Vapor-Deposited Porous Films for Energy Conversion

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The use of porous films is prevalent in many advanced electrochemical systems for energy conversion. For example, in both polymer exchange membrane fuel cells (PEMFCs) and solid-oxide fuel cells (SOFCs), porous films can be used to reform hydrocarbon fuels to liberate hydrogen gas and/or to serve as the conductive electrodes to transport current. Since miniaturized fuel cells have recently seen renewed interest for applications in portable power generation, the processing of film components at both low and high temperature becomes evermore significant for enhanced performance. In addition, methods for film processing integral components should be compatible with the device thermal history to ease manufacturing. Applications may cover the full range of consumer electronics that includes cell phones and laptop computers. Methods to produce metallic films with continuous porosity are described that use vapor deposition processes compatible with high-yield microelectronic processing methods. A low-temperature process method relies on (photolithographic) patterning and etching whereas a high-temperature process option eliminates the need of post-deposition process steps. These alternate methods are described within the context of synthesizing thin film fuel cells (TFFCs).

SOFCs are typically made using components from bulk ceramic powder processing in combination with a synthesis approach of layering the cermet electrode with the electrolyte layer. SOFCs can be operated at temperatures as low as 400•C or in excess of 1000•C for high performance. PEMFCs are often made as a laminate of a polymer electrolyte and typically operate below 125•C. In each application, coatings in thin or thick film form can be used for processing the electrolyte as well as the electrodes. The use of vapor deposition methods as sputtering readily accesses a wide range of target compositions to form the electrolyte or electrode layers that will enhance cell performance.

A fully integrated TFFC device is comprised of cell stacks that combine a fuel and oxidant gas to generate electric current. Each individual fuel cell level is based on an anode and cathode separated by an electrolyte layer. Thin film SOFCs and PEMFCs can be made using standard photolithographic patterning and etching combined with physical vapor deposition. This general approach leads to a TFFC on a chip, i.e. a miniature fuel cell, as shown in the schematic of Figure 1. A substrate (as silicon) suitable for anisotropic etching and a (removable) protective nitride layer provide the platform for the anode-electrolyte-cathode layer stack. For the case of one SOFC, the nickel anode and silver cathode as well as the yttria-stabilized zirconia electrolyte can all be as thin as a micrometer as synthesized using sputter deposition.

It is well established that the electrode layers should enable combination of the reactive gases and be conductive to transport the electric current. Thus a porous morphology is desirable for both electrodes. Standard lithography procedures yield an anode structure (imaged using scanning electron microscopy) as shown in Figure 2. The fuel cell output is enhanced through maximizing the contact area between the electrode and electrolyte. Thus further reducing the electrode pore size from five to ten micrometers may enhance the electrical performance and additionally, the mechanical strength of the support electrode. A method is developed to deposit an electrode with micron-scale porosity. A metallic sponge can be produced by appropriately controlling the sputtering conditions. By combining a moderate sputter gas pressure and an elevated substrate temperature, a sponge-like morphology is produced with micron-scaled porosity. The moderate sputter gas pressure creates a range of incident angles for deposition and the elevated temperature promotes a faceted crystalline growth. The result is the three-dimensional structure as seen for a nickel anode and silver cathode in Figures 3 and 4, respectively.

In summary, thin film deposition by sputtering alone or as in combination with photolithographic patterning and etching provides a means to synthesize porous films for energy conversion. Devices as TFFCs on a thin wafer platform, i.e. a miniature fuel cell on a silicon chip, can be synthesized through serial deposition of porous and dense component layers.

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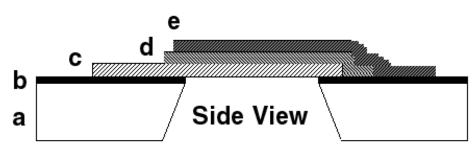

Fig. 1. This cross-section view of the thin-film fuel cell schematic shows the (a) host substrate, (b) protective nitride layer, (c) anode, (d) electrolyte and (e) cathode.

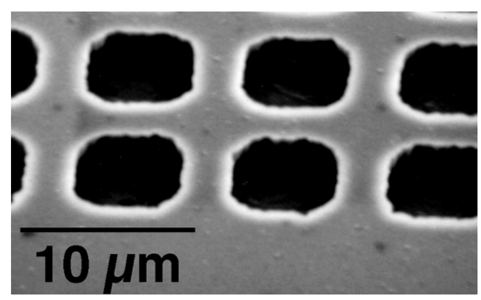

Fig. 2. The top-view of a nickel anode produced using photolithographic patterning and etching.

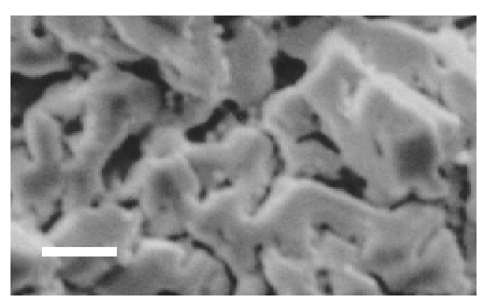

Fig. 3. The top view of a nickel anode produced at high temperature and sputter gas pressure. Bar = 0.5 microns.

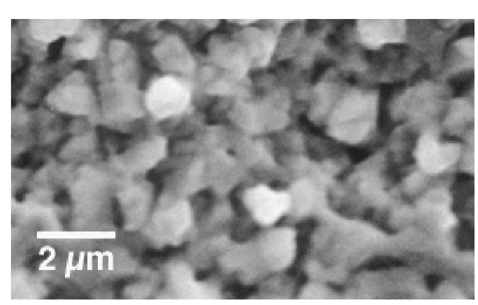

Fig. 4. The top view of a silver cathode produced from sputter deposition at high temperature and gas pressure.