HEFAT2014
10th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
14 – 16 July 2014
Orlando, Florida

MICROFLUIDIC COUPLER FOR HYBRID INTEGRATED LAB-ON-A-CHIP

Jayan Ozhikandathil and Muthukumaran Packirisamy*
Department of Mechanical and Industrial Engineering
Concordia University,
1455 de Maisonneuve Blvd. West, Montreal (Quebec),
Canada H3G 1M8
Email: pmuthu@alcor.concordia.ca

ABSTRACT

Lab-on-chips (LOCs) or miniaturized total analytical systems (μTAS) are attractive to perform chemical and biological analysis using small amounts of samples in a short time. Micro machined fluidics and optical devices are integral components of LOCs, which are fabricated monolithically or by hybrid integration in order to perform various analytical process in a single chip. In this work, simulation and implementation of a microfluidic coupler for the hybrid integration of an optical microfluidic system by using silica-on-silicon waveguides and polydimethylsiloxane (PDMS) microfluidic chips are demonstrated. The presented microfluidic coupler simplifies the fabrication of optical microfluidic systems by coupling the fluid from the PDMS chip to the micro channel in the silica-on-waveguide. The micro-flow behavior through the coupler is investigated by the simulations carried out using the COMSOL multiphysics and the experiments as well.

INTRODUCTION

Miniaturized total analytical systems (μTAS) are gaining lots of attentions as they are capable of performing multiple bioanalytical process such as sampling, filtration, chemical reaction, separation and detection by using small amounts of samples in a short time [1-3]. The use of existing and emerging microfabrication techniques made possible the fabrication of portable bioanalytical devices which can satisfy the requirements of point of care needs. The cost of μTAS can be reduced significantly compared to the macro-scale instruments by developing the device on semiconductors, glass or polymers. Two types of approaches, namely, monolithic and hybrid integration are commonly found in literature for the fabrication of μTAS. In monolithic integration, components for multiple bioanalytical process are monolithically integrated in a single chip, whereas, in certain applications, it is required to use multiple material platforms for various applications, hence the hybrid integration of μTAS is required.

Silicon, glass, polymeric materials such as SU8 [4], PDMS, and PMMA [4, 5] are the commonly used material for the fabrication of μTAS. Oftentimes, it is required to use the surface properties of different materials for various bioanalytical processes; hence a hybrid integration approach by using different material platforms has become attractive for the fabrication of μTAS. PDMS-Silicon biochips [6], glass-silicon biochips [7-9], PDMS-glass [8-10] biochips and silicon-on-silicon-PDMS biochips have been demonstrated in literatures for various applications with better performances.

We have previously demonstrated a hybrid integrated biochip fabricated by using silica-on-silicon (SOS) waveguides and PDMS for the fluorescence based biodetection applications [11, 12]. The low optical loss of SOS waveguide and the easily moldable nature of PDMS for the microfluidics circuits are used for the fabrication of a low cost lab-on-a-chip. Using the PDMS, any 3D-high aspect ratio microfluidics can be fabricated by soft lithography [13]. A straight microfluidics channel is fabricated on the SOS waveguide by using the diamond sawing method, subsequently the fluid was transported to the microchannel of SOS waveguide by the microfluidics circuits of PDMS and the hybrid integration. An integral component of the hybrid integration of the SOS and PDMS is a microfluidic coupler which carries the fluids to the microchannel of the SOS waveguide. In this work, simulation and the optimization of the geometry of a microfluidic coupler suitable for the hybrid integration of μTAS is carried. The effect of microflow behavior through the coupler under various flow velocities and the geometrical tuning has been analyzed. The microfluidic coupler was fabricated and the flow behaviors were experimentally validated with the simulation results.

METHOD

Fig 1 shows the design sketch of the microfluidic coupler for the hybrid integration of the μTAS. In this device, an optical microfluidic system is implemented by integrating a silica-on-silicon waveguide on the PDMS. It is a challenging and expensive process to fabricate a complex microfluidic circuits on the SOS as it requires photolithography and deep micromachining techniques such as DRIE or laser micromaching etc. However, it is an easy and inexpensive process to fabricate high-aspect ratio microfluidic components on the PDMS by using soft lithography. Hence, a straight microfluidic channel is fabricated on the SOS waveguide by diamond machining process, which is a low cost process and can be carried out in a general laboratory environment.

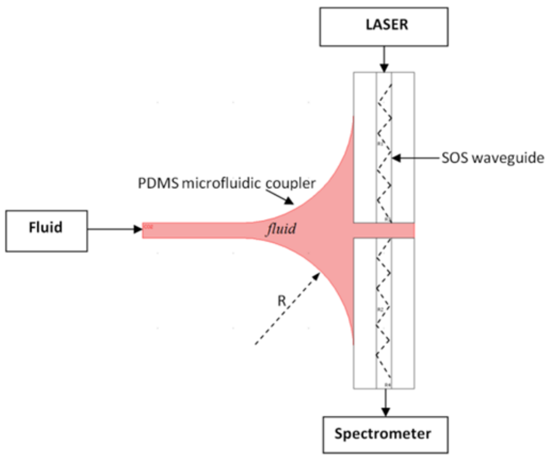


Fig 1. Schematic of the microfluidic coupler

The function of the microfluidic coupler is to couple the fluid from the PDMS microfluidic circuits to the microchannel of the SOS waveguide. The microfluidic coupler is designed to fabricate in a general laboratory environment without any expertise. The SOS chip was integrated on the PDMS by oxygen plasmas boding; herein the samples must be kept in contact as soon as they are exposed to the oxygen plasma, in order to form an irreversible bond. Since the microchannel width is of the order of 100μm, it is a challenging task to align the microchannel of SOS with PDMS. Hence, the fluid transition region from the microchannel of PDMS to the SOS is designed by chamfering the ends of channel as shown in Fig 1. In the simulation study, the radius of the chamfer (R) is varied and the flow behavior is analyzed.

COMSOL MODELING OF THE MICROFLUIDIC COUPLER

The flow in the viscous fluids can be described by the Navier-Stokes equations [14] with the assumption that the density and the viscosity are constant. The COMSOL Multiphysics^{TM} is commercially available software which can be used to solve the Navier-stokes equations by using the finite element method (FEM).

Fig 2 shows the microfluidic coupler modeled in the COMSOL Multiphysics^{TM}. The model composed of two microchannels connecting the PDMS microfluidic circuits and the microchannel in the SOS waveguide. The width and height of the microchannel was 100μm and the coupler dimension was varied by varying the chamfer radius R. In the model, the liquid flowing through the device was DI water with a density of 1000kg/m^3 and a dynamic viscosity of 10^{-3} Pa-s. All the boundaries of the device are set to no-slip boundary conditions. The velocities at the inlet are varied from 1 to 0.1 m/s and the outlet pressure was kept zero Pa.

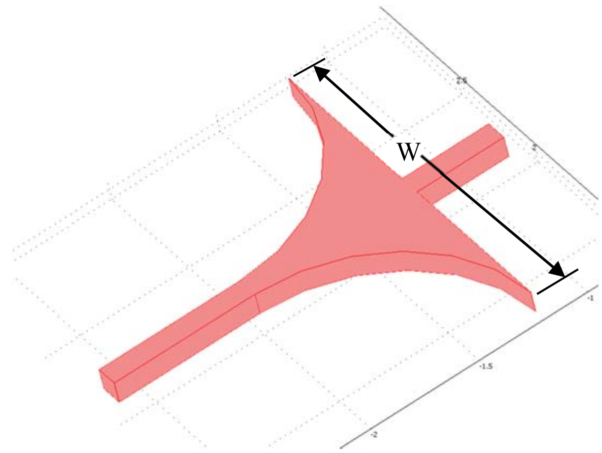


Fig 2 Microfluidic coupler modeled in the COMSOL Multiphysics

FABRICATION OF MICROFLUIDIC COUPLER

The microfluidic coupler is fabricated on the PDMS. A mold for casting the designed in a software Pro/Engineer and fabricated on the brass mold. The mold was coated with a thin layer of gold by electroplating, which is required to promote the easy removal of the PDMS. For the fabrication of PDMS microfluidics coupler, a two component silicon elastomer kit (SYLGARD 184, DOW Corning, MIDLAND MI, USA) was used. The PDMS base and curing agent are mixed in 10:1(%wt) ratio. The mixture was degassed to remove gas bubbles and casted in the mold. The PDMS was baked for 5 hours at 80^{0}C and the PDMS structure was removed from the mold. Detailed fabrication of the SOS waveguide and the integration with PDMS microfluidics was discussed in the ref [11]. The Fig 3 shows the microfluidic coupler fabricated on PDMS and integrated with the SOS waveguide. The DI water was injected into the microfluidic coupler.

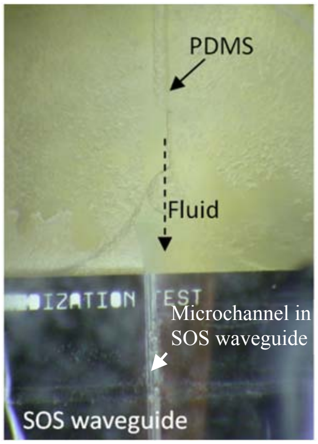
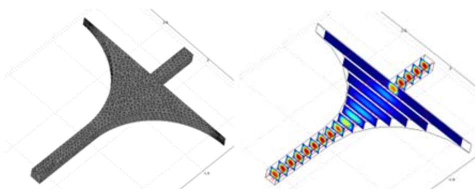


Fig 3 Fabricated micro fluidic coupler for the hybrid integration of SOS-PDMS lab-on-a-chip.

RESULTS AND DISCUSSION



(a) (b)

Fig 4 COMSOL simulation of Microfluidic coupler (a) geometry with mesh (b) simulated geometry.

Fig 4 shows the microfluidics coupler simulated using the COMSOL Multiphysics. The geometry broken up into tetrahedral mesh element for the FEM simulation is shown in Fig 4(a). The mesh is created by free mesh options of COMSOL. The extra fine and extremely fine mesh option give almost the same results; hence the extra fine mesh option is used for meshing the model. The flow stream line and the flow velocity of the fluid are calculated

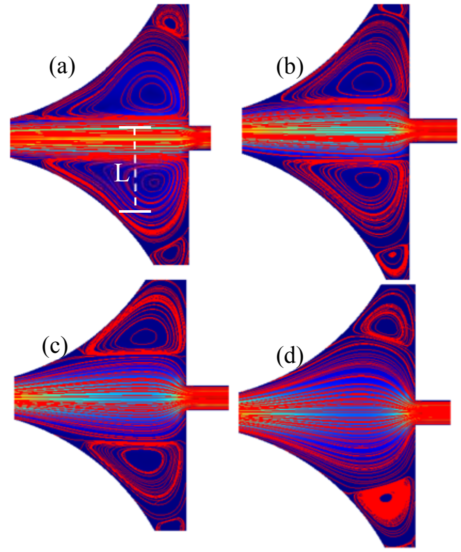


Fig 5 Micro flow behavior through the microfluidic coupler for various flow velocity and Reynolds number, (a) *v=1m/s Re 60(b) v=0.5 m/s Re= 30 (c) v=0.3 m/s Re= 12 (d) v=0.1m/s Re =3.*

Fig 5 shows the microflow stream line calculated for various Reynolds numbers, which shows that, for higher Reynolds number, two recirculation zones are forming on both sides of the flow path, which will prevent the proper cleaning of the device, as during the flow, there is a chance to accumulate the chemical waste on coupler. For the low Reynolds number (R#3 or less), the recirculation zone was moved to the extreme corner of the coupler. A plot for the separation length L (normalized with total width (W, See Fig 2) of the coupler, 2mm) against the Reynolds number is shown in Fig 6. The simulation was carried out to find an optimum geometry by varying the chamfer radius R to minimize the recirculation zone in the coupler. The increase in the separation distance (L) between recirculation zones pushes the recirculation to the corner of the coupler, which is good for the proper rinsing of the coupler. Fig 6 shows that the normalized separation distance between the recirculation is decreasing and the recirculation is approaching to the flow path for the high Reynolds number. The relation between the Reynolds number and the normalized separation distance for various chamfer radiuses(R) is shown in Fig 6. The maximum separation distance L was achieved for the R of 1 mm. Figure 7 shows the flow visualization carried out on the fabricated device, which is in good agreement with the flow pattern (Fig 5(d)) simulated by the COMSOL. The flow was imaged under a microscope with polystyrene spheres by using peristaltic pump. The input flow velocity was set to 0.1m/s. As can be seen in the Fig 7, the recirculation was found not completely removed. Hence the cleaning of the device was done by the pulsed flow through the device as shown in the Fig 8.

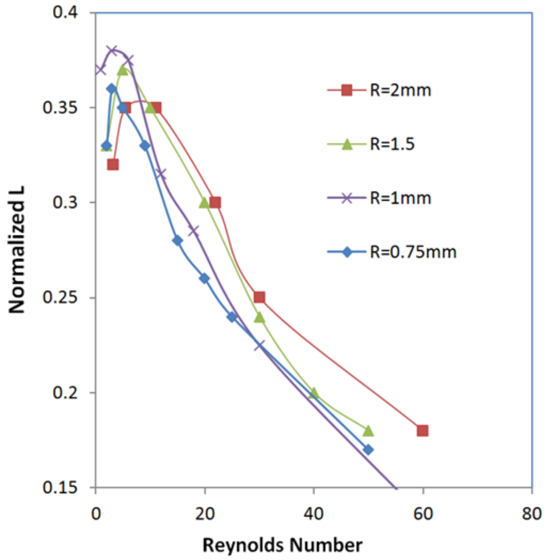


Fig 6 A plot of normalized L against Reynolds Number

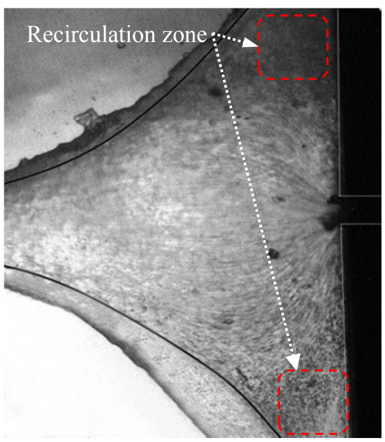


Fig 7 Flow pattern imaged on the microfluidic coupler

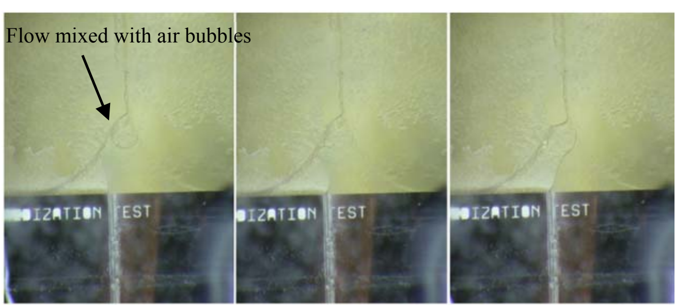


Fig 8 The flow pattern during cleaning of the device

Fig 8 shows the image of the flow of DI water through the microfluidic coupler. An intermittent flow was created by peristaltic pump at lower input velocity (~0.01m/s). In this case, the air bubbles are mixing with the DI water and breaking the bubbles in the microfluidic coupler, and water is reaching all the areas of the coupler, hence the cleaning of the device was done efficiently.

CONCLUSION

A microfliudic coupler useful for the hybrid integration of micro total analysis systems was simulated and implemented. The microfluidic coupler was designed to easily fabricate in a general laboratory environment. The effect of the Reynolds number and the flow pattern was analyzed by simulation and experiments, and the results were in agreement. Two recirculation zones were observed, which were moving to the corner of the coupler for the flow with low Reynolds numbers. The effect of recirculation was characterized by the normalized separation distance of the recirculation zone, which was observed to be depending on the geometry of the coupler. Also, the flow pattern was found to be depended on chamfer radius of the coupler.

ACKNOWLEDGMENT

Authors would like to thank Canadian Institute for Photonic Innovations (CIPI) for the financial support of the project.

REFERENCES

[1] D. R. Reyes, D. Iossifidis, P. A. Auroux and A. Manz, "Micro total analysis systems. 1. Introduction, theory, and technology," *Anal. Chem.*, vol. 74, pp. 2623-2636, 2002.

[2] P. A. Auroux, D. Iossifidis, D. R. Reyes and A. Manz, "Micro total analysis systems. 2. Analytical standard operations and applications," *Anal. Chem.*, vol. 74, pp. 2637-2652, 2002.

[3] T. Vilkner, D. Janasek and A. Manz, "Micro total analysis systems. Recent developments," *Anal. Chem.*, vol. 76, pp. 3373-3386, 2004.

[4] B. Bilenberg, T. Nielsen, B. Clausen and A. Kristensen, "PMMA to SU-8 bonding for polymer based lab-on-a-chip systems with integrated optics," *J Micromech Microengineering*, vol. 14, pp. 814, 2004.

[5] K. B. Mogensen, J. El-Ali, A. Wolff and J. P. Kutter, "Integration of polymer waveguides for optical detection in microfabricated chemical analysis systems," *Appl. Opt.*, vol. 42, pp. 4072-4079, 2003.

[6] W. J. Chang, D. Akin, M. Sedlak, M. R. Ladisch and R. Bashir, "Poly (dimethylsiloxane)(PDMS) and silicon hybrid biochip for bacterial culture," *Biomed. Microdevices*, vol. 5, pp. 281-290, 2003.

[7] T. A. Crowley and V. Pizziconi, "Isolation of plasma from whole blood using planar microfilters for lab-on-a-chip applications," *Lab Chip*, vol. 5, pp. 922-929, 2005.

[8] C. H. Cho, W. Cho, Y. Ahn and S. Y. Hwang, "PDMS–glass serpentine microchannel chip for time domain PCR with bubble suppression in sample injection," *J Micromech Microengineering*, vol. 17, pp. 1810, 2007.

[9] J. A. Kim, J. Y. Lee, S. Seong, S. H. Cha, S. H. Lee, J. J. Kim and T. H. Park, "Fabrication and characterization of a PDMS–glass hybrid continuous-flow PCR chip," *Biochem. Eng. J.*, vol. 29, pp. 91-97, 2006.

[10] I. K. Dimov, A. Riaz, J. Ducrée and L. P. Lee, "Hybrid integrated PDMS microfluidics with a silica capillary," *Lab Chip*, vol. 10, pp. 1468-1471, 2010.

[11] J. Ozhikandathil and M. Packirisamy. Silica-on-silicon waveguide integrated polydimethylsiloxane lab-on-a-chip for quantum dot fluorescence bio-detection. *J. Biomed. Opt. 17, 017006, 2012.*

[12] J. Ozhikandathil and M. Packirisamy, "Silica-on-silicon (SOS)-PDMS platform integrated lab-on-a-chip (LOC) for quantum dot applications," in *Proceedings of SPIE*, 2010, pp. 775004.

[13] D. A. Chang-Yen, R. K. Eich and B. K. Gale, "A monolithic PDMS waveguide system fabricated using soft-lithography techniques," *J. Lightwave Technol.*, vol. 23, pp. 2088, 2005.

[14] R. Rannacher, *Finite Element Methods for the Incompressible Navier-Stokes Equations.* IWR, 1999.