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This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 1: Fuel Cell Basics / Fuel Infrastructures
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-1
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-651-4

Optimization of Thermal Management in High Temperature Fuel Cells

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1 Introduction

Having numerous advantages over low temperature fuels cells, like a low CO-sensitivity and the absence of a complex water management, high temperature fuel cells still have to deal with one major challenge – a high output of lost heat. To prevent the fuel cell from a breakdown due to overheating, the lost heat needs to be properly dissipated and therefore makes high demands on the thermal management. The nowadays solutions, like water or air cooling, often have a large sized setup due to components like cooling fans, pumps and additional radiators which also make it difficult to control the heat dissipation. Also, the low thermal conductivity of these systems makes the heat dissipating process slow and therefore less effective. An improvement in the modern heat dissipating techniques, for example through the implementation of heat pipes, is essential and therefore the subject of the present work.

2 Heat Pipes as a Heat Dissipating Solution

Heat pipes are known to have a high thermal conductivity being space saving at the same time. They are usually known to be tubular shaped and are used for CPU-cooling or dissipating the heat in pipeline systems. Reducing the heat pipe dimensions combined with novel shapes gives the possibility to implement heat pipes in other systems like the high temperature fuel cells. Three different types of heat pipes are presented in this work including possibilities of their implementation in a high temperature fuel cell and the evaluation of their thermal conductivity.

Figure 1 shows the three heat pipe layouts. ***Figure 1a)*** shows a directly integrated assembly of four silicon heat pipes. It consists of two silicon plates (one of which containing the flowfield pattern on top) with groove shaped heat pipe structures (smaller image) which are bonded together. An opening close to the wafer frame is used for filling the working fluid inside the heat pipe and is sealed at the end of the filling process. ***Figure 1b)*** and ***c)*** show two layouts of graphite-heat pipe systems including commercialized copper heat pipes (round/flat). The graphite plates can easily be structured with a flowfield pattern on the outer side. In all three cases, the area of the flowfield was 2 cm x 5 cm.

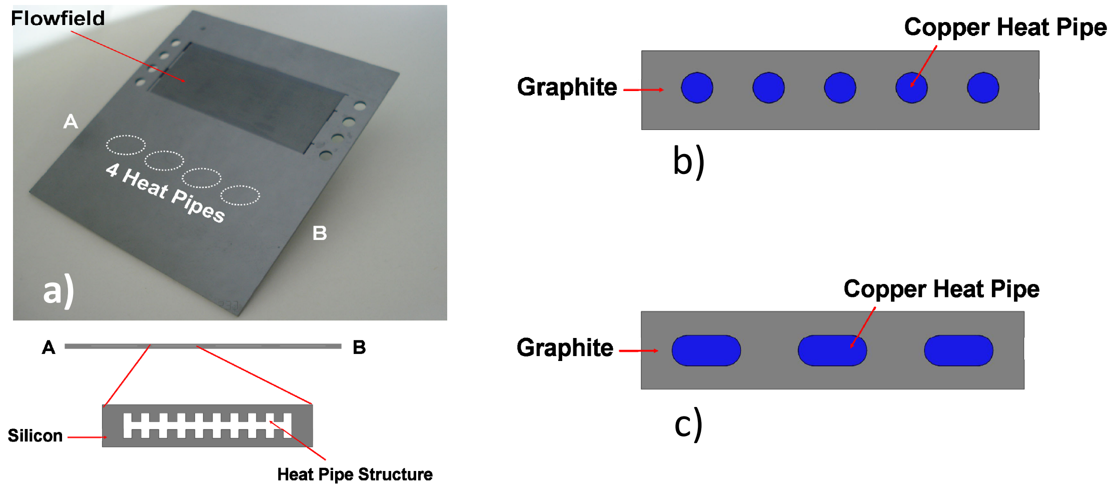

Figure 1: a) Silicon flowfield-integrated heat pipes, b) round copper heat pipes and c) flat copper heat pipes.

3 Simulation

An effective dissipation of heat in the fuel cell is strongly affected by the density of implemented heat pipes. The higher the density, the smaller the temperature peaks between the single elements. In case of silicon heat pipes this problem is solved through a maximum heat pipe density. In the case of round and flat copper heat pipes (***Figure 1b)*** and ***c)***) the temperature profile in the graphite plate cross section in dependence of the number of required copper heat pipes was calculated through a simulation. The maximum number of heat pipes was limited by the flowfield and the heat pipe width (3 mm for round heat pipes and 6 mm for flat heat pipes). The simulated temperature profiles are shown in ***Figure 2***.

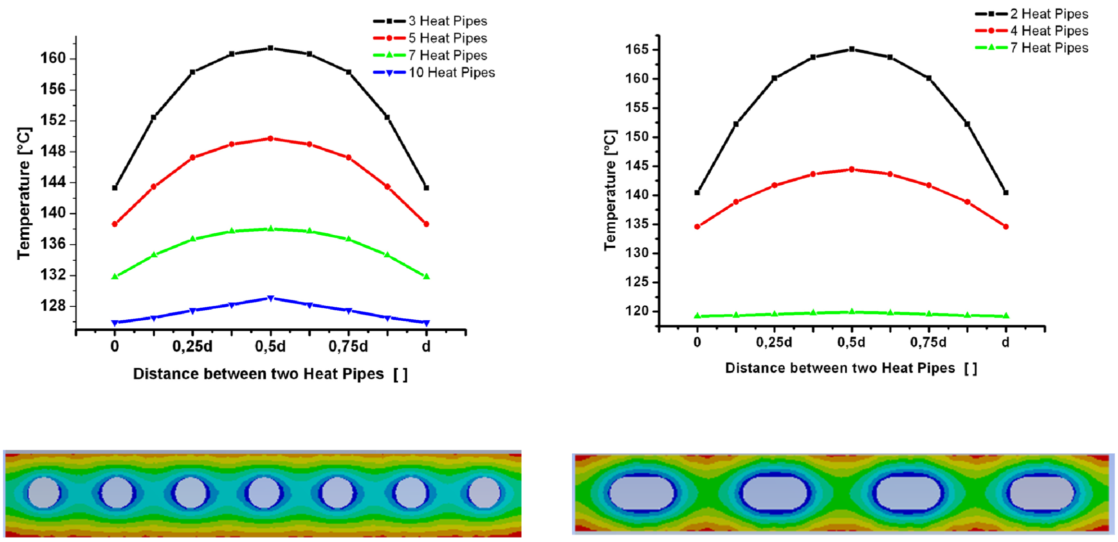

Figure 2: Temperature distribution between single heat pipes in dependence of the heat pipe number in the graphite plate.

To prevent the graphite surface from overheating, the temperature difference should not overrun the value of 10 °C. According to the simulation results, this is the case for 7 round and 4 flat heat pipes of the named dimensions.

4 Thermal conductivity

The thermal conductivity λ is an important parameter in order to compare the efficiency of single heat pipe types. Due to a high complexity of the measurement of λ, the calculation was done indirectly through a comparison of heat pipes with a silicon plate/copper bar of the same dimensions and a known thermal conductivity.

In the case of silicon heat pipes, the silicon plate with integrated heat pipes (filled and unfilled) and a solid silicon plate were heated on one end using a hot plate (temperature range: 100 – 170 °C) and cooled on the other end (PC-fan) and the temperature profile at defined measuring points (***Figure 3***) was measured with an infrared temperature measurement device.

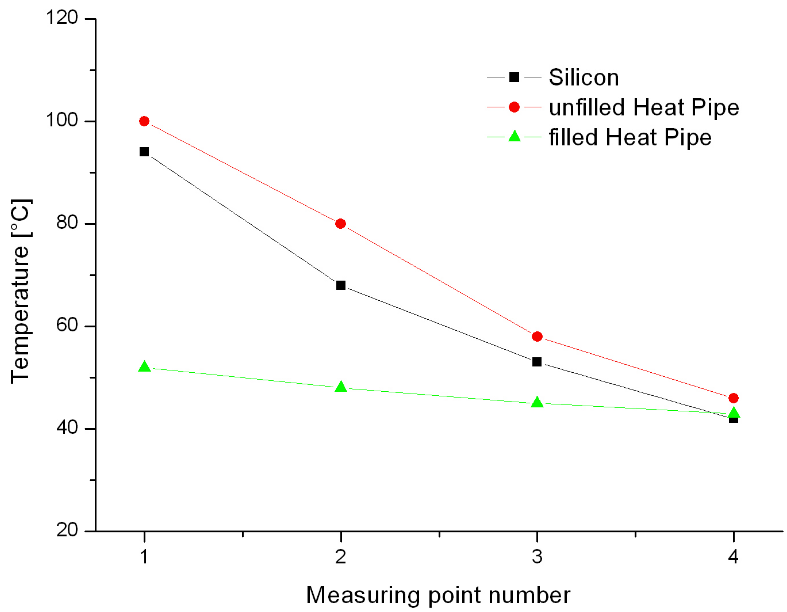

Figure 3: Temperature profile along a filled/unfilled silicon heat pipe compared to a solid silicon plate at a hotplate temperature of 170 °C.

Assuming a nearly equal heat input and having the same dimensions, the relationship of the unknown thermal conductivity λ_1 and the known thermal conductivity λ_2 is:

$$\frac{\lambda_1}{\lambda_2} = \frac{\Delta T_2}{\Delta T_1} .$$

As expected, the temperature profile of the heat pipe has a considerably smaller gradient than plain silicon and the unfilled heat pipe. Using the upper equation, the thermal conductivity of the heat pipe $\lambda_{Si\text{-}HP}$ results in:

$$\lambda_{SiHP} = \frac{\Delta T_{Si}}{\Delta T_{SiHP}} \lambda_{Si} \approx 1200 \frac{W}{mK}$$

The previously determined influences from the environment result in a decrease of λ of approximately 15-20%. Accordingly, the value of $\lambda_{Si\text{-}HP}$ including the environmental influences is ca. 1400 $\frac{W}{mK}$.

Similar to silicon heat pipes, the temperature profile along copper heat pipes was measured. Round copper heat pipes were therefore integrated in a graphite bipolar plate (***Figure 4a)***) and the determination of their thermal conductivity resulted from a comparison with a graphite/copper plate of same dimensions (725 W/mK, ***Figure 4b)***).

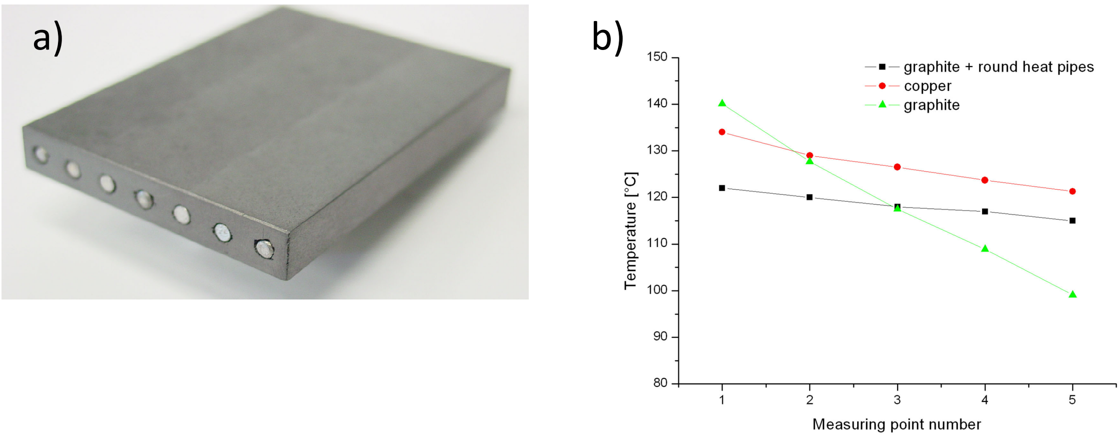

Figure 4: a) Graphite bipolar plate with integrated round copper heat pipes, b) temperature profiles of graphite+heat pipes, graphite and copper at a hotplate temperature of 170 °C.

In the case of flat copper heat pipes, the temperature profile was measured directly on the heat pipe surface due to its flatness and compared with a solid copper bar. The six measuring points were arranged along the centre line of the heat pipe and at the same intervals. The two outer points were arranged as close as possible to the hotplate/PC-fan. ***Figure 5a)*** shows the temperature profiles (at a hotplate temperature of 100 °C, 110 °C, 120 °C, 140 °C, 160 °C and 170 °C) along the heat pipe (mean value of 20 heat pipes) and the copper bar and the temperature difference between the outer points in dependence of the hotplate temperature (***Figure 5b)***, 3 heat pipes compared to 3 copper bars).

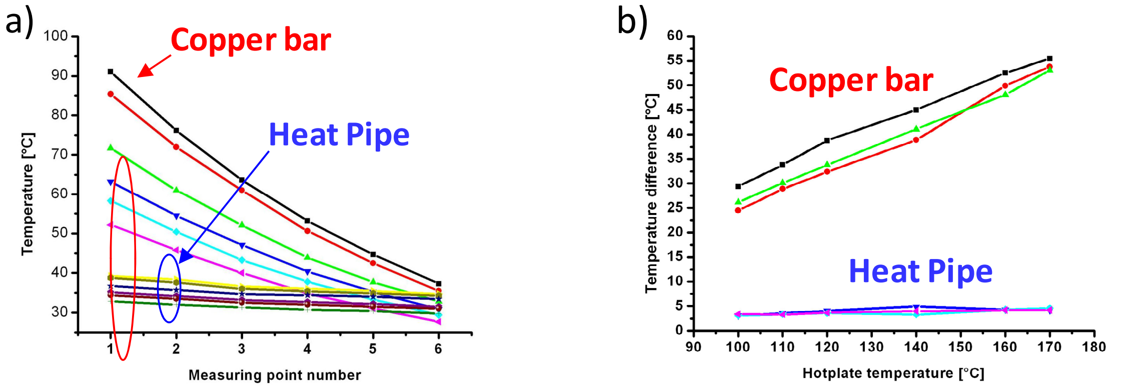

Figure 5: **a) Temperature profile along a heat pipe and b) temperature difference between the outer measuring points.**

Compared to the results of the copper bar, the temperature gradient of the heat pipe is extremely small and has a temperature difference between the outer measurement points of < 5 °C. The thermal conductivity of flat copper heat pipes can results in 36000 W/mK (including environmental influences).

5 Experimental setup

A model of the experimental setup including two flat copper heat pipes (with a width of 24 mm) and a high temperature fuel cell is shown in ***Figure 6***.

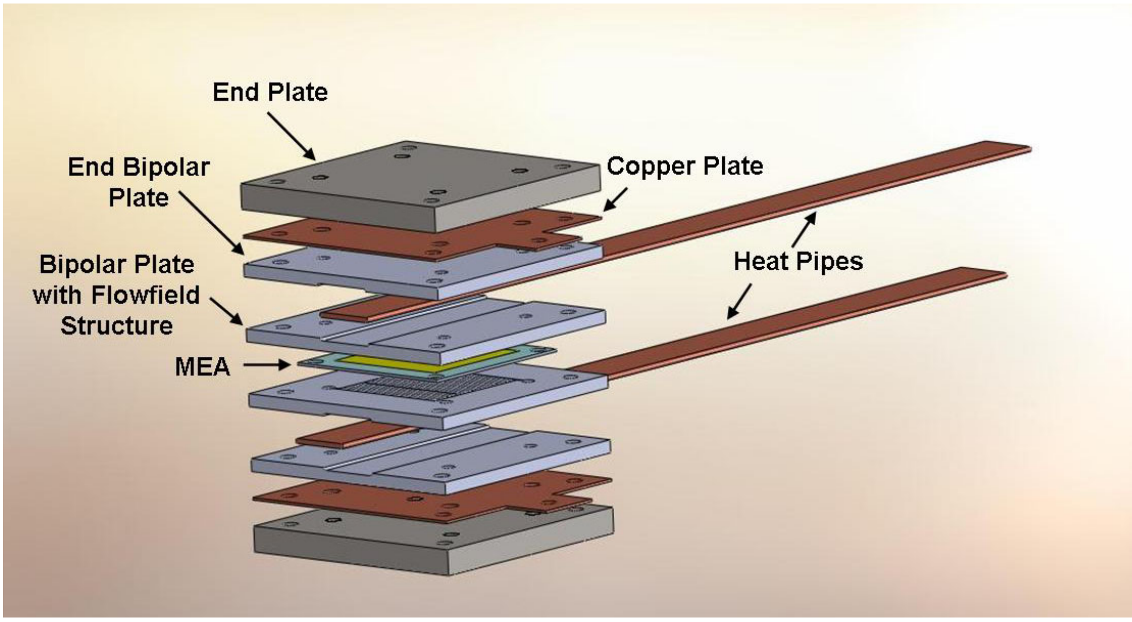

Figure 6: **Model of the experimental setup with two flat copper heat pipes.**

The model is symmetrical with the membrane electrode assembly (MEA) in the centre. The supply of hydrogen and oxygen, as well as the evacuation of the resulting water vapour and the unused hydrogen, occurs through the two end plates (stainless steel). The two inner bipolar plates (BPP) contain a rectangular groove shaped flowfield structure and the MEA between them, where the hydrogen is split in protons and electrons. To dissipate properly the generated lost heat, a heat pipe is adjoined directly on the outer side of the inner bipolar plate, opposite to the flowfield structure and closed with a second bipolar plate. Finally, the assembly contains two thin copper plates for electrical contacting. This model can easily be expanded to a stack by simply repeating the MEA-BPP-unit.

Figure 7 shows the experimental setup consisting of one cell with an active area of 25 cm^2, including fuel inlets, water vapour/unused hydrogen outlets and an ohmic resistance.

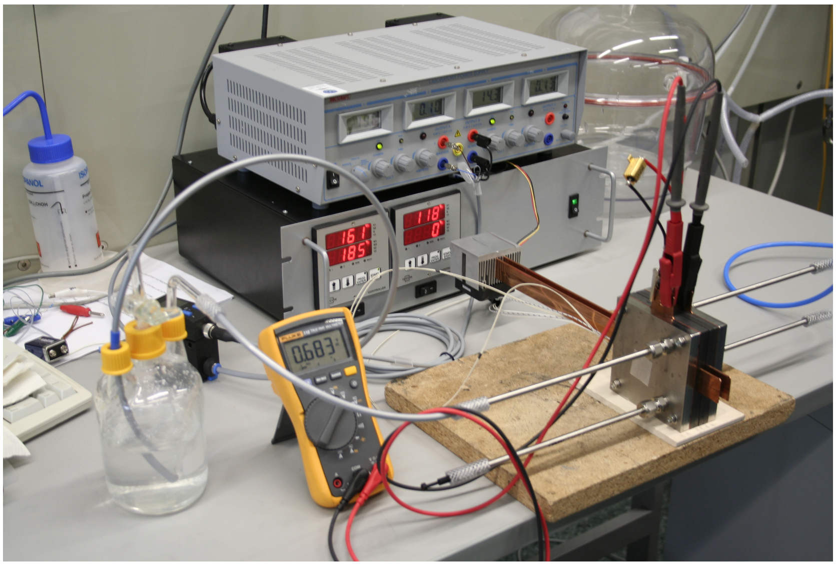

Figure 7: Integration of flat copper heat pipes in a high temperature fuel cell.

Using an external heat source and two flat copper heat pipes, the high temperature fuel cell was heated to a temperature of 135 °C. During the operation, the produced lost heat could successfully be conducted from the fuel cell using the heat pipes and hence be maintained at a constant operating temperature level. During the operating time of several hours a power density of 328 $mW/cm^2$was measured.

The effectively accomplished heat supply, as well as the lost heat dissipation has proven a successful functionality of the heat pipes.

6 Conclusions

A novel possibility of dissipating heat in high temperature fuel cells by the implementation of heat pipes was presented in this work. Three different heat pipe types were shown: a silicon heat pipe and two different copper heat pipes. The silicon heat pipe features its extremely high integrity into a fuel cell, its compact size and a high thermal conductivity, which is more than three times larger then the thermal conductivity of copper. The round and flat copper heat pipes could easily be integrated in a fuel cell by being placed inside a drilled hole of one bipolar plate or in a cavity between two bipolar plates. Especially the flat copper heat pipes have shown excellent results in thermal conductivity, which was 120 times as big as the thermal conductivity of copper. All three heat pipe types featured a remarkable temperature homogeneity over their length, which is essential for dissipating high amounts of lost heat in the high temperature fuel cell. An experimental investigation has proven the excellent functionality of heat pipes as a heat dissipating solution, by successfully conducting the start-up heat towards the fuel cell as well as discharging the lost heat from the fuel cell during its operation.