MOLDED BIOCOMPATIBLE AND DISPOSABLE PDMS/SU-8 INKJET DISPENSER

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ABSTRACT

This paper reports on the design, fabrication and demonstration of a polydimethylsiloxane (PDMS)/SU-8 inkjet dispenser with the following novel features: (1) the use of low-cost fabrication process and bio-compatible materials, (2) the use of hydrophobic SU-8 micro-nozzles to limit satellite droplet formation, (3) a modular device design that allows for the reuse of the external actuator, (4) the capability of printing hydrogel constructs, (5) a limited cross-contamination risk as the device is disposable, (6) and the potential for integration with other PDMS microfluidic systems. The device successfully dispenses droplets with diameters ranging from 80-130µm at rates of 2-1000 droplets/second.

KEYWORDS: Inkjet printing, Polydimethylsiloxane, SU-8, Disposable

INTRODUCTION

The formation of microfluidic systems out of polydimethylsiloxane (PDMS) is a well-established and widely used technology that easily allows for the integration of different flow control components, such as mixers, pumps, and valves [1]. These integrated microfluidic systems have applications in different fields, including biochemical analysis and cell-based assays. Combining such integrated PDMS-based microfluidic systems, that can manipulate and characterize suspensions, with a biocompatible and disposable inkjet dispensing system enables a broad range of applications that require accurate dispensing and patterning of various materials, such as cells into culture wells. Conventional inkjet dispenser units are reusable [2], and the relatively high cost of each cartridge makes it tempting to use different inks with the same unit. However, this involves a risk of cross-contamination, which may be a significant issue with biological materials.

In this paper, we present a biocompatible and disposable inkjet dispenser, with a modular design, made from PDMS and a photo-curable polymer, SU-8. Our design enables easy integration with other PDMS-based microfluidic systems fabricated using soft-lithography.

DEVICE FABRICATION

The device is comprised of a hydrophobic SU-8 micro-nozzle bonded to a PDMS microfluidic chip and an external piezoelectric stack actuator. The PDMS microfluidic chip was molded using a 3D-printed polymer mold (Figure 1), and then bonded to a molded PDMS cuboid such that the vertical guiding channel (for the actuator) of the cuboid is aligned with the chip's actuation membrane. To fabricate the SU-8 micro-nozzles, 300-400 µm long inward tapered SU-8 pillars on a 1 mm-thick glass substrate were fabricated in a process similar to that in [3] (Figure 2). Then, thin consecutive layers of SU-8 and PDMS were spin coated onto the substrate, improving the adhesion of the pillars to the substrate and filling uneven surface features. An aqueous 2% polyvinyl alcohol (PVA) solution was deposited and dried on the substrate to provide a sacrificial layer, followed by casting and cross-linking of SU-8 to form the inkjet nozzle structure (Figure 3).

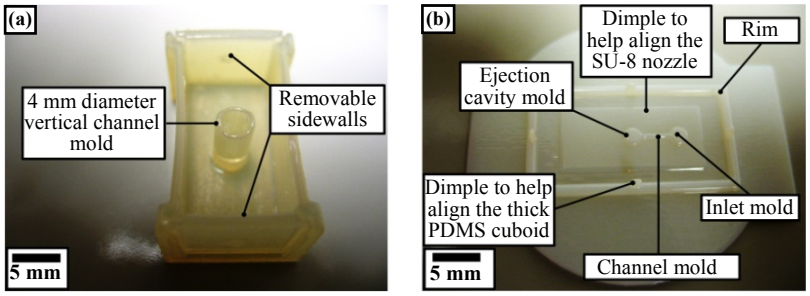

Figure 1: 3D printed molds (using Objet Alaris30/Alaris24 3D printers) to mold (a) a thick PDMS cuboid with a 4 mm-diameter vertical channel and (b) a PDMS microfluidic chip with chambers and a horizontal channel.

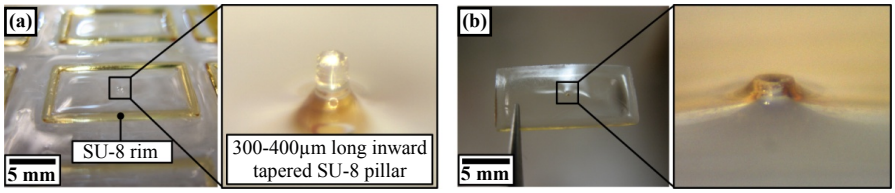

Figure 2: (a) The fabricated SU-8 mold with a close-up showing an SU-8 pillar, and (b) the fabricated SU-8 nozzle with a close-up showing the orifice.

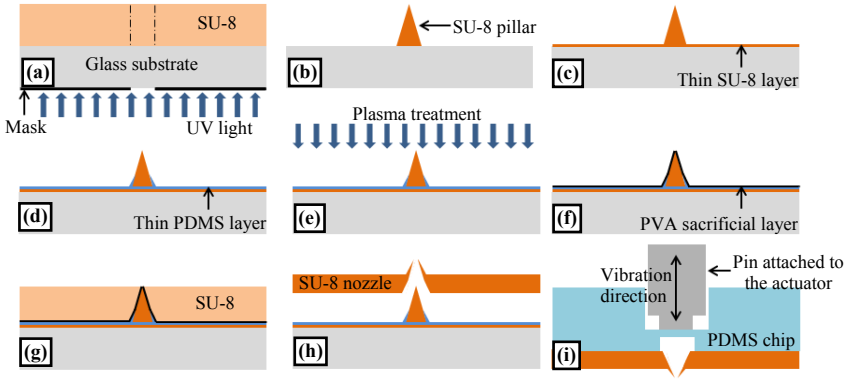

Figure 3: Cross-sectional view of the fabrication process steps for the disposable microfluidic and inkjet nozzle assembly: (a) SU-8 film is spin-coated and exposed through a mask; (b) the SU-8 film is developed leaving the SU-8 pillar; (c) a thin layer of SU-8 is spin-coated and cross-linked; (d) a thin layer of PDMS is spin-coated and cured; (e) plasma treatment improves the wettability; (f) PVA dissolved in water is cast and water evaporation leaves a thin sacrificial film of PVA; (g) SU-8 is cast onto the substrate and then cross-linked to form the nozzle; (h) the sacrificial layer of PVA is dissolved and the nozzle is peeled off; (i) a PDMS microfluidic chip is bonded to the SU-8 nozzle after PDMS treatment with nitrogen plasma.

The PDMS component was then bonded to the SU-8 nozzle at an elevated temperature (~150^{o} C) after PDMS treatment with nitrogen plasma using a process similar to that in [4] to form a complete device (Figure 4). To actuate the membrane, a plastic pin attached to the piezoelectric stack actuator was brought into contact with the PDMS membrane and guided by the vertical channel in the PDMS cuboid.

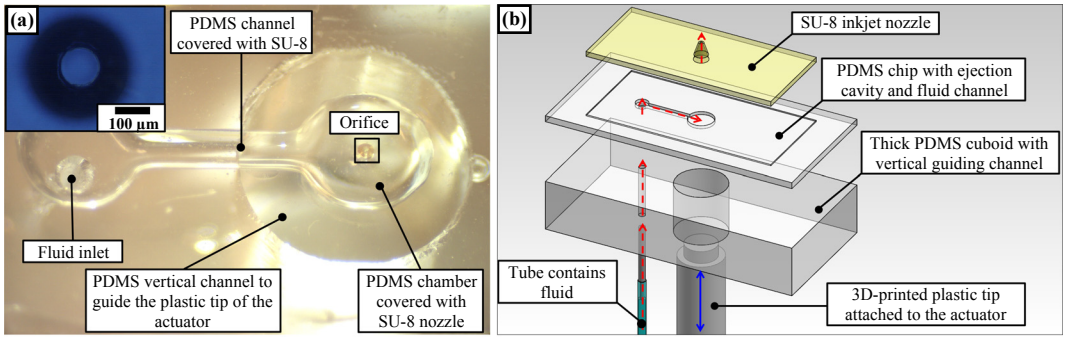

Figure 4: (a) A complete fabricated inkjet dispenser, inset: nozzle orifice, and (b) a 3D drawing of the device layers. The red dashed arrows show the fluid flow direction and the blue solid arrow shows the tip vibration direction.

RESULTS AND DISCUSSIONS

To visualize droplet formation, a stroboscopic imaging system comprised of a light emitting diode (LED) synchronized with a CMOS camera was used. The delay times for the CMOS camera and LED relative to the waveform applied to the piezoelectric stack actuator were controlled by a computer to observe the different droplet formation stages. In order to print arbitrary patterns, the device was mounted on a computer-controlled XY-stage. The experimental setup and droplet formation sequence from our device is shown in Figure 5.

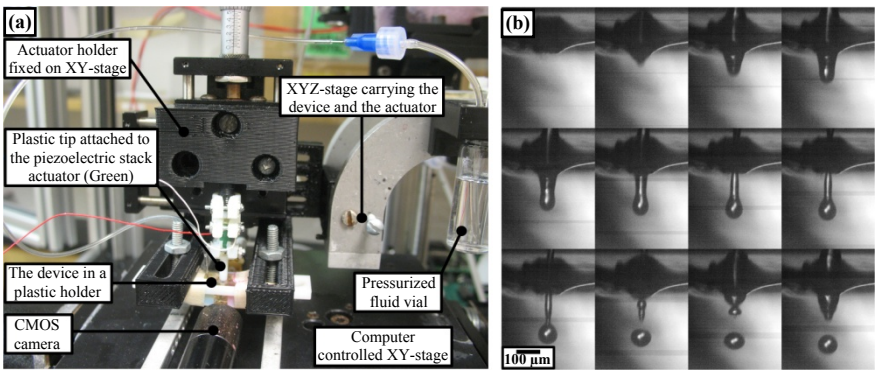

Figure 5: (a) Experimental setup showing a CMOS camera synchronized with the applied waveform, to monitor the droplet formation. (b) A sequence of stroboscopic images demonstrating droplet formation at 100 droplets/second using a double-positive peak waveform.

In order to print complex 3D hydrogel constructs for biological applications such as drug testing, the dispenser must be capable of printing hydrogel without satellite droplet formation. To demonstrate this, an aqueous 2% low viscosity alginate solution was printed, forming a gelled fiber (Figure 6a, b). Also, a "UBC" pattern was printed to demonstrate the device's capability to print arbitrary patterns without satellite droplets.

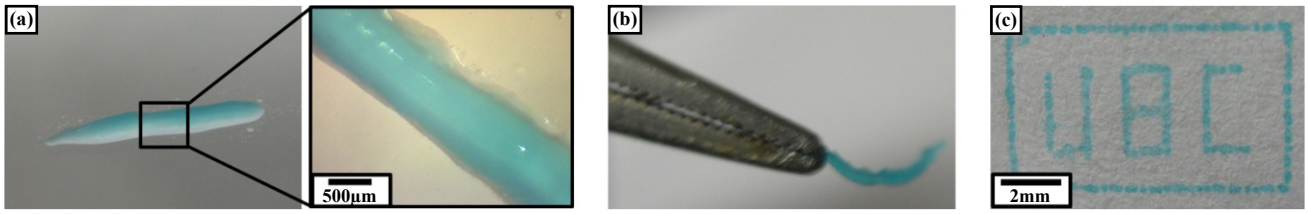

Figure 6: (a) A printed alginate fiber. The structure is sprayed with $CaCl_2$ solution after printing every other layer to gel the material. (b) A tweezer holding the fiber, showing that it is gelled. (c) A "UBC" pattern printed on paper showing that there are no satellite droplets. Blue food color is used to dye the alginate.

Though a disposable inkjet dispenser was reported in [2], it required laminar sheath flow to supply the fluid to the nozzle without any leakage. Furthermore, a glass plate was bonded to the PDMS membrane to increase its rigidity in order to control the droplet generation. The device reported here has the advantage of not requiring sheath flow or bonding to a glass plate. Additionally, the device reported in [2] can print only up to 10 droplets/second with droplet diameters in the range of 95-105 µm, whereas this device can print at rates of 2-1000 droplets/second with droplet diameters in the range of 80-130 µm, depending on the orifice diameter and the applied waveform. In other work, a dispenser chip called CellJet has been reported [5]; unlike the dispenser in [5], we create hydraulic access holes by simply punching through the PDMS rather than deep HF etching. Moreover, our fabrication process has the advantage over the devices in [2, 5] that it does not require any photolithography, with one exception in the fabrication of the reusable SU-8 molds for the nozzles. In addition to the fabrication advantages, the ejection nozzle proposed here consists of a hydrophobic polymer, which we have found to be advantageous in droplet breakup and in preventing ink accumulation on the tip.

CONCLUSIONS

In this paper, we presented an inkjet dispenser and demonstrated its capability of printing hydrogel structures and arbitrary patterns. The device is designed and fabricated to allow for the integration with other PDMS microfluidic modules, is based on low-cost materials and fabrication processes allowing for it to be disposed after use, and allows for the use of reusable external actuators. This technology has the potential for printing more complex 3D hydrogel structures that include living cells, and it can be used for printing multiple materials. These capabilities make this technology suitable for applications such as drug testing and other biochemical analysis and cell-based assays.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the Natural Sciences and Engineering Research Council (NSERC) of Canada and the partial support from CMC Microsystems. We acknowledge travel support from the Institute for Computing, Information and Cognitive Systems (ICICS) at UBC. The authors also thank Karen Cheung for the helpful discussions.

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