Rotary Fluidic Feed-through Device for Use in Microfluidics

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BRIEF. The fabrication of a novel microfluidic device for use in centrifugal microfluidics.

ABSTRACT. Microfluidics is an emerging field in science that deals with the precise control of fluids and cells at the micro scale through the use of specially engineered devices. These devices have a wide array of functions applicable in laboratory and clinical setting. In order to operate these devices, most microfluidics depend on an exterior pressure source; however these system tend to be bulky and expensive. This study addresses a drawback found in an alternative pressure system, centrifugal microfluidics, which is limited by its lack of media flow through. A device was fabricated to transfer fluid from a rotating to stationary channel. When the design was tested, it was ineffective at transferring adequate volumes of fluid. However, knowledge gained from this study will allow a future fully operating device to exist.

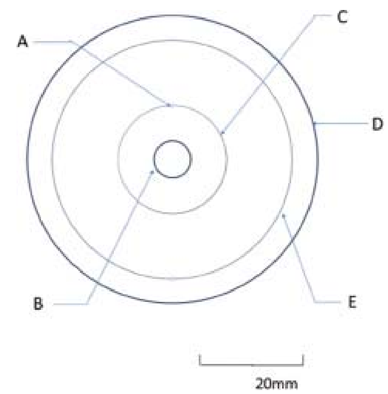

Figure 1. The AutoCAD of RFF device face. The second and third inner circles (with diameters 60mm and 15mm) are the devices circular channels intended to allow fluid passage during a full rotation. Channels are 150 microns wide and have input and output ports of 800 microns. Dimensions for design as labeled A-E are 800μm (output/input port not visible), 10mm, 28.4mm, 75mm, and 64.2mm.

INTRODUCTION.

Rapid, reliable disease detection using minimal resources has always been a desired goal in the clinical and research settings. However, this task is difficult. For, in order to study structures as minute as cells and bacteria, very precise instrumentation must be used. Microfluidic devices are engineered to handle extremely small samples with extreme accuracy, making them ideal candidates for the clinic or biomedical research. The devices, however, require the fluid and cell samples to be passed through the device with high precision in order to function.

Today, various technologies exist to provide devices with pressure, each acting to transfer and circulate fluids and suspended cells through a device at rates of the highest precision possible. The fluid movement within the device occurs in extremely miniscule volumes of microliters or even nanoliters ($10x10^{-6}$ ml). To achieve this accurate fluid movement in microfluidics there are several methods currently in use.

Of the most frequent usage today are the mechanisms incorporating syringes or peristaltic pumps to perform fluid movement; yet such devices are generally rather bulky and expensive. Other popular technologies such as acoustic pressure (a method making use of ultrasonic frequencies to exert force on a fluid) and electro kinetic (makes use of electroosmosis to generate pressure on electrolyte solutions) However these technologies suffer from similar disadvantages as syringes and peristaltic pumps [1].

However a fairly recent technology, centrifugal microfluidics, has presented itself as potentially more effective than conventional methods, as low production costs and small size are some of its key advantages. Incorporating forces similar to those used to dry fabrics in a dryer, centrifugal microfluidic devices use outward centrifugal force during rotation to provide pressure; thus allowing the device itself to act as the pump.

The following paper details the process used to fabricate the device described, the procedure used to test the device, and the resulting performance of the device.

MATERIALS AND METHODS.

AutoCAD Sketch.

The design of the Rotary Fluidic Feed-Through device (RFF) was first conceived in AutoCad 2011 (Figure 1). The design's features were then printed on a Mylar Mask, a polyester film that reflects Ultraviolet (UV) light. The features on the film are seen as gaps in the Mylar, serving to permit UV light to pass through during the process of photolithography.

Photolithography.

Photolithography is a technique commonly used in the design of the microfluidic devices. It is used to create a template for the device (process shown in Figure 2). In photolithography, a liquid substance, called photoresist, is poured onto a flat surface and then is exposed to UV light. The UV light initiates certain chemical reactions in the photoresist which effectively solidify it where exposed. If this process is controlled, such as through the use of the UV reflective Mylar mask, exposure can be made to only certain areas of the photoresist. It is through these means that we etched the raised features of our design on a photoresist template, creating a master for soft lithography used later in the study to fabricate the device.

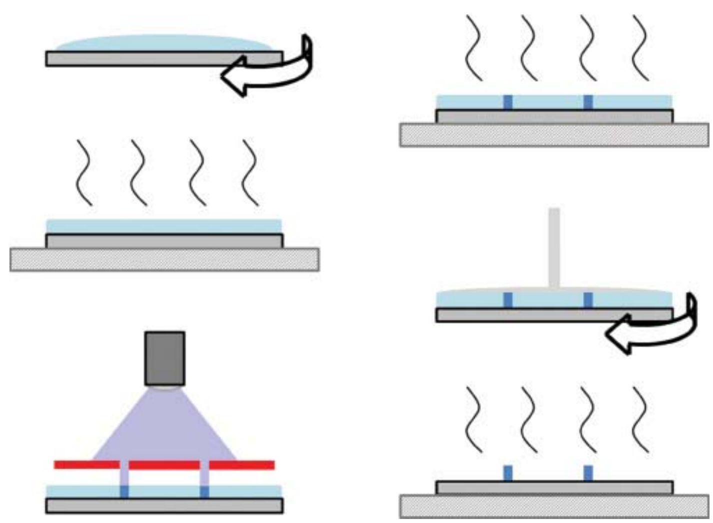

Figure 2. The photolithography process used in study. The steps progress as follows: Photoresist is spun on the silicon wafer (A), wafer is "soft baked" in which solvent of photoresist is evaporated (B), mylar mask is aligned and photoresist is exposed to UV light, initiating cross linking between molecules (C), post exposure bake, during which cross linking mainly takes place (D), SU-8 developer is spun on wafer and washes away excess SU-8 (E).

Soft Lithography.

Soft lithography is a frequently used process throughout microfluidics today and is ideal for creating the RFF device [2]. Polydimethylsiloxane (PDMS), an inert and hydrophobic material, was poured onto a design template created from photolithography. PDMS was used in the device construction primarily due to its hydrophobic attributes, hoping that it would retain solutions in the channels more aptly. Later, through a process accelerated by heating, the PDMS cures and is able to be used as a device. Using the template we had created earlier, two PDMS faces (labeled in Figure 3) were created through soft lithography. These faces serve as the main components of the design, having the channels which transfer the liquid.

Fabrication of Mechanical Components.

Once the PDMS faces were complete, the construction of the mechanical parts of the device followed. The faces were first adhered via static attraction to two borosilicate glass discs. Holes in the glass were drilled to access the PDMS channels. These glass discs were then attached at their center to brass flange bushings. The bushings were next placed on a stainless steel rod, which acted as the device's axis of rotation. Finally the two faces were placed flush together, allowing the circular channels of the design to align. To prevent friction during rotation and to prevent some leakage during testing, vacuum grease was added to the faces. The completed device is shown in Figure 3.

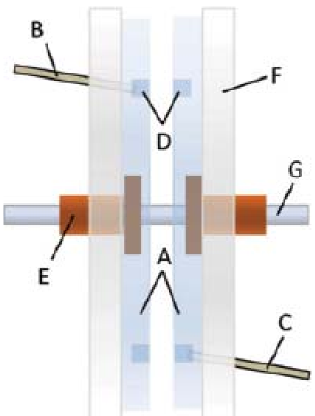

Figure 3. The completed devices with each PDMS face (A). The input (B) and output (C) are placed in the 800 micron ports connected to the circular channels (D). The output is similarly situated only opposite the input, although on the same channel. The bushings (E) are attached to the glass discs (F), and axis (G). Each face is in contact during operation and rotated at low rpms.

Experimental Procedure.

To test the RFF's ability to pass fluids from a stationary to rotating face, two syringes were connected to the PDMS channels through the drilled holes in the glass. On one side of the device, a syringe filled with a green dye solution was connected to a channel with peek tubing (labeled B in Figure 3), a very small volume tube. This green dye would be run through the device and collected on the opposite face in an empty syringe (attached at peek tubing labeled C). As the dye was run through the device, each face was rotating at low speeds in opposite directions, which was intended to illustrate the conditions under which a centrifugal device might operate. During operation, the progress of the dye and any signs of leakage were observed by the naked eye through the transparent glass discs (Figure 3F).

RESULTS.

In testing the design, six device faces, or three sets of faces, were fabricated. Only one set of the mechanical component of the design was made though, and all tests were performed using this set. Throughout the evaluation of the design several modifications were made to the protocol based on the performance of the previous trial tested, as indicated below in the observations.

Initial Design Trial.

This trial was conducted with the channels being aligned solely by the guidance of the device axis, which theoretically would allow proper alignment. Also a limited amount of vacuum grease was used during the operation of the device. Unfortunately, when the test was run and the dye was fed through into the device, it was found that a dye leakage was detected. It appeared that some malfunction in the device had caused a build-up of pressure at the dye's source, forcing apart the faces and overcoming the cohesion provided by the vacuum grease, which was thought to be able to assist in holding them together. Upon observing the result more closely, it was also noted that there may have been slight misalignment of the channels during operation, as the path of the green dye in the channels was not continuous in particular sections. These results of the first trial were a strong indication that the device, with these current faces at least, was not functioning properly and required some more precise aligning and greater cohesion.

Assisted Alignment Trial.

The second trial involved additional vacuum grease to improve cohesion the faces and more proper channel alignment through the use of a dissecting microscope. During this trial, the dye again leaked out of the channel during operation. However the cause of the leakage was thought to be a result of channel clogging caused by the vacuum grease, as the dye almost immediately leaked from the input, indicating a much higher pressure.

Final Trial.

The final trial was marked by more careful application of vacuum grease and the use of the more precise alignment from the second trial. Also it was hypothesized that perhaps an error had occurred during photolithography which had resulted in a faulty channel, which had been used for all previous trials. As a result another channel in the design (Figure 1C) was used to perhaps ascertain this premise. The results of the trial fell in line with those prior to it, even those from the alternate channel used. Once again the dye leaked across the face, however this time it was able to progress through the channels quite further than previous trials.

It seems that currently, with the given design of the faces at hand, the device is not functional. Most complications of the device may be pointed to the nature of the materials used, and the proper replacement of them with more resilient, stronger components may very well produce an effective operating device

DISCUSSION.

In many ways, the concept behind the rotary fluidic feed-through presented is quite straightforward; simply, the circular nature of the channels in the design should allow for a full 360 degrees of rotation without interruption. Such a device is plausible and likely, yet successful execution of such a design is quite difficult. In this study, we demonstrate a preliminary design for a rotary fluidic feed-through device by use of materials thought most appropriate for the device's task. However, when the device was tested, the materials used were found to not perform ideally and further investigation on more suitable materials may be needed.

The first trial certainly demonstrates that PDMS is not able to withstand moderate pressure. The early appearance of the dye leakage from the channels is a clear indicator that the case is such, as even with the minimal pressure given strength of the material failed to maintain the channels. Also, while attempts were made to optimize channel alignment, the second trial further displays the nature of the materials used, both illustrating the ineffectiveness of the PDMS in its containment of the fluid as well as the vacuum grease which disrupted the fluid flow in the channels. Trial three again demonstrated the ineffectiveness of the materials used, presenting both instances of leaking in the two channels. Each result consistently supported the fact that the current materials in the device were not working as intended. The properties for which the PDMS was chosen, such as its hydrophilic (attraction to water), led to its selection for the device's design. Yet, PDMS is also a flexible material, being pliable under pressure. And, while it was thought that its former attribute would overcome its weak strength while under the pressure of the sample, the trials indicate this not to be the case. Thus replacement of this particular material would certainly be the main modification to the faces of the design. Additionally, the lubricant, vacuum grease, used in this appeared to clog channels and prevent the fluid flow, and frequent and/or prolonged use of the device suggested complications. Although the design is unable to operate without the substance, a less obtrusive substitute for the vacuum grease or a protective barrier around the channels would certainly serve as an adequate modification to solve the problem.

CONCLUSION.

In this study, the fabrication of a rotary fluidic feed through was attempted to improve the field of centrifugal microfluidics and allow it a more versatile array of functions. The design presented was engineered as a device to precede the actual incorporation of the rotary fluidic feed through, made to demonstrate the effectiveness of the main components involved. However, the device which was made was unable to establish the current design as viable due to a number of complications resulting from the materials used in the device. Because of this, the device must be reworked and made more effective before it may be implemented into other areas.

Fortunately, the problems found in the device from experimentation primarily point to the materials used, and the design itself remains plausible. Thus it is feasible to say that were alterations made to these materials, a working device would be attainable.

Following the experiments that demonstrated that the flexibility of PDMS does not make it suitable for the device we designed, less elastic alternatives have been considered. One new protocol, a process which involves the etching of channels on the surface of quartz glass with hydrofluoric acid, has been seriously considered as an effective replacement for the PDMS. The quartz glass would provide a much more effective structure for the device and hopefully avoid any dye leakage. Other studies have shown this method of glass etching to be a very accurate and effective means of microfluidic fabrication, comparable to that used for the PDMS fabrication [3].

In addition to the replacement of the PDMS, the vacuum grease substitutes have also been considered. Not only would a replacement lubricant have to be obtained which is much thinner and less obtrusive to the channels, but barriers protecting the channels would also assist in preventing clogging. Improvements in this area would benefit the overall device to a similar degree as the replacement of the PDMS. A more effective alternative would allow the device to not only function properly but also operate at high speeds, something necessary for implementation in centrifugal microfluidics.

While the device presented in this study did contain flaws which hindered its ability to perform its task successfully, it did provide crucial information through which to improve its design and eventually reach a fully operable device. This prototype of the rotary fluidic flow through is simply a preliminary variant of which could very likely be modified into a working device.

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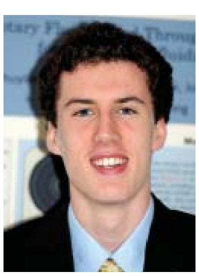

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