INTEGRATED MICRO FUEL CELL POWER SUPPLY

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ABSTRACT

An integrated thin film micro fuel cell power supply design is described in this paper. The device incorporates: 1) a microfabricated micro-fuel cell, 2) integrated heaters and temperature sensors, and 3) a novel electrode design configuration. The architecture of this design allows this device to be completely fabricated using standard micromachining techniques.

INTRODUCTION

Fuel cells are an attractive alternative to batteries for portable electronic devices. Microfabricated micro-fuel cells hold promise for being highly efficient with low cost. Several approaches have been reported for the fabrication of micro-fuel cells [1-4] using micromachining techniques. Most of these devices include micromachined fuel cell components combined with conventional macro MEAs (membrane electrode assemblies) [1-4]. Previous work has demonstrated the possibility of a completely microfabricated micro-fuel cell [5]. The present work combines surface and bulk micromachining technologies to produce thin film micro-fuel cells of various geometries with integrated heaters and temperature sensors. This novel device design demonstrates a truly integrated micro-fuel cell based power supply that is compatible with existing CMOS processes.

FABRICATION OF UM- μ PEMFC

A seven mask process for the UM- μ PEMFC has been developed. Figures 1a and 1b show the closed and exploded views of the device structure respectively.

Figure 1a. Closed view of the UM- μ PEMFC.

Figure 1b. Exploded view of the UM- μ PEMFC.

A stress relieved oxide-nitride-oxide (1 μm) dielectric layer was deposited onto a silicon substrate via LPCVD (low pressure chemical vapor deposition). A 6000 $\text{\AA}$ layer of polysilicon was deposited on top of the oxide and was subsequently doped with phosphorous for a sheet resistance of 18 $\Omega/\square$. Using RIE (reactive ion etching), the polysilicon layer was patterned into the heaters and temperature sensors shown in Figure 2.

Figure 2. Heaters and Temperature Sensors of UM- μ PEMFC.

A 0.5 μm protective layer of oxide layer was deposited via LPCVD on top of the heaters and temperature sensors in order to isolate them from the electrodes. The fuel cell (Ti/Pt) anode and catalyst layers were patterned onto the oxide surface using Electron Beam (E-beam) evaporation and metal lift-off techniques. Figure 3 shows the anode on top of the oxide layer above the heaters and temperature sensors. (Further details about the electrode will be illustrated later in the paper.)

Figure 3. UM- μ PEMFC Anode above Heaters/Sensors.

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The electrode was subsequently patterned with photoresist for an RIE step that takes place in the triangular openings of the electrode down to the silicon substrate. A second RIE processing step

removed the oxide layer above the heater and temperature sensor contact pads. A thin film of Nafion® solution (5% of a 950 weight equivalent) was spin casted onto the anode at 500 rpm for 45 seconds. The film was then cured in an oven set at 150 C for 45 min. It has previously been shown that Nafion® films cured under these conditions have excellent adhesion and chemical resistance [6]. The spin cast speed vs. thickness and stress of the Nafion® thin films are reported for the first time in Figure 4.

Figure 4. Nafion® thickness and stress correlation.

From the Figure 4 one can conclude that the stress contribution from the Nafion® thin film will not be significant (>100 MPa) for the overall thin film structure. The Nafion layer was then patterned with photoresist to open up contacts to the anode, heater, and temperature sensor contact pads. The fuel cell (Pt/Ti) catalyst and cathode layers were deposited and patterned on top of the Nafion® in a manner similar to the anode. The backside of the wafer was patterned with photoresist using backside alignment and the front side was bonded to a carrier wafer. Gas access to the anode was accomplished by using RIE and DRIE (deep reactive ion etching). The oxide/nitride/oxide layer was removed from the backside using RIE in the areas not protected by photoresist. DRIE is then used to selectively etch the silicon substrate down to the oxide dielectric layer. After DRIE the device wafer was separated from the carrier wafer. The integrated micro fuel cell was thus supported by the stress relieved oxide-nitride-oxide dielectric layer.

ELECTRODE DESIGN CONFIGURATION

In an effort to improve the active area of the triple phase boundary region, triangular vias were developed. This should result in improved intrinsic performance relative to designs reported by Morse et al [5]. In the Morse design cylindrical vias were used to provide continuous porosity for the anode and cathode shown in Figure 5.

Figure 5. Morse et al. electrode design [5].

Figure 6. UM-μPEMFC electrode design..

By taking the ratio of the electrode opening perimeter to area, the following comparison between the circular and triangular designs can be made (Figure 7).

$$\text{Ratio} = \frac{\text{Perimeter}}{\text{Area}}$$

$$R_c = \frac{2\pi R}{\pi R^2} = \frac{2}{R} \quad \text{Ratio} = \frac{3\sqrt{3}}{4R} \quad R_t = \frac{4}{R}$$

Figure 7. Ratio comparison of electrode via openings.

A direct comparison of the two shapes illustrates that triangular vias have twice the active surface area compared to the circular vias. Another advantage that triangular openings have over circular is with regard to nearest neighbor feature approach. By alternating the positions of the triangles (illustrated in Figure 3), it is possible to pack more via openings on a given electrode size while at the same time maintaining a fixed distance from opening to opening.

HEATER AND TEMPERATURE SENSOR DESIGN

Previous work has demonstrated the performance of micro fuel cells either at room temperature or with the use of an external heating source. Towards the realization of a fully integrated micro fuel cell for portable electronic applications, we integrated these devices with internal heating sources.

The heaters and temperature sensors for the micro fuel cell were tested and calibrated. Figure 8 illustrates the temperature vs. resistance for the polysilicon RTD.

Figure 8. Polysilicon RTD temperature versus resistance.

The Polysilicon RTD was calibrated in a thermal chamber that was controlled by a Labview® program written by the author. The parameters were then tabulated into a linear best fit equation which was used to control the power supply to the heaters. It was possible to control the heaters based on the response of the temperature sensor.

RESULTS AND CONCLUSIONS

This paper reports the design and fabrication of an integrated micro fuel cell power supply. A novel electrode design was presented that optimizes several micromachining techniques in order to improve the triple phase boundary region. In addition, the integration of heaters and temperature sensors was introduced as a possible method to improve the fuel cell reaction and hence device performance. Several device geometries have been fabricated using the device architecture described above. These results will be presented in a forthcoming publication. Figure 9 illustrates an integrated micro fuel cell with a dime mounted on a PC board prior to testing.

Figure 9. Integrated UM-µPEMFC on PC board.

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