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Development of a Versatile, High-Performance Solid Oxide Fuel Cell Stack Technology

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A high-performance solid oxide fuel cell (SOFC) stack technology is being developed, based on a design concept that incorporates prime-surface metallic interconnects with the versatility of stacking different types of single cells (sintered cells or metal-supported cells). A preliminary design of the prime-surface interconnect based on an egg-carton shape configuration has been advanced for this stack concept. Laboratory-scale prime-surface interconnects have successfully been fabricated by stamping and evaluated for mechanical loading, flow distribution and current collection properties. A process based on sputtering has been developed for fabricating supported thin-film (several micrometers thick) cells for this stack technology. Fabricated thin-film cells have shown desirable structural characteristics and exceptional performance on different fuels at reduced temperatures (550°-650°C). Sputtered cells (with yttria stabilized zirconia (YSZ) for the electrolyte, gadolinia-doped ceria (GDC) for the electrolyte/cathode interlayer, nickel-YSZ for the anode and lanthanum strontium cobalt iron perovskite (LSCF)–YSZ for the cathode) have exhibited peak power densities of ~1.7 W/cm^2 and ~2.1 W/cm^2 with hydrogen fuel and air at operating temperatures of 600°C and 650°C, respectively.

Stack Design

An advanced solid oxide fuel cell (SOFC) stack technology with the potential for high performance, improved reliability, and reduced cost is being developed for a variety of power generation applications. One of the main features of this stack design is the prime-surface interconnect, a one-piece metallic interconnect that incorporates both fuel and oxidant flow fields with peaks on one side of the interconnect serving as flow channels (valleys) on the other side (1). This stack design also permits stacking the prime-surface interconnect with different types of cell (sintered cells or metal-supported cells) without significant design modifications. Figure 1 shows the drawings of the design incorporating sintered cells (Figure 1A) and metal-supported cells (Figure 1B). The interconnect, shown in Figure 1 has an egg-carton flow field configuration and the stack includes two flat sheets bonded to interconnect dimples on both sides with openings for gas access to the cell.

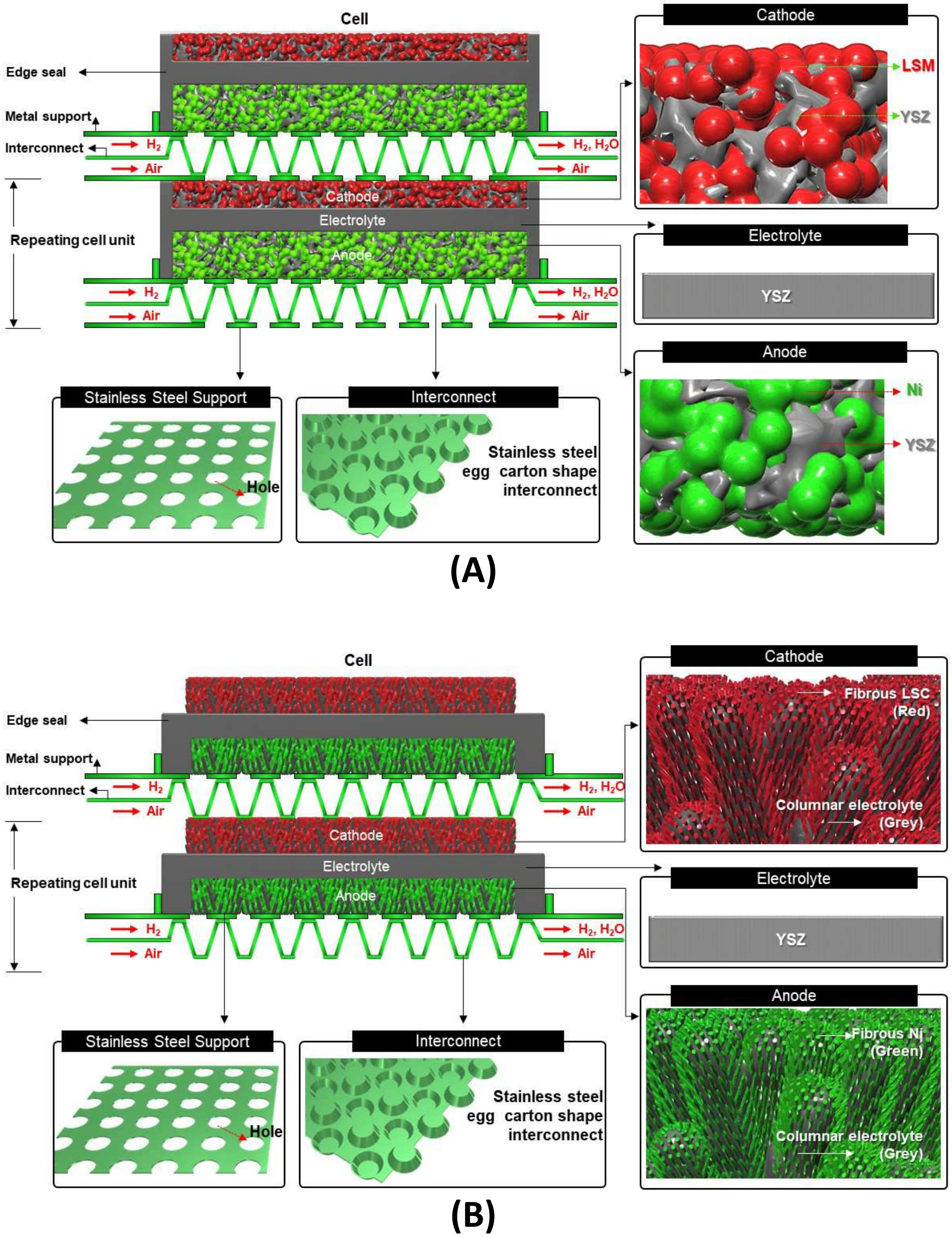
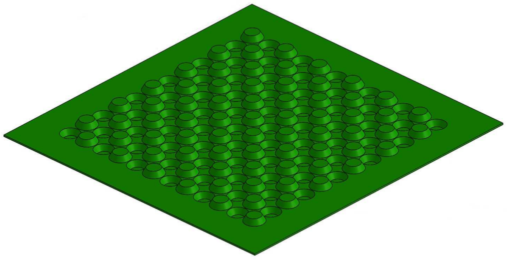
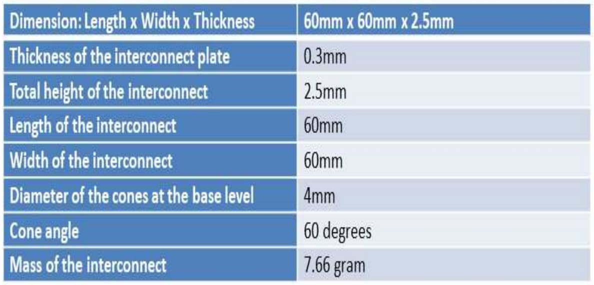


Figure 1. Stack design: (A) with sintered cells; (B) with metal-supported cells

Development of Prime-Surface Interconnects

The development of prime-surface interconnects for this stack technology has focused on evaluating the design with egg carton shaped flow fields. Figure 2 shows a 3D drawing of the interconnect design and the parameters selected for preliminary analysis. Stress evaluations have been conducted for this interconnect at different temperatures using finite element analysis from the consideration that the interconnect located at the bottom of an assembled stack would sustain the weight of 100 cell-interconnect repeat units mounted onto it. Figure 3 shows the distributions of the safety factor (safety factor = yield strength of material/maximum stress at a certain operating temperature) of the bottom interconnect, which is assumed to be made of stainless steel SUS441. The evaluation results show that the interconnect has a minimum safety factor of 2.24 and 1.12 at 750ºC and 800ºC, respectively. These safety factors are greater than 1.0, therefore the interconnect of this design is strong enough to work at operating temperatures up to 800 ºC. Simulation of gas flow velocity behavior shows uniform flow distribution within the interconnect channels (Figure 4).





Dimension: Length x Width x Thickness	60mm x 60mm x 2.5mm
Thickness of the interconnect plate	0.3mm
Total height of the interconnect	2.5mm
Length of the interconnect	60mm
Width of the interconnect	60mm
Diameter of the cones at the base level	4mm
Cone angle	60 degrees
Mass of the interconnect	7.66 gram

Figure 2. Prime-surface interconnect design

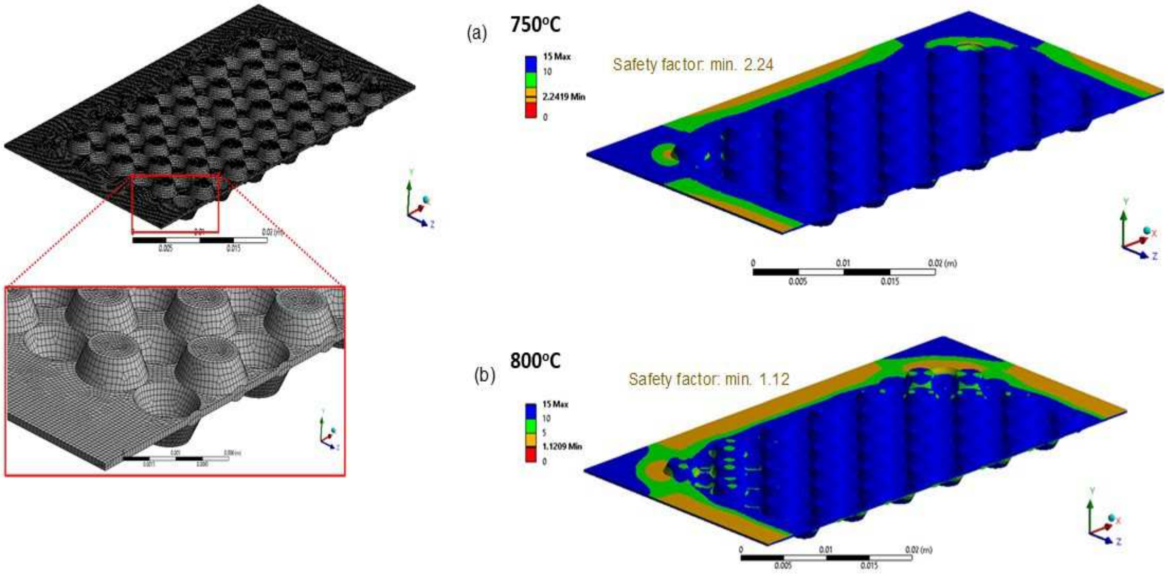


Figure 3. Safety factor analysis of prime-surface interconnect under load of 100 interconnect-cell repeat units

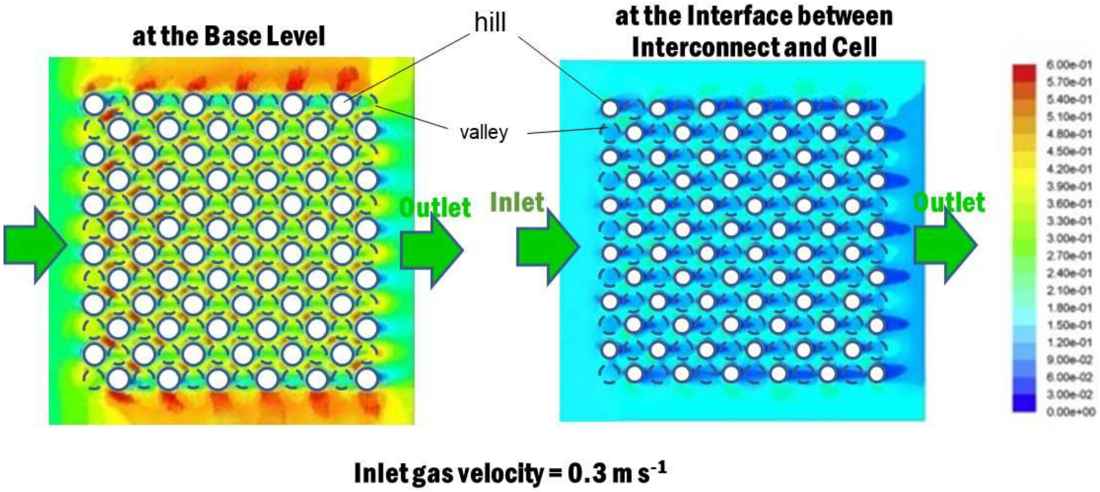


Figure 4. Gas flow velocity distribution within interconnect channel

Stamping has been selected as the baseline fabrication method to assess the formability of the prime-surface interconnect design shown in Figure 2. Figure 5 shows photographs of the interconnects with different heights (1 mm, 2 mm and 2.5 mm) made by stamping. As can be seen from Figure 5, the fabricated interconnect with a height of 2 mm shows a well-formed egg-carton shape with only minor thinning (as compared with the other heights). Area specific resistance (ASR) measurements indicate that the ASR difference between egg-carton interconnects with 2mm height and stainless steel plates is small (2-5%) and pressure drop evaluation shows insignificant pressure drop in the fabricated interconnect. Mechanical loading experiments with fabricated interconnect reveal that no creep or deformation occurs during after firing at 800ºC for 200 hours while under a mechanical load of the equivalent of 100 cell-interconnect repeat units.

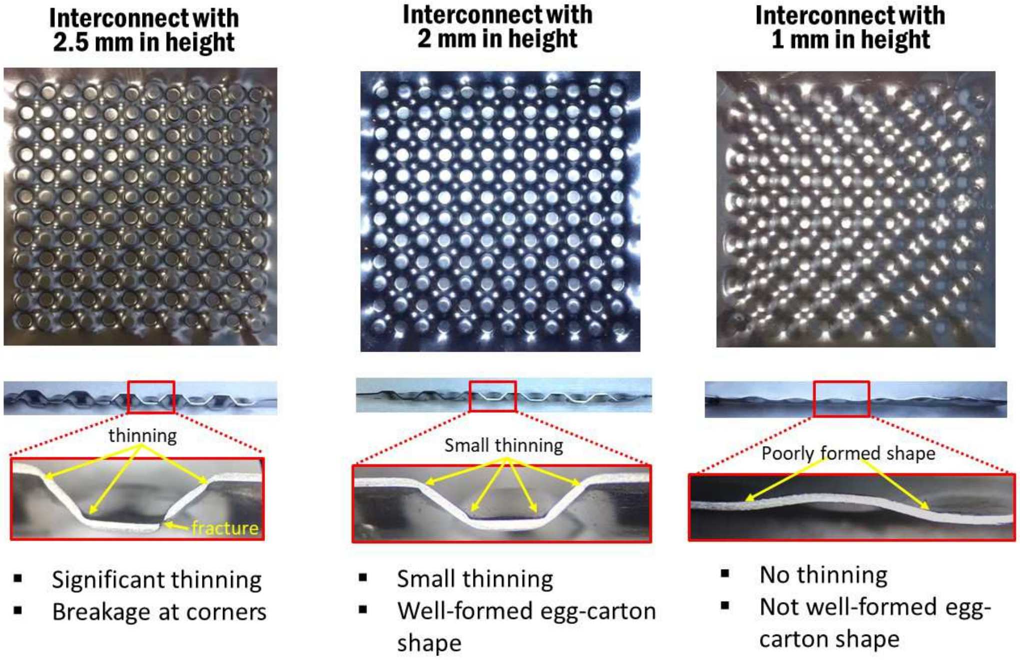


Figure 5. Egg carton interconnects with different heights fabricated by stamping

Development of Supported Thin-Film Cells

The development of metal-supported cells for this stack technology has focused on investigating sputtering as the fabrication technique for producing thin-film cells. Sputtering parameters and procedures including use of co-sputtering and selection of metal and/or ceramic targets have been studied. Cell components (electrolyte, anode, cathode and electrolyte/cathode interlayer) with required characteristics have been successfully fabricated. Figure 6 shows as an example micrographs of dense yttria stabilized zirconia (YSZ) electrolyte, porous Ni-YSZ anode, porous lanthanum strontium cobalt iron perovskite (LSCF)-YSZ cathode and porous lanthanum strontium cobalt perovskite (LSC)-YSZ cathode layers made by the sputtering process. Thin-film cells are made by sequentially sputtering cell components onto a substrate. Figure 7 is a transmission electron microscopy (TEM) photograph of a sputtered thin-film cell. As seen from the figure, the cell shows uniform component thicknesses and excellent interfaces between the components.

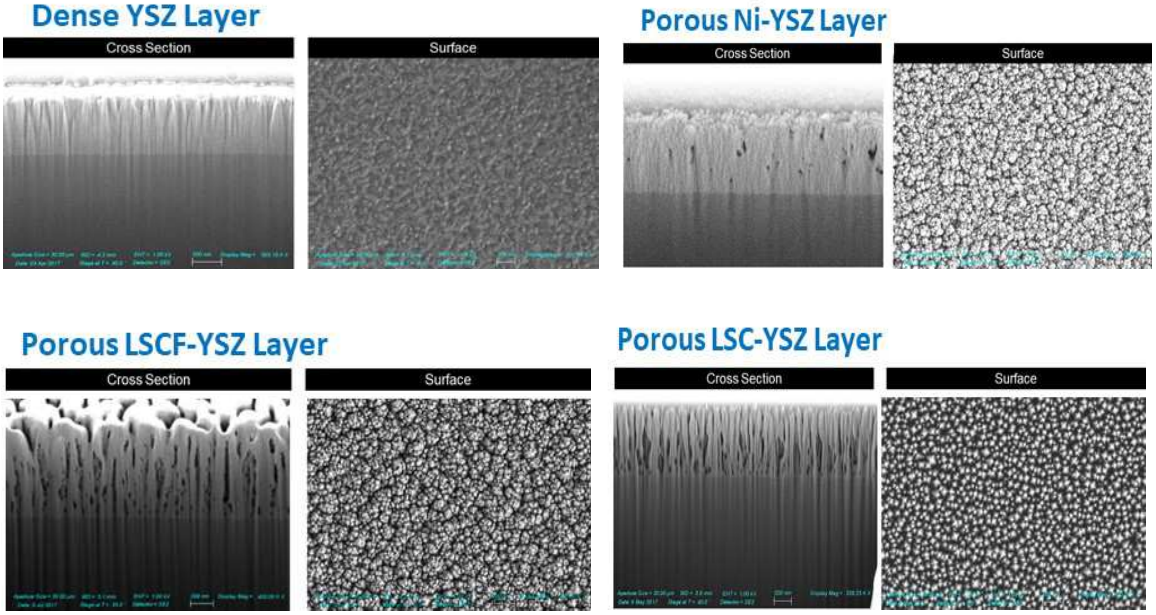


Figure 6. Micrographs of cell components made by sputtering

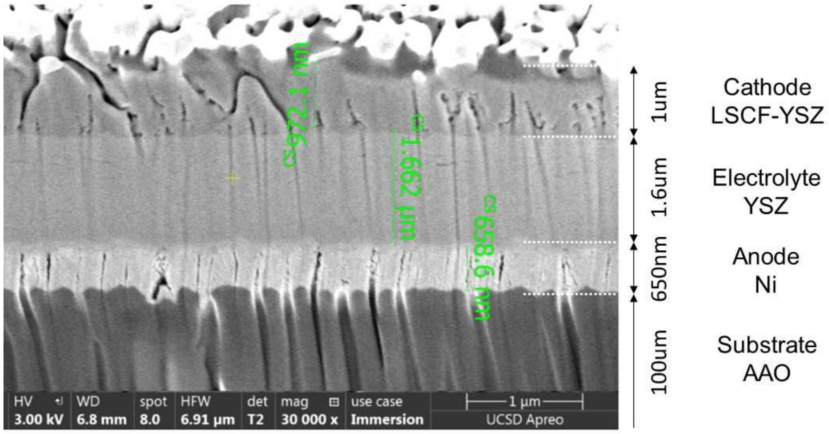


Figure 7. Sputtered single cell on anodized aluminum oxide (AAO) substrate

Sputtered thin-films cells have been made on porous AAO substrate for performance testing. Electrochemical evaluation of sputtered cells on AAO substrates has shown exceptional power densities. Figure 8 shows the performance curves of a sputtered cell with YSZ electrolyte, gadolinia-doped ceria (GDC) electrolyte/cathode interlayer, Ni-YSZ anode and LSCF–YSZ cathode. The cell exhibits an open circuit voltage (OCV) of ~1.0 V and peak power densities of ~1.7 W/cm^2 and ~2.1 W/cm^2 with hydrogen fuel and air at 600ºC and 650ºC, respectively. Sputtered cells also show excellent performance on different fuels (e.g., methane, ethanol) at reduced temperatures (550º-650ºC). Figure 9 shows as an example the current-voltage and power density curves for a sputtered cell (LSCF-YSZ/GDC/YSZ/Ru-GDC) on dry ethanol fuel.

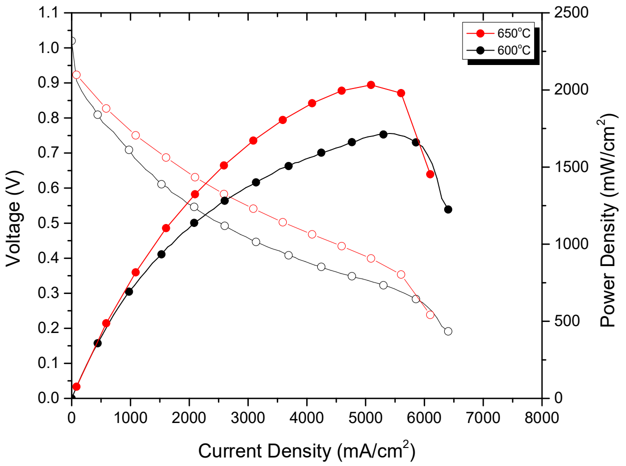


Figure 8. Sputtered cell (LSCF-YSZ/GDC/YSZ/Ni-YSZ) performance on hydrogen

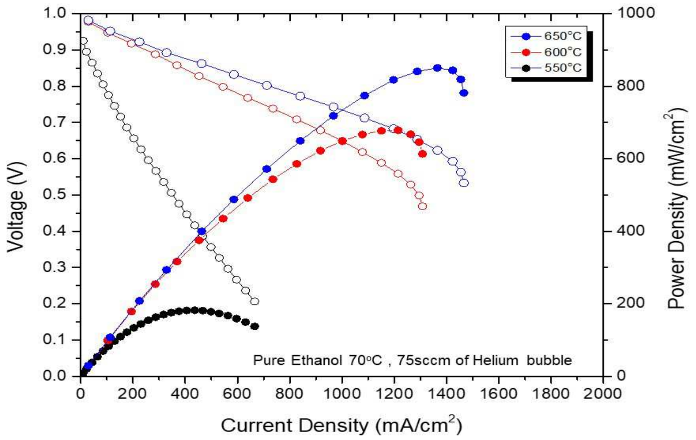


Figure 9. Sputtered cell (LSCF-GDC/GDC/YSZ/Ru-GDC) performance on dry ethanol

Acknowledgments

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