Fabrication of Precise Micro-fluidic Devices using a Low-cost and Simple Contact-exposure Tool for Lithography

Toshiyuki Horiuchi and Shinpei Yoshino
Tokyo Denki University, 5 Senju-Asahi-cho, Adachi-ku, Tokyo, Japan

Keywords: Micro-fluidic Device, Micro-mixer, Lithography, Thick Resist, Vertical Sidewall, Blue Filter.

Abstract: Various methods have been proposed for fabricating biochemical, pharmaceutical, and medical micro-fluidic devices. Among them, the new method using groove patterns formed in a thick resist film as the flow paths is promising. Because the flow paths are directly fabricated only using one lithography process, complicated flow paths can be obtained easily and precisely. However, it is often required to prepare an expensive exposure system newly for applying the method to practical fabrications of the devices. For this reason, the effective method has not been sufficiently utilized practically. Here, a very low-cost exposure tool was developed to make a breakthrough. In the new tool, functions were minimized, and limited to indispensable ones. However, because the required pattern widths were in the range of 50-200 μm, flow-path patterns were nicely fabricated. Assembling the fabricated micro-mixer chips with the vessels and lids, it was verified that two liquids were simultaneously injected into the mixer paths without leaks. Thus, it was clarified that the new exposure tool was useful. Micro-patterns fabricated using the new simple exposure tool will be useful for developing various micro-fluidic devices.

1 INTRODUCTION

Various original and characteristic micro-fluidic devices are proposed and fabricated for researches, and investigated in detail (Jacobs, et al., 2009) (Serra, et al., 2011) (Bouhadda, et al., 2012) (Curto, et al., 2012) (Kashkary, et al., 2012). However, on the final practical stage, the devices are generally thrown away after once used. Accordingly, it is necessary to fabricate them easily with a low cost. For this reason, various methods have been proposed for fabricating practical micro-fluidic devices. In most cases, the micro-fluidic devices are fabricated by duplicating the original device to plastic resins. As resins, poly-dimethyl-siloxane (PDMS), epoxy, and poly-methyl-methacrylate (PMMA) are used, for example (Lopez, et al., 2009) (Chen, et al., 2010) (Campbell, et al., 2011).

On the other hand, it is a very important subject how to fabricate the original devices or the original moulds of the device for the use of replicating the final working devices. Various methods are also proposed for preparing such original moulds. The most popular method is the one using the etching of silicon or glass substrates. In this method, flow-path moulds are fabricated by etching the substrates masked by the resist patterns (Avram, et al., 2008) (Eun, et al., 2008). The final working devices are fabricated using injection mould, hot stamp, or nano-imprint technologies (Yang, et al., 2009) (Oakley, et al., 2009).

In some cases, the original moulds are fabricated using resist patterns. As resins for this use, SU-8 and PMMA are mainly used (Riahi, et al., 2012). Methods for fabricating the moulds using metals such as nickel are also proposed (Liu, et al., 2013).

Comparing with these methods, the new method using deep grooves formed in thick resist films directly as flow paths is notable. Fine and deep fluid paths with any complicated shapes and rectangular cross-sections are easily and simply fabricated only using lithography process, and the fluid paths are easily but surely sealed only covering them by a flat plate lid and binding the substrate with fluid paths of resist and the lid using several bolts and nuts. Because the resist surfaces are almost perfectly flat and the resist films have appropriate elasticity, fluid paths are favourably sealed. In addition, sidewall profiles and angles of the fluid paths are controllable by selecting effectual lithography conditions. In many cases, perpendicular sidewalls or rectangular cross sections are preferred. For this reason, SU-8 is mainly used as a resist (Horiuchi, et al., 2010). The

Horiuchi T. and Yoshino S..
Fabrication of Precise Micro-fluidic Devices using a Low-cost and Simple Contact-exposure Tool for Lithography.
DOI: 10.5220/0004724900050011
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (BIODEVICES-2014), pages 5-11
ISBN: 978-989-758-013-0

main component of SU-8 is epoxy resin, and it is inert for blood and other body fluids.

However, low-cost and simple exposure tools for fabricating such resist patterns are not commercially available, or not accessible from the viewpoints of costs and flexibility for the applications. Generally speaking, conventional expensive lithography tools are unsuitable for small volume productions and specimen size variations.

In this paper, a very low-cost exposure tool is handmade to answer these subjects. Key ideas are the extremely simple contact exposure setup, and the insertion of a blue filter to the exposure optics.

Whitesides' group is researching paper-based micro-fluidic devices by patterning paper using SU-8 (Martinez, et al., 2008) (Martinez, et al., 2010). Here, thicker SU-8 film is coated on a silicon wafer, and sharper and clearer patterns are printed for obtaining deep grooves.

2 THICK RESIST PATTERNING USING CONTACT EXPOSURE

Contact exposure is the most simple lithography method which has been used for a long time. In general, mask aligners are used for this lithography. However, if fine and accurate alignment between a mask and a wafer is not required, indispensable equipments are limited to a light source for exposure and an exposure stage for placing the mask and wafer. For this reason, much simpler tools are applicable. Here, a versatile Ultra Violet (UV) light source (Sumita Optical Glass, LS-140UV) was used, as shown in Fig. 1. The light flux ejected in wide angles from the light guide was rearranged to almost parallel flux using a collective lens. In the case of fabricating fluid paths in a resist film, accurate alignment between a mask and a substrate is not required. Accordingly, if a mask is laid on a substrate as their corners are just fitted together, and placed on the stage, patterns on the mask are printed almost at an appropriate position on the substrate with good repeatability. Therefore, precise micro-mixers are easily fabricated in spite of using such a simple and low-cost scheme. The spectral light intensity distribution of the source is shown in Fig. 2. Silicon wafers with a size of 50-mm square and a thickness of 625 μm were used as substrates, and film masks with a size of 50-mm square and a thickness of 100 μm were used. The wafers were coated with a negative resist SU-8 (MicroChem). The thickness of the resist was controlled to

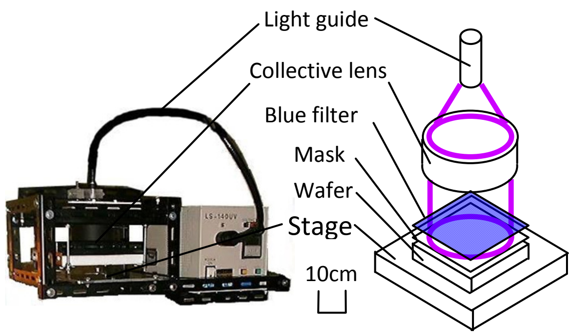

Figure 1: Simple exposure system used for this research.

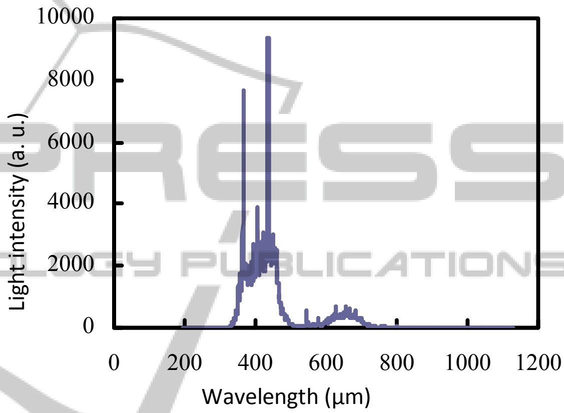

Figure 2: Spectral light intensity of exposure source.

approximately 100 μm. Spectral transmittance of the resist is shown in Fig. 3. Because light rays in UV and short-wavelength visible light regions are absorbed in the resist, the resist is sensitive to the light rays with wavelengths less than approximately 450 nm. Considering the spectral intensity of exposure source, it is supposed that the resist is most sensitive to 365-nm light. However, the absorption of 60% at 365-nm wavelength is too large to sensitize the thick resist film appropriately to the bottom. In other words, the exposure light energy is absorbed too much near the resist surface, and slightly absorbed near the bottom. As a result, patterns with T-shape or inversed-trapezoid cross sections are obtained. In some cases, eaves of the T-shape patterns hung down, as shown in Fig. 4. It is obvious that grooves with such cross-sections are inconvenient as flow paths.

It was supposed that sidewall profiles of the patterns would be improved to vertical ones if the difference of exposure intensity between the surface and the bottom was decreased. To realize these improvements, it is effective to remove or reduce the short UV-wavelength components in the exposure light rays. For this reason, a blue filter was inserted.

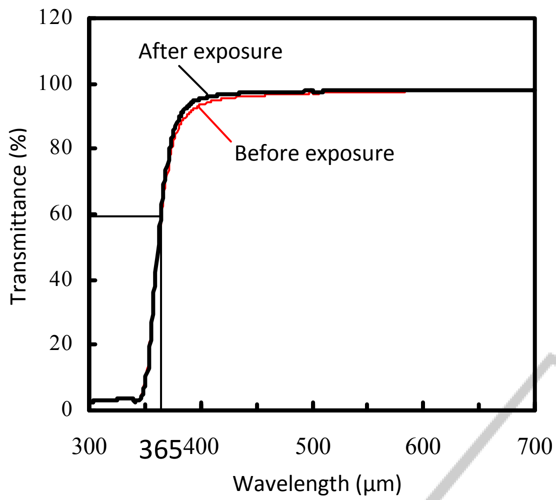

Figure 3: Transmittance of 100-μm thick SU-8 film.

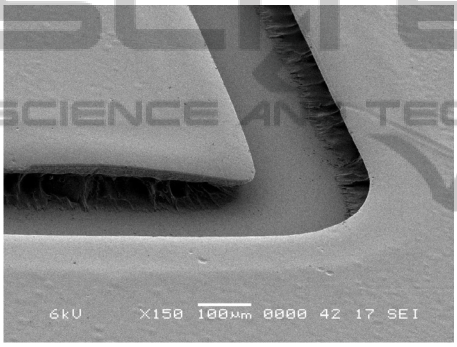

Figure 4: T-shape patterns with eaves hanging down.

The spectral transmittance of the blue filter was measured, as shown in Fig. 5.

As a result of inserting the blue filter, the spectral distribution of the exposure light on the wafer stage was improved, as shown in Fig. 6, and SU-8 patterns with almost rectangular cross sections were obtained, as shown in Fig. 7. The round shapes of corners depend on the mask patterns and are not caused by the light diffraction. To fabricate patterns with lower thicknesses is easier. However, deep grooves are preferable from the viewpoint of obtaining a Reynolds number as large as possible.

To evaluate the perpendicularity of sidewall profiles, pattern widths at the resist surface and the bottom were measured. As a result, differences of pattern widths between at the top and the bottom were less than 20 μm, that is almost 10% of the mean pattern widths, as shown in Fig. 8. Almost same results were obtained using a 405-nm narrow band-path filter with a full width half maximum (FWHM) of 10 nm. However, because only a little part of the exposure light rays were utilized, approximately

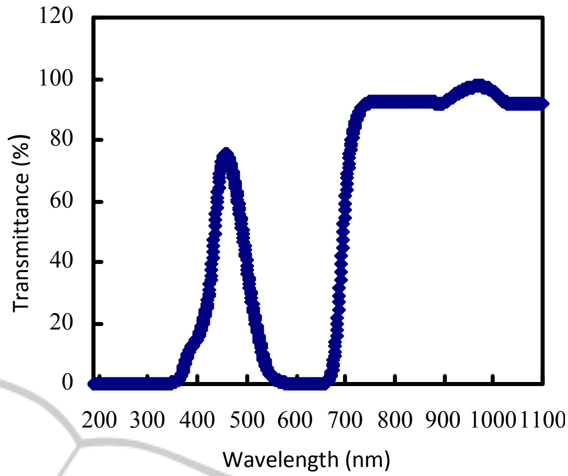

Figure 5: Spectral transmittance of the blue filter.

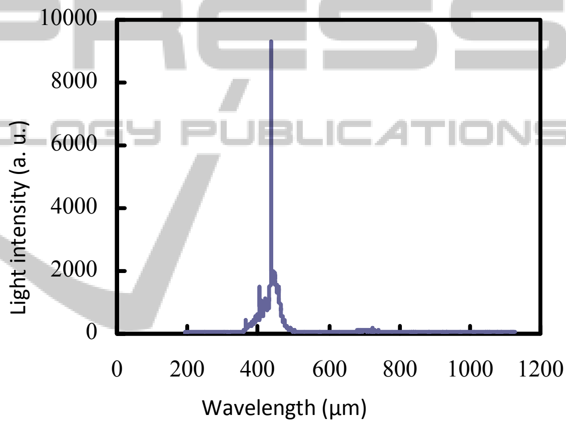

Figure 6: Spectral light intensity of exposure source when the blue filter is inserted.

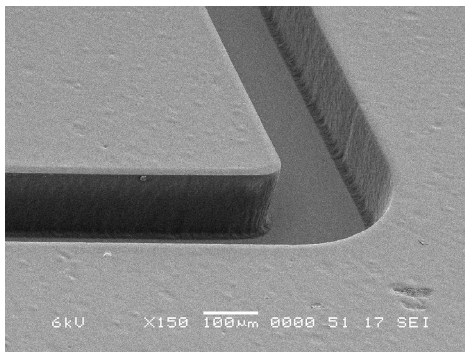

Figure 7: Trench pattern with perpendicular sidewalls.

twice exposure time was required.

Next, pattern width homogeneity in the exposure field of 15 mm square was investigated. The widths were measured using top view photographs of the patterns. Fig. 9 shows the results. Pattern widths were measured at 18 points shown in the figure. It was clarified that the widths were almost homogeneous, and the deviation were approximately within ±8 μm.

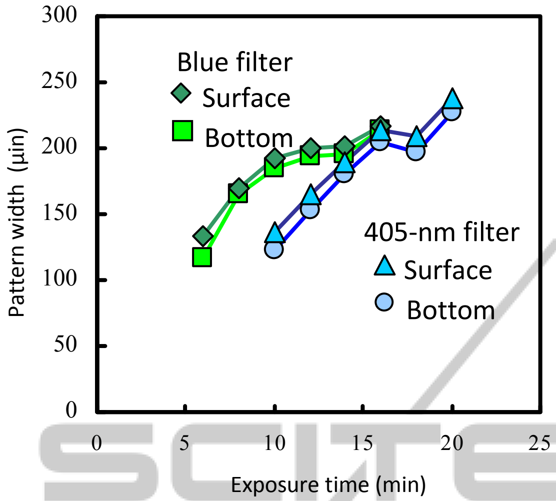

Figure 8: Evaluation results of sidewall perpendicularity.

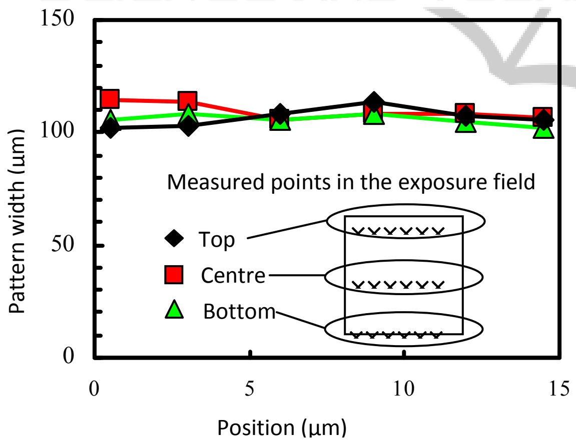

Figure 9: Homogeneity of pattern width in the exposure field.

3 FABRICATION OF MICRO- FLUIDIC DEVICE PATTERNS

Because the patterning tool was prepared, and the patterning processes were checked, patterns for the use of micro-fluidic paths were formed. An example of micro-mixer pattern is shown in Fig. 10. The sizes of the devices were 14.3 mm × 5.7 mm, and the favourable exposure dose was 3.5-4 J/cm^2. The designed widths of the Y-shape patterns at both entrances and the repeatedly winding parts were 50 and 100 μm, respectively. The widths were measured using the optional function prepared for the scanning electron microscope (JSM 5510, JEOL). Measured pattern widths were almost homogeneous, as shown in Fig. 11. The diameters of two inlet ports and an outlet port are 2mm.

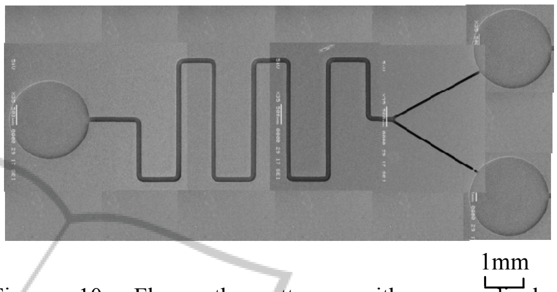

Figure 10: Flow-path patterns with perpendicular sidewalls.

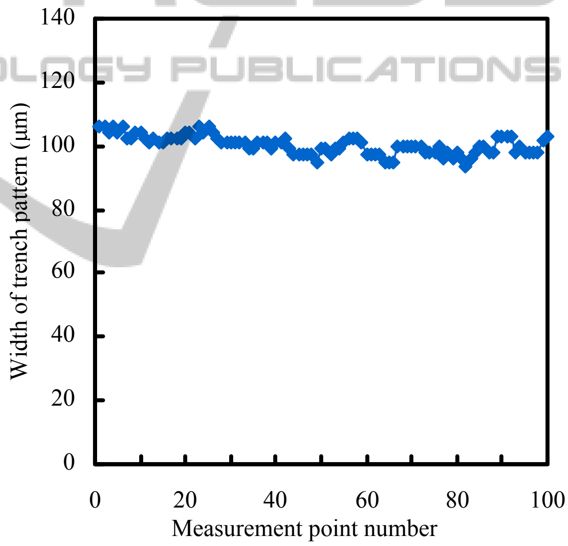

Figure 11: Width homogeneity of flow-path patterns.

4 ASSEMBLY OF MICRO-MIXERS

Micro-mixers were assembled using the resist micro-fluidic paths formed on silicon wafers. Plastic vessels and lids were fabricated using a simple 3 dimensional milling machine. A silicon wafer chip with the resist paths was embedded in a concave made on the vessel, and the resist surface was slightly stuck out from the top surface of the vessel, as shown in Fig. 12. As a result, the resist surface was homogeneously pressed by the flat lid. Each of the thickness of the vessel and the lid was as large as

5 mm so as not to be bent and curved when they were bound by bolts and nuts. Micro-tubes with inner and outer diameters of 1 and 2 mm were attached to the inlets and outlet using epoxy adhesive. No heat treatments were added to the resist paths after the patterning.

Fig. 13 shows the outside view of the assembled micro-mixer. The sizes of the device were 23×30×15 mm. The depth of the rectangular concave engraved on the vessel surface was made a little shallower than the total thickness of the micro-mixer chip. As a result, the resist-path surface became higher than the vessel surface. The height difference or stick-out height h is almost equal to the gap between the surface of vessel and the back surface of lid, as shown in the figure. It was clarified that the stick-out height h should be controlled between 35 and 45 µm to prevent the leaks.

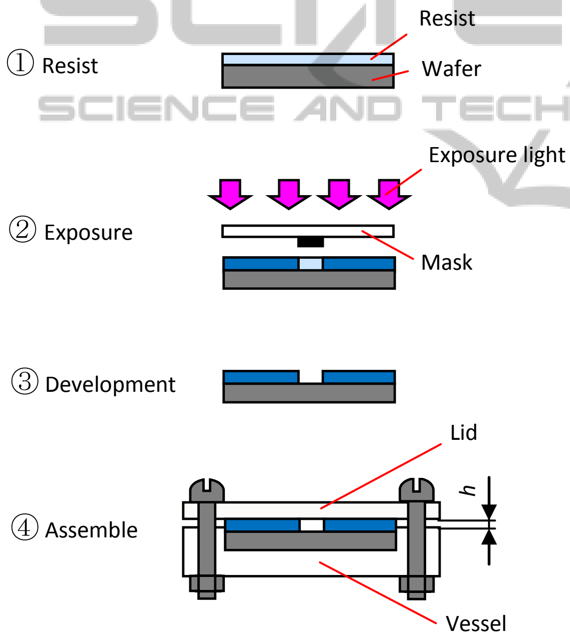

Figure 12: Fabrication method of micro-mixer.

5 FLOW TEST

Two coloured liquids were simultaneously injected from the Y-shape inlets for verifying that they did not leak out though the sealed gaps between the surfaces of resist patterns and the lid plate. The liquids were injected using manual syringes at the initial stage, and automatic syringe pumps at the final stage. Coloured waters were used as the liquids. Because the seal depends on the elastic deformation

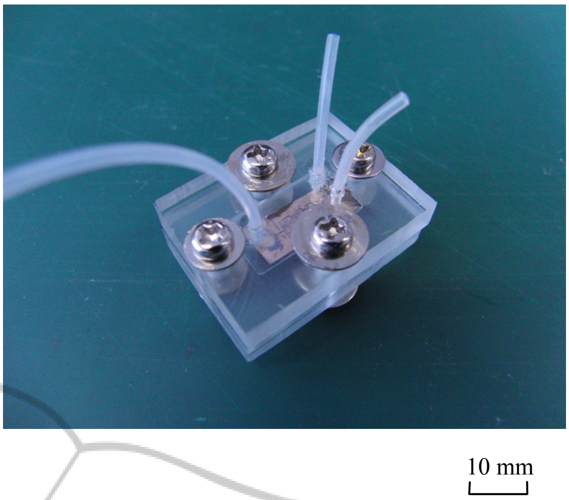

Figure 13: Outside View of the fabricated micro-mixer

Figure 14: Non-mixing flow of two coloured waters.

Blue and yellow waters flew without being mixed.

of the resist, it was necessary that the surface of the resist film was sufficiently stuck out from the vessel surface, as mentioned above. On the other hand, the lid plate is bended when it is bound with the vessel at the four corners, and the bending deformation increase depending on the stick-out height of the resist. For this reason, the optimum stick-out height should be decided considering the rigidity or thicknesses of the lid and the vessel.

Fig. 14 shows the flow in the mixer. When same liquids with yellow and blue colours were simultaneously injected, the two liquids were separately flown without being mixed together.

In the past research, two liquids prepared

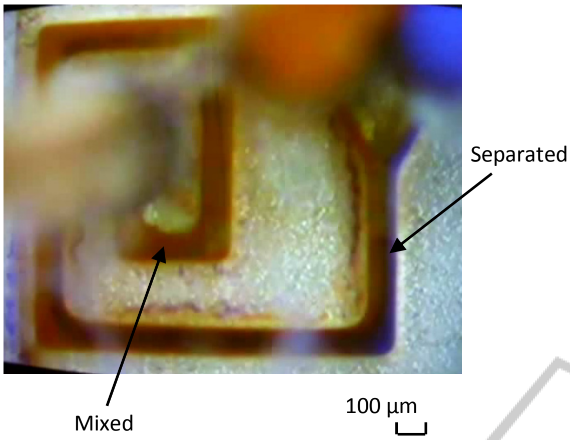

Figure 15: Example of micro-mixing.

similarly were successfully mixed in a snail-shape channel, as shown in Fig. 15. In this case, liquids coloured in red and blue were used. Separated red and blue flows were gradually mixed after they passed corners. Accordingly, it is thought that the liquids will be mixed if the shape of the channel is improved. A lot of papers had been written on micro-mixing in micro-fluidic devices (Jain, et al., 2013) (Rahimi, M., et al., 2014). Considering the reported remarks, vigorous research efforts should be done hereafter.

6 CONCLUSIONS

A very simple and low-cost exposure tool was developed, and applied to fabricate micro-fluidic devices in which resist patterns were directly used as flow paths. In spite of using such a simple and low-cost tool, precise flow-paths with perpendicular sidewalls were successfully fabricated, because a blue filter was inserted to adjust the light absorption of the thick resist film. Micro-fluidic device chips made by the resist were embedded in the plastic vessels, and capped by the lids. Although the lids were simply bound with the vessels using small bolts and nuts, injected fluids were flown without leaks. The developed tool and the method to fabricate micro-fluidic devices will be effective and useful for economical small-volume production.

ACKNOWLEDGEMENTS

This work was partially supported by Research Institute for Science and Technology of Tokyo Denki University, Grant Number Q13T-02.

REFERENCES

Avram, M., Iliescu, C., Volmer, M., Avram, A., 2008. Microfluidic device for magnetic separation in lab-on-a-chip systems, *Digest of Papers, Microprocesses and Nanotechnology 2008, 21st International Microprocesses and Nanotechnology Conference*, 442-443.

Bouhadda, I., Sagazan, O., Bihan, F. L., 2012. Suspended Gate Field Effect Transistor with an Integrated Micro-Fluidic Channel Performed by Surface Micromachining for Liquids Sensing, *Procedia Engineering* 47, 754-757.

Campbel, K., McGrath, T., Sjölander, S., Hanson, T., Tidare, M., Jansson, Ö., Moberg, A., Mooney, M., Elliott, C., Buijs, J., 2011. Use of a novel micro-fluidic device to create arrays for multiplex analysis of large and small molecular weight compounds by surface plasmon resonance, *Biosensors and Bioelectronics* 26, 3029-3036.

Chen, C. S., Chen, S. C., Liao, W. H., Chien, R. D., Lin, S. H., 2010. Micro injection molding of a micro-fluidic platform, *International Communications in Heart and Mass Transfer* 37, 1290-1294.Jacobs, T., Kutzner, C. Kropp, M., Brokmann, G., Lang, W., Steinke, A., Kienke, A., Hauptmann, P., 2009. Combination of a novel perforated thermoelectric flow and impedimetric sensor for monitoring chemical conversion in micro fluidic channels, *Procedia Chemistry* 1, 1127-1130.

Curto, V. F., Fay, C., Coyle, S., Byrne, R., O'Toole, C., Barry, C., Hughes, S., Moyna, N., Diamond, D., Lopez, F. B., 2012. Real-time sweat pH monitoring based on a wearable chemical barcode micro-fluidic platform incorporating ionic liquids, *Sensors and Actuators* B 171-172, 1327-1334.

Eun, D. S., Kong, D. Y., Chang, S. J., Yoo, J. H., Hong, Y. M., Shin, J. K., Lee, J. H., 2008. Micro-PCR Chip with Nanofluidic Heat-Sink for Faster Temperature Changes, Digest of Papers, *Microprocesses and Nanotechnology 2008, 21st International Microprocesses and Nanotechnology Conference* , 448-449.

Horiuchi, T., Watanabe, H., Hayashi, N., Kitamura, T., 2010. Simply Fabricated Precise microfluidic Mixer with Resist Flow Paths Sealed by an Acrylic Lid, *Proceedings of The third International Conference on Biomedical Electronics and Devices*, 82-87.

Jain, M., Nandakumar, K., 2013. Optimal patterning of heterogeneous surface charge for improved electrokinetic micromixing, *Computers and Chemical Engineering* 49, 18-24.

Kashkary, L., Kemp, C., Shaw, K. J., Greenway, G. M., Haswell, S. J., 2012. Improved DNA extraction efficiency from low level cell numbers using a silica monolith based micro fluidic device, *Analytica*

Chimica Acta 750, 127-131.

Liu, F., Tan, K. B., Malar, T. P., Bikkarolla, S. K., Kan, J. A., 2013. Fabrication of nickel molds using proton beam writing for micro/nano fluidic devices, *Microelectronic Engineering* 102, 36-39.

Lopez, F. B., Scarmagnani, S., Walsh, Z., Paull, B., Macka, M., Diamond, D., 2009. Spiropyran modified micro-fluidic chip channel as photonically controlled self-indicating system for metal ion accumulation and release, *Sensors and Actuators* B 140, 295-303.

Martinez, A. W., Phillips, S. T., Wiley, B. J., Gupta, M., Whiteside, G. M., 2008. Flash: A rapid method for prototyping paper-based microfluidic devise, *Lab Chip* 8, 2146-2150.

Martinez, A. W., Phillips, S. T., Whiteside, G. M., Carrilho, E., 2010. Diagnostics for the developing world: microfluidic paper-based analytical devices, *Anal. Chem*. 82, 3-10.

Oakley, J. A., Robinson, S., Dyer, C. E., Greenman, J., Greenway, G. M., Haswell, S. J., 2009. Development of a gel-to-gel electro-kinetic pinched injection method for an integrated micro-fluidic based DNA analyser, *Analytica Chimica Acta* 652, 239-244.

Rahimi, M., Azimi, N., Parvian, F., Alsairafi, A. A., 2014. Computational Fluid Dynamics modelling of micromixing performance in presence of microparticles in a tubular sonoreactor, *Computer and Chemical Engineering* 60, 403-412.

Riahi, M., 2012. Fabrication of a passive 3D mixer using CO2 laser ablation of PMMA and PDMS moldings, *Microchemical Journal* 100, 14-20.

Serra, N., Maeder, T., Gentsch, O., Ryser, P., 2011. Fabrication of polymer-based micro devices: Formulation study of the paste, *Sensors and Actuators* A 172, 336-340.

Yang, R., Lu, B. R., Wang, J., Xie, S. Q., Chen, Y., Huq, E., Q, X. P., Liu, R., 2009. Fabrication of micro/nano fluidic channels by nanoimprint lithography and bonding using SU-8, *Microelectronic Engineering* 86, 1379-1381.