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Thin Film Solid Oxide Fuel Cells for Lower Temperature Operations

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Abstract: - Thin film solid oxide fuel cells (SOFC) have been developed on metallic foil substrates with pulsed laser deposition and photolithography methods. Ultra-thin thin film yttria stabilized zirconia (YSZ) electrolyte (1-2 micron) was deposited on the metallic foil substrates which were processed into SOFC anodes by photolithography to develop porosity. This was followed by a further porous NiO-YSZ deposition for gas transport through the fuel cell. A composite $La_{0.5}Sr_{0.5}CoO_3$ cathode was then deposited on the YSZ electrolyte. The thin film deposition and photolithography procedures were optimized for better fuel cell performance. The resulted fuel cells have operated with reduced temperatures as low as 470 degree C and yielded maximum power density of 140mW/cm^2, showing good potential for power generation with low weight, small volume SOFCs at lowered temperatures.

Key Words: - Solid Oxide Fuel Cells; Pulsed Laser Deposition; Thin Films; Cathodes; Photolithography; Power Generation

1 Introduction

Energy crisis and fuel shortage is now becoming an important concern in the US and around the world. Solid oxide fuel cells (SOFCs) are highly attractive due to the high energy efficiency, energy density, and environmental friendliness [1,2]. Traditional SOFCs work at around 1000°C and face a lot of high temperature problems. People have been working hard to reduce the SOFC operation temperature [3]. In this paper, we present our work of making a thin film SOFC on metallic foil substrates with thin film deposition and photolithography method. The SOFC has a total thickness of only 20μm and generated power output of 140mW/cm^2 at reduced operation temperature range of 470-570°C. Also due to the ultra thin SOFC total thickness, one can put more SOFCs into a certain volume, and much higher energy density can be expected from such SOFCs. It is promising for making compact high efficiency power generation sources in broad applications.

2 Experimental

Yttria stabilized zirconia (YSZ) electrolyte thin films were deposited on metallic foil substrates such as nickel, copper, and atomically textured metallic foils. The films were deposited with pulsed laser deposition (PLD) [4] using a KrF laser in a 4% hydrogen balance with 96% argon ambient of 500 mTorr to reduce oxidization of the substrates. The substrates were heated to 350 to 750°C during the deposition. The YSZ film thicknesses were 1-2 microns. The films were checked with XRD, SEM and EDS analysis to show they are good quality films.

a)

b)

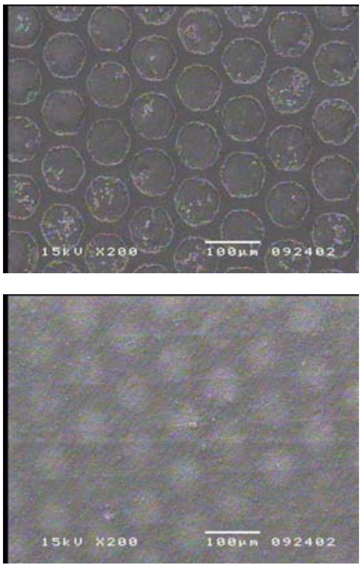

Fig. 1 SEM micrograph of YSZ electrolyte on porous Ni structure made with pulsed laser deposition and photolithography procedure: a) Ni anode side; b) YSZ side.

Although nickel and copper usually exist in fuel cell anodes, metallic foils lack porosity for gas and vapor transport for functioning as fuel cell anodes. To get the needed porosity, we used photolithography and etching process to develop arranged micro pores in the metallic foil substrates. Both wet chemical etching and electrochemical etching methods were used. Fig. 1 shows the SEM micrograph of a YSZ/Ni sample after the photolithography process. In Fig. 1a we see the hexagonally arranged pores etched in a 0.25M $FeCl_3$ solution through the nickel and the free standing YSZ behind the pores. The pores were 70 micron sized with 30 micron spacing between them. With this patterning, we do not only have adequate areas for gas transport through the anode, but also keep enough support for the fuel cell from the metal foil substrate. Fig. 1b is the SEM taken from the YSZ side, which shows the continuous YSZ electrolyte film over the porous nickel foil substrate, with the brighter areas indicating different electron reflection from the YSZ free standing areas over the etched pores. Later, porous NiO-YSZ thin films were deposited at the metal side to increase reactive sites, which distribute three dimensionally at the anode.

a)

b)

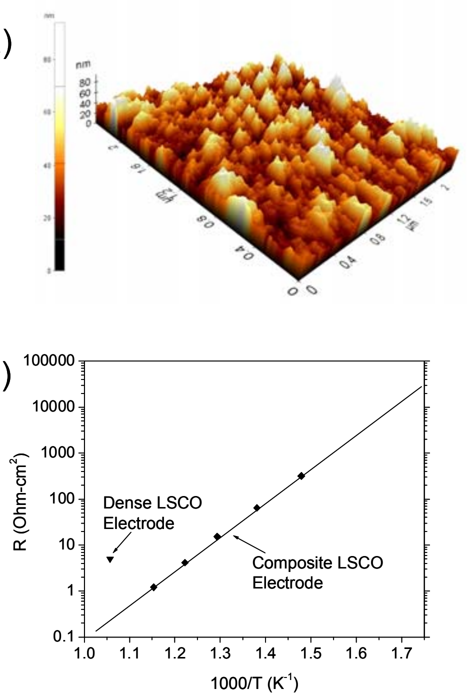

Fig. 2 AFM and impedance measurements on a porous LSCO film sample: a) AFM; b) the electrode area specific resistance obtained from impedance measurement.

$La_{0.5}Sr_{0.5}CoO_{3-\delta}$ (LSCO) cathode thin films were then deposited with PLD on the top of the YSZ electrolyte under optimized conditions. The LSCO thin films are composite structured with a dense bottom layer deposited at ~550°C and a top conducting porous layer developed with room temperature deposition and post annealing method.

Fig. 2a is the AFM image on the composite LSCO thin film, which shows bright nano hills and dark nano pore valleys on the micro-nano porous LSCO surface. Composite LSCO thin films were also symmetrically deposited on both sides of a YSZ wafer to do impedance measurements for LSCO electrode property test [4]. The composite electrode showed reduced resistance with the increase of temperature, and it is 1.5 orders lower than a comparing dense LSCO film sample, showing a good property of composite LSCO for using as SOFC electrodes working at lowered temperatures.

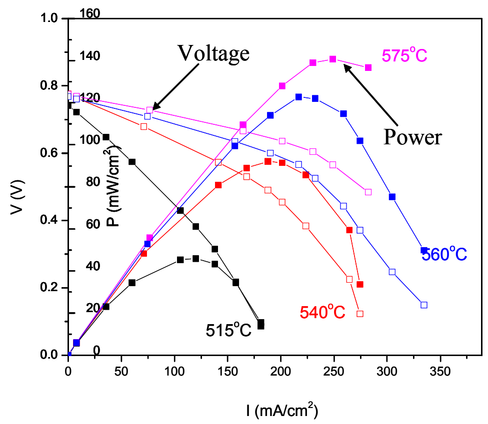

Fig. 3 A fuel cell performance test at different temperatures.

SOFCs made with the thin film deposition and photolithography process on metallic foil substrates were tested and showed good performance. Fig. 3 is a fuel cell output test result at different temperatures. It operated with hydrogen fuel and generated power output larger than 40mW/cm^2 at 515°C and 140mW/cm^2 at 575°C. We have tested the SOFCs at temperatures as low as 470°C and still get adequate power output from them. Moreover, the SOFCs are made on metallic foils of as thin as 6µm and have a total fuel cell thickness of only 20µm, so that much higher power output per volume and weight can be expected from such SOFCs.

3 Conclusion

We have fabricated ultra thin SOFCs on metallic foil substrates. They have been operated at reduced temperatures of 470-575°C and generated maximum power output of 140mW/cm^2. It shows good promise for making new high energy efficiency, energy density, and environmental friendly power generating devices and systems in a variety of applications.

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