Fabrication of a microfluidic channel with differently modified surfaces with a two component approach

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2014 J. Micromech. Microeng. 24 077001
(http://iopscience.iop.org/0960-1317/24/7/077001)

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 129.70.28.248
This content was downloaded on 17/09/2014 at 13:10

Please note that terms and conditions apply.
Technical Note

Fabrication of a microfluidic channel with differently modified surfaces with a two component approach

L Bogunovic, C Vosskötter and D Anselmetti

Experimental Biophysics and applied Nanoscience, Faculty of Physics, Bielefeld University, Universitätsstrasse 25, 33615 Bielefeld, Germany
E-mail: bogunovic@physik.uni-bielefeld.de

Received 7 March 2014, revised 29 April 2014
Accepted for publication 30 April 2014
Published 22 May 2014

Abstract
We report on a two-component fabrication technique for microfluidic channels, allowing for different chemical or physical surface modifications of channel walls within one single channel. The two components are made of polydimethylsiloxane and prepared via soft lithography independently. After appropriate pre-treatment with the desired functions, the two parts are bonded together using oxygen plasma and a Fineplacer® lambda system. As a proof of concept, we present the combination of electroosmosis and opposing hydrodynamic flow in a microfluidic channel leading to different velocity presigns of the resulting flow on opposite channel walls, due to different surface modifications. These results indicate an intact Pluronic® F108 surface coating after assembly.

Keywords: microfluidics, surface modification, electroosmotic flow, PDMS, SU-8, spincoating, hydrodynamics

(Some figures may appear in colour only in the online journal)

1. Introduction

Microfluidic systems usually exhibit an extremely high surface to volume ratio. Therefore the exact shape and, in particular, the chemical or physical modification of a channel surface play a crucial role in controlling the properties of (polydimethylsiloxane (PDMS) based) microfluidic chips, e.g. the electroosmotic flow (EOF), the control of undesired surface adhesion of analytes or the specific attachment of certain molecules to the surface for, e.g., immuno assays [1–7]. So far, modifying surfaces in a microfluidic channel with different functionalities can be a challenging endeavour, as most devices fabricated via, e.g., soft lithography [8], hot embossing [9] or injection molding [10], consist of a one side open channel, that is somehow sealed afterwards with a fourth wall. After assembly, the channel is filled with a solution containing surface modifying molecules, resulting in identical surface modifications for every wall the liquid is in contact with and not a desired subset of walls.

We propose a different fabrication and surface modification procedure, where one sidewall and the channel ceiling are located on one pre-structured and pre-modified PDMS piece and the other sidewall and the channel floor are arranged on a second piece of PDMS. Subsequent aligning and bonding of the two PDMS pieces leads to a microfluidic chip with differently coated and structured opposing walls. Another advantage is the freely changeable channel diameter (within certain boundaries) that can be set without redesigning photomasks, etc.

In this technical note, we will explain the fabrication procedure in detail, which relies very critically on the exact alignment of the two PDMS pieces. We will subsequently demonstrate the functionality of a Pluronic® F108 surface coating on two of the four channel walls after assembly.
microfluidic chips. PDMS slabs are now properly aligned and bonded together resulting in two component B (figure 1). Those two components are fabricated from the first part A and the opposing sidewall and the channel floor on a PDMS (apart from one side of the channel). Therefore our fabrication procedure envisions the assembly of two parts of the channel are moulded into one single piece of PDMS. The two pieces of PDMS are now cut out with a homemade tool, a sharpened 3 cm long slice of a pipe with rectangular cross section to obtain equally sized pieces of PDMS. The two pieces of PDMS are now endued with reservoir holes at the ends of the channels and successively cleaned in acetone, ethanol and deionized water in an ultrasonic bath (figure 1(e)).

2. Fabrication

Different surface modifications of microfluidic channel walls cannot be achieved inside the assembled chip system or with the standard soft lithography procedure, because all relevant parts of the channel are moulded into one single piece of PDMS (apart from one side of the channel). Therefore our fabrication procedure envisions the assembly of two parts where one sidewall and the channel ceiling are located on the first part A and the opposing sidewall and the channel floor on a second part B (figure 1). Those two components are fabricated and surface modified independently and subsequently pre-aligned and properly bonded using a Fineplacer® lambda system developed by Finetech, Germany.

The fabrication procedure (figure 1) begins with pre-cleaning two 4 inch silicon wafers A and B (figure 1(a)) with caroic acid, a 1:3 mixture of high purity hydrogen peroxide and sulphuric acid for at least 20 min. Afterwards, both wafers are thoroughly rinsed with deionized water spindried and heated up to 200 °C for 20 min, removing residual water on the surface. Depending on the desired thickness of the structure SU-8 (2), (5) or (10) is now applied to the wafer and spincoted for 5 s at 500 rpm and for 30 s at a pre-defined speed between 1500 and 3000 rpm according to the manual (for the experiment presented later, we used SU-8 (10) and 3000 rpm to fabricate a 10 μm deep channel). After the pre-bake procedure (40 °C, 60 °C for 5 min and 90 °C for 15 min, ramp rates: 3 °C min⁻¹, 2 °C min⁻¹, 2 °C min⁻¹) two chromium-glass masks are used to control cross linking of the resist with the i-line of a mercury pressure lamp with roughly 140 mJ cm⁻². The samples are post-baked with the same parameters as during the pre-bake and developed in MR-DEV 600 for 30 s, rinsed with acetone and isopropyl alcohol and dried with nitrogen. After an optical inspection under a microscope the wafers are heated up to 200 °C for a few min (hard bake) (figure 1(b)). To detain excessive sticking to the wafer surfaces in later process steps, the wafers are covered with a thin layer of tridecafluoro-1, 1, 2, 2-tetrahydrooctyl-trichlorosilane using chemical vapour deposition (figure 1(c)). A mixture of 20 g PDMS and 2 g of the corresponding curing agent is now cast onto each wafer and cured for 4 h at 85 °C in a drying oven (figure 1(d)). After cooling down, the two PDMS slabs are carefully peeled of the wafers and regions of interest are cut out with a homemade tool, a sharpened 3 cm long slice of a pipe with rectangular cross section to obtain equally sized pieces of PDMS. The two pieces of PDMS are now endued with reservoir holes at the ends of the channels and successively cleaned in acetone, ethanol and deionized water in an ultrasonic bath (figure 1(e)).

The two surfaces can now be treated with e.g. different chemical modifications or differently plasma oxidized depending on the actual application (figure 1(e)). Subsequently, the two parts A and B need to be very precisely aligned and bond onto each other to reproducibly build an actual microfluidic channel (figure 1(f)). This is accomplished by employing a Fineplacer® Lambda system (figure 2(a)). Using Finetech’s vision alignment system, a precise control of the x and y position of the bottom part B as well as the rotation angle of the upper part A is possible by using an internal microscope with an integrated beam-splitting mirror. Figure 2(b) shows both channel components properly aligned before bonding. Subsequently, a lever is used to approach both components and finally bind them together (figure 1(g)). The resulting microfluidic channels (figure 2(c)) have different surface modifications of opposed walls and even freely selectable width (within given boundaries).

The example in figure 2(b) demonstrates two channels with a maximum width of 50 μm and a minimum width of 30 μm. Comparing figures 2(b) and (c) shows no observable shifting of the aligned parts and especially no rotation of part A during bonding which would lead to channels with uneven width. Fabricating smaller channels should in general be possible as the manufacturer of the Fineplacer® system states its precision to be in the order of 500 nm. However,
Figure 2. A precise alignment of the two channel parts before attaching them to each other is crucial for reproducibly fabricating functional microfluidic devices with our technique. (a) Using the Fineplacer® lambda’s ‘vision alignment system’ alignment is visually performed with the help of a beam splitting mirror which merges the images of the bottom part B and the top part A (figure 1(f)) before the bonding takes place. Here, the bottom part is located on a movable stage while the upper part is attached to a lever system and fixed using underpressure. Using precision screws, x and y coordinates of the bottom part as well as the rotation angle of the top part may be adjusted. (b) If parts A and B are properly aligned, the microscope and the camera are shifted aside and the lever is used to bind both PDMS slabs together. Comparing (b) and (c) shows, that an exact preservation of channel geometries is possible during the bonding procedure.

Figure 3. Schematic of the two-component chip system that has been used to demonstrate the functionality of the differently modified surfaces in our experiment. The system consists of two PDMS parts A and B which are bound together according to chapter 2. Part A (ceiling and unstructured sidewall) has been plasma oxidized for 50 s (\(p_{\text{oxygen}} = 10^{-1}\text{mbar}, U_B = 50\text{kV} \atop@500\text{kHz},\text{electrode distance 6.15 cm}\)). Part B was immersed over night in a 500 \(\mu\text{M}\) Pluronic® F108 solution based on 100 mM phosphate buffer with pH 8.2, dried and subsequently plasma oxidized with the same parameters but for only 15 s. Right after the plasma treatment, both components A and B are bond together forming a microchannel that is schematically depicted in figure 4(a). In this context, the plasma oxidation of part B is not desired but necessary to establish stable bonds between parts A and B. Therefore a much lower dose is chosen for part B.

After bonding, the channel is filled with a thin solution of fluorescently labelled microbeads (\(d = 500\text{ nm}\)). These particles were washed in 100 mM NaOH, centrifuged and resuspended into water three times. Subsequently the particles were immersed into the same 500 \(\mu\text{M}\) Pluronic® F108 solution for 1 h to suppress electrophoresis and sticking to the non-coated surfaces during the experiment and resuspended into deionized water afterwards. The microbeads are used as tracer particles and observed using a video fluorescence microscope with a 100 × \(\text{NA}=1.3\) oil immersion objective. Its depth of field is sufficiently low to focus into five different heights within the 10 \(\mu\text{m}\) deep channel, so that 3D flow profiles can be acquired by considering only sharp particles for different computer controlled focal positions.

In the following experiment, we investigated the functionality of the individual surface modifications by observing their influence on EOF [11] in negative x-direction triggered by a voltage of \(U_{\text{dc}} = 30\text{ V}\) along the channel (figure 4(a)). A plasma treatment of PDMS surfaces with our parameters generates surface charge and thus increases the electroosmotic mobility by a factor of 2 [12]. We therefore expect the EOF to be faster near more oxidized surfaces. On the other hand, F108 coatings reduce the electroosmotic mobility up to 86% on PDMS surfaces [12]. The left parts of figures 4(b) and (c) provide a schematic ideal view of the expected EOF conditions in our channel. The channel floor is contributed by part B and is thus F108 coated. The ceiling we note that the elasticity of PDMS must be considered, so that reasonable channel diameters should be possible down to 5 \(\mu\text{m}\) with good reproducibility.

3. Proof of principle and discussion

To demonstrate, that opposing walls still have different surface characteristics after bonding, the microfluidic channel shown in figure 3 was devised. Part A contributes a flat sidewall and the ceiling to the final microchannel. Part B consists of the channel floor and a triangularly structured sidewall. Before assembly, both parts were pre-treated as follows. Part A has been plasma oxidized for 50 s (\(p_{\text{oxygen}} = 10^{-1}\text{mbar}, U_B = 50\text{kV} \atop@500\text{kHz},\text{electrode distance 6.15 cm}\)). Part B was
stems from part A and is only plasma treated. The resulting EOF is thus increasing from the channel floor to the ceiling (figure 4(b)). The structured sidewall was located on part B. Its F108 coating reduces EOF near the structures while it is expected to increase near the flat wall due to its strong plasma oxidation (figure 4(c)).

A hydrodynamic flow (HDF) in positive x-direction triggered by applying $Delta p = 1$ mbar along the channel is now superimposed against the EOF (figure 4(a)). In contrast to EOF, HDF is not dependent on chemical or electrostatic surface modifications but rather on geometric structures like the triangularly structured sidewall. Its typical parabolic flow profile is thus symmetric along the z-axis (figure 4(b)) but strongly asymmetric along the y-axis (figure 4(c)).

When the pressure gradient $Delta p$ and the applied voltage $U_{dc}$ are properly tuned, the superposition of HDF and EOF shows the characteristics in the right parts of figures 4(b) and (c). It is especially expected to be asymmetric in every possible dimension and to include regions, where the effective flow direction changes signs. Note again, that the F108 coating of the particles largely suppresses their electrophoretic mobility, so that the obtained velocity is only influenced by hydrodynamic friction according to the Stokes-law.

Our experimental result is presented in figure 4(d) in form of a flow profile $v_x (y, z)$ within the channel measured by tracking only sharply imaged beads for five different focal positions in $z$-direction. The typical parabola of the HDF is shifted into positive $y$-direction towards the flat sidewall because of the triangular structure. On the other hand, EOF drives the fluid into the negative $x$-direction and thus with negative velocity $v_x (y, z)$. On the channel walls that are modified with F108 (floor and structured sidewall) EOF is largely suppressed which means that the opposing HDF is not much hindered. However on the ceiling and the unstructured rear sidewall, the EOF is not suppressed and therefore reduces or even dominates the HDF. This leads to a reverse flow direction with negative net velocity in these areas whereas the net velocity is positive (HDF dominated) in all other areas. These results show that the F108 modifications of two out of four surfaces in the channel are still functional after the assembly procedure and furthermore, that this approach can be used to transport fluid into different directions within one single microfluidic channel.

This very general principle can be adapted to a wide range of possible applications. One can e.g. envision a microchannel with multiple integrated surface plasmon resonance-sensors with different specificities or separation systems where analyte molecules are transported into opposite directions depending on their position in the $y$, $z$-plane. However, future studies need to reveal the influence of specific functionalization strategies on the adhesion between the two oxidized PDMS components. In disadvantageous configurations, the actuation pressure gradients may possibly disrupt the final device. However, certain formulations may also enhance the binding forces that keep the device together.

4. Conclusions
We showed that it is possible to differently functionalize opposing walls in a microfluidic channel by using a two
component approach. We furthermore demonstrated that surface modifications with F108 remain intact after bonding by creating a stable total asymmetric flow within a microchannel over three dimensions.

Acknowledgment

This work was supported by the German Research Foundation (DFG) within the collaborative research centre SFB 613, subproject D2.

References


