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Thin Solid Oxide Fuel Cell Stack for Low Power Applications

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Abstract - Thin film solid oxide fuel cells (TSOFCs) operating at 550 ^{O}C were fabricated by pulsed laser deposition on a porous nickel foil substrate. Structural and surface morphology of the SOFC have been investigated and, enhancement of the performance of an individual SOFC cell was obtained by modifying the pore formation processing of the nickel foil anode. A small stack (2.5x2.5x2.5 cm) of 10 cells was fabricated with a power density of 1.3 W/cm^2.

***Index Terms* - fuel cell, solid oxide, stack, thin film, YSZ.**

I. INTRODUCTION

The increasing demand on energy has stimulated extensive research on renewable and alternative energy utilization. Within this area, research on fuel cells has accelerated due to their limiting emission of only water vapor. A number of different types of fuel cells have been developed; however, recent attention has focused on solid oxide fuel cells (SOFCs) due to their high efficiency (60–70%) [1- 5]. However, the current SOFCs suffer some short comings resulted principally from their high temperatures of operation (800 ^{O}C- 950 ^{O}C) [5, 6] which has led to large sized and high cost units. Thin film solid oxide fuel cells built with very thin electrolyte layers can offer a solution for the SOFC high temperature problem. It has been shown that thin film solid oxide fuel cells with an ultrathin electrolyte layer (1-2 μm) can reduce operating temperatures to less than 500 ^{O}C [7]. Such performance can reduce size and cost of the SOFC, and allows for increased general use. Most of the previous reports on thin film solid oxide fuel cells [4,5,7,8] investigated the performance of single cells. In this work we present the fabrication and design of a thin film solid oxide fuel cell stack with small volume which operates at low temperature and produces sufficient power density to run low power devices.

II. THIN SOLID OXIDE FUEL CELL FABRICATION PROCESS AND CELL CHARACTERIZATION

Thin film solid oxide fuel cells are constructed by thin film deposition of oxide electrolyte and cathode layers on a nickel foil substrates which is then made porous (to act as anode) by photolithographic patterning and etching. 10 μm thick nickel foil (1.6 cm x 1.6 cm) was used as the substrate upon which the electrolyte and the cathode layers were deposited. The nickel foil was treated in a mixture of Acetic, Nitric, Sulfuric, and Phosphoric Acids to remove the rolling marks, after which the foil was annealed at 650^{O}C for 2 hours in an Argon atmosphere to reinforce the (100) lattice direction normal to the foil surface. Films of yttria-stabilized zirconia (YSZ) electrolyte (~ 1.5 microns thick) and $La_{0.5}Sr_{0.5}CoO_{3-d}$ (LSCO) cathode (~ 2 microns thick) were deposited on the nickel foil using pulsed laser deposition (PLD - 248 nm KrF laser) at 650^{O}C. Hexagonal pores of about 50 μm diameter with 50 μm spacing were then formed in the nickel foil by photolithographic patterning followed by electrochemical etching (using 6M H_2SO_4) at room temperature [8] so as to form a porous nickel anode for the fuel cell elements.

The crystalline structure of the fuel cells layers was characterized by X-ray diffraction (XRD) measurements carried out using a Siemens D-5000 spectrometer. SEM surface analysis was carried out using a JEOL (JSM 5410) scanning electron microscope. The Fuel-Air performance of individual and stacked fuel cells as a function of operating temperature was tested in a tubular furnace at different temperatures and the V-I data were collected using a computerized setup.

The XRD scans of the successive fuel cell layers are shown in Figure 1. The XRD scans of both YSZ electrolyte/Ni sample and of the LSCO cathode /YSZ/Ni sample shows highly crystalline structures with (100)

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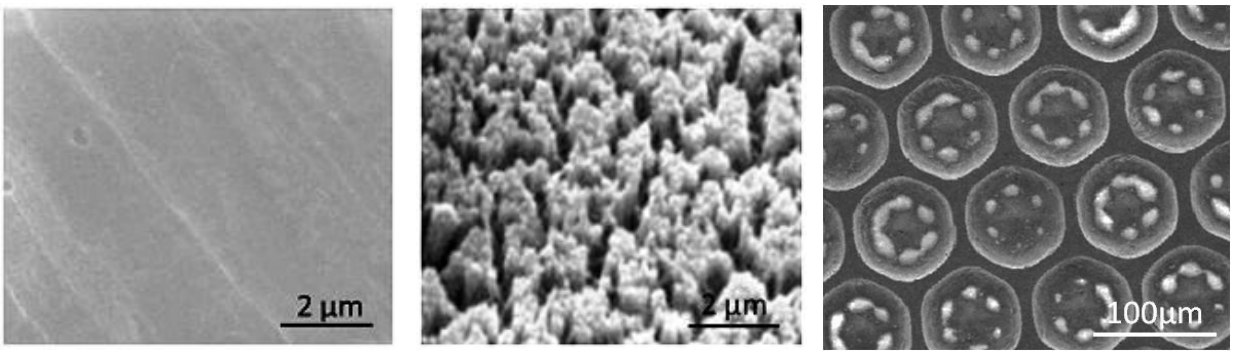
orientation normal to the surface. The PLD grown YSZ electrolyte shows a smooth continuous surface which is required to prevent hydrogen leakage to the cathode. The LSCO thin film cathode is porous to permit enhanced flow of oxygen to the YSZ top surface (see Figure 2a, b). Hexagonal micro pores were then photo lithographically patterned and electrochemically etched in the nickel foil at room temperature (using 6M H_2SO_4 for 3 min at 0.25 Amp) to allow for hydrogen fuel to reach the bottom electrolyte/anode interface. Anode porosity and pore structure (Figure 2c) was optimized so as to maximize mechanical stability of the film layers and to increase performance through increasing the triple-phase boundary [8]. Pore optimization yielded pores with unique linked nickel islands at the patterns of the pores which added structural support to the YSZ/LSCO thin membrane that covered the pore, and the island structure also increased the anode-electrolyte-fuel triple phase boundary at the pore.

(a) **(b)**

Fig 1. XRD scans for (a) YSZ/Ni, and (b) LSCO/YSZ/Ni films deposited by PLD.



(a) **(b)** **(c)**

Fig 2. Surface SEM micrographs of thin film solid oxide fuel cells layers (a) YSZ/Ni surface, (b) LSCO/YSZ/Ni surface, and (c) micro porous nickel anode side. Showing linked islands at the bottom of the pores.

III. THIN SOLID OXIDE FUEL CELLS STACKING PROCESS

The thin film fuel cell stack was comprised of micro formed stainless steel interconnects and cell elements connected in parallel. The parallel connection stacking was utilized to simplify the interconnect design and implementation. Ten individual thin solid oxide fuel cell elements were stacked on each other separated by interconnects, with interconnects electrically connected in parallel. A frame for the stack was machined from machine able glass-ceramic (Macor) and, fitted with two inlets for H_2 and Air. The interconnects were made in a zigzag shape from 0.12 mm thick (1.6 cm x 1.7 cm) stamped stainless-steel foil which was coated on both sides with a 200 nm thick gold layer deposited by e-beam evaporation. Each interconnects had a 0.3 cm x.03 cm extended tab which was used for the electrical connection. The gases were delivered to the anode and the cathode sides through openings in the ceramic (see Figure 3).

The zig-zag channels of the interconnect were set to be orthogonal to subsequent interconnects so as to allow for orthogonal H_2 and Air flows. The interconnect channel sides were sealed using liquid ceramic to avoid gas leaks. After stacking of 10 SOFC/interconnect pairs, two Macor square caps were fixed tightly on the stack frame by stainless steel bolts to contain the stack. Two stainless steel 1/4 inch tubes were attached orthogonal to the stack so as to deliver air and hydrogen to the stack. The total size of the stack was 2.5 cm x 2.5 cm x 2.5 cm. Finally, the orthogonally oriented interconnect tabs were electrically connected using gold paste to form the "+"

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and "-" electrical poles. The assembled stack was electrically connected to the testing setup using long isolated nickel wires as shown in Figure 3.

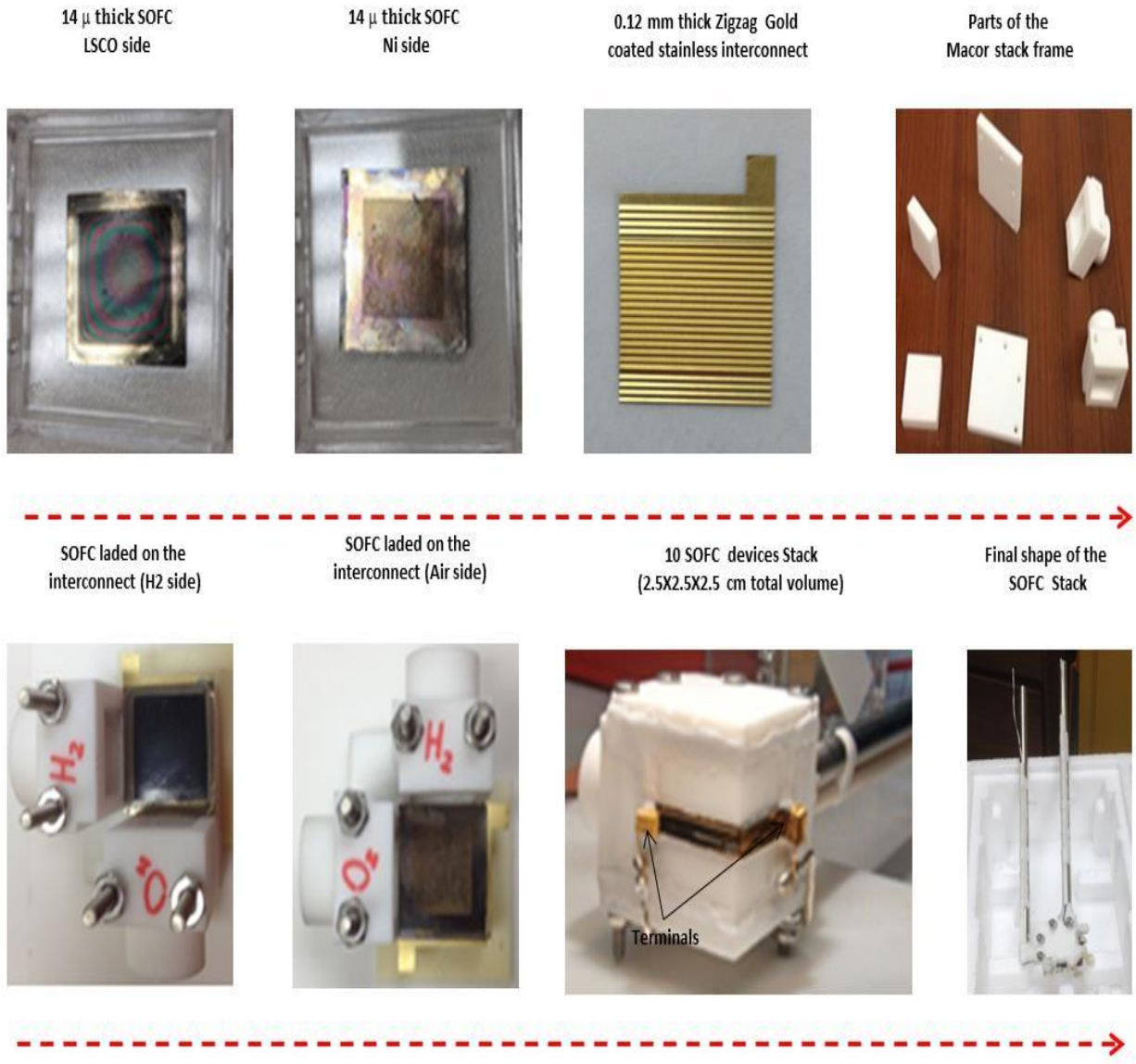

Fig 3. Thin solid oxide fuel cells stacking process

IV. FUEL-AIR PERFORMANCE MEASUREMENTS

The Fuel-Air performance of a single thin film solid oxide fuel cell element and of the 10 SOFC element stack was characterized in a temperature programmable tubular furnace using a testing system fitted with a computer and a Lab View program (see Figure 4). I-V scans and electric power data were recorded by changing an external load to the fuel cell (0 Ω to 2 KΩ) at fixed temperatures of 450 ^{O}C, 520 ^{O}C, and 550 ^{O}C, and at a fixed H_2/Air flow rate. The single SOFC cell showed an open circuit voltage up to 0.9 V, a closed circuit current of up to 39 mA, and a power density of up to 155 mW/cm^2 (see Figure 5). For the case of the SOFC stack (shown in Figure 6), an open circuit voltages of 7.1 V was measured along with a closed circuit current of 339 mA, and a stack power density of ~ 1270 mW/cm^2- about 8.6 times higher than that of a single cell. The drop in the stack open circuit voltage as temperature increased (Figure 6a) is due to an increase of the stack resistance with increasing temperature resulting from oxidation of the stainless steel interconnects. Figure 4 shows the SOFC stack in operation, where a small fan (shown in the Fig. 4 insert) was powered by the SOFC stack output. The stack was tested continuously at 550 ^{O}C for 24 hours, with no noticeable change in the output power.

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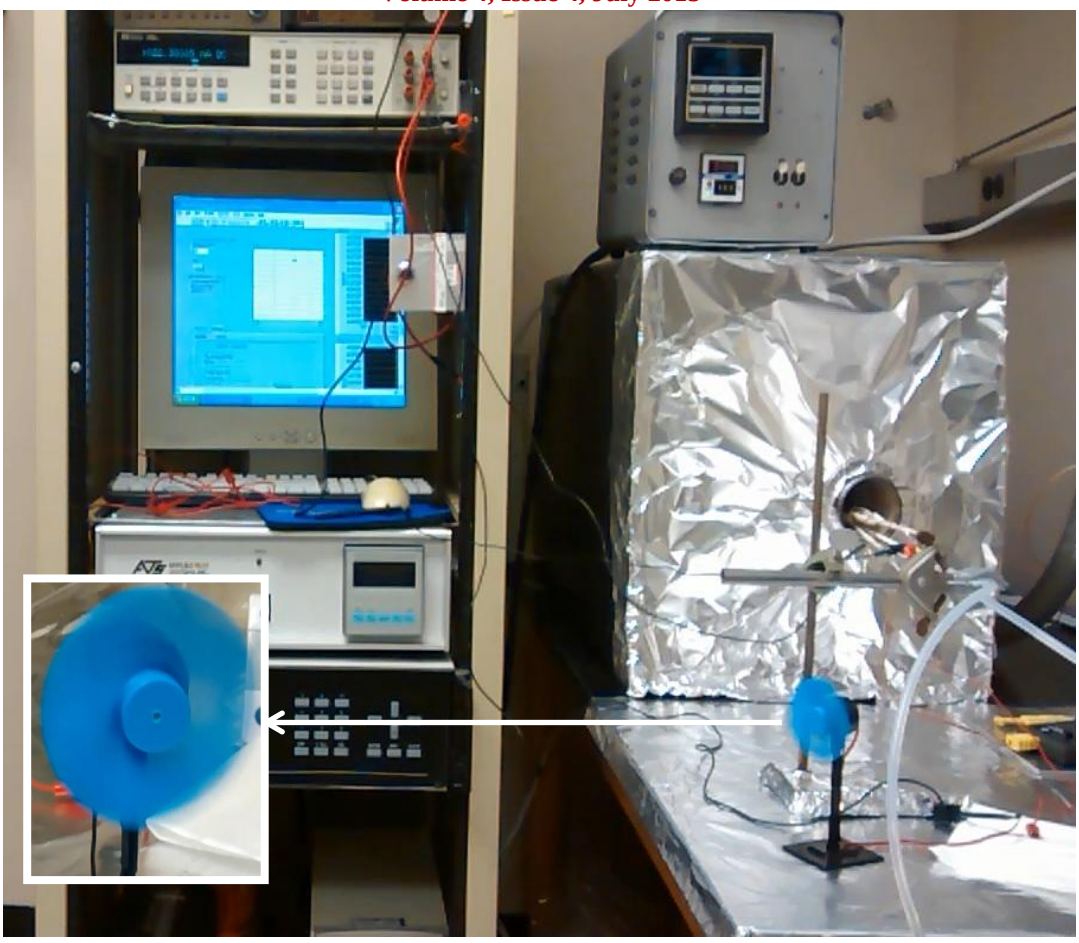

Fig 4. The Fuel-Air performance testing setup with the thin solid oxide fuel cell stack is in operation. The insert magnifies the fan being powered by the fuel cell.

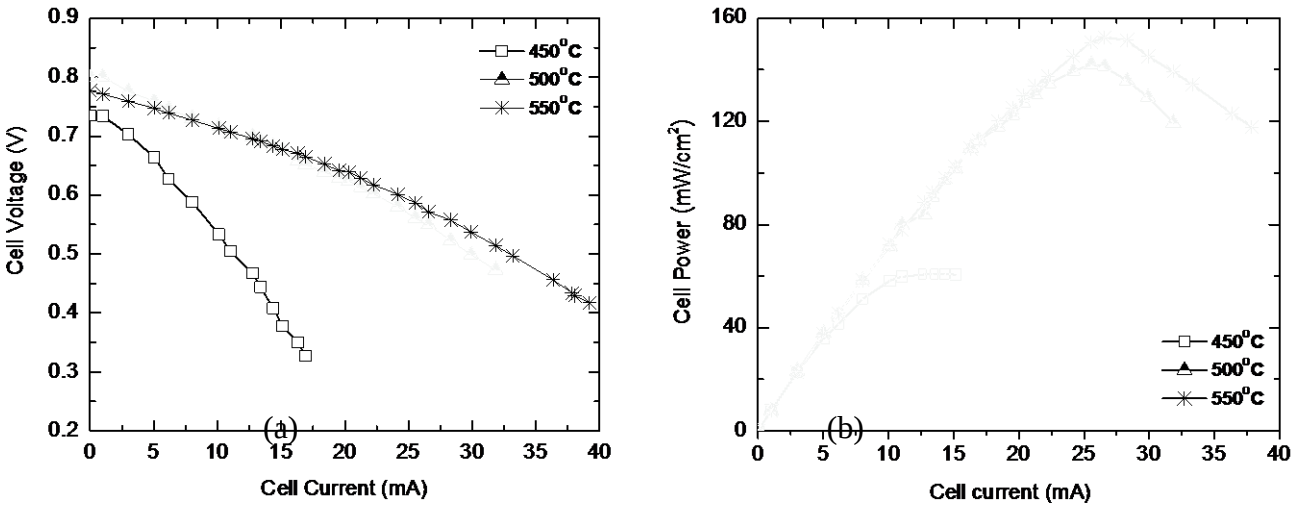

Fig 5. SOFCs performance as a function of operating temperatures (a) single cell current vs voltage, and (b) single current vs produced power.

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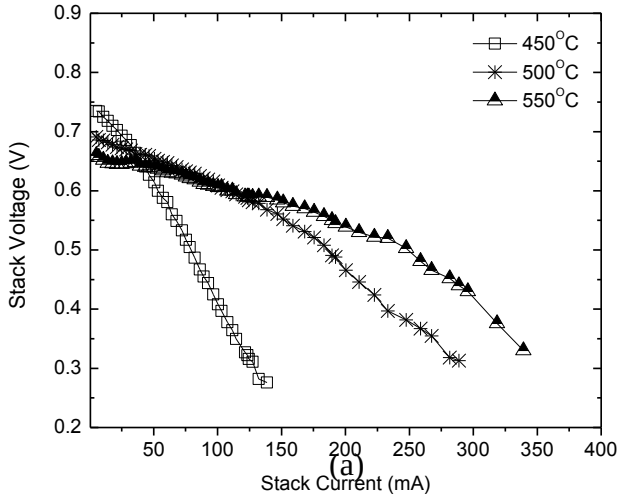

(a)

(b)

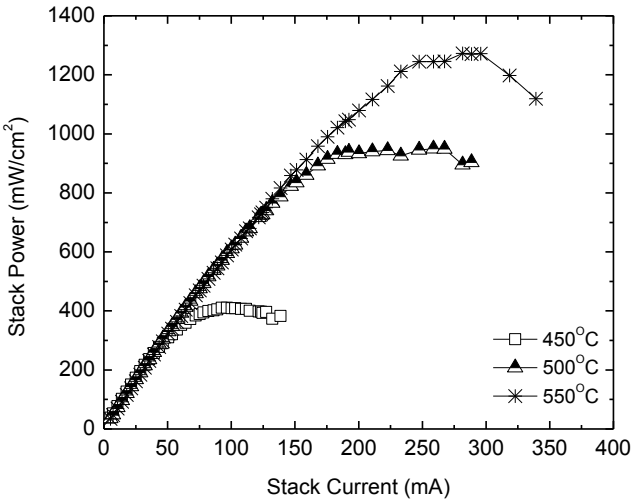

Fig 6. SOFCs performance as a function of operating temperatures (a) 10 cell stack current vs voltage, and (b) 10 cell stack current vs produced power.

V. CONCLUSION

A thin film solid oxide fuel cell stack was fabricated using thin film SOFC elements structurally optimized for maximum performance. The multi-layer thin film SOFC element was fabricated by pulsed laser deposition on a nickel foil post treated by photolithographic patterning and etching to form the cell anode. The anode micro pores were etched with a unique structure that enhances both the mechanical properties and the triple phase boundary of the cell. A 2.5 cm x 2.5 cm x 2.5 cm stack composed of 10 thin film solid oxide fuel cell elements was designed and tested. The Air-Fuel performance of a single cell element and of the stack of 10 cells showed maximum power density of 55 mW/cm^2 and 1270 mW/cm^2 respectively. These initial thin film solid oxide cell stack design data project the possibility of increasing stack output and decreasing stack frame size to yield a high power density solid oxide fuel cell stack operating at low temperature (< 500 ^{O}C).

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