Fabrication of Low Temperature Solid Oxide Fuel Cells with Ultra-Thin Film Yttria-Stabilized Zircona Electrolytes

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Abstract

Solid oxide fuel cells (SOFCs) have the potential to become the next major breakthrough as an alternative energy conversion device. They use the simple reaction of combining hydrogen and oxygen to produce electricity and water as a by-product. A SOFC is composed of an electrolyte sandwiched between two electrodes (anode and cathode) [1]. In SOFCs, oxygen ions (O^{2-}) are transported from the cathode of the fuel cell to the anode through the electrolyte made of a material known as yttria-stabilized zircona (YSZ). Electrons are transported through an external circuit, and the flow of electrons produces electricity. The various electrochemical reaction occurring are—at the anode: ½O_2 + 2e- = O, at the cathode: H_2 + ½O_2 = H_2O + 2e- and overall cell reaction: ½O_2 + H_2 = H_2O. The electrochemistry of a SOFC is depicted in Figure 1.

Introduction

SOFCs operate at very high temperatures of approximately 800°C-1000°C and this leads to two major problems. First, SOFCs have to be heated up slowly or else they will break due to differential thermal expansion. Secondly, most metals oxidize or corrode at the high operating temperature of SOFCs and therefore stop conducting oxygen ions across the electrolyte. The operating temperature of the fuel cell cannot simply be reduced because the ionic conductivity of the YSZ electrolyte is reduced at lower operating temperatures [2]. Ionic resistance, $R = \rho t/A$ where resistivity $\rho \sim e^{Ea/kT}$ ($Ea \sim 0.9$ eV). Therefore, decreasing the thickness, t, of the electrolyte will allow for lower operating temperatures, T. The optimal SOFC operating temperature is ~ 300°C, since this is the temperature at which the anode and cathode can perform catalytic activity, and metal can also be used for other components of the fuel cell since they will no longer melt. In order to have a SOFC operate at 300°C, the thickness of the YSZ electrolyte should be around 50 nm.

The second goal of the research was to study the porosity of platinum, which was used for making the anode and cathode, under different sputtering conditions so as to create electrodes with smaller pores to allow for more surface area for the oxygen ions, hydrogen and electrons to travel through and react on.

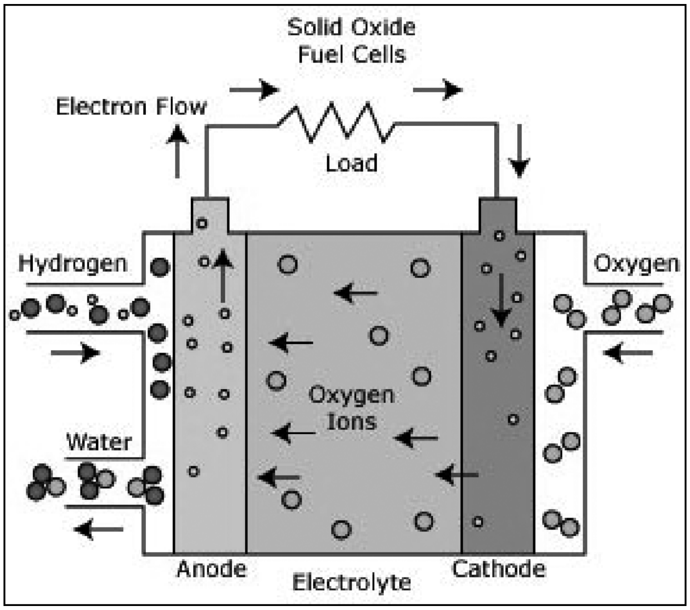

Figure 1: Electrochemistry of a solid oxide fuel cell.

Materials and Methods

Fabrication of a SOFC begins with a silicon wafer ~ 500 μm coated with silicon nitride (Si_3N_4 ~ 200 nm) on both sides using the process of low pressure chemical vapor deposition. Silicon nitride serves as an insulator to prevent any unwanted reactions from occurring between the YSZ and Si, since both are very good conducting materials. The next step is to sputter a thin layer of YSZ, the electrolyte, on top of the Si_3N_4 at a pressure of 5 mTorr, 100W power for 30 min to produce a thickness of ~ 40 nm. The next step is to pattern the back side of the chip and remove the patterned area of Si_3N_4 using reactive ion etch. The top of the chip is then patterned and a thin layer of titanium (Ti) is sputtered on the top of the chip at 4 mTorr, 250W for 2 min to produce a thickness of ~ 5 nm. Ti serves as an adhesive between the platinum electrodes and YSZ electrolyte. Platinum (Pt) is then sputtered on top of the Ti at 4 mTorr, 250W for 5 min to produce dense platinum with thickness of ~ 100 nm.

The reason for using dense platinum is that it has better electrical properties than porous platinum, so anywhere the platinum is not in direct contact with the YSZ electrolyte, as is found with the platinum on top of the titanium, there should be dense platinum.

The next step is to perform lift-off to remove the excess Ti/Pt coating. Pt is then sputtered throughout the top of the chip at 75 mTorr, 250W for 15 min to produce porous platinum which serves as the top electrode. Finally, in order to study the porosity of platinum under different conditions, we sputtered Pt by varying the following parameters; time from 5-80 min, pressure from 4-100 mTorr, and power from 100-250W, to produce platinum films with different thicknesses.

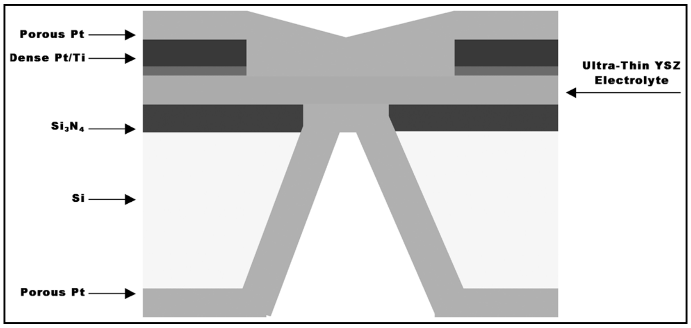

Figure 2: Fabricated solid oxide fuel cell.

Results and Discussion

Figure 2 shows the final fabricated solid oxide fuel cell. It can be seen from Figure 3 that increasing the thickness of the platinum yields larger pores with a relatively linear relationship, although neither pressure nor power have a significant effect on pore size. A possible explanation for this increase in pore size is that as more Pt atoms are added, they build outward from the existing grains, mainly upward, but also sideways so that some of the existing grains merge together to form larger pores.

Conclusions and Future Work

A SOFC with an ultra-thin YSZ electrolyte was successfully fabricated. There is a strong correlation between thickness of sputtered platinum coating and pore size where the pore size linearly increases with coating thickness. Future work includes measuring the conductivity of these fabricated SOFCs to verify that the conductivity does not decrease significantly at lower operating temperatures. Also, based on successful sputtering of platinum coatings for the anode and cathode, the next step is to create a lanthanum strontium cobalt iron oxide (LSCF) cathode and a nickel YSZ oxide anode, which are known to work well as electrodes to replace the expensive platinum.

Acknowledgments

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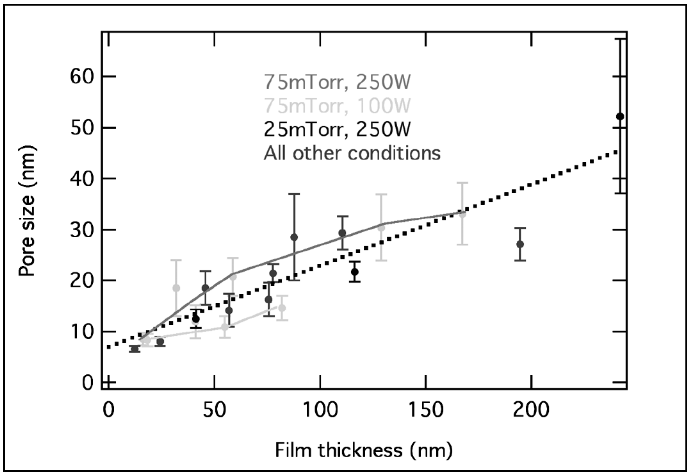

Figure 3: Effect of platinum thickness on pore size.