Micromachined Rubber O-ring Micro-Fluidic Couplers

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ABSTRACT

In this paper, we present a novel type of a "quick-connect" for micro-fluidic devices realized by a simple silicone-rubber O-ring MEMS coupler. As shown in this work, the proposed O-ring couplers are easy to fabricate and utilize, reusable, can withstand high pressure (>60psi), and provide good seals. In the paper, results from both the leak rate test and pull-out test are presented, demonstrating the functionality of the O-ring couplers.

INTRODUCTION

In the expanding field of microfluidics, it is clear that many micro-fluidic handling devices such as micro-pump [1], micro-valve [2], and micro-filters [3] have been demonstrated. However for a successful micro-fluidic system, it is still a very challenging task to connect the external macro-fluidic reservoir to a micro-fluidic system. This is shown in the rising interest in the development of fluidic interconnects [4-10]. There are still no working MEMS "quick-connect" yet. Some of the micro-fluidic interconnection schemes have been proposed either by conventional precision machining, injection molding or simply by gluing the capillary tubes into micromachined pits fabricated by iso- or anisotropic etching of the silicon substrate. However, injection molding is a relatively complicated fabrication process, and the precision machining is usually bulky. In addition, the gluing of the capillary tubes contributes to a low yield due to misalignment. Thus, in terms of a functional and simple fluidic coupler, new coupling methods must be proposed [7].

In this project, quick-connects that emphasizes reusability and good seal (minimum 10psi) have been successfully developed. Here, we present our first demonstration of a quick-connect coupler between a glass capillary tube and a silicon chip. More than 60psi seal has been achieved between a glass tube (860μm O.D.) and a rubber O-ring (400μm I.D.) without measurable leakage. The requirements of reusability and good seal are achieved by this new silicone-rubber O-ring technique. In the following, we will discuss the design, fabrication, and complete testing of the device. The extended goal is to achieve easy connection between a multi-port MEMS fluidic device and a fluidic board as shown in Fig. 1.

Design and Fabrication Process

The initial design of the rubber O-rings are for two sizes of capillary tubes (O.D. 860μm and 640μm). The process shown in Fig. 2 starts with etching of the silicon substrate to a depth of 250μm by deep reactive ion etching (DRIE) to define the O-ring shape. Then a 2.5μm thick SiO_2 is thermally grown to be used as the mask for later DRIE etching. A 1μm thick layer of Silicon Nitride (SiN_x) is then deposited on top of the SiO_2 to serve as the adhesion layer between the substrate and the silicone rubber. This step is necessary because the silicone rubber does not have very good adhesion on SiO_2. After nitride deposition, the silicone rubber is squeezed into the DRIE cavities to form the O-ring. The process is then followed by DRIE etching from the backside of the substrate to form the backside hole. The oxide and nitride membranes are then stripped off in buffered hydrofluoric acid (BHF) and SF_6 plasma.

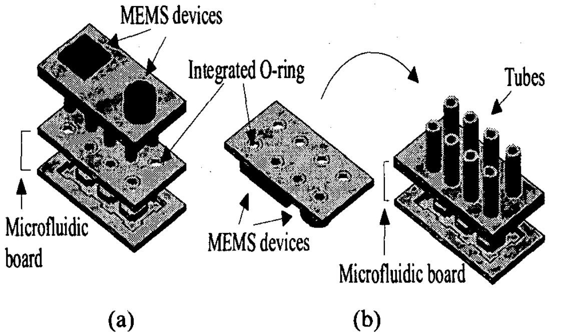

Fig.1 Schematic view of the O-ring coupler application
(a) A multi-port micro-fluidic device is plugged into a micro-fluidic board with O-ring couplers
(b) A MEMS micro-fluidic device with O-ring coupler is plugged into a micro-fluidic board

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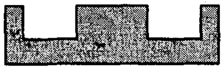
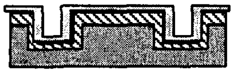
The finished O-ring dimensions are shown in Fig. 3. Various 250µm-thick silicone-rubber O-rings have been made. All of the O-rings have the same annulus width (500µm) but with different IDs ranging from 400 to 700µm. A schematic view of the couplers is shown in Fig. 4a. After a tube is inserted, the rubber O-ring deforms to establish a good seal, as pictured in Fig. 4(b,c).



(a) DRIE Front side holes 250 µm

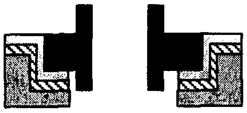


(b) 2µm thermal oxidation and 1500Å Nitride deposition

(c) Silicone Squeegee

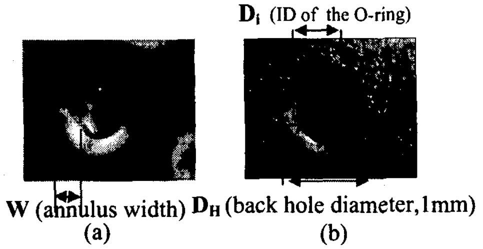
(d) DRIE etch from back side

(e) Strip Nitride and



(f) Tube insertion

Fig.2 Fabrication Process for O-ring Couplers

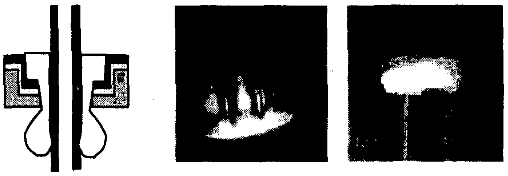


(a) (b)

Fig.3 (a) A capillary tube plugged into front side (b) O-ring is viewed from back side

Experimental Characterization

In order to characterize the performance of the rubber O-ring couplers, two of the most important tests are performed – leak rate tests and pull-out force measurements. First, Figure 5 shows the O-ring seals under pressure at 20 psi. There is no observable shape change of the O-rings found, which indirectly proves the mechanism of sealing we proposed in Fig. 4a. In short, the good seal is promoted by rubber deformation so that the effective rubber-tube contact thickness is much larger than the original rubber thickness (250µm).



(a) Schematic View (b) Front (c) Back

Fig.4 View of the assembled rubber O-rings and tube structure (a) Schematic drawing (b) front side (c) back Side

After the hypothesis is confirmed, subsequent tests were performed on the O-rings, including the leak test and pullout test. The experimental setup of the leak test is illustrated in Fig. 6. A blocked tube is first inserted into the O-ring chip. The front side is then sealed with a 10µl micropipette (filled with water to serve as a positive-displacement leak monitor). A pressure gauge is connected to monitor the backside chamber. . The results of the leak test for 860µm-OD tube coupled to a 400µm-ID O-ring is shown in Fig. 7. A good seal is maintained over 12 hrs with no measurable pressure drop (constant at 20.2psi). The same leak tests have been performed on the other O-ring couplers, with the results given in Table. 1. We conclude that tight seals can be achieved if the O-ring is properly designed (i.e. the ID of the O-rings is smaller than the tube OD). The experimental setup shown in Fig. 6 can only withstand pressures up to 60psi, with good seals achieved up to that pressure.

(a) 0 psi (b) 20 psi

Fig.5 Pressure test (a) at 0 psi (b) at 20 psi

The experimental setup for the pullout test is shown in Fig.8. A position stage is used to pull-out the tube from the O-ring couplers while the load cell is used to measure the resistant force when the position stage moves downward to push-out the tube. As the position stage slides downward and begins to push the tube, the reading on the load cell starts to increase. However, when the tube starts to move relative against the O-ring coupler, the force starts to decrease due to the fact that kinematic friction coefficient is smaller than static friction coefficient. Hence, the maximum reading on the load cell before the tube sliding is recorded in this experiment.

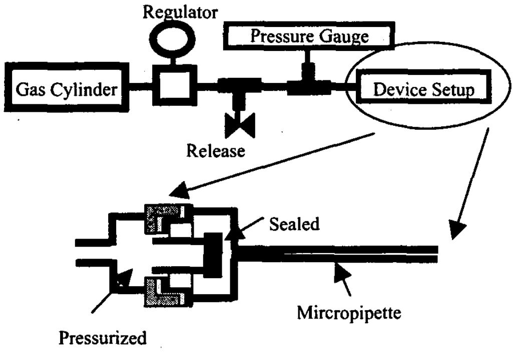


Fig. 6 Experimental setup for leak rate measurement

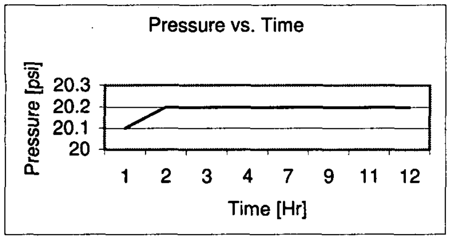


Fig.7 The tube under 20psi remains sealed over 12hrs

Tube O.D. (µm)	Inner Diameter of Rubber Mounts Di [µm]			
	400	500	600	700
860	Non-detectable*	Non-detectable*	Non-detectable*	Non-detectable*
640	Non-detectable*	1.11ml/min @ 11.5psi	Infinite**	Infinite**

Table1 Leak rate test on different tube diameters vs. inner diameter of Rubber O-rings.
*Non-detectable (<<0.1ml/min @ 20psi)
**Infinite (>>10ml/s @ 0.5psi)

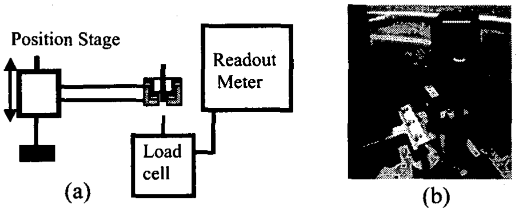


Fig.8 Experimental setup of pull-out test
(a) Schematic view (b) Photo of setup

The results of pull-out measurements are shown in Fig. 9ab. The results suggest that the force required to pull the tube out of the O-ring decreases as O-ring ID increases. Figure 9b shows the calculated theoretical holding pressures converted from the data in Fig. 9a. A wide range of holding pressures (all >10psi) has been achieved with the maximum around 80psi for the tube with OD 860µm against the O-ring ID 400µm. And all the results agree with our leak test data.

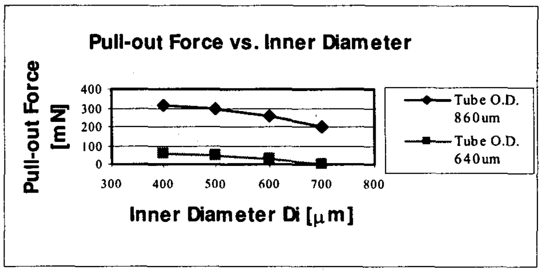


Fig.9a Pull-Out Force vs. Inner Diameter of rubber O-rings

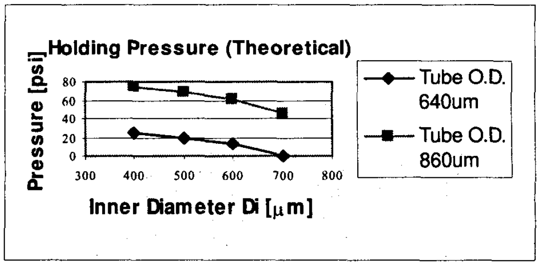


Fig.9b The Theoretical Holding Pressure calculated from Fig.9a

Reliability Test on O-ring Couplers

Finally, the pull-out tests were repeated several times to simulate the reusability of the devices (Fig.10). We observe that stabilization is reached after several cycles (showing no further decay), indicating reliability of the devices. A repetition test (>200 times) has also been performed, showing good adhesion between rubber and nitride side-wall. In a few instances, cracking of the O-rings around the inner diameter of the rubber membrane was observed. This problem is expected to be easily solved by using different silicone rubbers as O-ring materials.

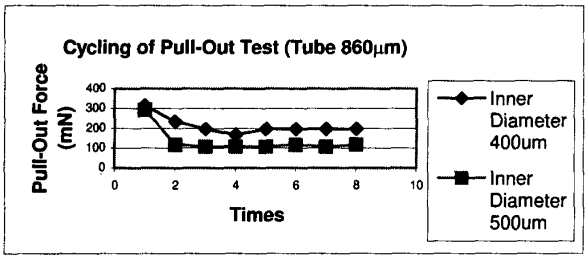


Fig.10 Cycling test of pull-out force on rubber O-rings

Conclusion

In this paper, a micromachined rubber O-ring coupler has been designed, fabricated and tested. The result shows the coupler is reusable and can maintain good seal as high as 60psi. The next step of this project will be putting micro-fluidic devices and the couplers together to make the micro-fluidic board as we proposed in the Fig.1.

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References

[1] C. Grosjean and Y.C. Tai, "A Thermopneumatic Peristaltic Micropump", Hilton Head '99, pp.1776-1779

[2] C. Grosjean, X.Y. Yang, and Y.C.Tai, "A Practical Thermopneumatic Valve," MEMS '99, pp. 147-152

[3] X. Yang, J.M. Yang, X.Q. Wang, E. Meng, Y.C. Tai and C.M. Ho, "Micromachined Membrane Particle Filter", MEMS '98, pp. 137-142

[4] D. Jaeggi, B.L. Gray, N.J. Mourlas, B.P. van Drieenhuizen, K.R. Williams, N.I. Maluf, and G.T.A. Kovacs, "Novel Interconnection Technologies for Integrated Microfluidic sytems", Hilton Head '98, pp. 112-115

[5] D. VerLee, A. Alcock, G. Clark, T.M. Huang, S. Kantor, T. Nemcek, J. Norlie, J. Pan, F. Walsworth, S. T. Wong, "Fluid Circuit Technology: Integrated Interconnect Technology for Miniature Fluidic Devices", Hilton Head '96, pp. 9-14

[6] N.J. Mourlas, D. Jaeggi, N.I. Maluf, and G.T.A. Kovacs, "Reusable Microfluidic Coupler with PDMS Gasket", Transducers '99, pp.1988-1989

[7] S.F. Trautweiler *et al*, MEMS '96, pp. 61-66

[8] T.S.J. Lammerink, V.L. Spiering, M. Elwenspoek, J.H.J. Fluitman and A. van den Berg, "Modular Concept for Fluid Handling Systems", MEMS '96, pp.389-394

[9] R.J. Reay, R. Dadoo, C.W. Storment, R.N. Zare, and G.T.A. Kovacs, "Microfabricated Electrochemical Detector for Capillary Electrophoresis", Hilton Head 94, pp.61-64

[10] N.J. Mourias, D. Jaeggi, A.F. Flannery, B.L. Gray, B.P. van Drieenhuizen, C.W. Stormant, N.I. Maluf, and G.T.A. Kovacs, "Novel Interconnection and Channel Technologies for Microfluidics", Proc. Of the Micro Total Analysis Systems Workshop '98, pp. 27-30