FABRICATION OF NANOCHANNELS WITH PDMS, SILICON AND GLASS WALLS AND SPONTANEOUS FILLING BY CAPILLARY FORCES

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ABSTRACT

Nanochannels provide volumes in the attoliter range, which are attractive for single-molecule detection, dispensing and fundamental studies of the electric double layer. Recently, the first fluidic applications in nm-sized channels were presented [1-3]. The realization of nanochannels for attoliter flow applications requires the study of fabrication, filling, pumping and detection aspects. In this study, we focus on the fabrication of nanochannels in silicon, PDMS and glass, and the spontaneous filling by capillary forces with respect to channel walls having different wetting properties.

Keywords: nanochannels, silicon, PDMS, capillary forces

INTRODUCTION

First experimental results have confirmed electroosmotic flow models predicting a reduced electroosmotic flow when channels dimensions approach the double layer thickness [4-6]. Fluids in the nanometer range also have a high specific interface area affecting the fluorescence lifetime and the viscosity [7]. Moreover, the transition from micro- to nanosized channels is especially challenging when dealing with biological samples such as DNA [8].

Several techniques, such as e-beam lithography (EBL), focused ion beam (FIB) or nanoimprint lithography (NIL), allow the fabrication of nanostructures [7, 8]. Since each material has specific advantages with regard to adsorption, filling, pumping and detection, the fabrication of nanochannels in different materials such as silicon, glass and PDMS was investigated in this study.

The exploration of wetting properties was our primary focus for the filling of nanochannels. The filling speed of a channel is proportional to the capillary forces present. According to Eq 1, capillary forces in rectangular channels depend on the height, width and contact angle to each single wall:

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$$P_c = -\gamma\left(\frac{\cos\Theta_b + \cos\Theta_t}{d} + \frac{\cos\Theta_l + \cos\Theta_r}{w}\right) \qquad (1)$$

where the indices b, t, l, r of the contact angle Θ refer to bottom, top, left and right walls [9]. Since capillary forces in hydrophilic nanochannels may reach a pressure of up to several bars, silicon nanochannels are instantaneously filled [6]. In the case of a combined system made of walls with hydrophilic and hydrophobic wetting properties, the filling becomes critical.

FABRICATION

Using EBL, we have fabricated nanochannels in silicon and PDMS. Nanochannels were written on a PMMA resin by e-beam and transferred into silicon by reactive-ion etching. This technique allows the fabrication of a great variety of channel shapes and configurations as illustrated in Fig. 1A, which shows a Y-shaped junction of two 70-nm-wide channels. Nanochannels in silicon were up to 3 mm long, 135 nm deep and had widths ranging from 200 nm to 1 μm. These channels were sealed with Pyrex coverslips with 1-mm holes serving as reservoirs (Fig. 1B). The spontaneous filling of the nanochannels was observed using a fluorescein solution (Fig. 1C). The fabrication of glass channels using EBL has also shown first promising results.

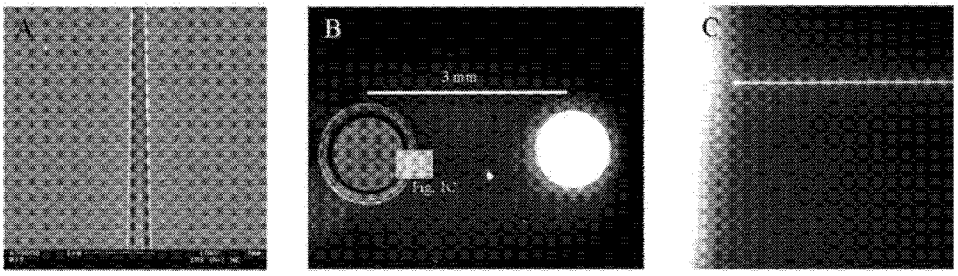

Figure 1. *Nanochannels in silicon: A) A junction of two nanochannels, each of 70-nm width. B) Fluorescein solution delivered into the right reservoir filled the 3-mm-long, 200-nm-deep and 400-nm-wide nanochannel spontaneously, as shown in Fig. 1C. C) Expanded view of the nanochannel in Fig. 1B in silicon filled with fluorescein solution.*

Nanochannels were also formed by replication in PDMS. Two approaches for fabrication of the masters were chosen: 1) Based on a chromium lift-off mask made using e-beam lithography, 100-nm-high and 300-nm-wide molds for nanochannels were transferred into silicon by KOH etching (Fig. 2A). 2) Local depassivation of a hydrogen-terminated silicon surface by means of a focused e-beam allowed the fabrication of

nanomolds down to 135 nm widths. The resulting pattern in silicon oxide was transferred into silicon by KOH etching, as shown in Fig. 2B [5]. Due to the higher exposure times needed to write on hydrogen-terminated silicon, the large inlet and outlet tapers were fabricated using the first approach. The nanomasters were then successfully molded in PDMS as shown in Fig. 2C.

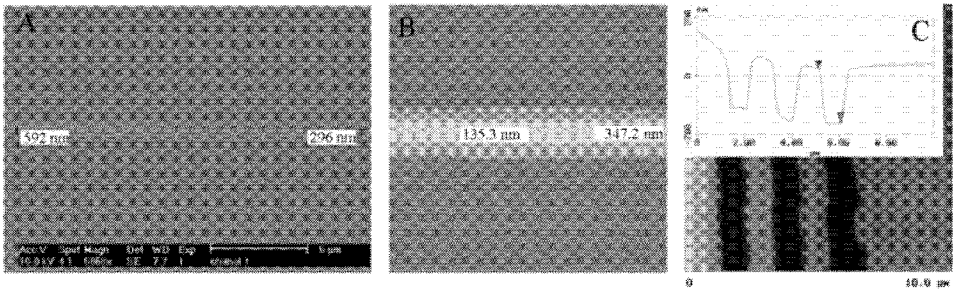

Figure 2. *PDMS-master fabrication and molded PDMS channels: A) E-beam lithography and chrome lift-off were used to produce nanochannels with widths down to 300 nm. This image shows the transition between the inlet taper and the 600-μm-long nanomold. B) 135-nm-wide nanomolds were accomplished by directly writing on hydrogen-terminated silicon. C) AFM micrograph showing three 1-μm-wide, 200-nm-deep channels in PDMS. An AFM profile of the same channels is shown in the inset.*

PDMS is a convenient material because of its fantastic molding properties, transparency, and sealing characteristics. PDMS surfaces, which have rather poor wetting properties, can be hydrophilized in an oxygen plasma. We found that this surface treatment was sufficient to induce spontaneous filling of PDMS with low-μm –dimensions. However, spontaneous filling of nanochannels has not yet been observed. As shown in Fig. 3A-C, filling experiments of 2-cm-long dead-end channels serve as a valuable tool to assess capillary forces in μm-wide, nm-deep channels with walls having different wetting properties (contact angles).

CONCLUSIONS

Nanochannels in silicon, Pyrex and PDMS were fabricated using EBL. The smallest channels were of approximately 200 nm width and height and mm-lengths. Due to capillary forces, the filling of nanochannels in silicon was spontaneously, whereas the filling of nanochannels in PDMS could not be observed yet. The combination of different materials allows simple fabrication methods but include the study of capillary forces in systems with hydrophilic and hydrophobic walls. The study of liquid propulsion through these nanochannels using pressure and EOF is foreseen in the near future.

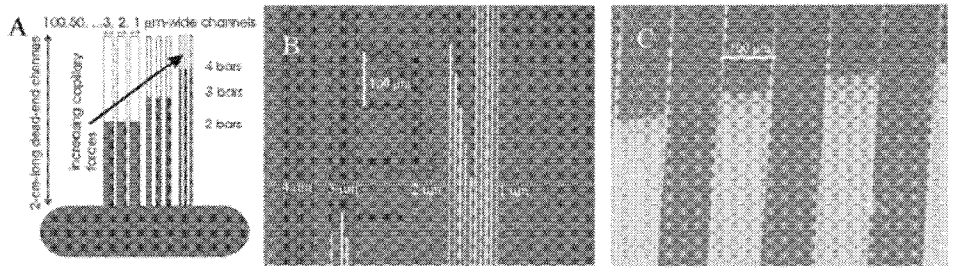

Figure 3. *A simple tool to measure capillarity in combined systems made of glass, silicon and PDMS walls. A) Spontaneous filling of dead-end-channels made in (oxidized) PDMS, glass and silicon was useful to study capillary forces in µm-wide channels with heights from 100 nm to 3 µm. B) This picture shows the different levels of spontaneous filling with a fluorescein solution in 1- to 4-µm-wide and 200-nm-high dead-end channels in silicon covered with a Pyrex coverslip. C) The menisci of PDMS-covered channels in silicon indicated the poor wetting properties of the PDMS wall, whereas the silicon channels were wetted over long distances.*

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