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Fabrication of Si-based thin film Solid Oxide Fuel Cell (SOFC)

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There have been many recent studies on sintered electrode supported thin film SOFCs. The typical electrolyte thickness found in most of these studies is around 5–20μm, with operating temperatures in the range of 500 - 800°C. Although sintered-fabricated electrodes offer a porous morphology for gas diffusion, it is difficult to deposit a thinner and pinhole free electrolyte layer onto these electrodes because the pore sizes are usually larger than the thickness of the electrolyte. In addition, the sintering method is not compatible with semiconductor techniques. In contrast, sputtering methods are widely used in semiconductor process flows and can yield a range of film morphologies (i.e. dense or porous films) by adjusting deposition parameters, such as gas pressure, deposition power and deposition temperature. We find that the ability to fabricate sputtered, nanoporous electrodes to be a critical enabling feature of our design. These nanoporous electrode structures grant process compatibility with our other fabrication steps while also offering the possibility to successfully support a thinner electrolyte.

Theoretically, reducing electrolyte thickness should result in better SOFC performance at a given temperature[1-3]. However, electrolyte scaling presents several major challenges, such as ensuring the mechanical stability of the structure, maintaining the electrical conductivity of the electrodes, avoiding electrical short circuit problems in the electrolyte, and ensuring gas tightness in the electrolyte layer.

In an effort to further reduce electrolyte thickness, several groups have adopted Si-based thin film SOFCs[4-6]. The thickness of electrolyte in these devices is around 1.2μm. These studies have used sputtering and photolithographic techniques in their fabrication.

In this study, we have targeted even thinner electrolyte layers. The stacking structure of our thin-film SOFC consists of a 150nm thick YSZ electrolyte layer sandwiched in-between two layers of 200nm thick nanoporous Pt electrode. Figure 1 shows the schematic of the thin film SOFC structure. DC- and RF-magnetron sputtering were used for the deposition of nanoporous Pt and dense YSZ layers respectively. Standard photolithographic techniques were used to fabricate the layered structure.

A thin smooth YSZ layer has been fabricated between non-smooth nanoporous Pt layers by using a novel fabrication process. YSZ was deposited on a smooth SiN layer and Pt was deposited onto the YSZ layer after etching of the SiN. Nano-scale porosity in the Pt films was achieved by varying the sputtering conditions. An example 200nm thick Pt film showing a columnar porous structure is presented in figure 2.

Because of the fragile nature of the thin-film structure, a difficult compromise between size and mechanical stability must be made. Larger device areas allow greater current/power production, but sacrifice mechanical strength. To ensure the mechanical stability of the membrane, we used small cell sizes of about 200 x 200μm^2 to 400 x 400μm^2. While each individual cell was extremely small, more than 1500 cells could be realized on a 4-inch silicon wafer. In order to ascertain the optimal compromise between cell size, power density, and mechanical stability, the shape and size of the windows on the silicon wafer as well as the processing methods were examined in detail. As further characterization, the impedance of the thin film YSZ, as well as OCV and I-V curves of the Si-based SOFCs were measured.

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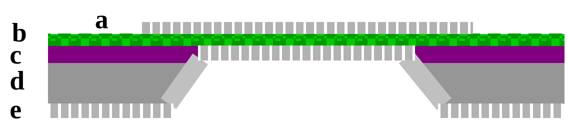

Figure 1. Cross-sectional view of the thin film SOFC. The window size on a silicon substrate is 200-400μm.
(a) Pt cathode (200nm), (b) YSZ electrode (150nm) (c) silicon nitride (500nm) (d) silicon substrate (375μm) and (e) Pt anode (200nm)

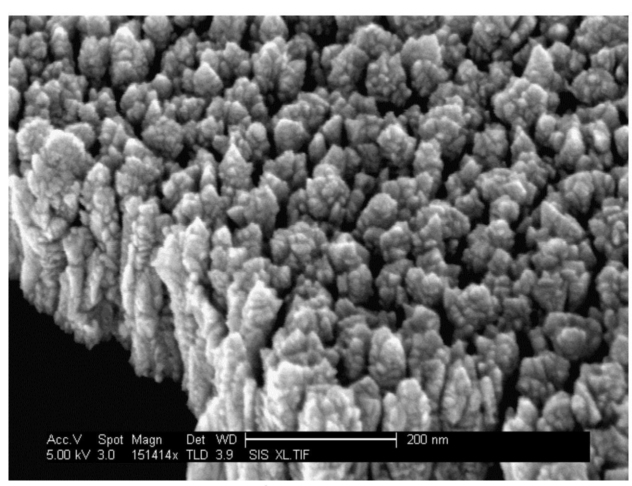

Figure 2. SEM image of the columnar porous Pt electrode.