacking unit, which consists of the ceramic electrolyte, the cermet anode, and the metallic flow fields and interconnect.

Results

The efforts this year focused on cell fabrication, seal and manifold development, and the design and construction of an apparatus for the electrochemical testing of a two-cell TuffCell stack using hydrogen and air.

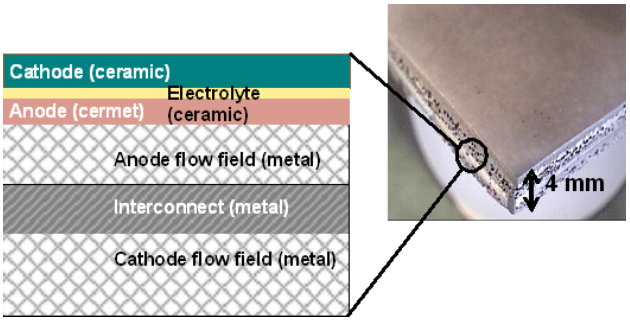

Figure 1. Schematic and Photograph of the Bipolar Plate-Supported SOFC Stacking Unit

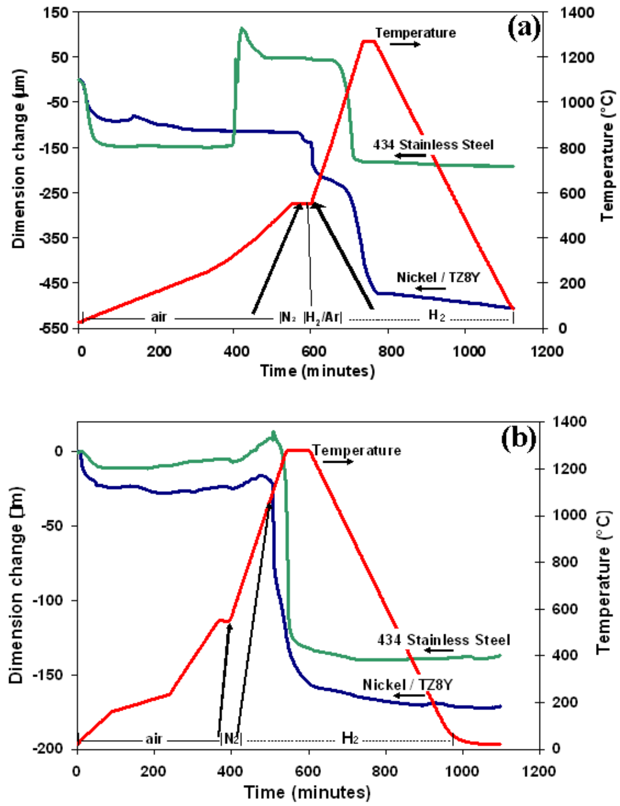

Figure 2. Dilatometer Traces Showing Shrinkages of the Bipolar Plate and Anode Tapes During the Sintering Profile: (a) Bipolar plate layer expands during binder burnout causing flaws in the bipolar plate; (b) Improved bipolar plate layer binder does not cause expansion during burnout.

Defect-free, gas impermeable bipolar plate layers were not a necessity for single-cell tests; indeed, the dense bipolar plate was intentionally perforated to allow gas access to the anode for the tests. Stack tests, on the other hand, require a gas-impermeable bipolar plate layer to prevent mixing of fuel and oxidant in the anode and cathode flow fields. Dilatometer studies of the tapes used for single cell fabrication showed that the bipolar plate tape expanded during the binder burnout step causing flaws in the bipolar plate layer (Figure 2a). We have developed a new binder for the bipolar plate tape that does not cause this expansion, resulting in gas-impermeable, flaw-free bipolar plates (Figure 2b).

A flexible stack test apparatus, shown in Figure 3, was designed and built. This design is based on clamping a flexible cylinder around the stack and two end caps resulting in the formation of four chambers, two for gas inlet and two for gas outlet. The cell size was successfully scaled up from 1" x 1" to 2" x 2". The seal between the test apparatus and the stack was formed using a gasket of glass in a porous ceramic substrate. Edge sealing of the flow fields was developed to prohibit cathode gas from entering the anode flow field and anode gas from entering the cathode flow field. This was accomplished by altering the metal slip composition used for the flow field and bipolar plate tapes to allow the metal to be injected into the edges of the flow field tape. A two-cell stack was fabricated with edge-seals, using the newly-developed bipolar plate tape binder, loaded into the test apparatus, and tested at 800°C using hydrogen anode gas and air cathode gas. Post-test analysis showed that the corner gaskets were too porous to eliminate gas leakage and

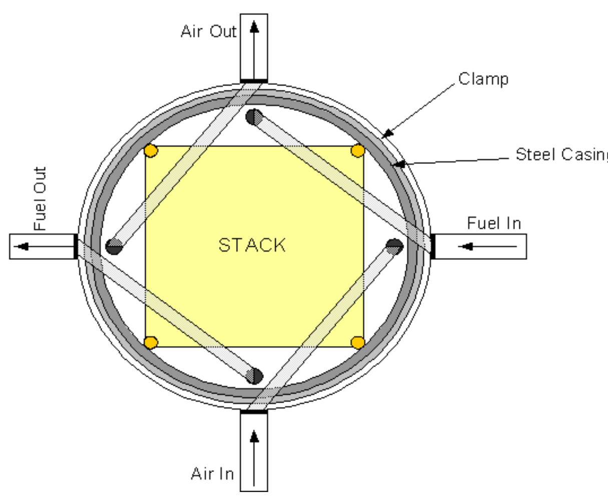

Figure 3. Stack Test Apparatus (A novel stack test apparatus was designed, consisting of a flexible cylinder clamped around two end caps and the stack, forming four separate chambers for cathode and anode gas inlets and exit.)

that there was poor electrical contact between adjacent cells.

Conclusions

- A design and fabrication procedure that improves the mechanical properties and lowers the cost of SOFCs has been developed and tested
- Single cells of the TuffCell design have failure strengths four times those of commercial anode-supported cells and have achieved power densities >260 mW/cm^2
- A 2" x 2" short TuffCell stack has been fabricated, edge and corner seals have been developed, and a stack test apparatus designed and built
- Improvements are being made in the cell-to-cell electrical contact and corner gaskets to allow electrochemical testing of the short stack on reformate and air

Special Recognitions & Awards/Patents Issued

1. Patent Application: US2003/0232230 A1: "Solid Oxide Fuel Cell with Improved Mechanical and Electrical Properties," John David Carter, Joong-Myeon Bae, Terry Alan Cruse, James Michael Ralph, Romesh Kumar, and Michael Krumpelt.