NOVEL PATTERNING TECHNOLOGY USING AIR-PRESSURE DISPENSER FOR FABRICATING MICRO-FLUIDIC DEVICES

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Abstract: A novel method was developed to easily fabricate micro-fluidic devices with a low cost. It will be especially useful at preliminary research stages. In the new method, inexpensive commercial air-pressure dispenser was used. Adopting originally developed “wire nozzles”, it was verified that fine resist patterns with widths down to 50 µm were successfully delineated. However, because patterns have to be delineated connecting simple line patterns, it was difficult to delineate trench or hole patterns by painting out a large area. Moreover, sidewalls of the delineated patterns were not sharp. For this reason, easy image-reverse process was thought out. In the novel process, opaque liquid patterns were delineated using the dispenser on a thick negative resist film coated on a substrate, and the resist film was exposed to flood exposure light. As a result, the resist was sensitized except under the opaque liquid patterns. Therefore, trench or hole patterns corresponding to the opaque liquid pattern shapes were obtained after developing the resist. Replicated thick resist patterns have sharply-cut sidewalls, and will be durable for micro-fluidic paths or vessels of bio-devices.

1 INTRODUCTION

Micro-reactors are useful for mixing a small quantity of bio-medical liquid and chemical reagents. Even simple micro-beakers without fluid paths are also effective, because liquids are often sufficiently mixed by leaving them for a time or shaking appropriately. For this reason, various methods for fabricating micro-reactors and micro-beakers are proposed. Generally speaking, micro-reactor trenches and micro-beaker holes are separately fabricated on substrates in advance, and they are capped or sealed afterwards. It is easiest as the seal to put lid plates on the trenches and holes and bind them. If the reactor or beaker materials are elastic, the trenches and holes are easily but completely sealed for the practical use. Such structures are conveniently fabricated by patterning in thick films of resists such as negative SU-8 (MicroChem) (Horiuchi, T; Watanabe, H., Hayashi, N., Kitamura, T., 2010) (Tsai, N. C.; Sue, C. Y., 2006), EPON (Hexion Specialty Chemicals) (Yang, R.; Soper, S. A., Wang, W., 2007) and positive poly-methyl-methacrylate (PMMA) (Nugen, S. R.; Asiello, P. J., Connelly, J. T., Baeumner, A. J., 2009) using lithography, or replicating the lithographically fabricated resist patterns to plastic materials such as Poly-dimethyl-siloxane (PDMS) (Lien, K. Y.; Liu, C. J., Lee, G. B., 2008) (Casquillas, G. V.; Bertholle, F., Berre, M., Meance, S., Malaquin, L., Greffet, J. J., Chen, Y., 2008).

However, only a few amounts of micro-reactors and micro-beakers are required at preliminary research stages. In addition, required pattern sizes are as large as around 100 µm. Accordingly, expensive lithography tools such as steppers and mask aligners are unsuitable from a view point of costs.

Moreover, to decide the best features, structures and sizes of the required devices, various candidates should be compared in the research. However, reticles and masks are also expensive and it takes at least a few days to prepare them.

Under these situations, direct writing using a dispenser is expected as a new patterning technology for making a breakthrough. Here, a newly developed process is investigated for fabricating various micro-fluidic patterns using an air-pressure dispenser with special nozzle (Otsuka, S; Horiuchi, T., 2010).

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2 EFECTIVENESS OF SIMPLE REACTORS MADE BY RESIST

Micro-flow-paths fabricated by patterning in thick resist are useful for creating various bio-fluidic devices such as micro-mixers, reactors and beakers, if they are suitably capped and sealed.

Very deep trench patterns with 50-400 µm depths and steep sidewalls perpendicular to the substrates are certainly formed if the negative resist SU-8 is used. Besides, the resist patterns have favourite elasticity to seal the flow paths formed between the patterns only by capping them with a flat lid and moderately binding the substrate and the lid using screws. The elastic resist film also acts a roll of sealant. For this reason, micro-fluidic devices are easily fabricated by the composition shown in Fig. 1, for example (Horiuchi, T., Watanabe, H., Hayashi, N., Kitamura, T.2010).

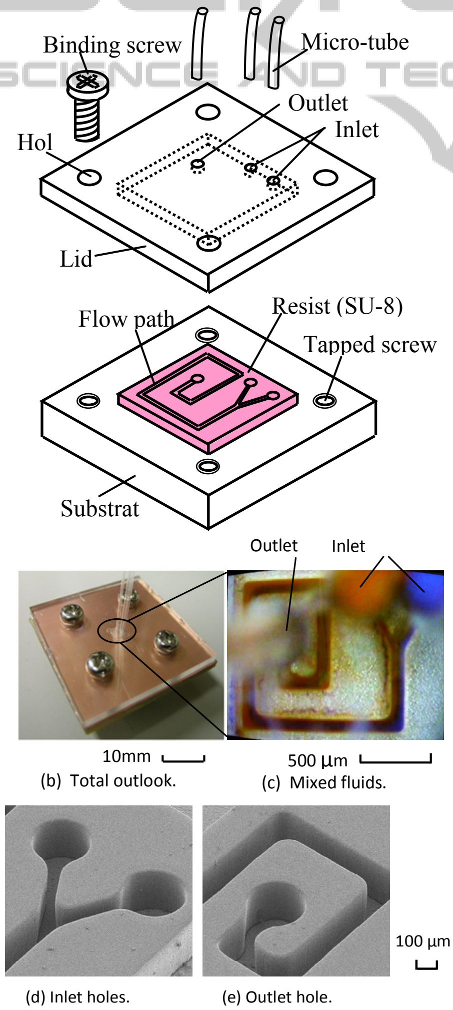

Figure 1: Micro-fluidic mixer simply fabricated by sealing SU-8 flow-paths binding a flat lid with screws.

SU-8 is mainly composed of epoxy resin, and convenient to use as the material for bio-fluidic devices because the epoxy resins are chemically stable and do not react with most of the body fluids.

Micro-fluidic devices are often fabricated by replicating original SU-8 mould patterns to PDMS. In the preliminary research stages, however, the image reverse replication process to PDMS is annoying, and not always necessary if the original SU-8 patterns are easily fabricated with a low cost, because only a few numbers of same micro-fluidic devices are required in such research levels. In addition, size parameters such as trench width, depth, path length and shape are often changed to find out the best feature of micro-fluidic devices. To correspond to such situations, a simple and low-cost fabrication method of micro-fluidic devices was investigated using an air-pressure dispenser.

3 PATTERN DELINEATION USING A DISPENSER

Because only a few numbers of same devices are necessary at the preliminary research stages, photo-lithography using a high-grade expensive stepper or a mask aligner is inexpedient. In addition, reticles and masks are also expensive, and the patterns on them cannot be revised or changed after once they are delivered, unless they are fabricated again. Moreover, turn-around time (TAT) from the pattern design to delivery is not short. It takes at least three days to obtain the ordered reticles or masks.

On the other hand, liquid dispenser systems have been gradually upgraded and inexpensively available. For this reason, various researches have been vigorously executed. (Otsuka, S; Horiuchi, T., 2010) (Fakhfouri, V.; Mermoud, G., Kim, J. Y., Martinoli A., Brugger, J., 2009) (Ohigashi, R.; Tsuchiya, K., Mita, Y. Fujita, H., 2008) (Ishida, Y.; Sogabe, K., Kai, S., Asano, T., 2008) (Murata, K., 2003).

Generally speaking, the minimum pattern size required for a micro-fluidic device is as large as around 100 µm, and such large patterns can be possibly delineated using dispenser systems.

In this research, a commercially available air-pressure dispenser system (Musashi Engineering, SHOT mini SL) shown in Fig. 2 was used for the pattern delineation. As a liquid, positive resist PMER P-LA900PM (Tokyo Ohka Kogyo) with viscosity of approximately 1500 mPa☉s at 22°C was used at first, and the resist was dispensed controlling the pressure by an air-pressure control unit (Musashi Engineering, ML-5000XⅡ).

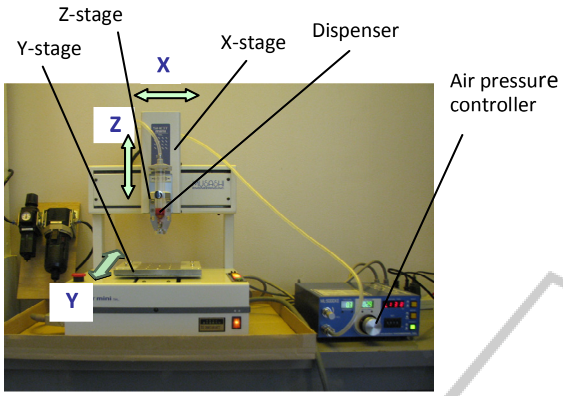

Figure 2: Air-pressure dispenser system used for the research.

It was difficult to delineate patterns with a width of around 100 µm when the commercial system was used as it was. However, applying a new idea, fine patterns with a uniform width were successfully delineated. Specifically speaking, a fine wire was inserted in the dispenser nozzle, and the tip of the wire was adjusted to slightly stick out of the nozzle, as shown in Fig. 3. As a result, various fundamental patterns were successfully delineated.

Figure 4 shows examples of line patterns delineated on a silicon wafer with a speed *v* of 10 mm/s, a wire height *h* of 10 µm and a stick-out length *s* of 30 µm. The patterns have very smooth linear edges, and the widths are almost uniform.

The pattern widths were controllable by changing the air-pressure for dispensing the resist and the delineation speed *v*, which was controlled by changing the driving speeds of X and Y stages, as shown in Fig. 5. Because both stages were driven by pulse motors, the speeds were accurately controlled by inputting appropriate pulse rate.

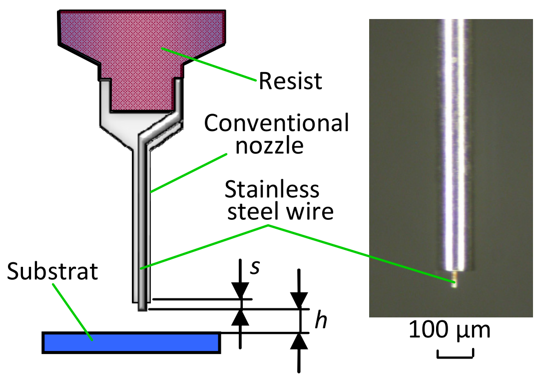

Figure 3: Newly developed wire nozzle.

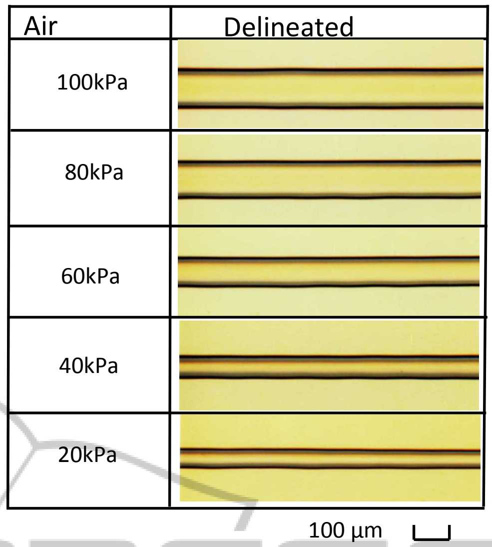

Figure 4: Delineated line patterns.

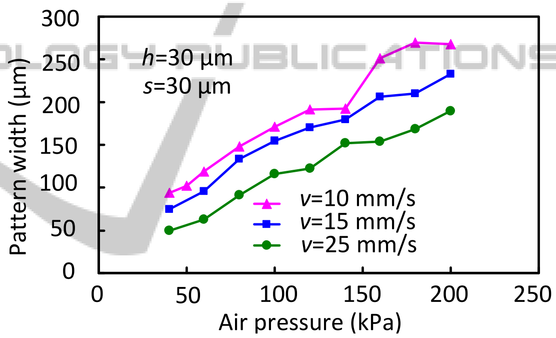

Figure 5: Pattern width dependence on scan speed and air pressure.

The width did not almost depend on *h* and *s* especially when low air-pressures were supplied, as shown in Figs. 6 and 7. The minimum line pattern width was approximately 50 µm.

Circularly curved patterns are also obtained, as shown in Fig. 8. Although the fine pattern edges were slightly waved, almost smooth edges were obtained for widths of more than 100 µm.

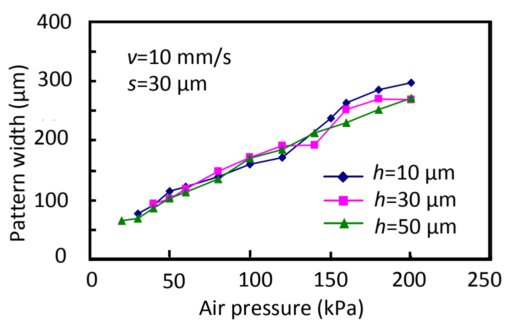

Figure 6: Pattern width independence on wire height.

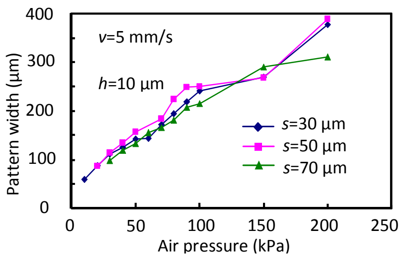

Figure 7: Pattern width independence on wire length.

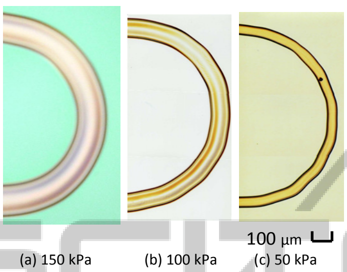

Figure 8: Circularly curved patterns delineated with a speed v of 5 mm/s, a wire length s of 50 μm and a wire height h of 30μm. The circular radius is 1 mm.

Next, micro-mixer patterns were actually delineated under the conditions of h=30 μm, s=50 μm and v=10 mm/s at the straight parts and 5 mm/s at the curved parts. Figure 9 shows the patterns. Not only the straight parts, but also the curved parts, cross point, and end points were successfully delineated.

However, cross sectional profiles of delineated PMER patterns were flat and round, as shown in Fig. 10. Measured thickness broadly distributed, as shown in Fig. 11. Such patterns were not directly available for fabricating micro-flow-paths.

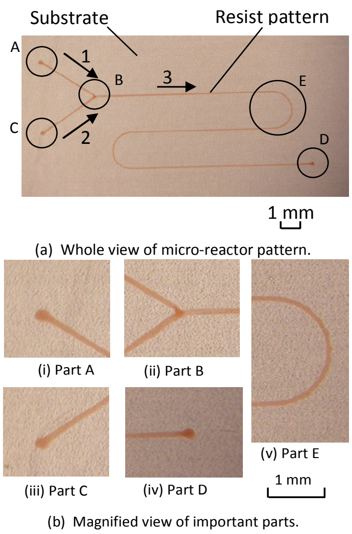

Figure 9: Micro-mixer patterns of resist PMER P-LA900PM delineated on a copper-clad plastic substrate using the air-pressure dispenser.

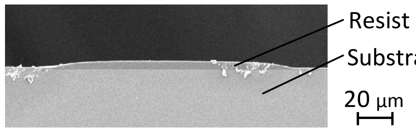

Figure 10: Typical cross section of a pattern delineated by a dispenser.

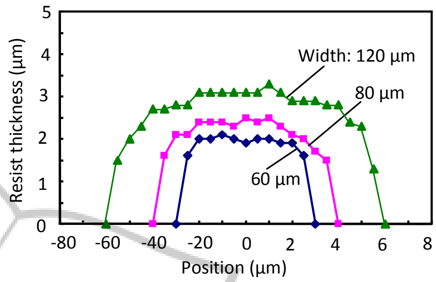

Figure 11: Thickness distribution of PMER patterns delineated using the air-pressure dispenser.

Therefore, a new idea should be thought out for transforming the flat dispenser patterns to steep and deep SU-8 patterns easily.

4 NEW PATTERNING PROCESS

Figure 12 shows the novel patterning process using the air-pressure dispenser for fabricating deep trenches of micro-fluidic mixer and holes of micro-beakers with vertical sidewalls into films of SU-8.

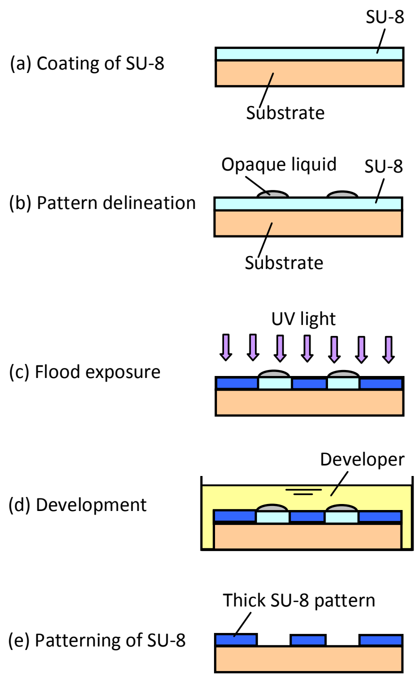

Figure 12: Newly developed pattern process.

In the new process, thick SU-8 film is coated on a substrate at first, as shown in (a). Next, patterns are delineated using the air-pressure dispenser as shown in (b). In this step, an opaque liquid such as a black water colour is used for the material to be dispensed. It is not necessary that the liquid has sensitivity to exposure light. In addition, because the negative image patterns of the micro-fluidic devices are needed, only the delineation of lines, dots, and some simple figures is required. Next, the substrate with the patterns is exposed to flood ultra violet (UV) light as shown in (c). Because the SU-8 film is partially covered by the opaque liquid patterns, only the parts under them are not sensitized to the UV light. The opaque liquid patterns are removed in the development process, as shown in (d). Through these processes, trench or hole patterns of micro-fluidic devices with steep sidewalls are made of thick SU-8, as shown in (e).

To confirm the principal feasibility of the novel process, black watercolour dissolved with water was used as an opaque liquid. They were blended by 1:1 weight ratio. After delineating line patterns on SU-8 film coated on a silicon wafer, the wafer was baked in an oven for 20 min at 90°C. Next, it was exposed to UV light using a UV lamp (Sumita Optical Glass, LS-140S) for 10 s, and developed for 10 min in the SU-8 developer. A typical cross section of SU-8 pattern is shown in Fig. 13. It was verified that approximately 100-µm thick SU-8 patterns with sharp sidewalls were successfully formed. Although the opaque liquid and the process conditions have not been optimized, very good prospects for fabricating micro-fluidic devices were obtained. The width of the groove shown in Fig. 13 was approximately 300 µm, and the minimum width should be reduced down to less than 100µm hereafter.

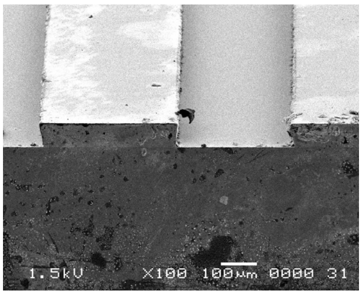

Figure 13: SU-8 patterns converted from the dispenser pattern using the novel image-reverse process.

Total TAT to fabricate a test micro-fluidic device using the new method was estimated and compared with the TAT of when the device was fabricated by the conventional projection or contact exposure lithography using a reticle or a mask.

Table 1 shows the typical processing time for the dispenser method. To print thick SU-8 patterns directly using projection or contact exposure lithography, a reticle or a mask has to be prepared in advance. It takes at least 3 days to obtain a reticle or a mask after sending the order to a mask maker, even when the patterns are very simple. On the other hand, patterning using an air-pressure dispenser is ready at any time if the flow-path design is finished. Actually effective patterning to delineate favourable patterns should be carried out after some trials. However, the time for delineation is short in most cases. The flood exposure time is comparable with the time required for the direct lithographic patterning. Times for the pre-bake and the post exposure bake are also almost the same with those for the direct lithographic patterning.

Accordingly, although the time for delineating patterns using the dispenser is additionally needed, total TAT is drastically improved from 4 days to 1 day or approximately 8 hours.

Table 1: Typical processing times for the new method.

	Process	Time
1	Coating of SU-8	3 min/substrate
2	Pre-bake	
	Hold for slow heating (65ºC)	20 min
	Bake (90ºC)	50 min
	Slow cool down	2 hr
3	Patterning trial	1 hr
4	Actual delineation	3-10 min
5	UV flood exposure	10 s
6	Post exposure bake	
	Hold for slow heating (65ºC)	20 min
	Bake (90ºC)	50 min
	Slow cool down	2 hr
7	Development and rinse	10+2 min

5 CONCLUSIONS

To promote the development of bio-fluidic devices, novel technology for easily fabricating micro-mixers and micro-beakers with a low cost was developed. In the novel method, micro-fluidic device patterns are delineated using an inexpensive air-pressure dispenser. After patterns were delineated using an opaque liquid on a thick SU-8 film coated on a substrate, they were exposed to UV light. Because only the parts of SU-8 behind the opaque liquid patterns were sheltered from the UV light, they were dissolved during the development. As a result, SU-8 structures with micro-flow-paths or micro-beaker holes were obtained. The principal feasibility was verified by the experiments, and very good prospects for the practical use were obtained.

As future works, a few subjects should be resolved. Main subject is the optimization of opaque liquid material and delineation conditions. Although fine patterns with a width of down to 50 µm were successfully delineated using a resist PMER P-LA900PM, patterns with a large width of 200-300 µm were just delineated using the water paint as an opaque liquid. Considering the difference of viscosity, parameters of the wire-nozzle such as wire and nozzle diameters, and delineation conditions have to be optimized. After enabling to delineate patterns finer than 100 µm, practical micro-fluidic devices will be developed.

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