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LAB-ON-A-CHIP MICRODEVICE WITH CONTACTLESS CONDUCTIVITY DETECTOR

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Abstract

This paper describes a new contactless conductivity detector, whose electrodes are constructed of microchannels filled with solution of KCl – called pseudoelectrodes. The lab-on-a-chip microdevice was fabricated in poly(dimethylsiloxane) PDMS, using a moulding technique. The mould was made from a dry negative photoresist with a thickness of 50 μm. During the tests, the dimension and arrangement of pseudoelectrodes` microchannels were evaluated. The analyte was pumped into the microchannel using a syringe pump with a flow rate of 50 μL/min. Reproducible changes of the signal were obtained.

Keywords: lab-on-a-chip, poly(dimethylsiloxane), contactless conductivity, pseudoelectrodes, microfluidic

1.Introduction

The lab-on-a-chip also called a micro total analysis system (μTAS), integrates all analytical steps (i.e. pre-treatment of sample, sampling, reaction, mixing and detection) in one miniaturized structure [1,2]. Microdevices allow the use of smaller amounts of reagents, which directly reduces the cost of a single analysis. On the other hand, it is possible to invest in expensive more durable materials, which due to the small size of the devices does not much affect the cost of the whole analysis. Reduction of the size of devices has also allowed the use of a smaller sample volume required to complete the entire analytical procedure. Forensic medicine and medicine have gained an additional analytical tool. Such microdevices are utilized in biological tests, for example in cell analysis [3,4] or cytotoxic tests [5]. First microstructures were fabricated from silicon and presented as gas chromatographic analyzer in 1975 [6].

Initially glass [7,8,9] and silicon [10] dominated as substrates in lab-on-a-chip. Now there is the trend toward the application of polymers. Polymer materials as opposed to the glass materials are easier to handle. However, in comparison with silicon they are inexpensive. At present, there are numerous types of polymer microfabrication techniques e.g. hot-embossing [11], injection, laser ablation [12,13], photolithography with moulding and milling. Another advantage is also a wide range of available polymers such as: poly(carbonate) PC, poly(methyl methacrylate) PMMA [14,15,16,17,18,19], poly(dimethylsiloxane) PDMS [20,21,22]. Polymers used must be appropriately selected, for example due to the mechanical properties and possible way of treatment. The choice of material is determined by the lifetime of the microdevice. For disposable microdevices (e.g. for the analysis of explosives [23] or biological material) a low-cost material would be appropriate. In contrast, when a microdevice will serve for a longer period of time (e.g. in a flow microreactor) the cost of the material will not be a major determinant in the choice of material.

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PDMS is often used for fabrication of microfluidic devices. PDMS is characterized by flexibility, porosity and transparency. PDMS as the material allows a rapid full cycle of design, fabrication and testing of microfluidic system. This makes it a very attractive material for the fabrication of structures at the stage of testing the size, shape and layout of elements in the microdevice.
Many traditional detection techniques are encountered in lab-on-a-chip microdevices [24]. Among them, electrochemical detection covers a large part of applications, next to the spectrophotometric techniques. Conductometric detection has gained more importance in analytical microdevices, especially in a dynamically developing microcapillary electrophoresis – μCE [25]. Conductivity detection can be performed either through galvanic contact or in a contactless mode [14].
Contactless detection is particularly important in the case of μCE, because the signal from electrodes is not affected by the separation electric field in the capillary. The contactless mode offers several advantages comparing with contact detection. Additionally there is no direct contact between the electrodes and the analyte so the electrodes` surface characteristic is the same during the whole measurement. Moreover, in a chip with contact mode, air bubbles can be formed by the electrode reactions and as a result the measurement may be inaccurate.
There are many possible implementations of non-contact measurement of conductivity, mainly due to the way of the location of the electrodes relative to the channel. The electrodes of a contactless detector may be placed under a microchannel [26], around a microchannel [27] and in the plane of a microchannel [28]. Also interesting is the variety of materials used to construct the electrodes. For example, the electrodes have been cut from stainless steel syringe needles [29], soldered coils of copper [30] or a strip of aluminium foil [27].

2. Preparation of a microdevice

2.1. Capillary film

In this work, a commercially available capillary film (Pro/Cap, Chromaline) was used [31]. Fig. 1 shows the process of manufacturing the mould. The capillary film (Fig.1a) consists of a dry photosensitive emulsion and an elastic polymeric support, so it can be called a dry photoresist. The thickness of the emulsion layer (ranging from 15 to 700 μm, in this work 50 μm) determines the height of the microchannel. During the photolithography process the capillary film is irradiated through a photomask with a previously defined pattern (Fig.1b). Dimensions of the pattern on the photomask determine the width of the microchannel. The photomask was designed in Corel Draw and printed on the foil with a resolution of 3600 dpi. The capillary film was exposed to an UV lamp with a dose of 780mJ/cm^2 for 1 minute. The exposed parts of the film polymerize and become insoluble in water. Unexposed parts are removed using a tap water jet (Fig. 1c). After washing, the mould was dried in an air stream of nitrogen. It is not recommended that the capillary film remains in long contact with water, because it can be delaminated from the supporting foil. Due to this fact, washing and drying were repeated 3-4 times to obtain a microstructure of a desired resolution. Fig. 1 depicts the whole process to obtain a mould from the capillary film. It is necessary to control the production process of mould. Any errors in the manufacturing process of the mould can be unnecessarily duplicated in the manufactured microdevices. The mould (Fig.1d) in this study was controlled using a laser confocal microscope, Olimpus LEXT OLS4000 3D Laser Measuring Microscope. Fig. 2 shows an image obtained using a laser confocal microscope.

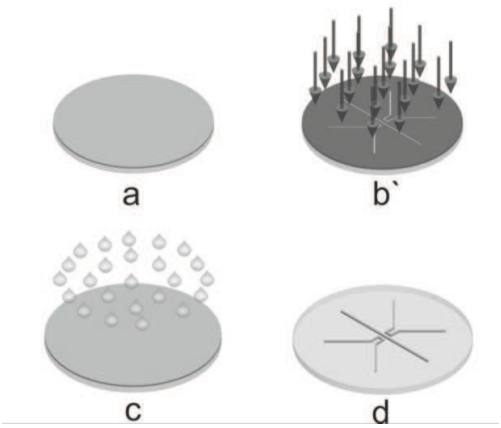

Fig. 1a. Capillary film with plastic support; 1b. Capillary film exposed to an UV lamp; 1c Tap water jet removes unexposed parts of the capillary film; 1d. The mould obtained in capillary film.

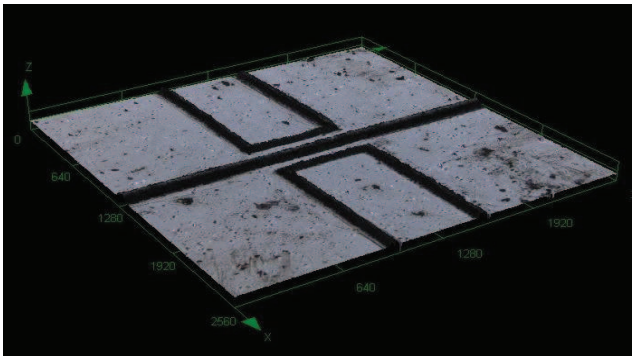

Fig. 2. A laser confocal microscope examination of the detection zone.

2.2. PDMS structure

The microdevice was fabricated in PDMS (Sylgard 184, Dow Corning). The technology is characterized by low cost of obtaining the microdevice without involving expensive special equipment. Furthermore the whole microsystem is performed in about 3 hours. The PDMS prepolymer was prepared by mixing a polymer base and curing agent (weight ratio of 10:1). The mould (Fig. 3a.) was filled with liquid PDMS (Fig. 3c.) and heated in an oven for 2h at 70ºC. After this time the polymerized PDMS structure was peeled off the mould (Fig. 3d.). In many cases, the stamp is not destroyed and can be reused, what is the advantage of the presented technology. Since PDMS is an elastometric material, microchannel inlets and outlets were drilled after the PDMS was cooled down in liquid nitrogen. After the application of liquid nitrogen, the polymer has become hard which facilitates the implementation of holes with smooth internal walls. The diameter of holes (1,35 mm) was matched to the diameter of available tubing supplying the analyte to the microchannel.

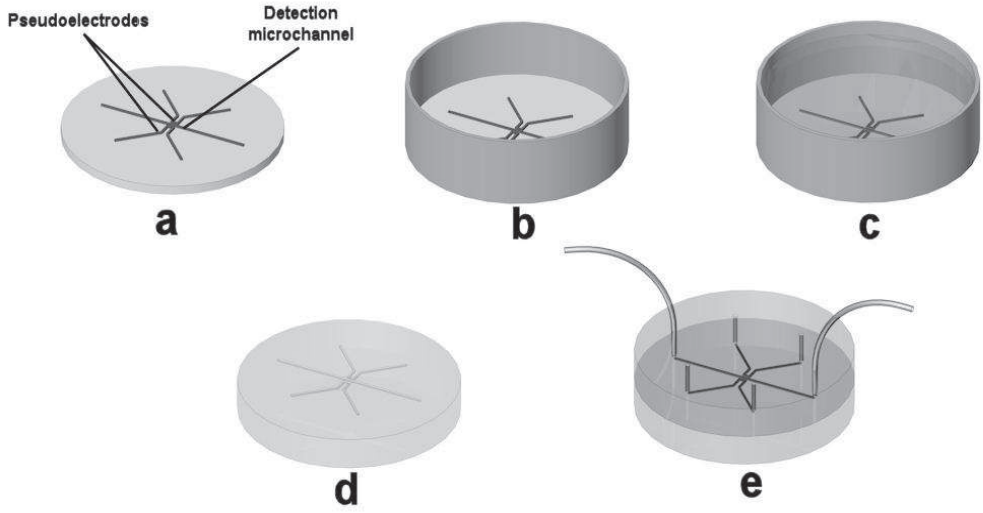

Fig. 3a. The mould obtained in capillary film; 3b. Mould in plastic Petri dish; 3c. Liquid PDMS in the mould; 3d. Microchannels defined in PDMS; 3e. PDMS microfluidic structure after oxygen plasma bonding.

In order to seal the whole microsystem, a flat PDMS slab was prepared. The final microsystem was obtained after plasma bonding of a PDMS plate with microchannels and a flat PDMS slab (Fig. 3e.). Fig. 4 and Fig. 5 depict SEM images (microscope HITACHI TM-1000) of the microchannel before and after oxygen plasma bonding.

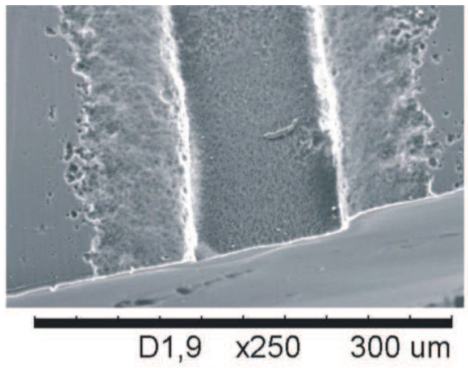

Fig. 4. SEM image of the microchannel in PDMS before bonding.

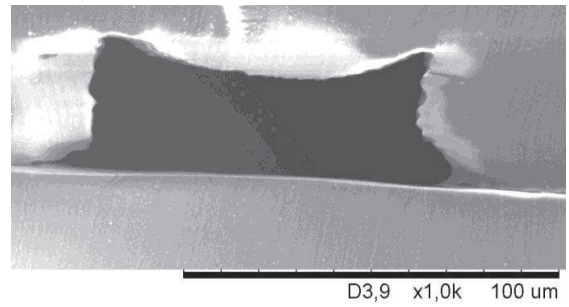

Fig. 5. SEM image of sealed microchannel.

3. Measurements and results

The presented microsystem consists of a detection channel and the pseudoelectrodes (i.e. microchannels with a liquid solution inside) which are placed on both sides of the detection channel. The detection channel and the pseudoelectrodes were manufactured during the same fabrication step, which decreases the cost of the device and shortens the time of production. Pseudoelectrodes were filled with 1M solution of inorganic salt solutions. The connections between pseudoelectrodes and the measuring system were provided by wires immersed in the

electrolyte filling the microchannel. The measurement set-up consisted of a generator, a signal amplifier, a meter and a computer where the results were recorded (Fig.6).

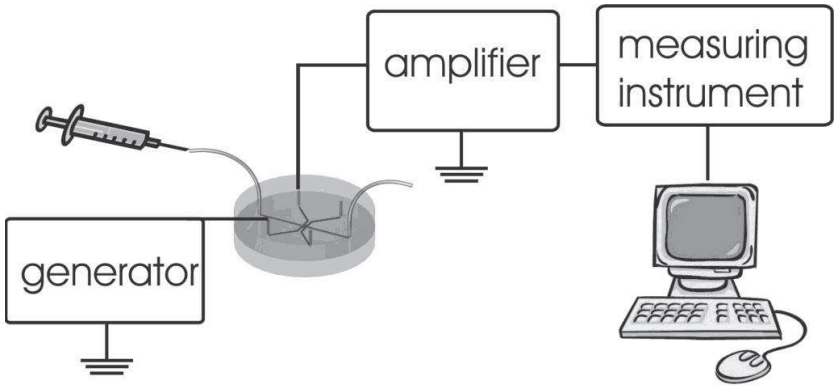

Fig. 6. Scheme of the measurement set-up.

As filling microchannels pseudoelectrode, three different electrolytes were tested for each concentration of 1M. The identified electrolytes were: KCl, $NaNO_3$ and $CuSO_4$. These three electrolytes were chosen because of their high conductivity. Fig. 7 shows a graph of conductivity of the detector, of the time for different concentrations of the analyte and for the three fillings pseudoelectrodes`. The KCl solution was selected for further study due to the greater relative change in signal compared to the other two electrolytes.

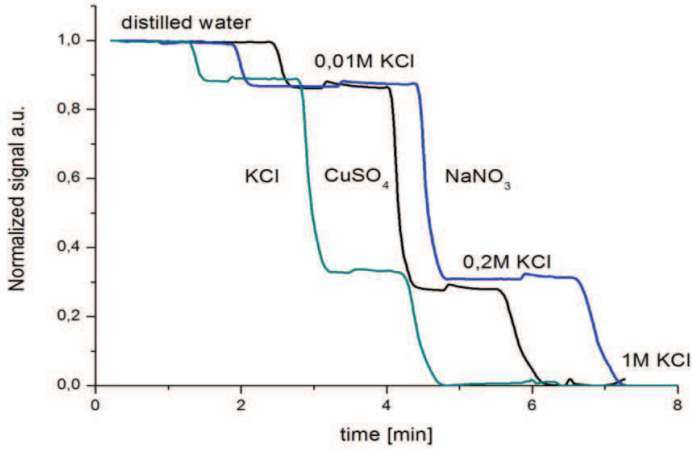

Fig. 7. A graph from different filling inside the pseudoelectrodes` microchannel.

Analyte was pumped into the microchannel using a syringe pump with a flow rate of 50 µL/min. The flow rate was selected experimentally, since a too rapid flow could damage the microdevice, whereas a too slow flow would extend the analysis time. The signal from the measuring instrument was recorded by a computer equipped with software developed in LabView (National Instruments). Fig. 8 shows repeatable changes in the signal.

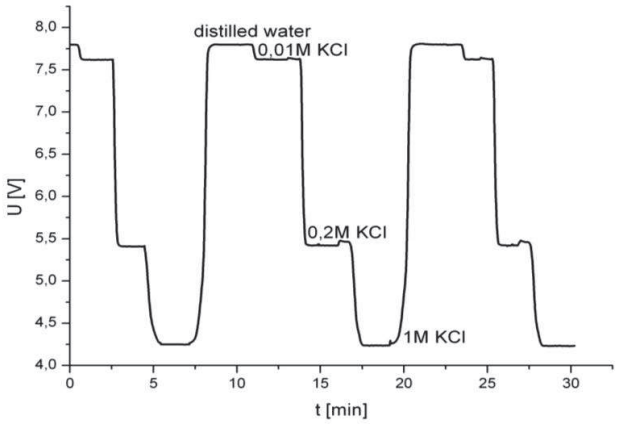

Fig. 8. Graphs from the analysis of KCl solution with use of the presented detector.

After the preliminary tests, a metal layer covering the walls of the pseudoelectrodes was made. A silver layer was fabricated by Tollens' reagent, traditionally used as a method for the detection of compounds as well as the aldehydes suitable for the detection of sugars such as glucose or fructose. In the present study we used this reaction to form a coat of silver; therefore glucose was deliberately added to the previously prepared Tollens` reagent. Despite the silver layer, the detector response in both types of pseudoelectrodes was similar. Fig. 8 shows the result with and without the silver cover.

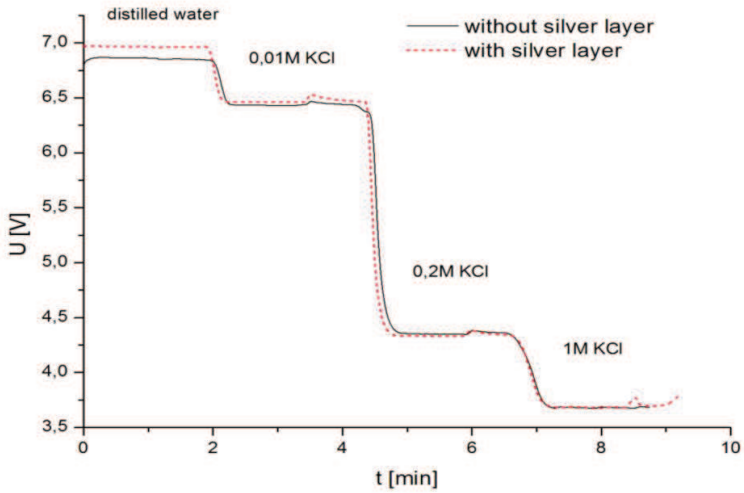

Fig. 9. A graph from analysis with and without a silver layer inside pseudocelctrodes` microchannels.

During the tests, evaporation of the electrolyte solution from pseudoelectrodes` microchannels was observed. This is due to the fact that there was a small volume of the solution filling the pseudoelectrodes. It was decided to seal the inlets with parafilm and as a consequence a better stability of measurement was observed. Furthermore, the graphs show small peaks associated with the change of the syringe with the solution proposed in the future to design the metering valve. Fig. 10 shows the indication of the detector for various solutions of KCl.

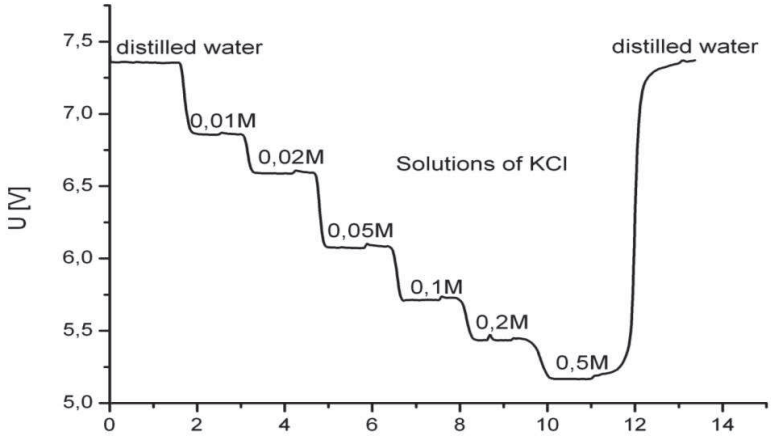

Fig. 10. A graph from different concentrations of the KCl solution.

4. Conclusion

It was demonstrated that contactless conductivity detection with microchannels filled with an electrolyte solution is a good alternative to traditional conductivity detectors. The presented microdevice can be made using other fabrication techniques and other materials. The layout of pseudoelectrodes and the microchannel detection can be easily modified, which opens opportunities for future research and future applications. It is planned to implement the system with four electrodes, which will be placed close to each microchannel wall. It is expected to improve signal detection.

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