RAPID PROTOTYPING OF MESO-SCALE FLUIDIC DEVICES AND MASTERS FOR PDMS MOLDING

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We describe a new and simple fabrication method that enables inexpensive and rapid prototyping of meso-scale fluidic systems and interconnect structures between micro- and meso-scale fluidic devices. Devices and systems are designed using simple CAD software and printed in a few minutes using an inexpensive MakerBot 3D printer. Printed structures are used directly or as a master for molding of polydimethylsiloxane (PDMS) structures via soft lithography. Using this method, input and output ports, and interfaces to a meso-scale fluidic board or between meso-scale fluidic components, can be placed with high geometric versatility. Our method offers a cost-effective alternative to prototyping of meso-fluidic systems using conventional microfabrication, or using injection-molding/conventional machining of polymers. This paper introduces the MakerBot 3D printer for prototyping of meso-scale fluidic structures and shows a demonstration of interconnect between MakerBot-printed and PDMS structures. Initial results show that the cylinder and hole interconnect structures result in a reversible mechanical and fluidic bond.

INTRODUCTION

Microfluidics is the science of moving, mixing, separating or otherwise processing small volumes (typically less than 1 µl) of fluid using microfluidic channels whose dimensions are most easily measure in micrometers. Microfluidics has been a very successful tool for development of portable diagnostics and lab-on-a-chip (LOC) systems. However, often somewhat larger fluidic systems, called meso-scale fluidic systems, are required in order to have enough samples in which to perform tests. Furthermore, both meso- and micro- fluidic systems require methods to easily prototype and hook together components that may be fabricated and optimized using different materials (silicon, glass, polymers) and fabrication processes. Such prototyping allows development of fluidic systems that can be attached using standardized interconnect structures, thus facilitating prototyping of micro- and meso- scale fluidic systems [1].

There are currently a wide variety of methods for prototyping of micro/mesofluidic systems. The most common methods involve a lack of any standardized interface and the development of interfaces as needed during system development. Other methods may be expensive or time consuming at the prototyping stage compared to our method. LabSmith Inc., has developed micro/mesofluidic prototyping kits, but their price ranges are in the 40 to 150€ range [2]. Other methods involve microfluidic boards, chip-to-chip interconnection between microchannel containing components in disparate materials, or other methods based on microfabrication [1], [3], [4], and [5]. For most interconnect packages in microfluidics, silicon, SU-8 photopolymer, glass, polydimethylsiloxane (PDMS), or other polymer platforms are typically employed. Such micro/mesofluidic chips may have integrated interconnect structures that are also developed in the same materials to directly connect to other chips or to a prototyping board. In the case of silicon and glass, or injection molded/embossed polymers, these interfaces can be expensive and time consuming to make at the prototyping stage. Furthermore, while commercial micro/mesofluidic kits are available, the geometry of the packages, and placement of input/output ports for each component, are limited [2], [6].

We report for the first time in this paper a new method of prototyping mesofluidic devices and interconnect packages for use between meso-scale channel-containing substrates and microfluidic chips. We also report on a method of molding PDMS structures using 3D-printed polymers as a master mold. The interconnect packages that we have developed could be employed to interconnect silicon, SU-8, glass, PDMS, or other polymer microfluidic chips to meso-scale fluidic board structures for prototyping. Using our method, input and output ports, and interfaces to a meso-scale fluidic board or between meso-scale fluidic components, can be placed with less geometric constraint.

Our prototyped structures and master molds were developed in the polymer Acrylonitrile Butadiene Styrene (ABS) using the MakerBot 3D printer [7]. While 3D printing of fluidic structures has been demonstrated by other researchers [8], most 3D printers are of relatively high cost compared to the MakerBot (which costs less than $3000). Our method offers a cost-effective, rapid alternative to prototyping of meso-fluidic systems using expensive 3D printers. Our method also offers an alternative to conventional microfabrication, or injection-molding/conventional machining of polymers, for prototyping purposes.

As a first demonstration of our ability to rapidly prototype mesofluidic systems and standardized micro/mesofluidic interfaces using the inexpensive, rapid MakerBot 3D printer, we present mechanical and fluidic interconnects based on interlocking cylinder-in-hole structures. One half of an interconnect structure consists of a cylinder fabricated by the MakerBot printer in ABS. Cylinder structures are mated to PDMS holes fabricated via soft lithography molding against 3D printed masters. The initial results presented in this paper are promising, and show that the PDMS and ABS chips can be attached, resulting in a reversible mechanical and fluidic bond.

DESIGN AND FABRICATION

CAD Design Details

The designs for the meso-scale fluidics and interconnect structures were created in a CAD program called SketchUp [9]. SketchUp is a 3D modeling program for architects, civil and mechanical engineers, film and video game makers, but has also been adapted for use in 3D printing via, eg., MakerBot. First, the simple case of interconnection was created using SketchUp. Figures 1 and 2 show the designs of the cylinders and molds for PDMS holes for a single cylinder-in-hole interconnect. Figures 3 and 4 show designs for a package containing a 2 by 3 array of interconnect structures. In order for MakerBot to read the file from SketchUp, the files were exported from .skp file format to 3D models in .STL or .obj. Once this was accomplished, the MakerBot was employed to print the interconnect cylinders and molds for PDMS soft lithography.


Figure 1. The 3D CAD design of a master for PDMS molding with single hole interconnect.


Figure 2. The 3D CAD design for single cylindrical interconnect in ABS.


Figure 3. 3D CAD design of master for PDMS with 2X3 hole interconnects.


Figure 4. 3D CAD design with 2X3 cylindrical ABS interconnects.

MakerBot Printing Details

A MakerBot Replicator (model 2X) was employed for fabrication of all structures and molds. The 2X model is intended to work in a build envelope (285 mm x 153 mm) and has a printing rate of 100 μm per layer. It has an enclosed build area, dual-extruder support, and the ability to print with ABS plastic, PLA, Flexible, and Dissolvable filaments [7]. The most common filaments are ABS plastic or PLA natural filaments. A PLA filament is a renewable bio-plastic made from corn. However, ABS filaments are good for detailed prints and can be used in conjunction with the MakerBot dissolvable filament. The dissolvable filament acts as a solid infill material. The ABS filament was used to obtain all results presented in this paper [7].

After designing each component in SketchUp, the design was exported to a .thing file by MakerWare BETA software [10], which is a visual platform of MakerBot. The scale and position of the design was also set in MakerWare software before printing.

ABS plastic was chosen for the interconnect packages and for the master for molding of PDMS structures. ABS is very inexpensive, costing $48 ($US) per 1 kg roll [7]. Figures 5, 6, and 7 show the printed results of the MakerBot designs for both directly printed ABS cylinders, and ABS molds for making PDMS mating hole structures. Each of these designs took around 15 minutes to complete depending on their size.

Figure 5. Photographs of printed interconnect (left) and mold (right) by MakerBot. The width and length of the chips are 10mm and 25mm, respectively. The inner and outer cylinder diameters are 1mm and 3mm, respectively.

Figure 6. Photograph of printed interconnect mold by MakerBot ready for PDMS molding. The width and length of the chip are 20mm and 30mm, respectively. The inner and outer cylinder diameters are 1mm and 2mm, respectively.

Figure 7. Photograph of printed interconnect by MakerBot. The width and length are 20mm and 30mm, respectively. The inner and outer cylinder diameters are 1mm and 2mm, respectively.

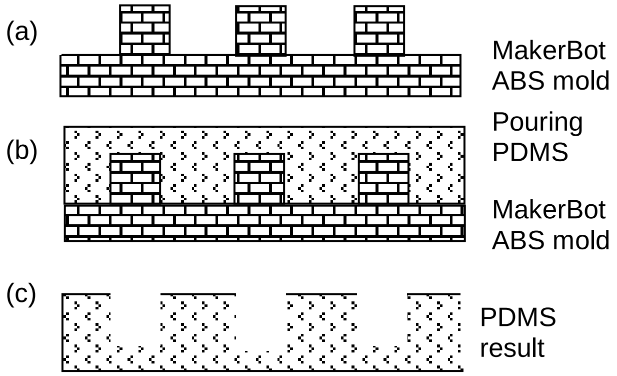

Figure 8. Fabrication process for PDMS interconnects. Note the darker shades denote the MakerBot mold and brighter shades denote the PDMS which is cured and peeled from mold. The process consists of: (a) MakerBot mold; next the PDMS mixture is poured into mold (b) and cured; then in (c) the PDMS is peeled from mold master.

Molding of PDMS using MakerBot ABS masters

A 10:1 ratio of PDMS pre-polymer and curing agent was prepared and stirred for roughly 5 min. Bubbles were removed by placing the mixture into a vacuum chamber. Next, the mixture was poured into the ABS masters that were previously printed using the MakerBot, and cured for 30 min at 70 ºC. After curing, the PDMS structures were peeled from the masters. This fabrication process is shown in Figure 8.

EXPERIMENTAL RESULTS

Figures 9 and 10 show the resulting PDMS parts. The inset of Figure 9 also shows a microscopic photograph of a PDMS hole interconnected to an ABS cylinder under microscope.

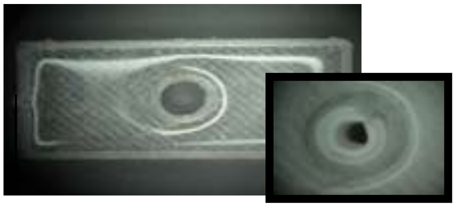

Figure 9. Image of single PDMS hole interconnect. The inset shows a closer look at its connection with ABS interconnect structure (ABS cylinder in PDMS hole), with inner and outer cylinder diameter of 1mm and 2 mm, respectively.

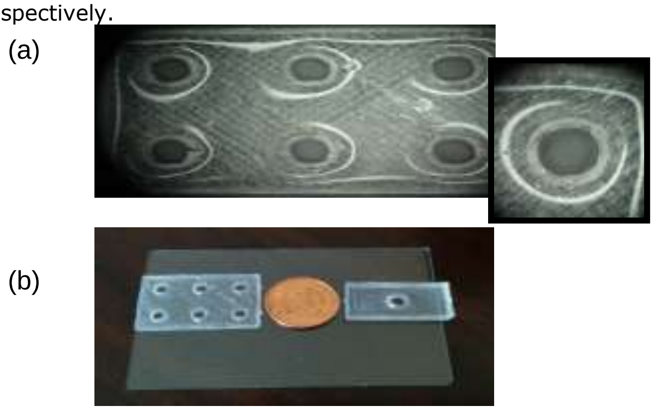

Figure 10. (a) Microscopic image of 2 by 3 PDMS interconnects; the inset shows a closer image of a hole structure. The hole has a diameter of 2 mm. (b) Photograph of PDMS holes that were molded against MakerBot ABS masters with penny for size comparison.

The PDMS holes and MakerBot cylinder interconnects were assembled manually for testing. Testing consisted of lifting the entire assembly up only by the PDMS part to test that it did not separate from the ABS part during manual manipulation. In the future, weights will be used to determine the interconnect disassembly force [11]. In addition, silicone tubes were connected to the ABS interconnects structures and fluid (mixture of dye and water) flowed into the ASB part to demonstrate the mesofluidic capabilities of the MakerBot-printed structures. Figure 11 shows the connection and fluid flow facilitated by the tight connections between the MakerBot cylindrical structures and the PDMS holes. Figure 12 shows a photograph of the connection between the silicone tubes and the ABS structure with the PDMS.

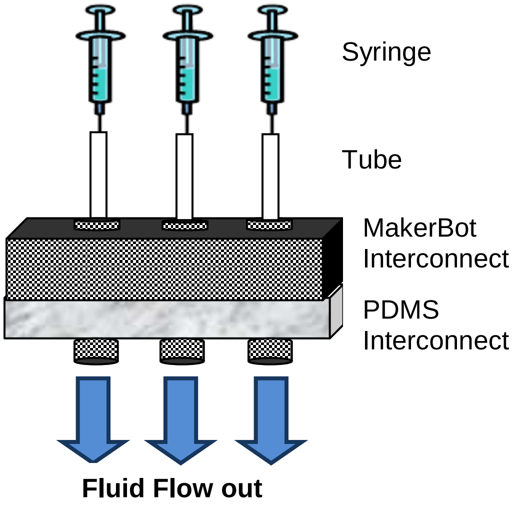

Figure 11. Diagram of interlocking mechanical structures, showing assembly and interconnect between MakerBot-printed ABS cylinder and PDMS hole structures. This diagram also shows the testing method showing fluid flow into the MakerBot-printed structure.

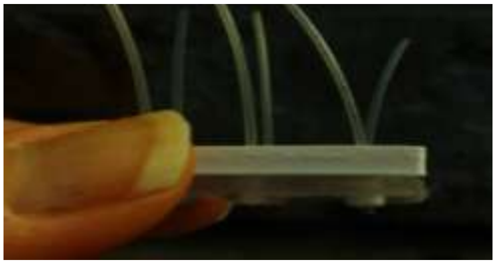

Figure 12. Photographs of fabricated interconnects with silicone tubing showing fluid flow through the cylinder-in-hole interconnects.

CONCLUSION

We have introduced a new very low cost, rapid method to fabricate meso-scale fluidic structures and packages for micro/mesofluidics. Our method is based on rapid prototyping of structures and mold masters using an inexpensive, tabletop, moderate resolution (100 μm) 3D printing device. The entire fabrication process, from designing in CAD software to printing with MakerBot, plus soft lithography for PDMS, took less than an hour. In addition, the mesofluidic capability of the ABS structures and PDMS were tested. In the future, weights will be used to determine the interconnect disassembly force and maximum pressurization tests [1] will be used to better characterize the interconnect structures.

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