The Fifth International Workshop on Micro and Nanotechnology
for Power Generation and Energy Conversion Applications
PowerMEMS 2005
Nov. 28-30, 2005
Takeda Hall, The University of Tokyo, Tokyo, Japan

Button Cell Sized Micro Fuel Cell System

R. Hahn, S. Wagner, T. Stolle, K. Marquardt*, H. Reichl
Fraunhofer Institut for Reliability and Microintegration, IZM
Gustav-Meyer-Allee 25, 13355 Berlin, Germany
*Technical University Berlin
Sekr. TIB 4/1-2, Gustav-Meyer-Allee 25, 13355 Berlin, Germany

Abstract

Prototypes of self breathing PEM fuel cells with a size of 1 x 1 cm^2 and 200 µm thickness were fabricated by means of foil processing and micro patterning. V/I curves were measured for a lot of different designs at a variety of ambient conditions. Fuel cells with 40 mA output current at 1.5 V (25°C, 50 % RH) have been successfully demonstrated.
Cell performance was validated under varying ambient conditions. Stable long term operation of 2500 hours at 80 mW/cm^2 was achieved. Since storage of gaseous hydrogen is not practical in small size applications, the "on demand" hydrogen generation from $NaBH_4$ as well as Zn-KOH reaction was investigated.
A demonstrator of 4 cm^3 volume yields an energy of 2.1 Wh. Higher energy densities can be achieved with hydrogen from $NaBH_4$. With these promising results, the realization of complete fuel cell systems with a volume of only 1 to 10 cm^3 is within reach.

Keywords: PEM fuel cell, micro patterning, hydrogen generation, energy density

1 INTRODUCTION

Most of the micro fuel cell activities are focussing on direct methanol fuel cells (DMFC) because of the high energy density and the ease of handling small amounts of fuel. Nevertheless there are still several issues which are related to materials, reliability and system cost of DMFCs. The electrode efficiency is dramatically low at low temperature, gases are produced at the electrode and need to be regularly evacuated and methanol has the trend to cross over the protonic conducting membrane, diminishing the cell yield (cross-over phenomena). So far this prevented micro DMFCs from appearing on the market.

Planar self breathing PEM hydrogen fuel cells are delivering high energy density and system reliability which is sufficient for a lot of electronics and micro system applications. But hydrogen fuel cells are limited by the storage difficulties for miniaturized systems as they need heavy tanks for compressed hydrogen or reversible metallic hydrides. Therefore we have chosen a different approach by combining micro PEM fuel cells with MEMS hydrogen generation technology based on inorganic materials. This technology has the potential of achieving two to three times the energy density of Li-polymer batteries or alkaline primary batteries at low cost.

2 FUEL CELL DEVELOPMENT

2,1 Fuel cell concept

Technologies for the wafer level fabrication of planar PEM fuel cells between 1 mm^2 and approximately 1 cm^2 were developed [1-8]. The thickness of the fuel cell is below 300 µm. The major difference to conventional fuel cell systems consists in the fact, that gas diffusion layers are not needed because of the micro patterning of the current collectors. The system comprises only three components as can be seen in figure 2. The investigations focus on pattering technologies and design studies for integrated flow fields, material compatibility, patterning of membrane electrodes, serial interconnection of single cells in a planar arrangement, laminating and assembling processes.

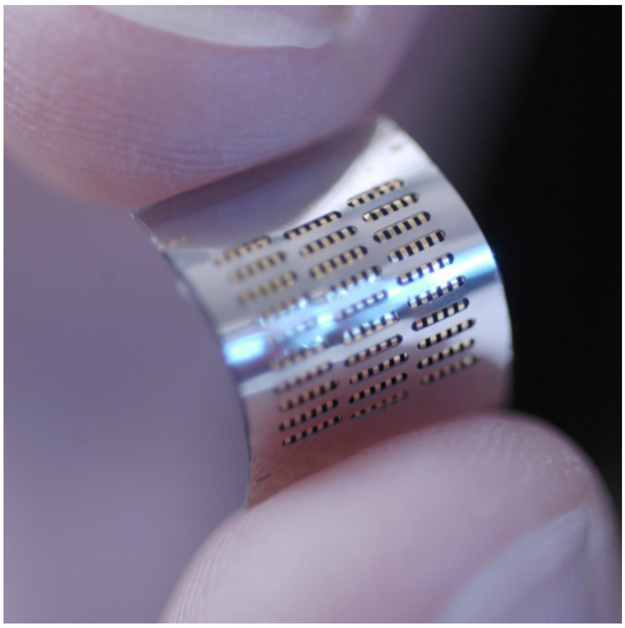

Figure 1: Foil- type micro fuel cell. 1.5 V, 40 mA

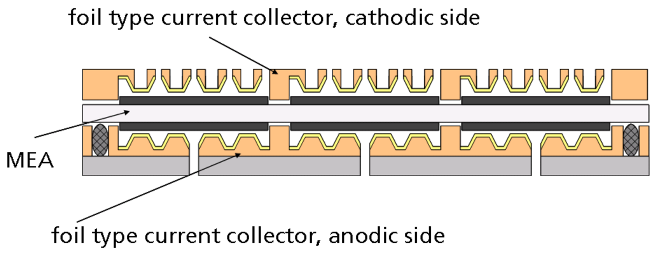

Figure 2: Cross sectional view of planar foil type fuel cell

Although wafer technologies were applied during the developing phase, foil materials were used which allow low-cost fabrication in future production. Figure 1 shows a demonstrator with an active area of 0.5 cm^2 and three serial interconnected cells.

Typical V/I curves are given in figure 3. It can be seen, that the influence of ambient condition is much higher than the design variation. In that case the design with a better low cost production potential was chosen for further investigations.

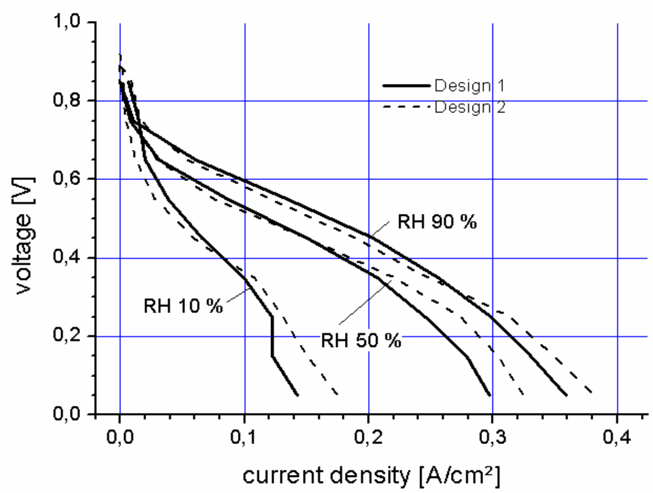

Figure 3: Micro fuel cell V/I curves for two flow field designs at varying ambient humidity, T= 45 °C

2.2 Low cost production

Low cost production was a major concern during all development steps since the fuel cell has to compete with batteries at costs of few cents.

The following technologies were developed for micro foil fuel cells: sandwich laminate of metal mesh and dielectric mesh for cathode current collector with air openings, hot embossing and laser patterning of anode side flow field/current collector and laser patterning of MEA electrodes. A variety of adhesive technologies for hydrogen tight sealing of the membrane and electrical interconnection were investigated.
The foil-based design of the fuel cell facilitates an efficient and low cost reel to reel manufacturing process. Reel-to-reel processing is a well accepted and widely spread concept in the industry. Whenever substrate and materials become very thin and flexible this production technology offers many benefits for efficient and low cost manufacturing of micro fuel cells. The basic platform used in this process is a high precision pick and place equipment, which is well-known as chip- or die bonder in the semiconductor industry. An endless substrate tape with the anode structure is transported into the machine which than deposits the sealing material, accurately places the MEA into the previously formed gasket and mounts the cathode foil in the same manner followed by curing processes. Completed fuel cells will be punched out and sealed into the hydrogen manifold. This technology makes a low-cost mass production of highly miniaturized fuel cells possible.

3 HYDROGEN MICRO GENERATOR

Since storage of gaseous hydrogen is not practical in small size applications, the "on demand" hydrogen generation from $NaBH_4$ as well as Zn-KOH reaction was investigated. The advantage of hydrogen generation from Zn-KOH catalytic reaction is, that the hydrogen flow can be directly controlled by the cell current. In principle the energy density of zinc air batteries can be achieved but at a much higher long time stability since the fuel cell protects the hydrogen cell from environmental driven degradation.
The Zn-KOH system is housed in a button cell (figure 4) with a non noble catalyst on a hydrogen permeable membrane.

Figure 4: Button cell hydrogen generator, size 3.5 cm^3

The hydrogen generation rate is proportional to the current across the button cell. Therefore valves or pressure controllers which are usually used for hydrogen systems are not necessary. Thus system efficiency and miniaturization can be improved dramatically. Figure 5 shows the current of the fuel cell at a constant potential of 0.3 volts which is proportional to the hydrogen flow which is controlled by current steps applied to the hydrogen cell.

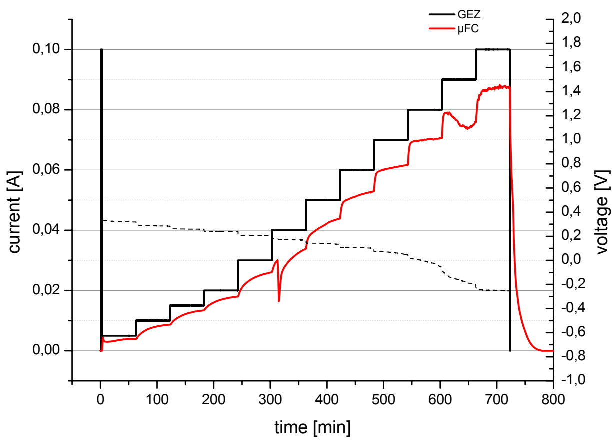

Figure 5: Demonstration of proportional currents in micro fuel cell (µFC) and hydrogen generation cell (GEZ, step curve).

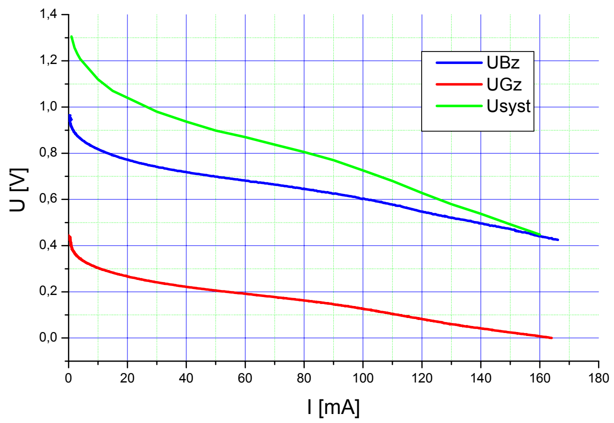

Figure 6: V/I curve of hydrogen cell (UGz, below), fuel cell (UBz, middle) and system (Usyst, above).

Since the hydrogen generation cell and the fuel cell are connected in series, the voltage of the hydrogen cell also contributes to power generation. Figure 6 shows the V/I curves of fuel cell and hydrogen cell as well as the sum voltage. Since the hydrogen cell currently is not optimized for high flow rates, best efficiency is obtained at low current levels.

For higher energy densities another approach was selected using $NaBH_4$ and water for hydrogen generation. Figure 7 shows a schematic of an 1 cm^3 micro system including fuel storage, fuel cells and electronic module.
As shown in figure 8 a number of catalysts and catalyst preparation methods were tested which showed sufficient hydrogen generation rate in a continuous power mode. Experiments with pressure driven intermittent control of hydrogen generation yielded response times of up to 30 minutes. Thus a passively working hydrogen generator is not suited for applications with varying power levels. At $NaBH_4$ concentrations above 30 % problems arise due to the precipitation of the reaction products on the catalyst.

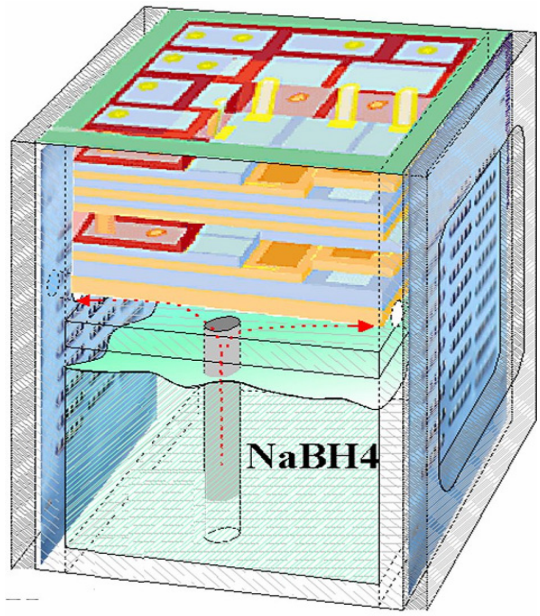

Figure 7: Schematic of micro system with integrated fuel cells and chemical hydride.

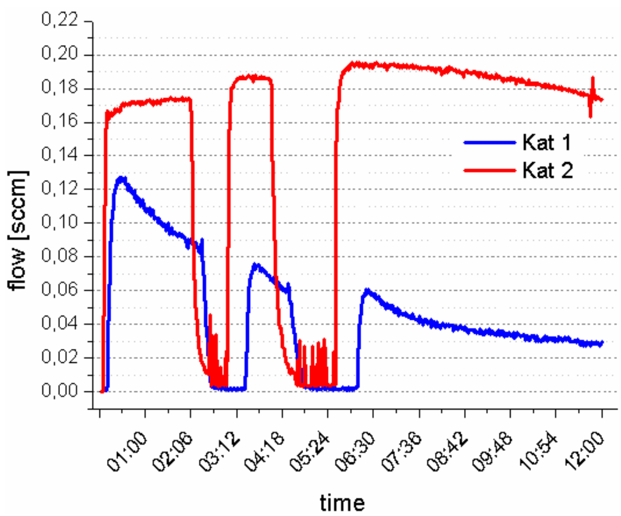

Figure 8: Hydrogen evolution from NaBH4 as function of time and catalyst used.

4 ENERGY DESNITY COMPARISON

Table 1 gives an overview of the energy obtained in a 4 cm^3 fuel cell system based on Zn KOH hydrogen generation in comparison with Li Polymer and alkaline batteries. Capacity was measured at similar power level.

Table 1: Energy density comparison

	Fuel cell + hydrogen cell	Li polymer battery	Alkaline primary battery
Size	4 cm^3	4 cm^3	4 cm^3
design	Button cell diameter: 25 mm	Prismatic, foil package	AAA cell
Energy [Wh]	2.1	1.2	0.96
Energy density Wh/l	525	300	240

It can be seen from table 1 that the fuel cell system reaches approximately twice the energy density of batteries. The energy content of the button cell can be further improved up to 800 … 1000 Wh/l.

5 CONCLUSIONS and OUTLOOK

We successfully demonstrated a micro PEM fuel cell technology based on commercially available MEAs and foil processes. Stable long term operation at 80 mW/cm^2 at room temperature, natural air convection was shown.
Considerable achievements have been made, but still a great effort is needed to commercialize micro fuel cells.
The use of electronic manufacturing and assembling technologies is a key to low cost mass production of micro fuel cells.

Future work will include an active $NaBH_4$ hydrogen system using novel catalyst and micro pumps.
Long term tests will be performed with the hydrogen generators as well.

Acknowledgements

The project was partly funded by the German ministry of research and education under contract BMBF02PI1065
www.pro-zell.de, www.fzk.de/pft/ncp.

REFERENCES

(1) R. Hahn, S. Wagner, A. Schmitz, H. Reichl, “Development of a planar micro fuel cell with thin film and micro patterning technologies”, Journal of Power Sources 131 (2004) pp. 73-78.

(2) R. Hahn, Autonomous energy supply for electronic grains and wireless sensors, Frequenz 3-4/2004, 87-91.

(3) S.Wagner, R. Hahn, R. God, H.-P. Monser, „Low Cost Manufacturing of foil-type micro fuel cells“, mst news No. 4/05 August 2005, pp.34-36

(4) Schmitz, R. Hahn, C. Hebling, et.al. Planar self breathing fuel cells, J. Power Sources, Vol. 118, pp. 162-171 (2003)

(5) Schmitz, A. Hahn, R. Hebling, C. et.al., MEA-Segmentation using LASER Ablation, J. Fuel Cells, Vol. 4 (3) pp. 190-195 (2004).

(6) S. Wagner, R. Hahn, H. Reichl, Foil type of MEMS Fuel Cells, 7th Annual SMALL FUEL CELLS 2005 Conference, Washington, April 2005.

(7) R. Hahn, „The status of micro fuel cell technology and its contribution to the energy supply of autonomous sensors“ SENSOR 2005, 11. May 2005, Nürnberg, pp. 341-346.

(8) R. Hahn “Miniaturization of Fuel Cells – low-cost manufacture of micro fuel cells with the help of microelectronics” f-cell 2005, Stuttgart, Germany, Sept. 26-28, 2005.