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The Parylene Bowed-Type Valves

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Abstract

This paper demonstrates a newly developed parylene bowed-type valve with the same working principle of the "buckled straw". Such a new design of the valve uses the buckled region of plastic tubes as the on/off switch for flow control, and there is no need of adding deformable diaphragms or sealing parts into the valve device. By the merit of its concise mechanism, i.e., a straight pipeline with the region for buckling, the bowed-type valve intrinsically operates with almost zero dead volume. The fabrication sequence of this new valve combines the techniques of sacrificial mould of capillary glass tubes, conformal coating of parylene and SU-8 photolithography. A valve device of 1 cm long, 0.8 cm wide is demonstrated, and the turn-on angle of this valve verified as 135° experimentally.

***Key Words*:** Bowed-type valve, Circular microchannel, Parylene, SU-8

1. Introduction

It's well known that many micro-valves have no characteristic of zero dead volume [1]. In other words, micro valves don't close or open until certain volumetric amount (the dead volume) of working fluid has been pumped into or out of the controlled actuators. This deficiency introduces the delayed time of valves and lowers the working bandwidth of fluid actuators. Yao proposed the "buckled straw" concept in Figure 1 to the design and the fabrication of a new valve in 2001 [2]. He also made the first generation of the bowed-type micro valve as well as the correlated microfluidic system shown in Figure 2 by parylene MEMS process [3]. However, that micro valve hasn't verified its functionality yet. One probable reason is that no sufficient buckling force was provided for the device. Another reason is that no proper geometric configuration of the microchannel was available for the valve then.

In the past, the microchannels with rectangular cross sections are usually applied to microfluidics. There's no exception in the work of ref. [2]. But by the clarification of Figure 3, it's obvious that fluid leakage still remains as

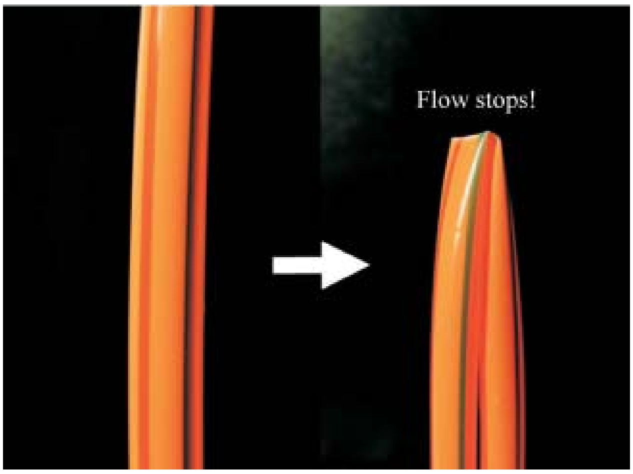

Figure 1. Large-scaled straight & bowed plastic straws.

the bowed-type valve turns on (flow closing) with voids showing up at both sides of the buckled region of the rectangular channel. It seems that no successful bowed-type valves can be made if no microchannels with circular cross sections are provided.

2. Design and Fabrication

According to the reasons mentioned above, the first step for making the bowed-type valve to block the work-

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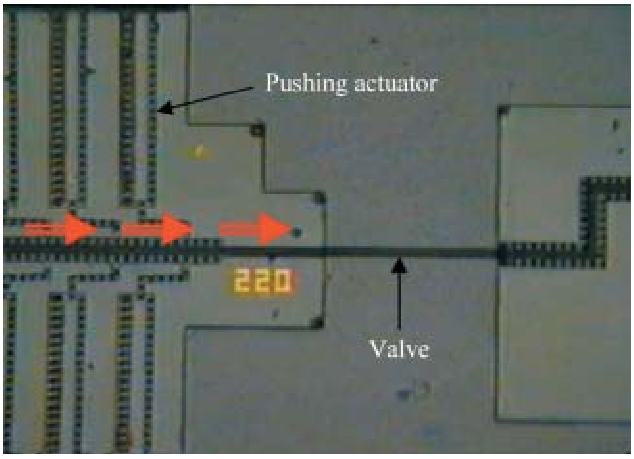

Figure 2. The first generation of the bowed-type valve [2].

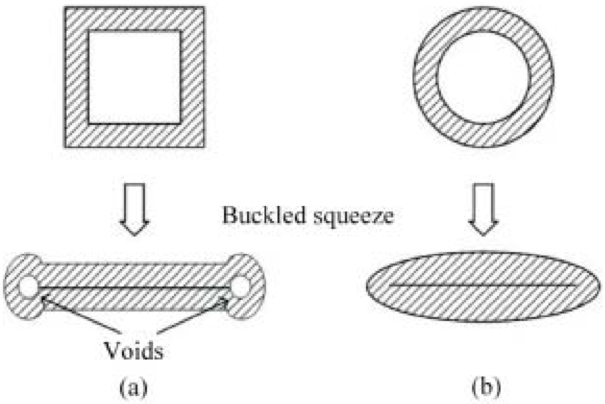

Figure 3. Operation of the bowed-type valves with different cross sections of channels: (a) Rectangular one; (b) Circular one.

ing fluid effectively is to fabricate a microchannel with a circular cross section. Fortunately, a newly developed technique of fabricating SU-8 circular microchannel [4] provides a concise approach to solve the issue we concerned. The process used a glass capillary or an optical-fiber as a sacrificial material for the circular microchannel. At least three SU-8 layers were spun and coated as a structure material surrounding the sacrificial core. Subtly baking and well-controlled ultraviolet exposure was operated to cross-link and strengthen the SU-8 without leaving apparent residual stress, and the portions of etching windows for core-stripping were recessed simultaneously. Finally, immersing the SU-8 samples in hydrofluoric (HF) acid for certain period of time would remove the sacrificial fiber, and the circular microchannel was formed.

Based on the prior art, this paper furthermore proposes to wrap the sacrificial glass capillaries with parylene shell and embed the valve module in SU-8 base. Using the well definition of UV exposure and post exposure baking, the inlet/outlet as well as the buckled region of the SU-8 base for the valve module is stripped out selectively. We remove the sacrificial glass capillary and make the buckled region of the circular microchannel free-standing, then the new design and process of parylene bowed-type valves are completed finally.

Regarding to the packaging of the parylene bowed-type valve, we still used SU-8 to glue a suitable polyethylene (PE) tube which connects the sacrificial glass capillary in advance. The SU-8 module sets formed on a glass substrate firmly, and peered off individually from the glass substrate after the well crosslinking of SU-8 base. The PE tube can be connected to a syringe needle #21 tightly, with a glass capillary tube as an entrance of the microchannel at the start of process. This packaging step leads the marching or the start of follow-up experiment measurement successfully.

The detailed process flow is depicted in Figure 4. First, a parylene layer of 10-30 μm thick is coated on the outer surface of capillary tubes (Figure 4(a)). Second, we mount the parylene-coated capillary tubes on a glass substrate by the glue packaging sequence of SU-8 resist mentioned in the previous paragraph (Figure 4(b)). Third, a thick layer of SU-8 resist (about 300-500 μm thick) is spun above the capillary tubes and patterned lithographically (Figure 4(c)). Fourth, we detach the valve module from the glass substrate, remove the embedded capillary tubes by HF acid, and obtain the parylene hollow micro-tube as the bowed hinge connecting the inlet/ outlet platform. The centered micro-tube assigned as the buckled region of the completed valve in Figure 4(d) is then purely made of parylene and is ready for large deformation (buckling) testing. Figure 4(e) shows the bowed-type valve module subject to the buckling testing.

3. Preliminary Experiment Result

The complete bowed-type valve is put on a home-made poly-methyl-meth-acrylate (PMMA) experimental platform for testing, as shown in Figure 4(e). The testing setup includes a bowed-type valve module connecting the PMMA hinge-like platform, a needle #21 and a sy-

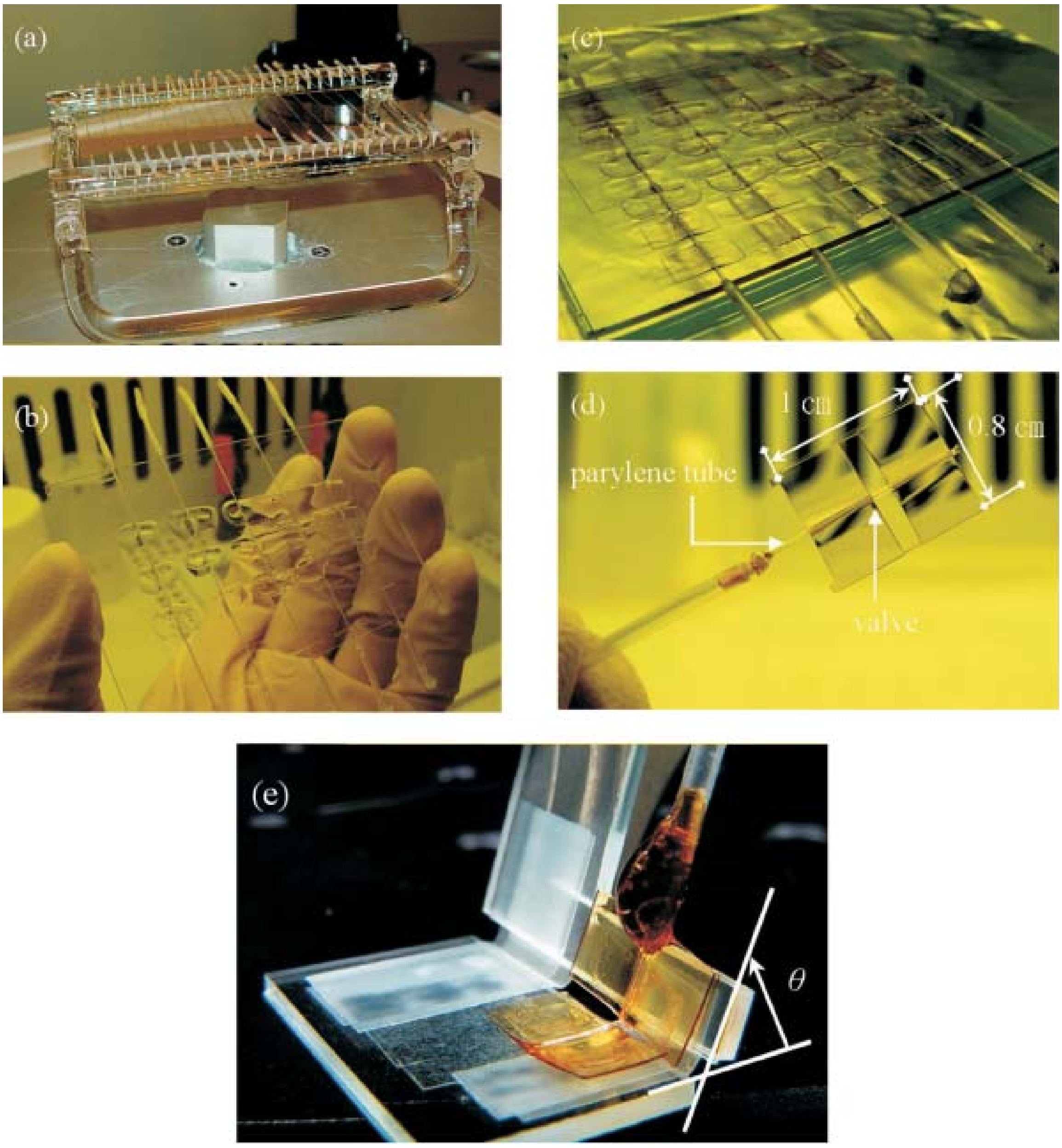

Figure 4. Fabrication process of the parylene bowed-type valve: (a) Coating parylene around the capillary tubes (with the outer diameter of 350 μm); (b) Mounting the capillary tubes on a glass substrate; (c) Covering & patterning the top SU-8 to burry the capillary tubes; (d) Delaminating the valve module from the glass substrate; (e) Removing the capillary tubes & leakage testing (the turn-on angle is denoted by θ).

ringe pump with a 10 c.c. syringe. We inject working fluid into the micro valve by a syringe pump, and check what the bowed angle of the new valve functions well.

Table 1 lists the turn-on (flow closing) angles θ of some bowed-type valves with different materials and dimensions subject to external loadings. Similar bowed type valves using ordinary plastic straw and PE tubing are tested as the reference data comparable to the parylene one. Basically, the turn-on angles for all the successful cases in Table 1 are around 130°, no matter how small the valve dimension is. Too much larger angle induces undetermined constraint on the buckled region and is no more beneficial to the valve operation. Moreover, the hyper-elastic material, e.g., PE, is soft enough for the valve to stop the flow genetically. Experimental results also show that the parylene material, with Poisson's ratio of about 0.4, meets the anti-leakage requirement and is a good candidate of elastic materials for bowed-type micro-valves.

Table 1. The turn-on (flow closing) angles θ of some bowed-type valves with different materials and dimensions

Sample #	Materials for valves	Thickness-to-diameter ratio	Outer diameter mm)	Turn-on angle θ
A	plastic straw	2.7%	5.60	N. A. (Fails to stop flow)
B	PE	15.6%	6.40	130°
C	PE	16.7%	1.27	130°
D	parylene	4.4%	0.35	135°

4. Discussion and Conclusion

Yao [3] proposed the "buckled straw" concept and used parylene MEMS technology to complete an original bowed-type valve in 2001. However, the original bowed-type valve can't block a fluid in the channel and transfer its flow switching state into original form effectively. We think a possible reason comes from the improper usage of a microchannel with a rectangular cross section. Therefore, this work shows an approach to fabricate a novel bowed-type valve module which has a bowed-type valve with a parylene circular microchannel by sacrificial capillary molds in SU-8 resist base. The globe size of the valve module is 1 cm × 0.8 cm, and the turn-on angle θ for flow stopping is 135°. This investigation demonstrates that the concept of what Yao proposed is feasible.

The new design of the bowed-type valve utilizes a buckled circular microchannel as a switch to control the turn-on or turn-off states of a flow valve, and manipulate the fluid inside the corresponding flow channel to pass through or not. This valve module doesn't add the moving parts like diaphragms or sealing chambers but can still make the device operate well with almost zero dead volume or non-return effectively by a concise mechanism of buckled neck. In other words, just a straight pipeline with a bulked region can control the fluid in a microchannel to pass through or not.

Restated, the feasibility of bowed-type micro-valve is demonstrated preliminarily successfully herein. The detailed design of buckling force and the following integration of actuating mechanism into the whole microfluidic system will be studied under way in the very future.

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