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### Journal

Electrochemical and Solid State Letters, 6(9)

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### Publication Date

2003-01-07

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## METAL-SUPPORTED SOLID OXIDE FUEL CELLS

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January 2003

Submitted to *Electrochemical and Solid State Letters*

## METAL- SUPPORTED SOLID OXIDE FUEL CELLS

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### ***Abstract***

Low cost, colloidal deposition methods have been utilized to produce novel solid oxide fuel cell structures on metal alloy support electrodes. YSZ films were deposited on iron-chrome supports on top of a thin Ni/YSZ catalytic layer, and sintered at 1350°C, in a reducing atmosphere. Dense, 20 μm YSZ electrolyte films were obtained on highly porous stainless steel substrates. These metal-supported fuel cells were tested at 800 and 900°C, achieving power densities of over 200 mW/cm<sup>2</sup> at 900°C, using platinum paste cathodes. The cells have shown excellent resistance to thermal cycling, and open up a new low cost path to SOFC commercialization.

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## **Introduction**

For SOFC's to become economically competitive, both the materials and the of system fabrication cost must be dramatically reduced. Pre-commercial thin-film SOFC cells generally consist of Ni/YSZ supporting the YSZ electrolyte as well as the Lanthanum Strontium Manganate (LSM) cathodes. The possibility of making durable and low cost SOFC membranes and some initial results were presented earlier by Jacobson *et al.*,<sup>1</sup> and by Visco *et al.*<sup>2</sup> Here, we report results on SOFC membranes for which the Ni/YSZ support anode has been replaced by a porous stainless steel support structure, retaining only a thin Ni/YSZ layer for catalysis. In addition to lowering the projected overall cost, the metal alloy is both thermally and electronically highly conductive, and allows for simple sealing strategies compared to the usual, brittle NiO/YSZ supporting anodes. Other than related work by Carter *et al.*,<sup>3</sup> previous work with metallic substrates has involved relatively expensive fabrication techniques such as plasma spray and MOCVD.<sup>4-7</sup> Our approach combines low cost colloidal processing with a steel supporting structure.

## **Experimental**

Stainless steel powder (70/30 Fe/Cr AMETEK) was mixed with stearic acid and pressed into 1 mm thick disks. The disks were then pre-fired at 400°C in reducing atmosphere (flowing 4% hydrogen in nitrogen). A mixture of 50wt% NiO (Baker), 50wt% YSZ (Tosoh), polyethylene glycol and polyvinyl butyrol, was tape-cast across the surface of the disk. The disk was fired in air at 600°C. YSZ was applied to the surface

of the disk by a colloidal spray technique. The structure was then fired in reducing atmosphere at 1350°C for 4 hours.

The cell was mounted on an alumina tube, and platinum paste (Heraeus) mixed with  $\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.8}\text{Fe}_{0.2}\text{O}_3$  was applied to form the cathode. Platinum mesh was used as the current collector on both electrodes. Two wires were spot-welded to each current collector in a four-probe arrangement as described earlier.<sup>8</sup> This cathode was sintered in-situ at 850°C while maintaining flowing hydrogen on the anode side of the cell. Tests were conducted at 800 and 900°C using humidified hydrogen as the fuel, and stagnant air as the oxidant gas.

Current-controlled current/voltage data were obtained using an EG&G 371 potentiostat-galvanostat interfaced with a computer running LABVIEW. Impedance data were obtained using a Solartron 1260 FRA in combination with a Solartron 1286 electrochemical interface and Zplot software (Scribner associates). After cell testing, cross-sections of the cell were examined using a JEOL scanning electron microscope and a KEYENCE optical microscope.

## Results and Discussion

*Structure.*— Figure 1 presents a polished cross-sectional optical micrograph of the cell. In this figure, we can observe three distinct layers: the stainless steel (FeCr) support, the Ni/YSZ catalytic layer, and the YSZ electrolyte. The FeCr support structure provides mechanical strength and acts as the current collector in this system. The large porosity in the FeCr support is required for the fuel gas to penetrate to the *catalytic*

Ni/YSZ layer. The porous Ni/YSZ layer is approximately 20  $\mu\text{m}$  thick, and it is here that the anode reaction takes place. This micrograph indicates that the porosity in the Ni/YSZ catalytic layer was lower than optimal, and further efforts to improve the structure of this layer are continuing. The micrograph also shows that the YSZ electrolyte is nearly fully dense.

*Electrochemical testing.*—Both current/voltage data and AC impedance spectra were obtained. Figures 2 and 3 show polarization and power curves for the FeCr supported cells at 800 and 900°C. Maximum power densities of 100 and 200  $\text{mW}/\text{cm}^2$  were obtained at 800 and 900°C, respectively. These power densities are as yet not as high as those typically obtained for Ni/YSZ supported cells at similar temperatures under similar testing conditions. EDAX analyses of cross-sections of the cells showed significant chromium diffusion into the Ni/YSZ catalytic layer during sintering. While these results are encouraging, and demonstrate the proof-of-principle, it is likely that chromium contamination as well as excessive densification of the Ni/YSZ catalytic layer cause the comparatively lower performance of these cells. We are currently working on ways to alleviate these problems.

Figure 4 shows the impedance response for the entire FeCr supported cell. The impedance spectra may be interpreted as containing one or more depressed semicircles. Multiple depressed semicircles are typical for whole cell impedances.<sup>9,10</sup> Further work is required to clarify the details of the impedance spectra and the corresponding electrode processes.

*Thermal cycling.*—Thermal cycling has been identified as a potential degradation mechanism in Ni/YSZ supported SOFCs. To evaluate the effects of thermal cycling on our alloy-supported cells, we cycled our cell 50 times at temperatures from 200 to 800°C in 4%H balance nitrogen with heating and cooling rates of approximately 50°C/min. No significant performance change was observed.

### **Conclusion**

A novel technique for producing solid oxide fuel cell structures on highly porous metallic support structures has been developed. Dense electrolyte films and encouraging power densities have been obtained. Cells fabricated using these techniques have also shown excellent resistance to thermal cycling.

### **Acknowledgments**

This work was performed in the Materials Sciences Division of the Lawrence Berkeley National Laboratory with funding from the U.S. Department of Energy through the National Energy Technology Laboratory under contract DE-AC03-76SF00098. Additional support from Ikerlan-Mondragon is gratefully acknowledged.

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Figure 1. Cross-sectional optical micrograph of stainless steel supported cell.

Figure 2. Power density curve from a FeCr/Ni-YSZ/YSZ/Pt-LSCF cell at 800 and 900°C.

Figure 3. I-V characteristics of the FeCr/Ni-YSZ/YSZ/Pt-LSCF cell at 800 and 900°C.

Figure 4. Impedance spectra from stainless steel supported cell at 900°C.

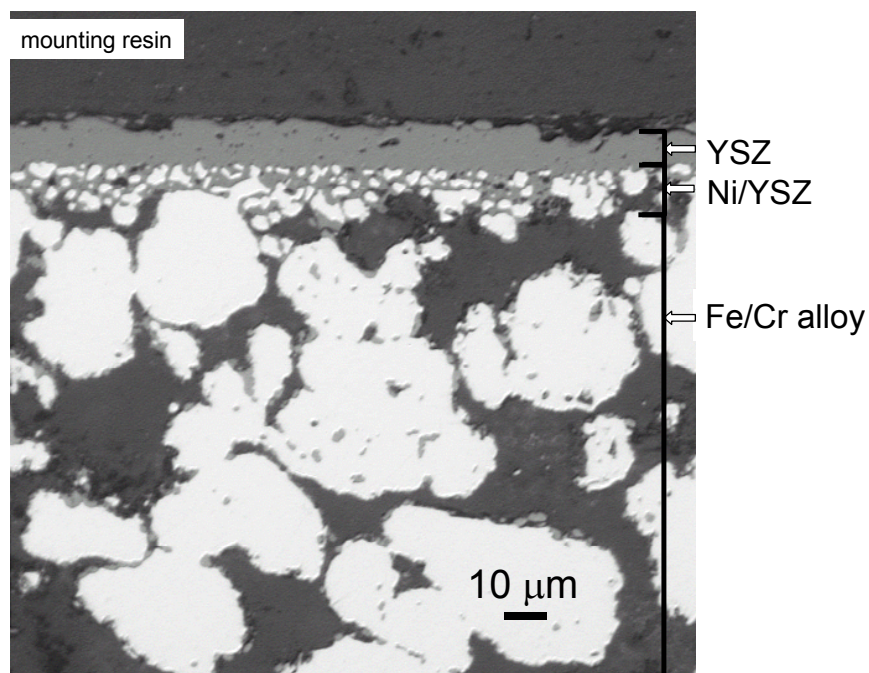


Figure 1. Cross-sectional optical micrograph of stainless steel supported cell.

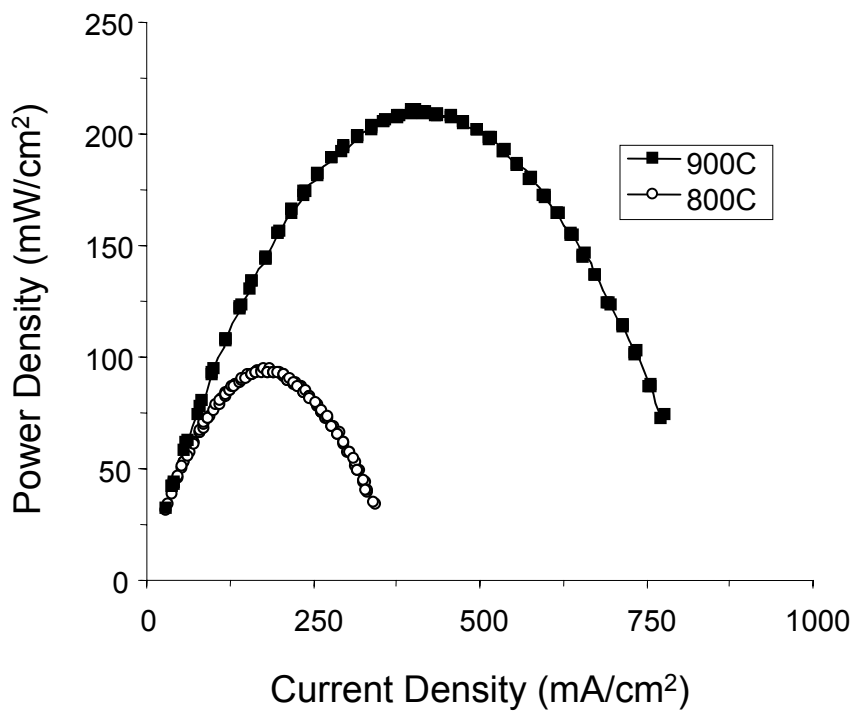


Figure 2. Power density curve from a FeCr/Ni-YSZ/YSZ/Pt-LSCF cell at 800 and 900°C.

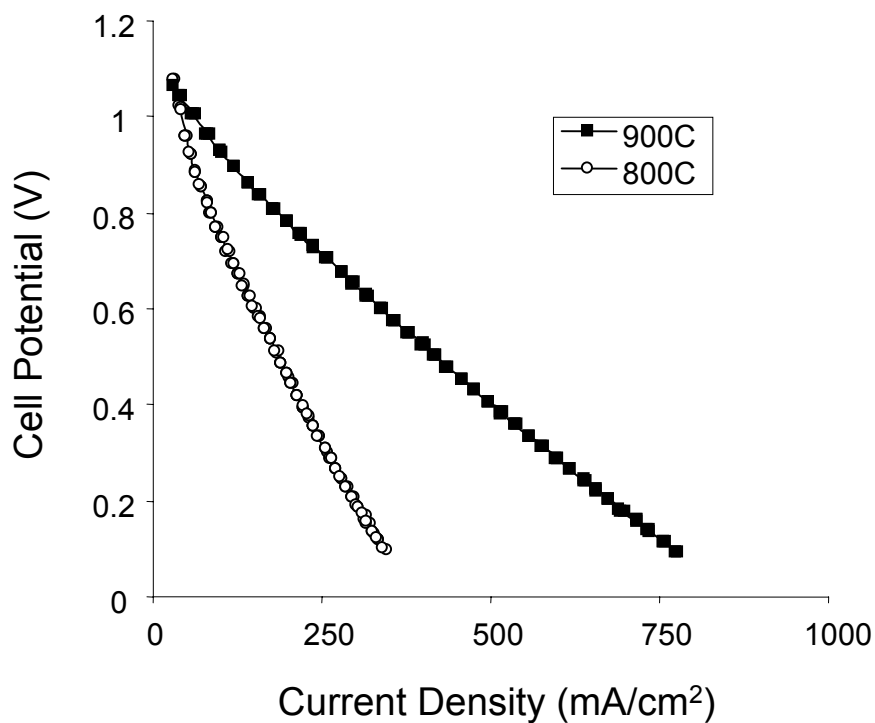


Figure 3. I-V characteristics of the FeCr/Ni-YSZ/YSZ/Pt-LSCF cell at 800 and 900°C.

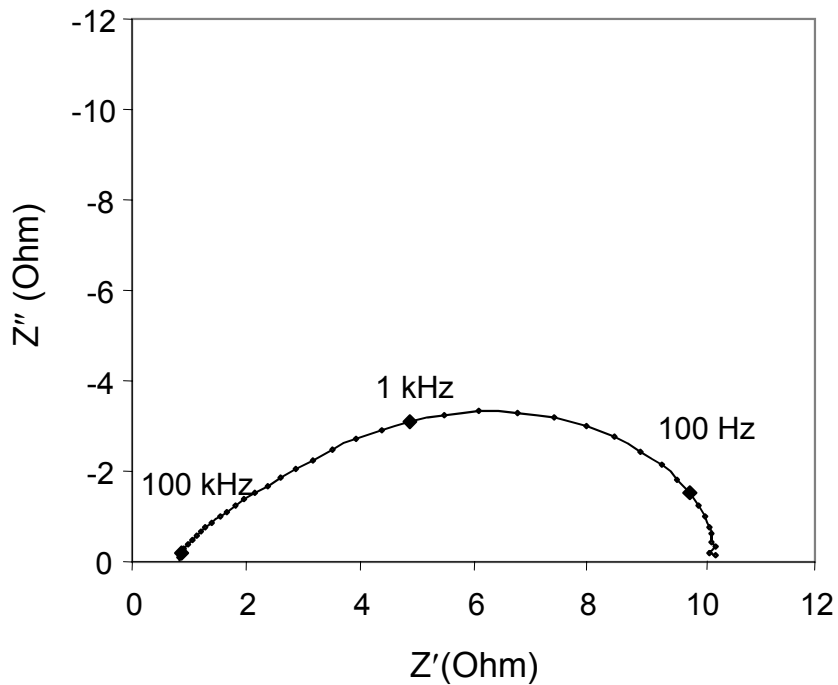


Figure 4. Impedance spectra from stainless steel supported cell at 900°C.