CAPILLARY MICROFLUIDIC CHIP WITH INTEGRATED PUMP AND VALVE ACTUATOR

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I. INTRODUCTION

Glycated Hemoglobin (HbA1c) is a long term blood glucose marker currently only available by laboratory testing. Main hurdle for point-of-care testing of HbA1c is the necessary on-chip sample preparation. One limiting factor is the lack of miniaturized, time-controlled liquid actuation functionality.
In the presented concept electrochemical pumping in an active and disposable microfluidic lab-on-a-chip is used for the required flow control. In contrast to previous works the sample is directly used as working liquid for pumping and valving. A novel gel-based check valve approach is used to avoid undesired liquid movement towards the inlet of the chip. This method results in a miniaturization of the chip design and sample volume, the combination of passive and active microfluidics, and the elimination of external handling steps. The system utilizes well known technologies like hot embossing, physical vapor deposition (PVD) and laser micro machining to realize the innovative chip concept. The complex parameter HbA1c is supposed to be determined from a drop of capillary blood (5µl) after a chip internal sample preparation step.

II. ASSEMBLY

The polymer chip consists of a transparent, hot embossed channel layer (polycarbonate) and a metalized bottom layer (gold on polycarbonate) for electrode integration as shown in Figure 1 A. The chip dimensions are 39 mm x 6 mm.

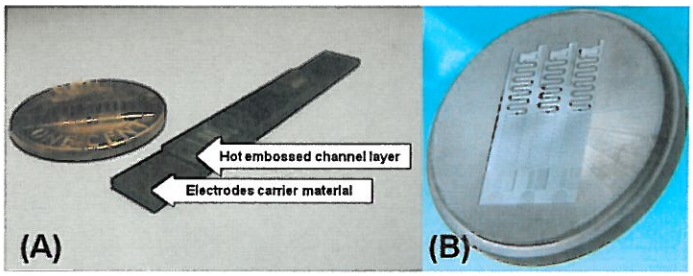


Figure 1: (A) chip for HbA1c-detection (design by SensLab and ENAS)
(B) Embossing die with microfluidic structures (silicon carbide)

fabrication steps:

(1) PVD-coating electrode substrate
(Gold as the electrode material was deposited on a black polycarbonate foil)
(2) laser structuring of the electrodes
(pw, 355 nm, 20 psec pulse width)
(3) hot embossing of the channel substrate
(4) hydrogel integration
(5) laser welding

hot embossing

The microchannel substrate was fabricated by hot embossing which enables fast and economic replication of microfluidic elements with the requested structural sizes. In hot embossing processes, a master structure on a mould surface (figure 1 B) is pressed into a substrate at elevated temperatures, forming a negative relief replica of the master topography. By this method different materials like plastics, metal and glass can be structured with a high reliability. The dimensional accuracy of single parts during hot embossing is under 1 µm. It is possible to specifically rework the surfaces of hot embossing tools using laser micromachining in order to obtain defined roughness profiles. Among other processes laser polishing can be used to reach a surface roughness below Rz 2 µm.

laser welding

Laser contour welding was employed to join the two layers. Therefore, a continuous 20W IR-fiber laser with attached scanner system and a spot size of 50µm was used. The thermal influence of the laser beam is limited to the welded structures with only minor thermal effects in the surrounding material. This allows the integration of a (temperature sensitive) biochemical coating before joining. Only for the sealing of the electrode areas small adhesive tapes were used since laser welding would result in the destruction of the electrodes.

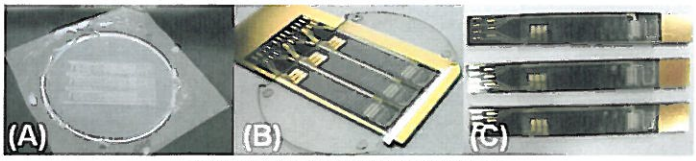


Figure 2: (A) the hot embossed polycarbonate
(B) the two layers after laser welding
(C) isolated HbA1c-Chip

III. MICROFLUIDIC WORKFLOW

The functional areas are shown in figure 3. The Chip is separated into a wide supply channel, which uses capillary filling and a thin channel in which the sample will be pumped with controlled flow velocity. Electrolysis is applied in two areas of the supply channel: to close the check valve next to the channel inlet area and to pump the sample into the functionalized thin capillary channel.

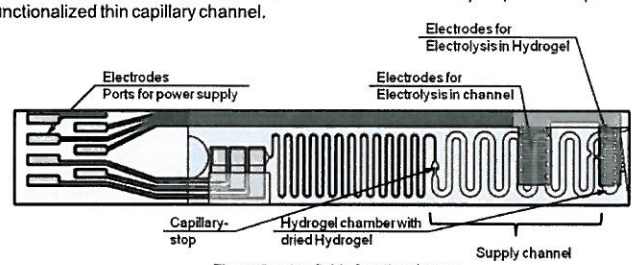
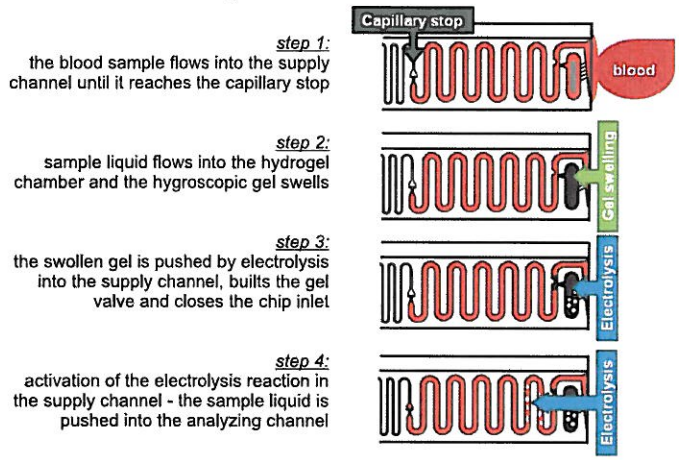


Figure 3: microfluidc functional areas



step 1: the blood sample flows into the supply channel until it reaches the capillary stop

step 2: sample liquid flows into the hydrogel chamber and the hygroscopic gel swells

step 3: the swollen gel is pushed by electrolysis into the supply channel, builts the gel valve and closes the chip inlet

step 4: activation of the electrolysis reaction in the supply channel - the sample liquid is pushed into the analyzing channel

Figure 4: schematic pictures of the functional steps

IV. EXPERIMENTAL

The experiments have shown that both, distilled water and human whole blood (figures 5), can be used for gel formation. The figure 4, Step 3 shows a microscopic picture of the creation of a gel valve with distilled water as medium. If distilled water is used, a small amount of super absorber is sufficient for swelling and building up a valve. With growing number of ions in the medium (such as for blood) the amount of super absorber has to be increased. In the next step the sample is further pushed towards the functionalized channel by a second electrolysis actuator, which is placed after the first actuator within the inlet channel. The gel valve avoids liquid movement towards the inlet. The whole process flow was tested with distilled water and human capillary blood as sample medium shown in figure 5, Step 4.

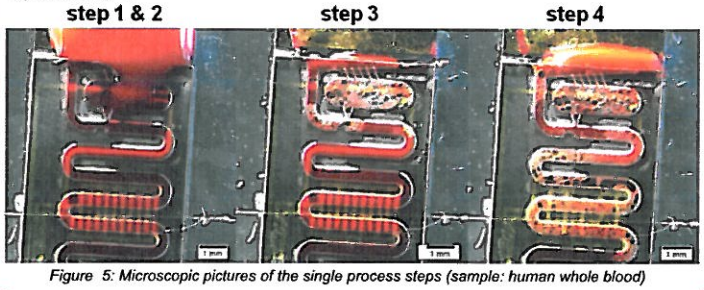


Figure 5: Microscopic pictures of the single process steps (sample: human whole blood)

V. CONCLUSION

A microfluidic chip combining capillary and active flow control has been presented. The chip uses a novel approach for electrochemical pumps based on hydrogel swelling and electrolysis. Inlet sealing is carried out "on-chip" by an innovative valving concept. The functionality of the novel approach has been demonstrated for distilled water and capillary whole blood.

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Acknowledgement: This presented work was performed in the project GlykHbLab (FKZ V4MOD023) funded by the German Federal Ministry of Education and Research.
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