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Applying Methanol Vapor in Passive Planar DMFC as Micro Power Sources

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1 Introduction

The today's personal electronic devices challenge the power sources more strongly due to the enhanced features of the devices which consume much more energy than before. For example, the electrocardiography (ECG) device as demonstrator shown in this work can only work for approx. 24 hours with one piece of normal AA battery. This gives patients and doctors inconvenience for a long-term and non-Stop monitoring as well as data recording. Beside high capacity batteries like Li-ion battery the fuel cells, especially direct methanol fuel cells (DMFCs), seem to be suitable potential solution for replacing the conventional batteries because of the high energy density of liquid methanol, easy recharging and handling [1].

However, the special characteristics of DMFC, methanol crossover, determines that only diluted methanol solution (normally 1 – 2 mol/l) could be used in DMFC and in the most cases pumps, valves or other side equipments are needed. This increases the complexity of BOP (Balance of Plant) and therefore reduces the system efficiency [2-5].

In this work a unique planar DMFC system designed as micro power sources with fully passive operation is introduced. The specialty is to use methanol vapor passively at anode side under methanol boiling point which is realized by a phase separation membrane as the evaporator. The air-breathing cathode allows oxygen to enter fuel cell by natural diffusion. Based on the previous studies [6,7] the DMFC fed with methanol vapor (vDMFC) shows more advantages than the traditional liquid DMFC. The gaseous reactant has better reaction kinetics than liquid feed. The single gas phase inside fuel cell reduces the mass transport problem, for instance, no more block of methanol to catalyst layer by produced CO_2 bubbles. Using high concentrated or even pure methanol becomes possible because no liquid methanol directly touch the anode catalyst layer, but only methanol vapor. Therefore, the methanol crossover problem is not as big as liquid DMFC. As consequence the energy density can be greatly increased. The passive delivery means no active devices like pumps etc. needed so that the vDMFC system could be constructed with very compact design and light weight which is suitable for the portable applications.

2 Working principle of vapor fed DMFC (vDMFC)

One of the core components in vDMFC is the phase separation membrane (PS-membrane) working as passive evaporator shown in Fig. 1. The PS-membrane is a polymer-based fine porous layer covered with very thin silicon film on one side. The liquid methanol can not directly go through this PS-membrane, but is first absorbed on the silicon side, then diffuses through the membrane to the other side and is desorbed as vapor phase from the other side. This absorption / desorption process realizes methanol change from liquid phase to vapor phase. The PS-membrane can also prevent overload of liquid (pure) methanol to the anode which can cause overheating by enormous methanol crossover. So this membrane can also work as self-regulator.

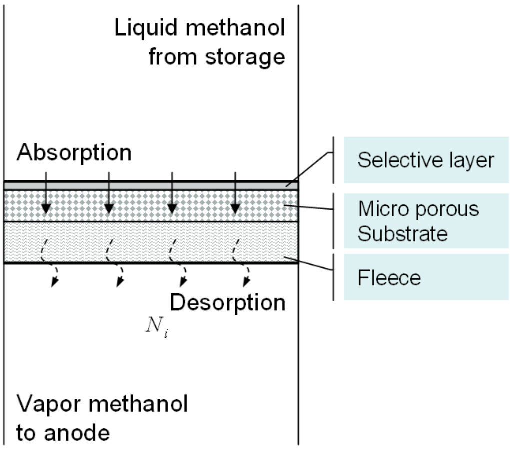

Figure 1: Schematic representation of phase separation membrane which consists of 3 layers: Selective silicon layer, micro porous substrate and fleece.

The pure methanol is used in this work without extra water supply. The water required for anodic reaction comes from ambient humidity. The water vapor from the air diffuses from cathode side through the membrane to the anode to start the reaction. Once the reaction is activated, the more water will be produced at the cathode side and go back to the anode by back-diffusion.

3 Characterization of vDMFC-operation

To evidence that water vapor in the air with normal relative humidity (rH) is sufficient for activating the reaction, an “air-box” with closed and defined volume was constructed for testing condition change affected by the open cathode. Several sensors were integrated in the “air-box” to measure the environmental parameters such as concentration of oxygen, methanol, rH, temperature, pressure and so on. Fig. 2 shows a typical measurement curves recorded during the vDMFC working in the “air-box”. During the first several minutes the rH (green line) in the box reduced quickly from 50% to 45% and then kept increasing up to 70%. This evidences that the water is consumed from the environment to activate the reaction and then produced from the reaction. The temperature (black line) rise from room temperature 25°C to 33°C and oxygen concentration (blue line) decrease confirm the reaction taking place. The methanol concentration (red line) in the box at the cathode side was recorded about 16 times higher than that at beginning which means methanol crossover still existed with methanol vapor feed at anode, but acceptable with 100% methanol in the anode tank.

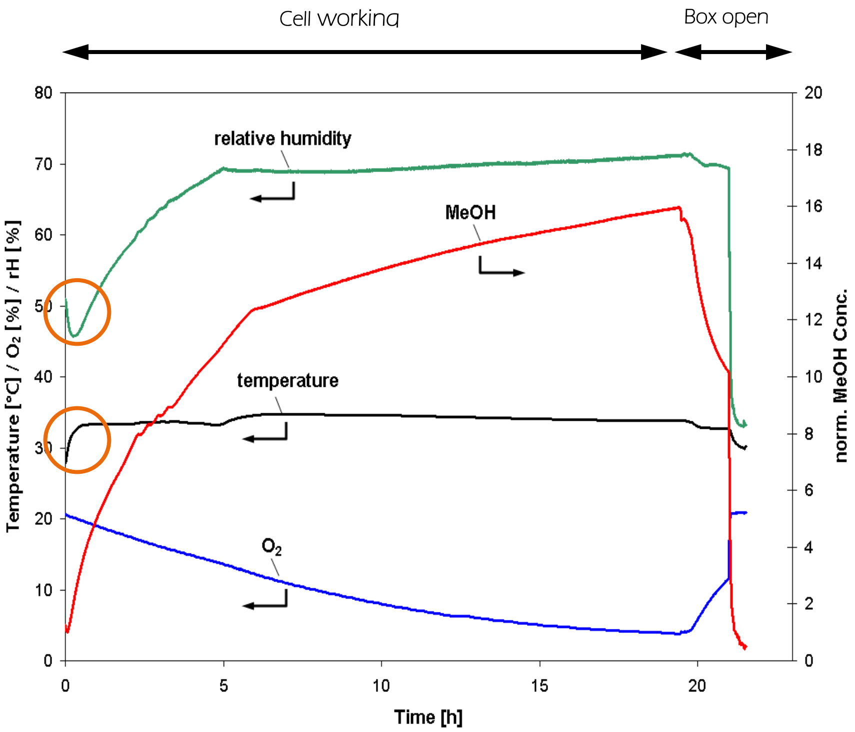

Figure 2: **Measurement curves of environmental parameters recorded in the „air-box“ during the vDMFC working. Cathode side faces into box. Anode side is coupled with methanol tank containing pure methanol. Experiment was conducted at room temperature without heating device.**

Several measurements were carried out with vapor and liquid methanol solution in the test cell setup described in [5] which was fully passive operated and temperature controlled. A comparison result is shown in Fig.3. At 50°C and passive operation the vDMFC yields over 20 mW / cm² which is higher than 0.5 M and 1 M liquid methanol DMFC.

A number of MEAs designed for vDMFC were screened in the test cell setup at 30°C and 50°C, respectively. The maximal power densities of each MEA are summarized in Fig.4. Most of the MEAs work at high temperature well with about 20 mW / cm² or more. At lower temperature the produced power densities are generally much lower than that at 50°C due to the worse reaction kinetics and less methanol vapor evaporation.

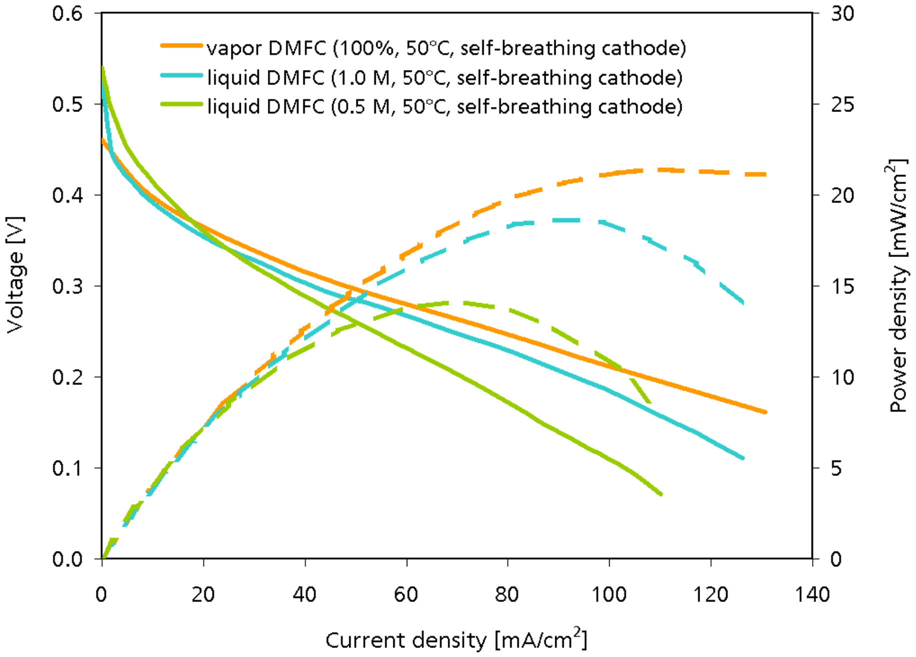

Figure 3: **Comparison of cell performance of vDMFC (100% methanol) and liquid DMFC (0.5 M / 1 M) at the same condition.**

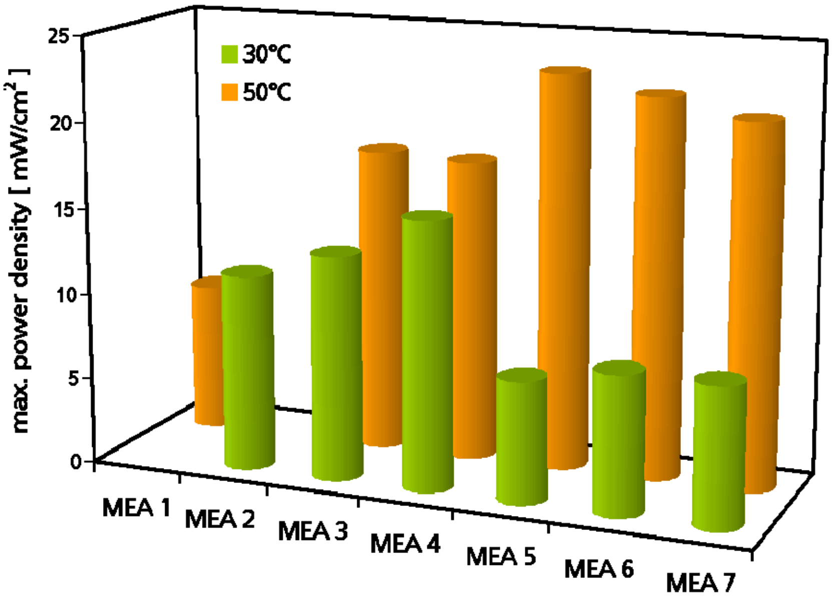

Figure 4: **Summary of max. power densities of different MEAs in vDMFC at 30°C and 50°C.**

4 Realization of vDMFC-prototype

The cross-section illustration of a vDMFC module is shown in Fig.5 (a) which includes CO_2 absorber, methanol tank and vDMFC. The methanol vapor and produced CO_2 can enter or get out of the cell through the separated channels. Because the single vDMFC has a very low working voltage, in the final demonstrator a 4-cell system with series connection was designed for a high total voltage as shown in Fig.5 (b). The size of the planar vDMFC is 47x75x4 mm and the whole system is 15 mm thick. In the methanol tank min. 6 ml Methanol can be stored and delivered passively into anode independent of position. The entire system can deliver about 50 mW so far.

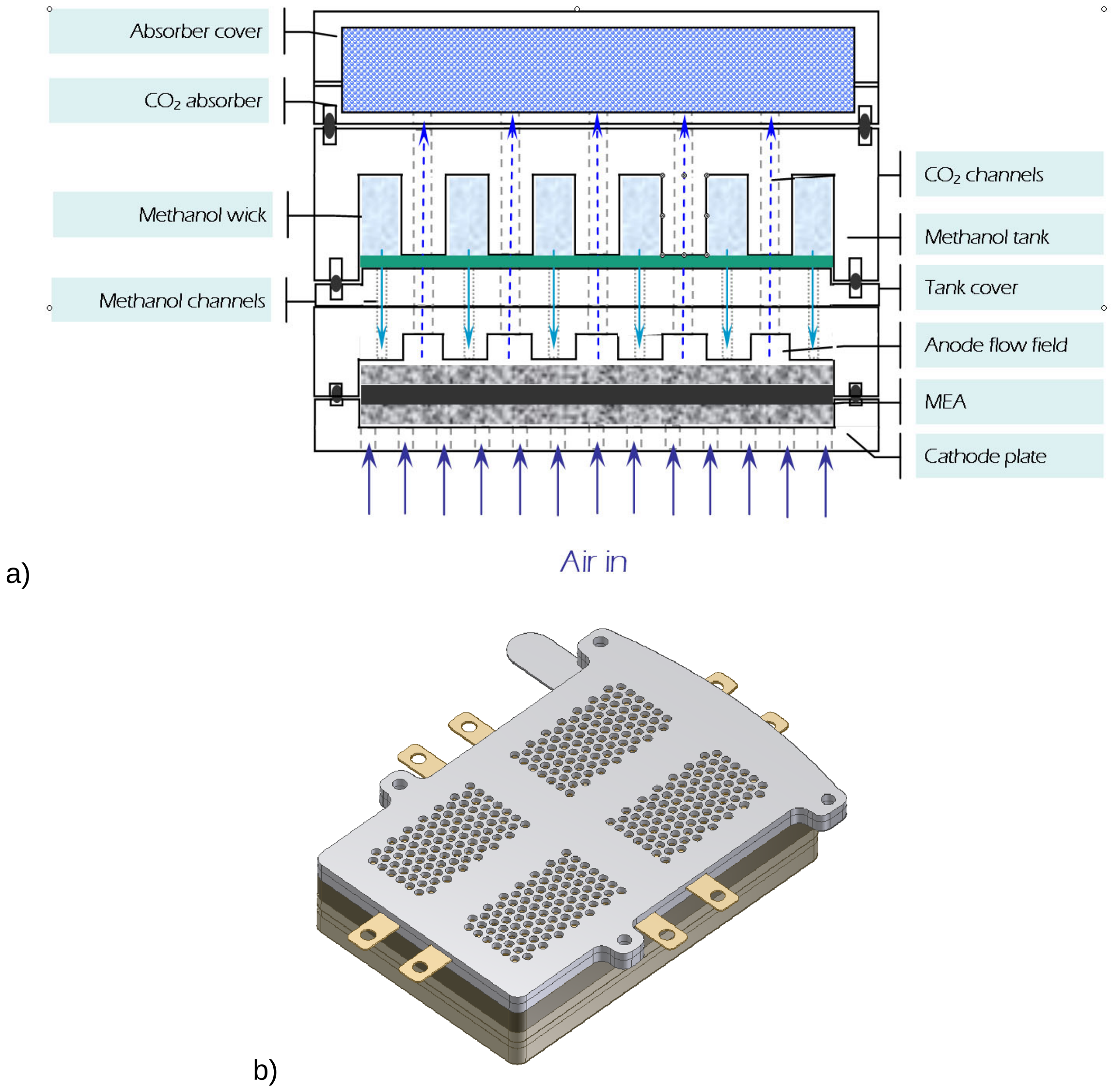

Figure 5: (a) Illustration of a vDMFC cross-section and (b) complete 4-cell system assembly.

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