A MULTIPORT METERING VALVE TECHNOLOGY FOR ON-CHIP VALVING

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ABSTRACT

Most assays in chemistry, biology or diagnostics incorporate different liquids. In order to control these liquids or even dose them in defined quantities, the standard solution is to use valves. Therefore, a multitude of approaches to realize such valves on-chip exist. Most of these approaches are based on a flexible membrane (usually PDMS or another elastomer) which can be actuated e.g. by air. These approaches however have limitations especially with respect to industrial manufacturability. We have therefore developed a valve system based on a rotary valve concept which allows a switching of different channels (in our current design up to 9 channels) as well as a metering of liquids directly in the valve and which is easy to manufacture and assemble by industrial methods.

KEYWORDS

Microfluidics, valves, injection molding.

INTRODUCTION

Most assays in chemistry, biology or diagnostics require a variety of liquids. In order to control or switch these liquids or even to dose them in defined quantities, the most common solution is the use of valves. Therefore, a multitude of approaches to realize such valves on-chip exist [1]. Most of these approaches are based on a flexible membrane (usually PDMS or another elastomer [2]) which can be actuated e.g. by air or other liquids as well as actuators such a piezoelectric actuators. These approaches however have limitations especially with respect to scalability for industrial manufacturability. Especially for disposable devices for applications such as point-of-care testing (POCT), the manufacturing cost for such devices are under extreme pressure and should be of the order of 2$ or less. On the other hand, especially diagnostic assays based on molecular diagnostic protocols usually contain a rather complex sequence of fluidic handling steps and therefore many fluidic switching steps. It is therefore desirable to have a valve which is not only able to open or close a microchannel but can also route liquids into different outlets. We have therefore developed a valve system based on a rotary valve concept which allows a switching of different channels (in our current design up to 9 channels) as well as a metering of liquids directly in the valve and which is, in contrast to other reported turning valve solutions [3], easy to manufacture and assemble by industrial methods.

EXPERIMENTAL SET-UP

The principle set-up of our valveing concept is shown in cross-section in Fig. 1. A device incorporating such a valve consists out of three components, the microfluidic chip with the microchannel itself, the valve body and the valve holder. All these components are made using injection molding, the chip and the valve holder by conventional single material molding; the actual valve body by two-component molding. The main part of the valve body and the side open to the actuator is molded using a hard polymer (e.g. polycarbonate) and the valve seat in a softer component such as a thermoplastic elastomer (TPE). Assembly of the valve body and holder onto the microfluidic chip can be automated and actuation is done using a stepper motor with moderate torque. We have used a modular approach to making different types of valves. Two diameters for the valve body are available (11 mm and 8 mm diameter). The actual design of the soft component valve seat determines the actual functionality of the valve. Depending on this design, such a valve can be a simple switch valve combining one inlet to different outlets, a complex switching valve, combining different inlets with different outlets simultaneously or a metering valve where a defined volume is incorporated in the shape of the valve seat. Figure 2 shows different examples of two-component injection molded valve bodies.

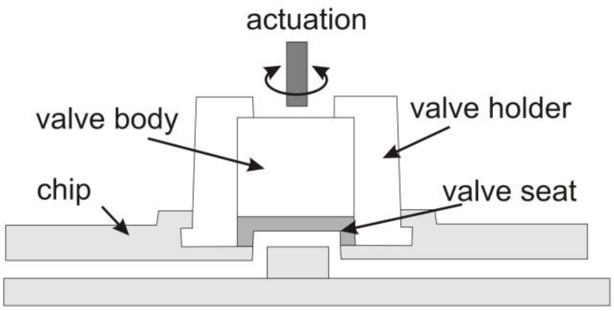


Fig. 1: Concept of the rotary valve. All components are manufactured using injection molding. Assembly can be automated.

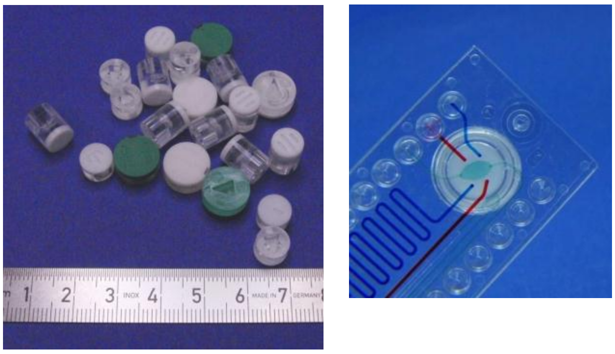
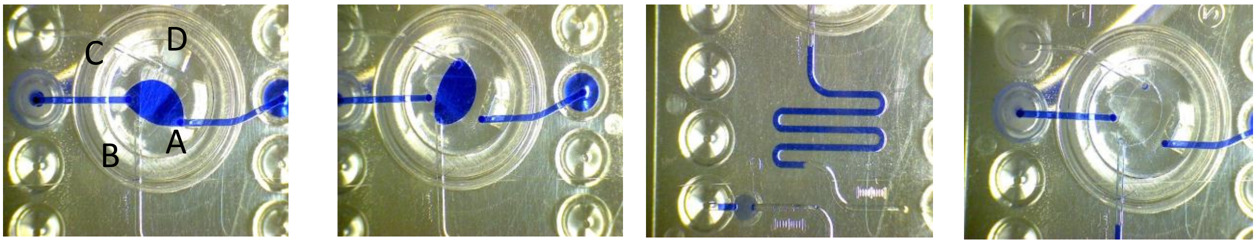


Fig. 2: Different examples of the two-component injection molded valve body (left) and a complete valve assembly on a microfluidic chip (right).

EXPERIMENTAL RESULTS

In order to demonstrate the basic usability of the concept for metering liquids on a chip, a valve seat with a lenticular metering structure on the 8 mm diameter platform was designed, connecting four different fluidic ports. The sequence for metering a volume is shown in Fig. 3 a-d. The ports which are connected in this valve design are labelled A, B, C and D. The chip itself is a standard microscopy-slide sized (25.5 mm × 75.5 mm) device with 14 Mini-Luer connectors on either of the long sides of the chip, allowing for a sufficiently high number of liquid ports even for complex fluidic protocols. The valve is filled by rotating the valve so it is connecting ports A and C (Fig. 3a). The valve is rotated (Fig. 3b) and a geometrically defined amount of liquid is transferred into the channel connected to port B (Fig. 3c) by applying air (alternatively a second liquid) at port D. The transfer is done with very little carry-over (Fig. 3d).



a *b* *c* *d*

Fig. 3: Sequence for metering volumes in the valve: Liquid is injected through ports A and C (a). The valve rotates (b) and ejects the liquid through port B (c). The metering chamber is completely emptied in the process (d).

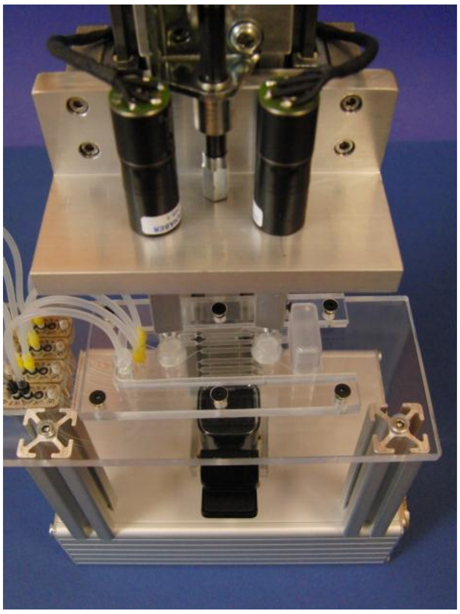


Fig. 4: Experimental set-up for the valve experiments.

Figure 4 shows the experimental set-up for such experiments in order to convey a sense for the required sizes of motors turning the valve. The test set-up can operate two turning valves which are positioned on a standardized microfluidic platform. An example of such a microfluidic platform chip can be seen in the middle of Fig. 4. In order to have sufficient headspace for handling the chip, aluminum distance holders between the motors and the valves are inserted which would not be needed in a specialized application.

The achievable metering reproducibility from chip-to-chip is shown in Fig. 5. A series of 20 chips was measured, yielding an average metering volume of 5.25±0.15 µl, indicating a high reproducibility in the manufacturing process (CV <3%). This is important for a large number of commercial applications, as many protocols require the dosing of absolute amounts of reagents which is difficult to achieve with other types of valves.

In order to minimize the size of the actuators needed to turn the valves which in turn is important for the size of a possible instrument to run the chip as well as to minimize the energy consumption for a given protocol, the torque necessary to start actuating the valve was evaluated and different surface modifications of the valve seat were carried out in order to find a material combination which requires minimum torque. Figure 6 shows the torque necessary to actuate the 8 mm diameter valve as a function of the surface treatments. A is the native state of the materials, B a Teflon coating at 45˚C, C a hydrophilization and D a Teflon coating at room temperature. It can be seen that the Teflon coatings have an influence of the torque, however the initial material combination (TPE/COP) has proven to be a good choice and is already within 10% of these values. For most practical applications, from the manufacturing perspective the additional manufacturing cost would therefore be hard to justify. The average torque of around 20 mNm however can be delivered by simple standard motors, thus allowing for rather compact and low-cost instrumentation.

CONCLUSIONS

In this paper, we present a platform concept for rotary valves on a chip. This valve type can fulfill a variety of different tasks in a microfluidic device, from switching single channels to complex simultaneous switching of a multitude of channels and the metering of volumes directly in the valve body. Emphasis has been put on to the industrial manufacturability of the solution, as many applications are under high cost pressure. By using two-component injection molding, all parts of the valve can be molded and assembled in an automated fashion. The valves performed well in the pressure ranges normally used in microfluidic chips (<2 bar) and show a high degree of reproducibility in the metered volumes (CV <3%). The torque necessary to actuate the valves is compatible with simple off-the-shelf electric motors, thus allowing the integration of such valves in simple instruments. We have developed a multitude of chips with these integrated valves, performing a variety of protocols including PCR and we expect this technology to become a viable commercial alternative to the mostly academically used membrane valves.

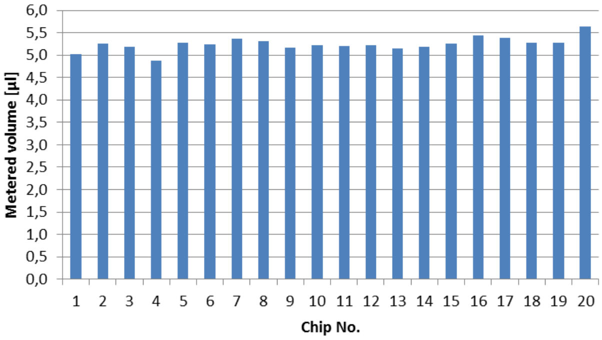


Fig. 5: Metering reproducibility measured with 20 different chips. CV is <3%.

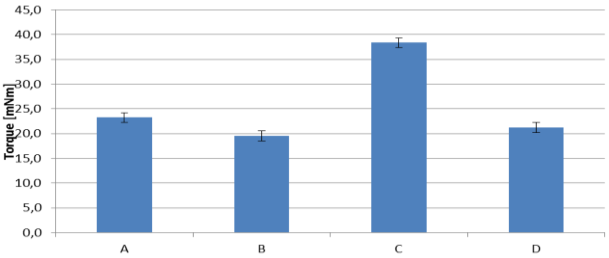


Fig. 6: Torque measurements with different surface modifications: A: native materials, B: Teflon at 45˚C, C: hydrophilization, D: Teflon at room temperature.

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