A NOVEL FABRICATION OF IN-CHANNEL 3-D MICROMESH STRUCTURE USING MASKLESS MULTI-ANGLE EXPOSURE AND ITS MICROFILTER APPLICATION

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ABSTRACT

This paper presents a novel fabrication method of ***in-channel three-dimensional*** micromesh structures using the conventional photolithography. The micromesh was realized by exposing UV light from the backside of the SU-8 coated metal-patterned glass substrate for different angles. Numbers of exposure and irradiation angle decided the shape and the size of micromesh. Based on this technique, three different micromesh-inserted microchannel structures were fabricated. For hydrodynamic characterization, their flow resistances were measured. Finally, for the application of Micro Total Analysis System (μTAS), the microfilter was fabricated and its filtering property was demonstrated.

INTROCUCTION

The 3-dimensional porous structures are useful for the application of microfiltering and micromixing. A microfilter was fabricated by using the conventional micromachining on the plane, indicating to two-dimensional structure [1]. Since it was made separately with the microchannel, the bonding process was needed to combine with the microfilter structure and the microchannel. However, stacking the structures requires precise alignment. It also causes the hydrodynamic pressure loss and the flow stagnation. The in-channel porous structure for the use of micromixer was fabricated using the microstereolithography [2]. This process can provide the manufacturing of complex objects by the layer-by-layer light-induced polymerization of a liquid resin. Compared with the conventional UV photolithography, however, its resolution is not higher and much longer time is consumed to fabricate complex mesh structures. Also, the special equipment is required.

To this end, we propose a simple fabrication method to obtain the in-channel 3-D micromesh structures using the conventional photolithography. In order to obtain the fine line width and the high aspect ratio, we use direct coating of the thick photo-resistive on a metal-patterned glass substrate and UV light exposure from backside [3]. The three-dimensional micromesh structures are achieved simultaneously with the microchannel by controlling the number of exposure for different UV irradiation angles. Then, the plain microchannel and the micromesh-inserted microchannels were compared by measuring the flow resistances. Finally, the microfilter was demonstrated for the application of μTAS.

FABRICATION PROCESS

Figure 1 shows the fabrication process of the micromesh-inserted microchannel. Only one photo mask is needed to fabricate micromesh structure, regardless of the complexity of structures. Firstly, the Cr was evaporated on a glass substrate and lifted off. The thickness of the evaporated Cr was decided more than 1500Å to prevent UV light from passing trough the thin film of Cr. In particular, the Cr pattern is critical to decide pore size and shape of the micropillar consisting the micromesh. In the process step of Fig. 1(b), the SU-8 was spin-coated over the Cr patterned glass. The target thickness of the SU-8 was 200μm. The process step of Fig. 1(c) defines the micromesh. The UV irradiation from the backside of the glass substrate was repeated for different exposure angles by tilting the substrate. The tilting angles play a key role in achieving the micropillar net. The number of UV irradiation and the exposure angle decide the size and shape of the micromesh. Since the SU-8 was coated directly on the metal-patterned glass substrate, the perfect contact and self-alignment was achieved. As a result, light diffraction occurring at the interface of photoresist and mask could be reduced dramatically, compared with the conventional photolithography [3]. In the process step of Fig. 1(d), the SU-8 film was exposed from front-side using an additional photomask to fabricate the micromesh-inserted microchannel. Finally, the SU-8 was developed and then the micromesh-

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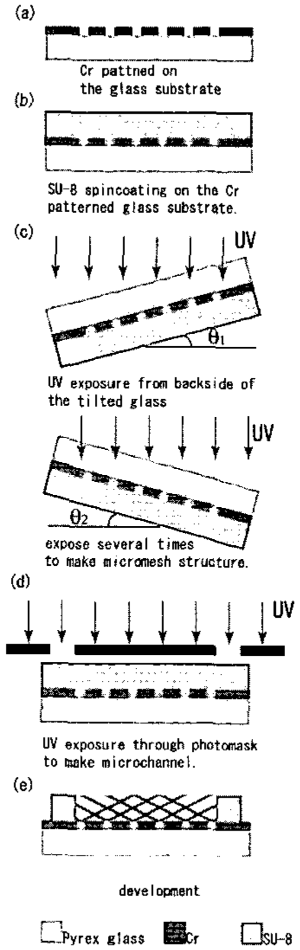


Figure 1: Fabrication process of an in-channel 3-D micromesh structure

inserted microchannel was obtained simultaneously (Fig.1 (e)). Fig. 2 shows a SEM image of the fabricated in-channel micromesh structure. The diameter and height of the micropillar was measured to be 10μm and 200μm, respectively.

Using the backside exposure for the various irradiating angles, we fabricated the three types of the in-channel micromesh structures. Fig. 3(a) and Fig. 3(b) shows the in-channel micromesh structures obtained from the backside exposure for two different substrate tilting angle conditions. The conditions of the exposure angle were θ_1=45°, θ_2=−45° (Fig.3(a)) and θ_1=45°, θ_2=0° (Fig.3(b)), respectively. In Fig. 4, the mesh structure fabricated from triple exposure was shown. The condition of the exposure angle was θ_1=45°, θ_2=−45°, and θ_3=0°. Based on the SEM photomicrographs, it was

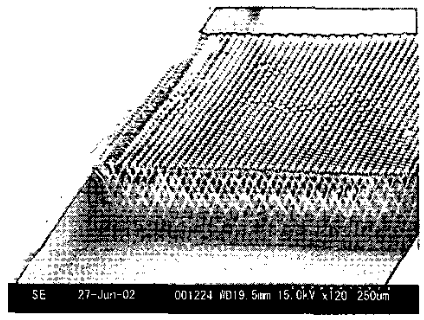
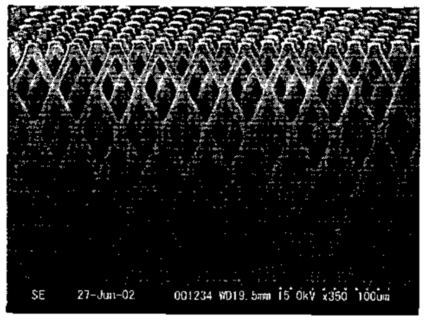
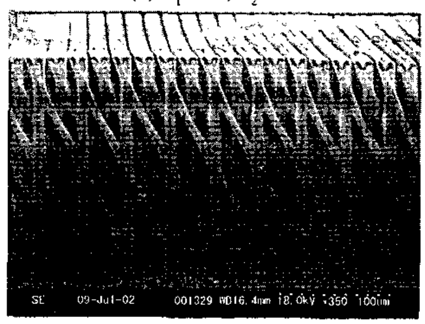


Figure 2: SEM photograph of a 3-D micromesh structure



(a) θ_1=45°, θ_2=−45°



(b) θ_1=45°, θ_2=0°

Figure 3: Micromesh structures fabricated by double exposure

determined that for the same Cr pattern on a glass substrate, the three types of the in-channel micromesh structures had the different pore shape and size. It indicates that we can control the size and shape of the micromesh pore.

RELATIONSHIP BETWEEN EXPOSURE ANGLE AND THE ANGLE OF STRUCTURES

It was also determined that the fabricated structure angle was different from the exposure angle due to the refraction of UV light in the composite material. To

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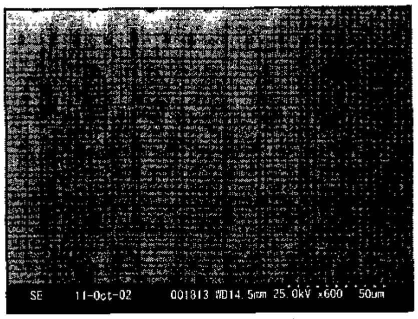

Figure 4: Micromesh fabricated by triple exposure (θ_1=45°, θ_2=–45° θ_3=0°).

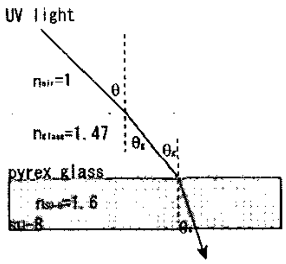

Figure 5: Schematic view of UV light pass through air, glass and SU-8

examine the fabricated structure angle, the refraction index of each material was taken into account.

Figure 5 illustrates the schematic view of the incident UV light, passing through the glass and SU-8. Since each material has the different refractive indexes, the UV light is refracted. Thus, the incident angle of the UV light is changed to the transmitted angle. Finally, the fabricated angle is decreased compared with the exposure angel. Based on the Snell's law, the transmitting angle can be obtained:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (1)$$

where n represents the refractive index and θ denotes the transmitting angle from the normal line.

For experimental evaluation, we fabricated the simple structures by varying the exposure angles and compared to the fabricated structure angles. The comparative angles were summarized in Table 1. We used n_{air}=1, n_{glass}=1.47, and n_{SU-8}=1.6 respectively. In common, the refractive index of SU-8 depends on the wavelength of the incident UV light. We defined the refractive index of the SU-8 to be 1.6 for the UV light of about 350-400nm. There shows a good agreement between the estimated angle and that of the fabricated structure.

Due to the refraction of UV light, there also exists limitation of the angle of UV light incident to the SU-8 film. It was determined that the theoretical limit of the fabricated structure angle θ_s was 38.7° at θ=90°.

Table1: Relation between the exposure angle and the fabricated structure angle

exposure angle θ [deg]	structure angel θs [deg]	
	estimated	fabricated
30	18.2	20.1
45	26.2	26.5
60	32.7	33.5
70	36	37.6

MICROFILTER

It was shown that it was possible to control the pore size and shape of micromesh structure by changing exposure angle. This directly indicates that the micromesh-inserted channel can be applied to an in-channel 3-D microfilter for Micro Total Analysis System (μTAS). To seal microchannel, a PDMS plate with an inlet and an outlet was attached to SU-8 microchannel and then they were mechanically clamped. The microchannel and the micromesh of microfilter was fabricated simultaneously and self-aligned, while in the case of the conventional two-dimensional microfilter, microchannel and filter structure were fabricated separately and precise alignment to bond them was needed.

We fabricated two microfilters with different hole size. The micromesh structure was formed in the area of 200μm × 200μm. One was a fine microfilter the other was a coarse microfilter. The exposure condition of each filter was same as shown in Fig. 3(a) (two times exposure, θ_1=45°,θ_2=–45°) because the micromesh exposed with this condition had good symmetry. The opening factor of the fine one was calculated to be 55.4% and in the case of the coarse one, the opening factor of 72.8% was obtained (Table 2).

In addition, the hydrodynamic flow resistances of two microfilters were compared (Figure 6). The flow rate was measured by ramping the applied pressure. Based on the relationship between applied pressure and flow rate, their flow resistances were obtained. Table 3 shows that the largest flow resistance was obtained in the fine microfilter.

Moreover, we demonstrated filtering property of

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the fine microfilter. For visualization, florescent beads with two different sizes were used. Diameter of florescent microbeads was ϕ20μm and ϕ0.8μm, respectively. They were introduced into the fine microfilter at the same time. The microbeads of ϕ20μm were completely trapped, while the microbeads of ϕ0.8μm could freely pass through microfilter (Figure 7).

Table2: Fabricated microfilters

filter	Hole Size [μm^2]	Opening Factor [%]
fine(mesh1)	$6.27*10^2$	55.4
coarse(mesh2)	$2.03*10^3$	72.8

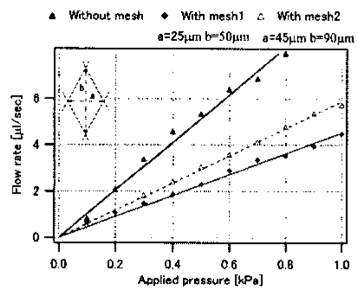

Figure 6: Flow resistance measurement

Table3: Comparison of flow resistance

	resistance[kPa/μl sec]
Without mesh	0.1
fine(mesh1)	0.23
coarse(mesh2)	0.17

CONCLUSION

The fabrication method of an in-channel three-dimensional micromesh structure was presented by using conventional photolithography. The UV irradiation from the backside of the metal-patterned glass substrate was repeated by tilting the substrate. The fabricated micromesh structure consisted of SU-8 micropillar nets with high aspect ratio. It was concluded that the size and shape of the micromesh depended on the number of exposure and tilting angle of the substrate.

To understand the mechanism of backside UV irradiation, Snell's law was taken into account. It was determined that the fabricated structure angle was different from the irradiation angle due to the refraction at the interface of air-glass and glass-photoresist. Theoretically, it was also obtained that the theoretical limit of

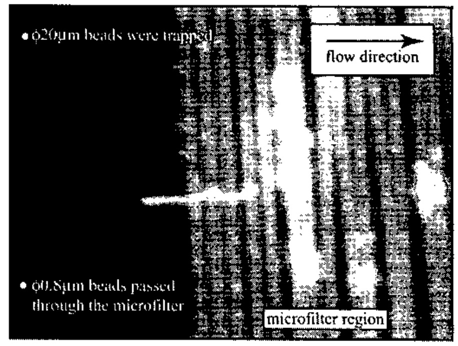

Figure 7: Filtering visualization using fluorescent beads

structure angle θ_s was 38.7° at θ=90°. For experimental evaluation, we fabricated two different microfilters and their flow resistances were compared to that of a plain microchannel. For the application of Micro Total Analysis System, the filtering property of the microfilter was demonstrated successfully.

The most significant contribution lies not only in development of a new fabrication method of itself but also in shedding light on further research works associated with application using the proposed fabrication method

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