A HIGH-POWER MICRO FUEL CELL MICROFABRICATED FROM ALUMINUM

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Abstract: We present a hydrogen micro fuel cell (MFC) microfabricated from an aluminum wafer with integrated gas diffusion layer, capable of producing in excess of 1 A cm^{-2} of current density. Using aluminum for a microfabricated MFC brings benefits in terms of sturdiness compared to silicon or polymers, and it is also very conductive – no separate current collector is needed. Aluminum is also easily etched in phosphoric acid-based aluminum etchants. While only isotropic etching is possible, isotropically-etched microchannels are not a disadvantage for this type of microfluidic device.

Keywords: aluminum, microfabrication, microfluidics, micro fuel cells, gas diffusion layer

INTRODUCTION

Microfluidic devices such as microreactors, micro fuel cells (MFC), PCR chips etc. have been fabricated from polymers, silicon and glass [1-4], while micro-solid oxide fuel cells (SOFC) often use Foturan® photostructurable glass ceramic as substrate [5]. In micro fuel cells where the flowfield acts as a current collector, it is useful if the bulk material is conductive. For this purpose, highly-doped silicon is a good choice because of the availability of mature microfabrication technologies [4]. Joo et al. [6] used unstructured metallic nickel as a substrate for a micro-SOFC. Silicon is somewhat fragile, and in some cases a more robust material would be beneficial, for instance in vertical stacks of MFCs; a high compressive force is usually applied to stacks to minimize contact resistance between cells. For this reason, stainless steel or other metallic foil is sometimes used in MFCs [4], [7]. We have investigated aluminum as a cheap yet robust material, in which deep (50 µm – 100 µm) microfluidic structures can be fabricated with wet etching and using simple photoresist masks. The MFC microfabricated from aluminum in this work, uses carbon felt as a gas diffusion layer (GDL), integrated in similar fashion as in [8], apart from the lack of silicon nanograss as a contacting interface.

EXPERIMENTAL

The MFC is constructed by sandwiching a commercial membrane-electrode assembly (MEA), Gore Primea®, Pt loading of 0.3 mg cm^{-2} on the cathode and 0.1 mg cm^{-2} on the anode side, between two carbon felts (E-Tek ELAT® GDL LT1200N) and then two aluminum chips on the outside (figure 1). The chips have a basin that houses the carbon felt, which is similar to the silicon MFCs presented earlier [8]. The gases (oxygen or artificial air at the cathode, hydrogen at the anode side) enter the flowfield and then the carbon felt, through 1 mm diameter holes drilled at two diagonal points in the aluminum chips.

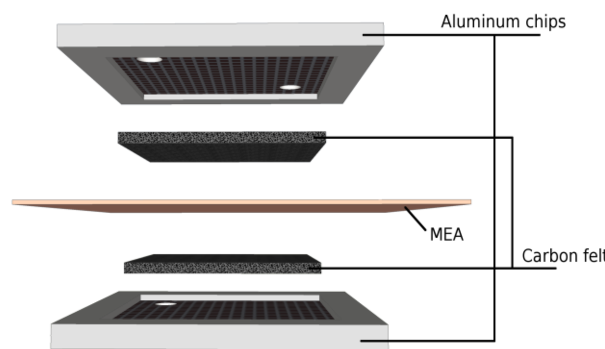

Fig. 1: Construction of a MFC with aluminum chips and carbon felt as GDL.

Figure 2 illustrates the fabrication steps for the microfabrication of the aluminum MFC chips. The MFC chips are microfabricated from 1 mm thick, 10 cm diameter aluminum wafers: AZ4562 resist is spun at 4000 RPM (for a thickness of 6.2 µm) and patterned with the first mask, defining the flowfield areas. The same resist is spun on the back of the wafer for protection during etching (figure 2 (a)). The flowfield areas are etched with a phosphoric acid-based commercial etchant (Honeywell PWS 80-16-4 (65) PURANAL®: 74% H_3PO_4, 2.5% HNO_3, remainder is H_2O) at 50°C for 50 minutes to reach a depth of 100 µm (figure 2 (b)). The AZ 4562 resist is spun and patterned on the front a second time, to obtain the flowfield channels (figures 2 (c)), etched 30 minutes for a 40 µm depth of the channels (figure 2

(d)). The resist is stripped and the top side of the wafer is sputtered with a 40 nm thick layer of chromium, to protect it from corrosion. The last step is drilling the wafer for the gas inlet holes on a CNC machine, and dicing of the wafer to separate the chips. The MFC is assembled according to figure 1 and placed in a measurement jig (figure 3).

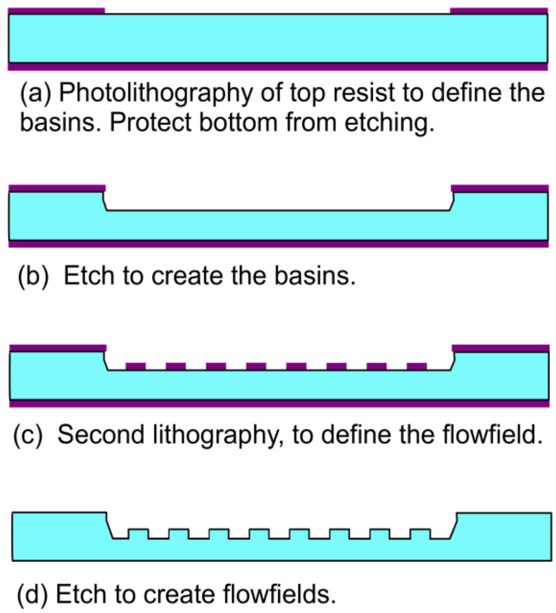

Fig. 2: Microfabrication process flow for a MFC chip

The measurement jig is composed of two aluminum blocks, electrically connected to a computer-controller potentiostat. Reactant gases are brought to the MFC through receptacles threaded into the aluminum blocks (figure 3) at a flow rate of 50 ml min^{-1}. The jig is than tightened with 8 screws to 1 Nm torque, to ensure low contact resistance and proper sealing of the MFC.

Polarization curves for the aluminum MFCs were obtained by sweeping the voltage with a computer-controlled Autolab® PGSTAT100 (Metrohm) potentiostat, from open-circuit (OCV) to 0.1 V at a rate of 1 mV s^{-1}, while the current generated by the MFC is measured and logged.

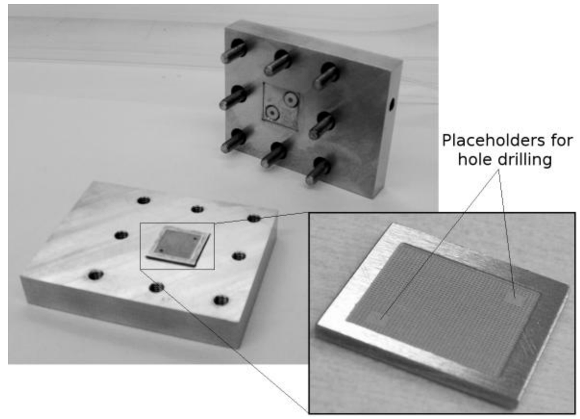

Fig.3: Measurement jig with one aluminum MFC chip inserted. Inset: enlarged image of MFC chip, before drilling.

RESULTS AND DISCUSSION

Scanning electron microscope (SEM) images on figures 4, 5 and 6 show the resulting flowfield and surfaces of aluminum, after the etching steps.

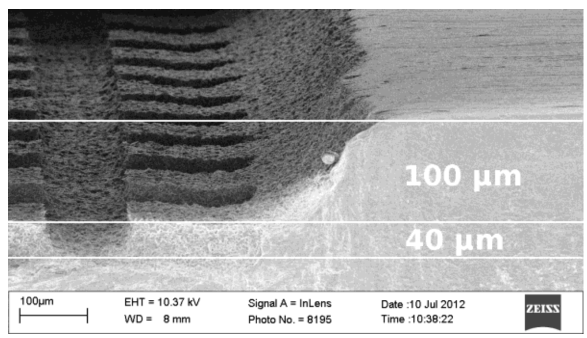

Fig.4: SEM micrograph of MFC flowfield edge.

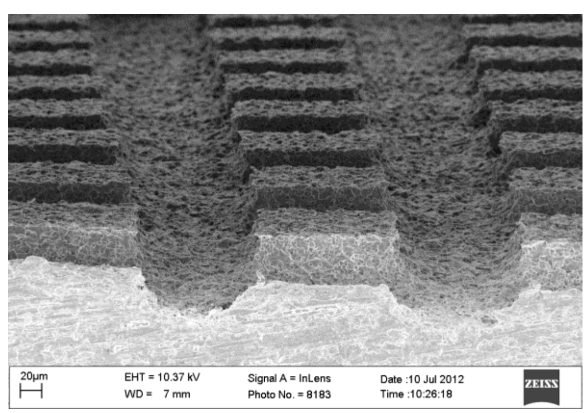

Fig.5: SEM micrograph of MFC flowfield, showing the channel and pillar width.

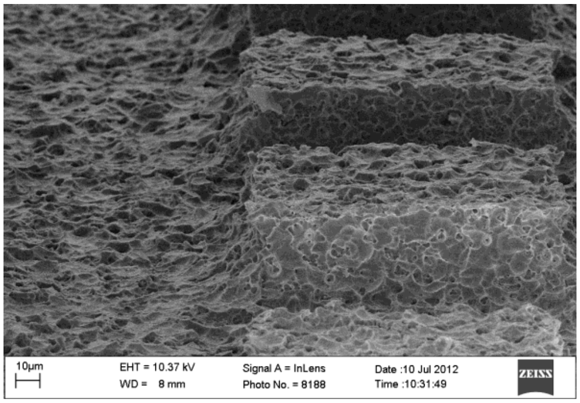

Fig.6: Close-up SEM micrograph of MFC, showing the detail of etched aluminum surface

Figures 4 and 5 show the characteristic round shapes of isotropically etched structures. Especially the sidewall of the 100 µm deep basin is actually slanted at about 45º, with rounded corners (figure 4). Likewise, the bottom of the channels is curved and not flat (figure 5). Neither of these features interferes with the function of the device. Every etched surface shows considerable asperity, with characteristic sizes of a few µm. It is likely that this asperity is the result of grain boundaries in the aluminum bulk. The high surface roughness has no adverse effect on the performance of the MFC. In fact, the larger contact area at the top of the pillars could increase electron conductivity between the flowfield and the carbon felt GDL.

MFC polarization curves with oxygen as oxidant are presented on figure 7. The performance of the cells matches or exceeds the best SOFC [9] (246 mW cm^{-2} at 600°C and propane as fuel) or PEM [10] (105 mW cm^{-2} with air as oxidant) MFCs.

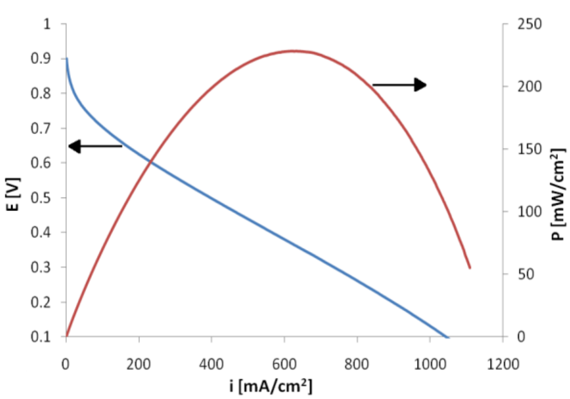

Fig.7: Polarization curves for aluminum MFC, with oxygen as oxidant

The good performance can be partially explained by the presence of carbon felt as GDL. Integration of carbon felt, a traditional macro-fuel cell GDL, with silicon MFCs has proven beneficial for the performance of silicon MFCs [8] (127 mW cm^{-2} power density). The high conductivity of aluminum and the high force applicable to the MFC assembly (which eliminates leaks and improves contact conductivity between elements of the stack) could further increase current and power density.

Polarization curves obtained by using air as oxidant were also measured (figure 8). The maximum current density is almost an order of magnitude smaller than in the case of oxygen (1109 mA cm^{-2} vs. 146 mA cm^{-2}), and the power density is almost 5 times smaller (228 mW cm^{-2} vs. 48 mW cm^{-2}). This drop in overall performance is more severe than would be expected, and at the moment we do not have a clear explanation for the phenomenon. It may be that the high performance of the MFC depletes the oxygen content in the air that diffuses to the PEM, while the rest of the air flows out the cell: the GDL is relatively thick (100 µm) relative to the active area of only 1 cm^2, and the flowfield channels are 40 µm deep, so some of the oxygen-rich air might flow out of the flowfield faster than diffusing to the PEM. This increases the mass transport losses, which can be seen in figure 8 at current densities above 100 mA cm^{-2} as a steeper loss of voltage against current density increase.

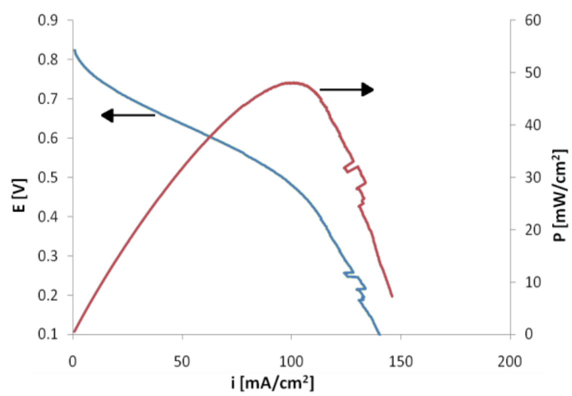

Fig.8: Polarization curves for aluminum MFC, with artificial air as oxidant

CONCLUSION

We have fabricated MFC chips from an aluminum wafer by isotropically etching flowfield channel into the bulk of the aluminum. This flowfield is located at the bottom of a basin which was also etched isotropically with the same liquid etchant, to house a carbon felt GDL. The design proved to be successful and the microfabrication procedure adequate for an application where channel wall quality, or the lack of straight sidewalls, are not an issue. The technology provides advantages in economic sense, as the etchant, mask and substrate (aluminum) are all cheap and the process itself (wet etching) is technologically simple and does not require expensive cleanroom tools.

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