International Training Program
MESA+ Institute for Nanotechnology, University of Twente, Netherlands

Department of Semiconductor Electronics and Integration Sciences,
Graduate School of Advanced Sciences of Mater, Hiroshima University, Japan
Shugo Okabe

As the long-term placement program of International Training Program (ITP), I have studied about low cost material micro analysis chip at University of Twente. The duration of visit was two months (8th January 2012 to 16th March 2012). I worked at the BIOS Lab on a Chip group of Prof. Albert van den Berg. The summary of the visit is reported below.

1. The life in Twente University

In this program, I lived in the dormitory on a premise of university. In this dormitory there were about 4~7 students. It had a communal restroom, bathroom, kitchen and laundry room. Because the rules and curfew are not particularly, the lifestyle seemed to be different for each dormitory. In the university, it is convenient for both transportation and living because there are a supermarket, hairdressing salon and some bus stop. It takes about 15 minutes to walk from lived dormitory to MESA+ lab. Most of students seemed to go to school by bicycle, so, there are well-paved wide cycle road. In the laboratory, most of members worked from 9:00 to 18:00 including lunch and two coffee times. However, they can obtain the results efficiently by virtue of supporting from technical staffs and doing frequent short discussion. Once a week, I discussed with super visor about progress of my research too.

2. The background and purpose of my research

I have been studying the processing method for the precise structure on a paper by hot embossing process using Si-die in Hiroshima University (Figure 1). However, this analysis chips demand more processing accuracy to practical clinical use. On the other hand, such technology and know-how is currently still a few precedents. Therefore, in this program, I wanted to survey and study micro-fabrication technologies for some low cost materials in addition to paper.

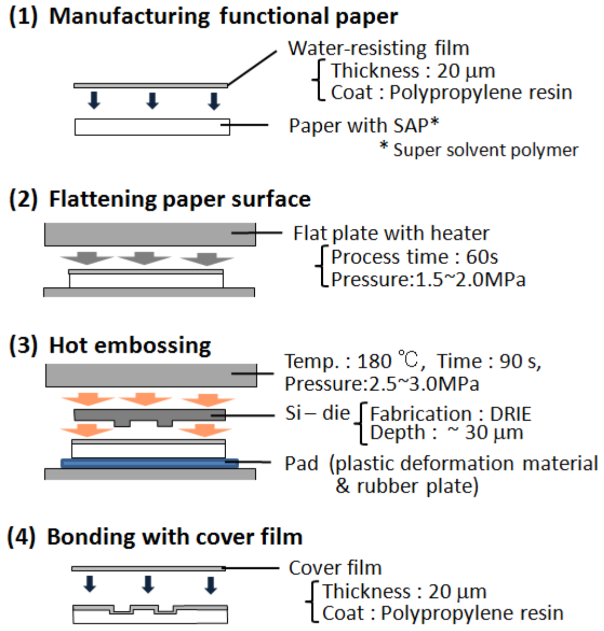


Figure 1: Fabrication process of paper chip

3. The content of my research

In this program, I researched hot embossing process using PDMS mold onto Polystyrene (PS) that known as low cost material. The PS has numerous advantages for micro devices including low cost, rigidity, chemical stability, and facility molding. Using PDMS as a mold presents several advantages. Because of its elasticity and low surface energy, the demolding process after embossing the micro structured surface is straightforward. Also, topographical features at the nanoscale can be easily-replicated. However, since PDMS is a soft material, it is prone to mechanical damage especially for microstructures with large aspect ratio and small cross-sectional area such as the micropillars. Furthermore, it should be noted that because of the softness of the PDMS mold, excess embossing force should be avoided during embossing to prevent any excess geometrical deformation of the PDMS mold which will result in poor replication.

In this program, PhD. Adithya Sridhar as supervisor has been a great help to me.

1st Week: After completed some procedures and be introduced members of BIOS group, I discussed with supervisor about purpose and strategy of my research.

2nd Week: In order to make PDMS mold, fundamental procedures were practiced by fabricating prototype. The PDMS mold was fabricated from mother die that made by using SU-8 resist on Si wafer. A PDMS prepolymer (10 : 1 w/w) was cast onto the etched wafer and cured at 60 ◦C for 4 hours. The PDMS mold was carefully peeled away and was ready for hot embossing.

3rd - 4th Week: I was taught how to the hot embossing using PDMS mold on PS. The microwells structures (diameter: 100 μm, depth: 180 μm) intended to cell culture were fabricated for testing. As the base material, PS dishes were used. The hot embossing process was used a hot embossing equipment for PS dishes such as Figure 2. PS dishes placed above copper disc and heat selectively applied temp regulated by soldering iron. Only region is contact with copper melts. Pressure can be varied by adjusting screws. The fabrication process was written below. First, after setting PS dish and PDMS mold on copper plate, it is started to emboss. After elapsed any embossing time, it is cooled at room temperature on holding applied pressure. Finally, the PDMS mold is carefully peeled from PS after unfixed from the equipment. The best condition had ever fabricated was embossing temperature: 180 ℃, embossing time: 15 min (Figure 3).

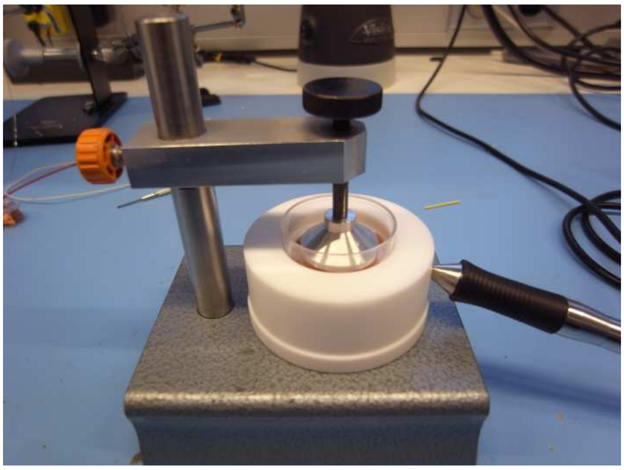


Figure 2: Hot embossing equipment for PS dishes

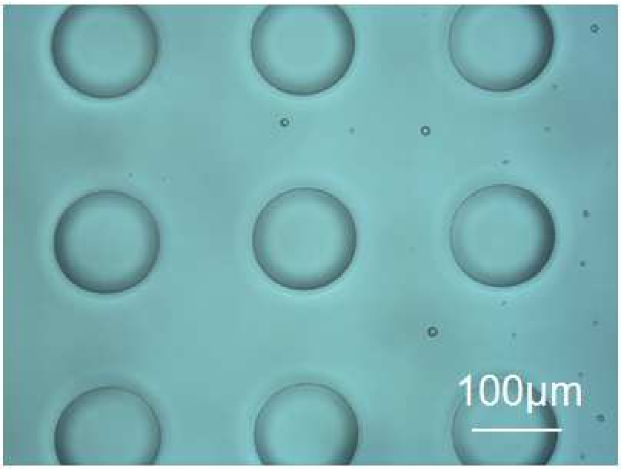


Figure 3: Photo of fabricated microwells
(180℃, 15min)

5th - 8th Week: I have surveyed about difference of formability between using Si mold and PDMS mold for hot embossing on PS. According to my survey in Hiroshima University, I had found that it can be cause of resistance of a fluid to flow depending on range of channel corner radius. So, I focused attention on fabrication accuracy of channel corner used each mold.

PS slides (25 mm × 75 mm, thickness: 1 mm) were prepared for accommodating large scale mold. Figure 4 shows the hot embossing process for PS slides. A hot plate can be heated to 180℃ was prepared for heating PS slides. A 1 kg weight was prepared for pressurize. Si mold for test molding (channel width: 100 µm, depth: 30 µm, length: 15 mm) was brought from Japan, and PDMS mold has same structure was fabricated.

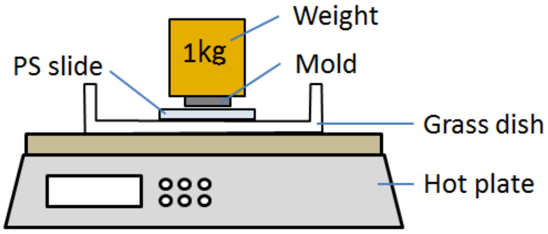


Figure 4: Hot embossing process for PS slides

As preliminary research, the hot embossing using each molds on PS slide were tried the cases that change embossing temperatures (110 ~ 170 ℃) and embossing times (30 ~ 90 min). As results of preliminary research, at temperatures below 140 ℃, the depth of microchannle was not enough because of PS couldn't be softening and flowing enough. On the other hand, breakage of Si mold at demolding process were happened at temperatures over 160 ℃. Therefore, embossing temperature was defined as 150 ℃. Embossing time (30 ~ 90 min) was selected as main factors. Each condition was fabricated 3 times. The fabrication accuracy of channel corner was evaluated by observing microscope. As is shown in Figure 5, W1 was defined as the width of the mold's microchannel, W2 as thetop of the width of the microchannel, F as the fabrication accuracy of microchannel in width. From the mold mentioned above, I can know W1 equal to 100µm. F was selected as the main evaluation indexes. The equation of F is as follow:

$$F = \frac{|W_2 - W_1|}{W_1} \times 100 \quad [\%]$$

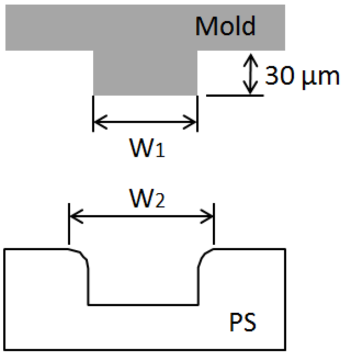


Figure 5: Definitions of W1 and W2

Experimental results were listed in Table 1, and diagram was drawn as shown Figure 6. FP was defined as fabrication accuracy of microchannel for PDMS mold, FS fabrication accuracy of microchannel for Si mold. With the lengthening of embossing time, the curve of both FS and FP declined dramatically, and reach the bottom when the embossing time was 90 min. However, both inclination of curve were looked so different.

Table 1: Experimental results

150 degree, 1 kg pressure

Embossing time [s]	FS [%]	FP [%]
30	84.3	16.0
60	21.4	12.4
90	8.8	7.2

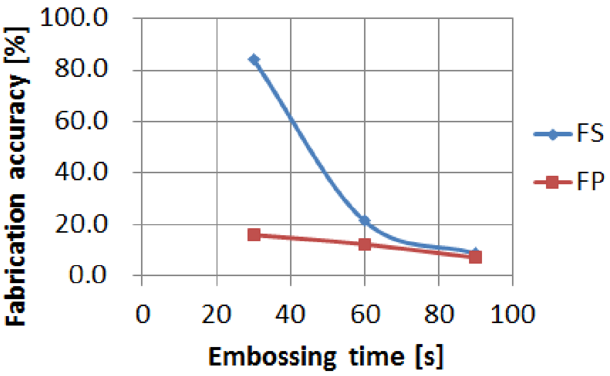


Figure 6: Relationship between embossing time and fabrication accuracy

This result was discussed below. The polymer would gradually fill the gap between the substrate and the mold during maintaining temperature and pressure stage [1]. A schematic diagram illustrating the flow behavior of the polymer during embossing is given in Figure 7. If the above process of flow behavior of the polymer was applicable this result, the case of PDMS mold can be thought to proceed faster to the phase (b) and (c) than the case of Si mold. As supposable reason, the uniform pressure applied with the surface of polymer by pressure deformation of PDMS mold. The embossing pressure by using each mold was measured by pressure indicating film (Prescale; FUJIFILM co.) as shown in Figure 8. It was confirmed that the case of used PDMS mold was possible to pressurize the PS uniformly as compared with the case of used Si mold. Therefore, I think that the melted PS at the phase (a) would be caught trying to get away by PDMS mold as shown in Figure 9.

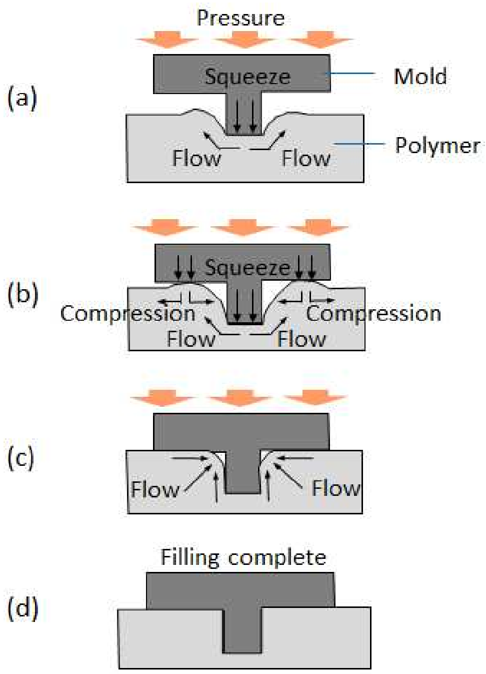
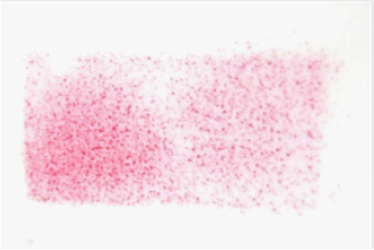


Figure 7: Schematic of polymer flow behavior during hot embossing

Si mold



PDMS mold

Figure 8: Pressure measurement

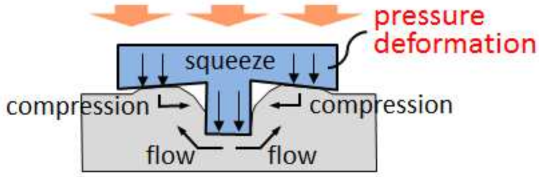


Figure 9: Schematic of polymer flow behavior by using PDMS mold

In this program, I got some new technical expertise regarding micro-fabrication technologies for low cost material. Also, I learned how to study and develop the chip devices, especially theoretical approach. After living in a foreign country, I've become mentally strong. Thanks to support from many people, I could accomplish this program. I deeply appreciate for BIOS Lab on a Chip group staffs in University of Twente and Research Center for Plasma ITP Secretariat staffs in Nagoya University.

Reference

[1] J.M.Li, C.Liu, J.Peng : Effect of hot embossing process parameters on polymer flow and microchannel accuracy produced without vacuum Journal of Materials Processing Technology, 207 (2008.10) 163.