Microfluidics Labs Using Devices Fabricated By Soft-Lithographic Replication of Scotch-Tape Molds

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Abstract

We present the use of Scotch® tape to fabricate microfluidic devices in basic teaching labs of high schools and colleges; this technique is an alternative to using photoresist in a cleanroom. Microfluidic devices, beyond their multiple applications as portable, biomedical, analytical labs on a chip, provide the opportunity to creating fluidic environments dominated by viscous and capillary forces. Those microfluidic environments provide educational opportunities to enlighten the unintuitive effects of fluid flows governed by low Reynolds numbers and capillarity. Often, access to a cleanroom and to conventional technologies of microfabrication is limited in high schools and teaching-intensive colleges. We have developed a technique that allows the fabrication of microfluidic devices using bench top tools only: Scotch® tape, scalpel, 65°C oven, glass slides, commercial uncured silicone—poly(dimethylsiloxane) or PDMS,—and polystyrene Petri dishes (or another suitable container). First we patterned Scotch tape (adhered to a glass slide) with the scalpel. The tape patterns (without the need of any chemical treatment) were then casted in PDMS, yielding microfluidic devices with a height of ~ 60 µm—or multiples of 60 µm, if several layers of tape were stacked. This technology makes it possible to create microfluidic devices with any planar (2D) design that the students can draw on a paper. After the drawing is finished, it takes only 1 hour to fabricate a microfluidic device with the shape of that drawing. We believe that this technique will enable the study of microfluidics in educational settings limited in their access to cleanroom facilities. We present a demonstrator that illustrates the potential of this technique in standard teaching labs.

Introduction

In this paper, we describe a method to fabricate microfluidic devices using only bench-top materials and tools (Scotch® tape, scalpel, 65°C oven, glass slides, commercial uncured silicone—poly(dimethylsiloxane) or PDMS[1],—and polystyrene Petri dishes). We believe that this technique will circumvent the limited access to cleanroom facilities that most high school and colleges have and provide them with a fabrication technique that students can use in standard teaching laboratories. As a demonstrator of the method, we present the fabrication of a microfluidic device consisting of three individually-addressable microchannels.

Microfluidic devices have at least one of their dimensions (height, width, and/or length) smaller than 1 mm. As a result, flow in microfluidic devices is governed by viscous and capillary forces[2-3]. Low Reynolds numbers (corresponding to the dominating role of viscous over inertial forces) are determinant in the swimming mechanisms of microorganisms such as bacteria and algae as well as in the transport of molecules, which occurs by diffusion in the microscale (e.g., exchange of oxygen and carbon dioxide in lungs or the immunological response) and by convection in the macroscale. Capillary forces, which result from the need of fluids to minimize their surface energy at all times, are key in the formation of bubbles and droplets, in the flotation of water striders, or in eggs not adhering to a Teflon® pan. Viscous and capillary forces are basic in our everyday lives and relevant in the design of many commercial products, including fluid dispensers and collectors, energy-harvesting machines, or coatings for longer-lasting furniture and tools. Students of all branches of engineering need to understand and to gain the ability to regulate the flow of fluids under conditions of laminar flow (low Reynolds numbers) and/or high relevance of capillarity. We expect the Scotch-tape-based technique presented here to enable the study of microfluidics in settings that do not have easy access to a cleanroom.

Experimental Design

Our goal in this project was to develop a technique for fabricating microfluidic devices on a benchtop. We based our developments on soft lithography[4], which is the most broadly used technique for fabricating microfluidic devices in academic settings. Simplicity is the main advantage of soft lithography: microfluidic devices result from casting PDMS on a master composed of features with at least one dimension smaller than 1 mm. The micro-featured master is typically made of photoresist, which is patterned using conventional photolithography in a cleanroom. One master can be used for casting PDMS tens to hundreds of times. Access to a cleanroom and to photolithographic equipment, however, is often limited in non-research-intensive settings. To avoid this limitation, we developed a technique to form masters with benchtop materials and tools:

- Glass slides, pre cleaned from Manufacturer (75mm x 50mm x 1mm, Fisher Sci. 12-550-C).
- Scotch tape (3M Scotch® Transparent Tape 600).
- Stainless steel Scalpel or surgical blade with (Feather Safety Razor Co., LTD, Cat. No. 2976#11).
- Polystyrene Petri dish (Fisher Scientific, 100mm x 15mm, Cat. No. 08-757-12).
- Oven or hot plate (to work at 65°C).
- PDMS silicone elastomer base and curing agent (Sylgard 184, Dow Corning).
- Green and red ink (Waterman, south sea blue sr. no. 51060-W7 and red sr. no. 51060-W3)
- Punching/Coring tool made using 18 gauge syringe needle.
- Tweezers.
- Gloves and eye protection glasses. (do not use latex gloves)

Results and Discussion

1. Fabrication of Scotch-tape masters.

First we designed the layout of the master and transferred the chosen design to paper by hand drawing or by printing a computer-generated figure. (Details of the design fabricated here as a demonstrator are shown in Fig. 1). We then attached a strip of Scotch tape to a clean glass slide (Fig. 2A). After positioning the tape-covered slide (tape facing up) over the printed design on a flat surface (Fig. 2B), we cut Scotch tape with a scalpel (or razor blade) following the lines of the design (Fig. 2C) and removed the extra Scotch tape that did not belong to the final design of the master (Fig. 2D).

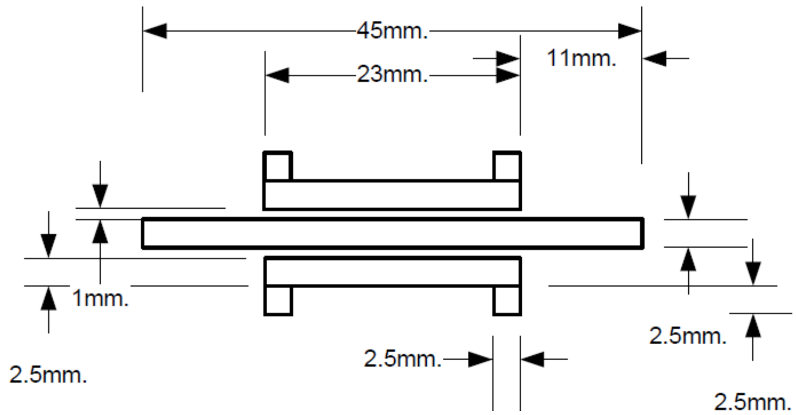

Fig. 1. Layout of the Scotch-tape master. Top view.

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We finished the preparation of the master by placing the glass slide with patterned Scotch tape in a heating oven at 65ºC for 2–3 min. This treatment improves the adhesion of the patterned Scotch tape to the glass substrate and facilitates the separation (later) of the master and the PDMS replica. We determined the conditions of the thermal treatment experimentally. At this point, the Scotch-tape masters were ready to be replicated by casting PDMS and required no additional chemical treatment—such as the silanization procedure required in masters made of photoresist for preventing the adhesion of the PDMS replica to the master.

2. Fabrication of PDMS microfluidic devices by replica molding of Scotch-tape masters.

We placed the glass slide with patterned Scotch tape in a Petri dish (Fig. 3A). We then poured a degassed mixture of PDMS base and curing agent (10:1 wt) into the Petri dish (Fig. 3B) until the master was completely covered by a 2-3 mm-thick layer of PDMS. We allowed PDMS to cure in a convection oven for 1 hour at 65ºC—alternatively, PDMS could be allowed to cure at room temperature for 1-2 days.

The cured PDMS replica was cut with a scalpel (Fig.3C) and peeled off from the master. Then the inlet and outlet ports of the microfluidic device were opened using a coring tool such as a blunt needle or a biopsy puncher (Fig. 3D).

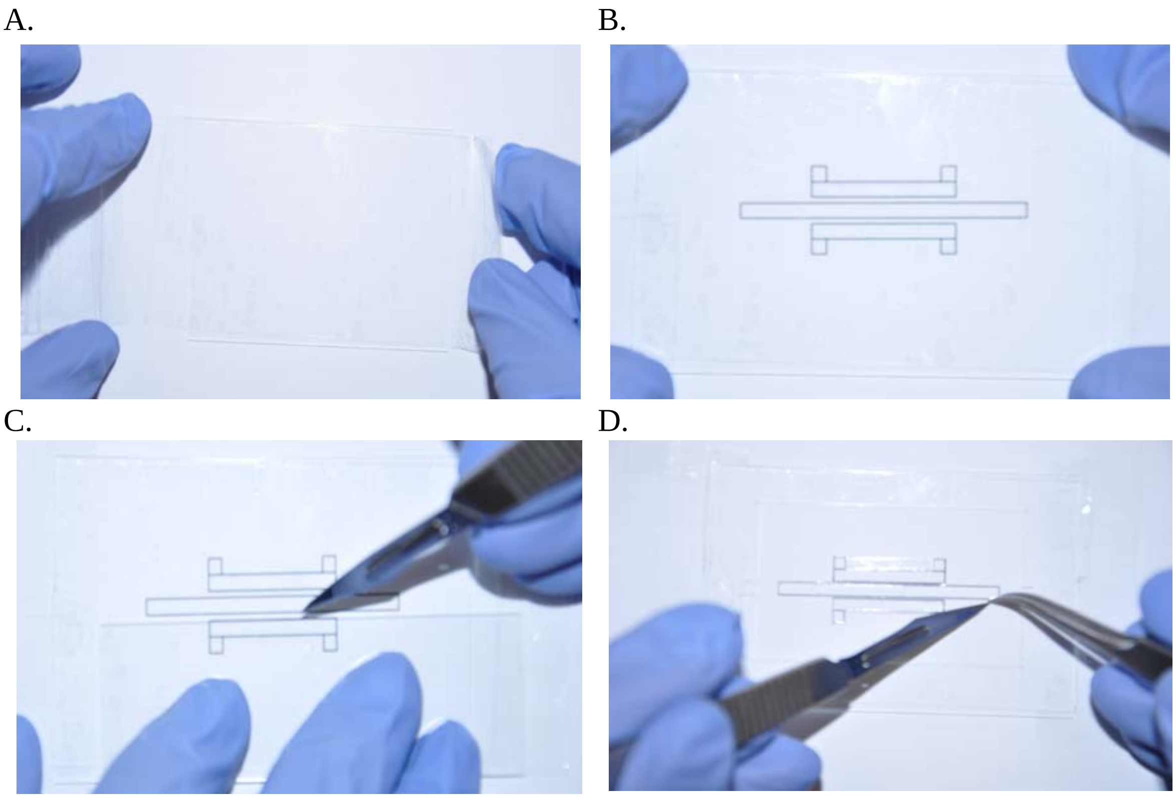

Fig. 2. Preparation of the Scotch® tape master. A) Attach Scotch tape on a glass slide. B) Place the tape-covered glass slide (tape facing up) over the device layout printed on paper. C) Using a scalpel, pattern the Scotch tape according to the master layout. (For easier visualization, a second glass slide was used here as a ruler to guide the movement of the scalpel.) D) Remove the areas of extra Scotch tape.

Fabrication of microfluidic devices ends with the attachment of the PDMS replica (facing down) to a glass slide. Reversible sealing results from the spontaneous adhesion of PDMS to smooth, clean substrates. Alternatively, PDMS and glass can be sealed irreversibly[5] after exposing the two materials to oxygen plasma (Fig. 4A). We used the inlet ports to fill the microchannels with red or blue ink (Fig. 4B) and observed no leakage between adjacent channels.

Conclusions

We have described the fabrication of microfluidic devices by replicating masters with micrometric features made of commercial Scotch® tape. The thickness of the tape (~ 60 µm, according to the supplier[6]) determined the height of the microchannels. For fabricating microfluidic devices with larger heights, several layers of Scotch tape were stacked, resulting in microchannels with heights that are multiples of 60 µm.

This technology makes it possible to create microfluidic devices with planar layouts simply drawn on a paper. Focused on matching the resources found in standard teaching labs, we used a handheld cutting tool (scalpel) to pattern the Scotch-tape master. As a result, the minimal size of the features of the master was limited by the manual skills for patterning the Scotch tape with a blade. We found that channels with planar dimensions (width, length) smaller that 0.25 mm were difficult to cut reproducibly. For masters with smaller features, a laser cutting machine could be used, instead of a scalpel.

This Scotch-tape-based fabrication technique offers a benchtop route for students to explore all stages of the development of microfluidic devices: from the design to the experimental characterization of the device, providing educational opportunities to enlighten the unintuitive effects of fluid flows governed by low Reynolds numbers and capillarity. This method could also be useful to engineers and scientists for rapidly prototyping microfluidic devices.

We believe that the fabrication of operational microfluidic devices using benchtop materials and tools will favor the development of microfluidics labs in educational settings lacking cleanroom facilities. Even for those with access to cleanrooms, the fabrication method presented here provides some major advantages: it is (i) fast—after the layout is printed, it takes only about 1 hour to fabricate a microfluidic device with the chosen layout); (ii) inexpensive—less than $1 per microfluidic device; and (iii) safe—it does not require the use of harmful chemicals or UV light.

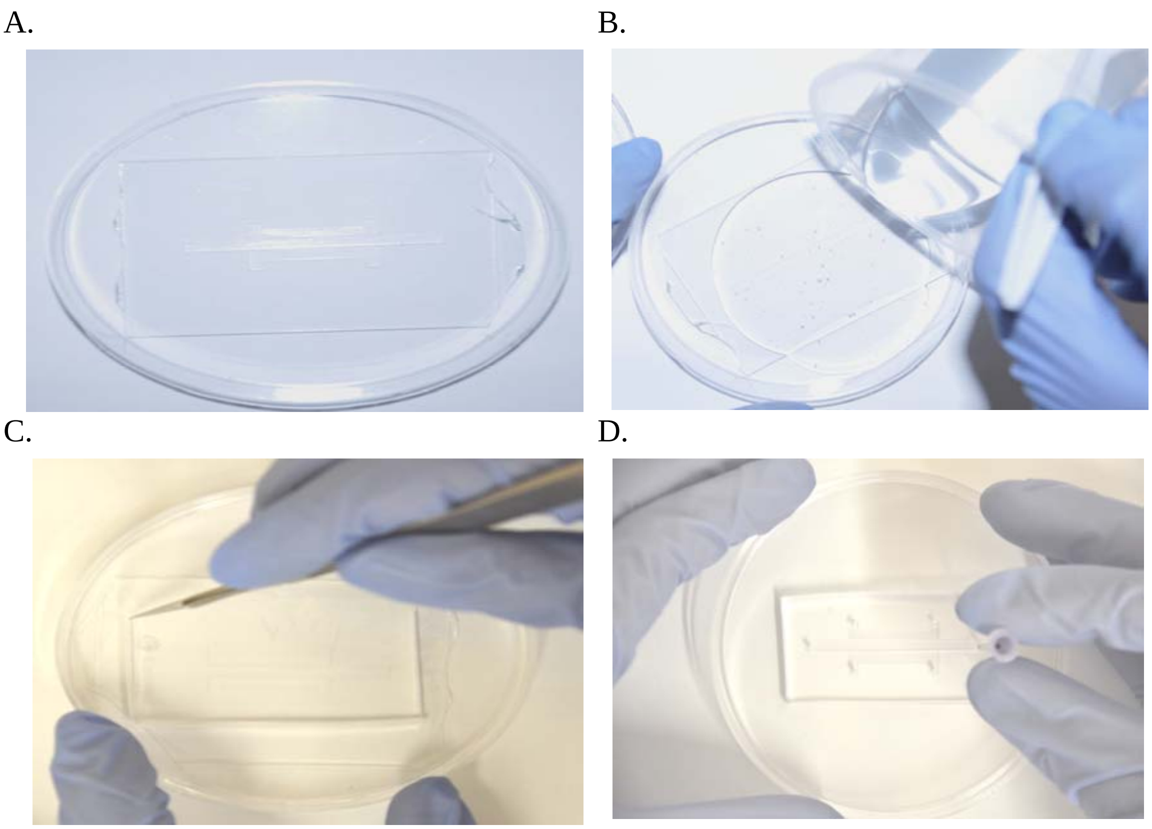

Fig. 3. Fabrication of PDMS microfluidic devices by replica molding of Scotch-tape masters. A) Place the Scotch-tape-and-glass master in a Petri dish. B) Pour degassed PDMS pre-polymer mixture in a Petri dish. C) When cured, cut the edges of the PDMS replica with a scalpel. D) After peeling off the replica from the master, open inlet and outlet ports with a puncher—in this case, we used a blunt syringe needle.

A.

B.

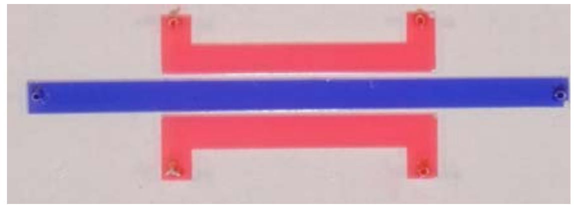

Fig. 4. Test of PDMS microfluidic device fabricated by replica molding of a Scotch-tape master. A) Image of a microfluidic device consisting of three independently-addressable microchannels. B) Microchannels filled with red or blue ink.

Bibliography

1. Dow Corning Product Information, "Information about Dow Corning® brand Silicone Encapsulants," http://www3.dowcorning.com/DataFiles/090007c88020bcca.pdf.
2. E.M. Purcell, *Am. J. Physics*, 1977, 45, 3-11.
3. H.A. Stone, A.D. Stroock, and A. Ajdari, *Annu. Rev. Fluid Mech.*, 2004, 36, 381-411.
4. Y. Xia and G. M. Whitesides, *Annu. Rev. Sci.*, 1998, 28, 153-184.
5. M. K. Chaudhury and G. M. Whitesides, *Langmuir*, 1991, 7, 1013-1025.
6. 3M Scotch® Transparent Tape 600; www.3m.com