All Polymer, Injection Molded Nanoslits, Fabricated Through Two-Level UV-LIGA Processes

P. F. Østergaard*, M. Matteucci*, R. Marie*, A. Kristensen*, R. Taboryski*†

* DTU Nanotech, Ørsted Plads, Building 345 east,
Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark
† e-mail: rata@nanotech.dtu.dk, phone: +45 4525 2155, fax: +45 4588 7762

ABSTRACT

Introducing double stranded DNA (dsDNA) into confined channels with height and/or width smaller than the radius of gyration of the molecule, forces it to elongate in the channel, as described by the de Gennes theory [1].
Such systems have typically been fabricated in silicon and glass, with the use of electron beam lithography to define the nanofluidic channels.
This article describes, how nano- and microchannels can be transfered from silicon masters to a mass production polymer platform, greatly reducing the price of the system, along with the time used on the individual chip.
Since the systems described in this article are intended to be used with long strand DNA, nanoslits are required, making it necessary to bond low aspect structures in polymer materials. Aspect ratios of 1:200 have been achieved.

Keywords: UV-lithography, injection molding, polymer fabrication, nanoslits

1 MOTIVATION

Rough sequencing of DNA can be performed by melting mapping experiments of elongated DNA, as explained by Reisner et al. [2].
Polymer-based systems intended for such purposes have been fabricated by the use of injection molding [3], but for long strands of DNA, low-aspect ratio nanoslits are preferable to narrow nanochannels, where the DNA can block the channel [4].
Where nanochannels have dimensions in the nanometer scale in both width and height, nanoslits have widths in the micrometer scale, while the height is still in the nanometer scale.
These systems are mostly fabricated in silicon and glass, mostly because of the excelent optical properties of glass, but also because of the rigidity of the materials, assuring that the nanoslit is not occluded due to torsial or strain forces distorting the structure, [5]. In addition, silicon fabrication process knowledge obtained over the last decades has made fabrication of such structures routine on this substrate.
However, even though silicon processing is highly developed, the cost and time used for processing a silicon wafer is still prohibitive in many applications, calling for cheaper and faster alternative fabrication methods.
This can be obtained by moving production over to a polymer-based platform, based on injection molding. Such a transfer requires the processing of a single silicon master wafer, that can be replicated in hundreds to thousands of identical chips by injection molding.

2 FABRICATION

Production of polymer chips in the injection molder requires several preparatory steps, starting with the design and routing of the microfluidic channels, followed by processing of a silicon master wafer in the cleanroom and electroplating of the silicon wafer. Actual fabrication begins with injection molding, and finally bonding of the molded chip with a foil in order to create a sealed system.

2.1 Design

In order to avoid costly electron beam lithography, as used by Utko et. al [3], and instead employ the cheaper, UV lithography, all length scales are chosen to be larger than 1 µm
The proposed design is a two layer design, with one layer defining the nanoslits, and the other layer defining the microchannels leading to the slits, as seen in Fig. 1.
Dark field chromium masks were used for the UV-lithography.

2.2 Cleanroom Work

The initial silicon master is fabricated using standard UV-lithography, and Reactive Ion Etching (RIE). First, an oxide layer is grown on top of the wafer, Fig. 2(a). This has a thickness of 100 nm, which will define the height of the nanoslit. UV-lithography is performed, followed by an oxide specific RIE, Fig. 2(b)+(c). The width of the structures in this step is 20 µm, giving an aspect ratio of 1:200 of the structures. A second UV-lithography step is performed, defining 50 µm wide microchannels, followed by a RIE that goes through the oxide layer and 5 µm into silicon layer, Fig. 2(d)+(e). This ends the process for the silicon master wafer.

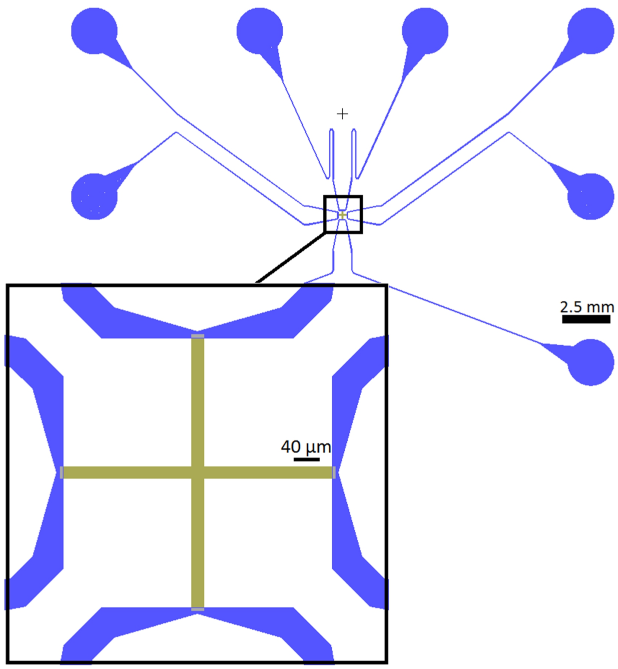


Figure 1: CAD drawing of the proposed design. Microchannels, drawn in blue, lead to the nanoslit, drawn in green. No dimensions on the design are smaller than 20 µm.

2.3 Electroplating

The nickel shim to be used as an insert in the IM, is made by electroplating the silicon wafer. To accomplish this, a 100 nm layer of Ni/V is sputtered on top of the wafer in order to obtain an electrically conductive layer on top of the silicon surface, Fig. 2f). Electroplating is performed until a 300 µm thick nickel layer is obtained, Fig. 2(g). The wafer is removed, either by being lifted off or by being dissolved in KOH, Fig. 2(h).
Finally, the finished nickel-shim is punched out in a dedicated tool, to fit into the injection molder.

2.4 Injection Molding

Injection molding is performed in an ENGEL injection molder, (see Fig. 3(a)) using the COC co-polymer TOPAS 5013L-10 [6]. Molding is performed in a variotherm process, where the polymer is injected into the mold cavity while the mold is maintained at the glass transition temperature (T_g) of the polymer [7]. The mold is then cooled down to 70 °C, the chip is demolded, and transfered to a conveyor belt, see Fig. 3(b).
The mold containing the shim in the injection molder includes standard LUER-fittings that are integrated into all molded parts. This makes it easy to use the finished chips in experimental setups, as no custom fittings are needed between potentiostats, pumps, etc. and the polymer chip, [8].

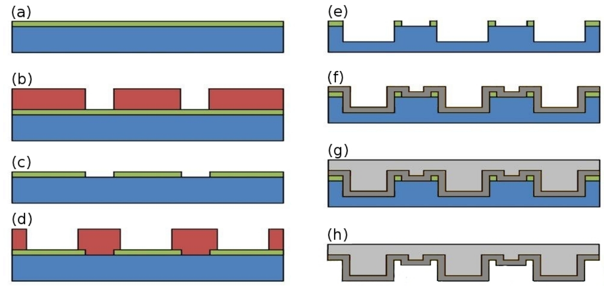


Figure 2: Process flow for the silicon wafer: (a) An oxide layer is grown on top of the silicon wafer. (b) Photoresist is spun on, and UV lithography is performed in order to define the nanoslits. (c) Oxide specific RIE etch is performed. (d) Second level of UV-lithography to define microchannels. (e) RIE etch, etching through first the oxide layer, then into the silicon. (f) Ni/V is sputtered onto the sample. (g) The wafer is electroplated, creating a Ni-shim. (h) The silicon wafer is removed.

2.5 Bonding

To finish the chip, a COC polymer foil of same grade as the polymer used in the injection process, is bonded onto the chip.
To facilitate the bonding, foil and chip are exposed to UV-light for 30 sec prior to bonding. This decreases the glass transition temperature, T_g at the surface, making it possible to bond at lower temperatures, avoiding deformations of the structures in the chip, [9].
The chip is placed in a dedicated holder with the foil on top, with UV-treated surfaces toward each other. A nickel plate with mirror-like finish is placed on top of the foil, and a piece of PDMS is placed on top of this.
The entire stack is placed inside a press, and bonded for 10 min at 115 °C with a pressure of 50 bar, [10].
If 100 chips are made, based on the above mentioned steps, the individual chip has a unit price of $100 USD, roughly 1/10 of the price for a silicon chip produced in a cleanroom.

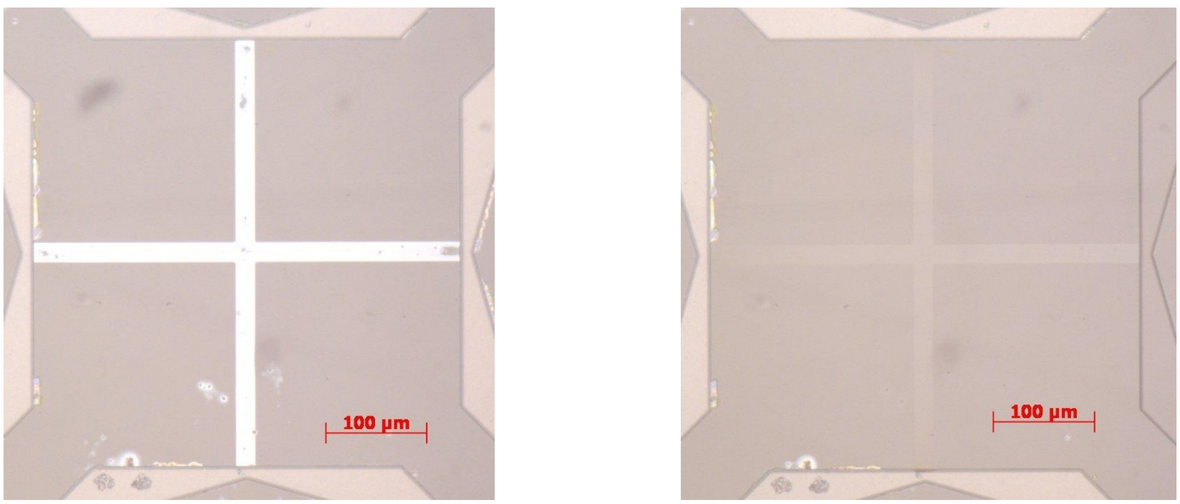
3 TESTING

To verify that the nanoslits have not collapsed during bonding, the chip is placed under a reflective microscope. All the parts of the chip that are not bonded with the foil, i.e. the microchannels and the nanoslits, appear, as shown in Fig. 4(a) because of the difference in refractive index between air and polymer.
In order to confirm that the transition between microchannel and nanoslit is not blocked, the nanoslit can be filled with ethanol, purely by capillary forces. This is seen in Fig. 4(b).

(a) The injection molder.

(b) Molded chips are transported to a conveyor belt for temporary storage.

Figure 3: Injection molding equipment used for fabrication of the fluidic chips.



(a) Empty nanoslit.

(b) Filled nanoslit

Figure 4: When microchannels and nanoslits are filled with ethanol, it is easy to see, that they are not collapsed.

4 RESULTS AND DISCUSSION

We have shown, how structures can be transfered from silicon, where many well-known techniques exist for surface processing, to a cheap polymer platform.
During this work, we were able to fabricate extremely low aspect ratio structures (1:200) in soft materials.
The prospect of making large quantities of microfluidic systems in polymers, in almost the same time it takes to make a single system in silicon, will leave scientists with more time for doing actual experiments, as less time is consumed by cleanroom work.
A reduction by a factor of 10 or more in the cost of the individual system also allows for chips to be considered as disposables. This greatly reduces the chance of cross-contamination between experiments, ultimately increasing experimental validity.

5 ACKNOWLEDGEMENTS

This work is supported by the Danish Council for Strategic Research through the Strategic Research Center PolyNano (grant no. 10-092322/DSF)

REFERENCES

[1] M. Rubinstein, R. H. Colby, "Polymer Physics", Oxford University Press, Oxford, 2003.

[2] W. Reisner et. al, "Single-molecule denaturation mapping of DNA in nanofluidic channels" PNAS, 107 (30), 13294-13299, 2010.

[3] P. Utko et. al, "Injection molded nanofluidic chips: Fabrication method and functional tests using single-molecule DNA experiments", Lab on a Chip, 2, 303-308, 2010.

[4] J. Tang et. al, “Revisiting the Conformation and Dynamics of DNA in Slitlike Confinement”, Macromolecules, 43(17), 7368-7377, 2010

[5] K. Rasmussen et. al, “A device for extraction, manipulation and stretching of DNA from single human chromosomes”, Lab on a Chip, 11(8), 1431-1433, 2011.

[6] T. Nielsen et. al, “Nanoimprint lithography in the cyclic olen copolymer, Topas® , a highly ultraviolet-transparent and chemically resistant thermoplast”, American Vacuum Society, 22(4), 1770-1775, 2004

[7] L. Xie and G. Ziegmann, “A visual mold with variotherm system for weld line study in micro injection molding”, Microsystem Technologies, 14 (6), 809-814, 2008

[8] K. Ø Andresen et. al, “Injection molded chips with integrated conducting polymer electrodes for electroporation of cells”, Journal of Micromechanics and Microengineering, 20 (5), 055010, 2010.

[9] C.-W. Tsao and D. L. DeVoe, “Low temperature bonding of PMMA and COC microfluidic substrates using UV/ozone surface treatment”, Lab on a Chip, 7, 499-505, 2007

[10] M. Matteucci et. al, “A simple model for estimating the delamination pressure in allpolymer microchannels and optimization of bonding strength with a razor blade test”, submitted for publication.