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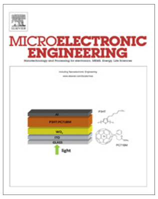

Fabricating embedded SU-8 microstructures with asymmetric inside cross section by double-side multiple partial exposure method

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ABSTRACT

Here a double-side multiple partial exposure (DoMPE) method is proposed to fabricate an embedded SU-8 microstructure with more flexible inside cross section. The proposed method uses standard lithography equipment and needs only single-layer coating of negative photoresist SU-8 on glass substrate without bonding process.

Process parameters, including development thickness at different front and back-side partial exposure doses, are experimentally characterized. Reflection effect due to Cr layer on glass substrate is shown to have influence on the development depth of SU-8 in front partial exposure. It is found that coating thicker SU-8 not only can reduce reflection effect, but also can attenuate cross-link effect due to exposure dose accumulation on SU-8 from both front and back sides. Finally, an embedded SU-8 microstructure is demonstrated to verify that the proposed DoMPE method needs only single-layer SU-8 coating to fabricate not just embedded microstructures, but also embedded microstructure with asymmetric inside cross section.

1. Introduction

Negative photoresist SU-8 has been used as structure material in micro components due to its excellent material properties, such as good chemical compatibility and biocompatibility [1]. On common approach to fabricate an embedded SU-8 microstructure is to combine photolithography process on SU-8 with the bonding process [2], which requires more facilities and may have alignment or bonding strength issue. There are also other methods reported to fabricate embedded SU-8 microstructures without bonding, such as coating double-layer photoresist with multi-exposure and controlled UV exposure time [3–5], using multistep inclined UV lithography to construct oblique SU-8 microstructures [6], controlling the trajectory of a moving mask to adjust exposure position and dosage on the SU-8 [7], and using the gray-tone lithography that changes the UV-light transmission through the mask to modulating the exposure intensity on the substrate front side [8]. However, all these methods either required multiple coating or special equipment, and the shapes of inside cross section of embedded microstructures were quite limited.

In our previous investigations [9,10], a double-side multiple partial exposure (DoMPE) process on positive photoresist was proposed and shown to enhance the complexity of suspended 3D microstructures. Here, we further extend DoMPE method to negative photoresist to fabricate an embedded SU-8 microstructure with more flexible shape at internal cross section. The proposed method needs only single-layer coating of negative photoresist SU-8 on glass substrate without bonding process.

2. Concepts and fabrication processes

The DoMPE method comprises multiple front partial exposure and back-side partial exposure, and requires only standard IC-compatible equipment, such as a spin coater, aligner, wet bench, and physical vapor deposition (PVD) system. Process flow to fabricate an embedded SU-8 microstructure with internal asymmetric shape by DoMPE method is illustrated in Fig. 1 and described below:

(a) A Cr layer is deposited on glass substrate and patterned using the lift-off process as a mask for later back-side partial exposure. Negative photoresist SU-8 is then spin-coated and soft baked. (b) After rehydration, photoresist is exposed on front to define the supporting structures with coated thickness *h*. (c) SU-8 photoresist

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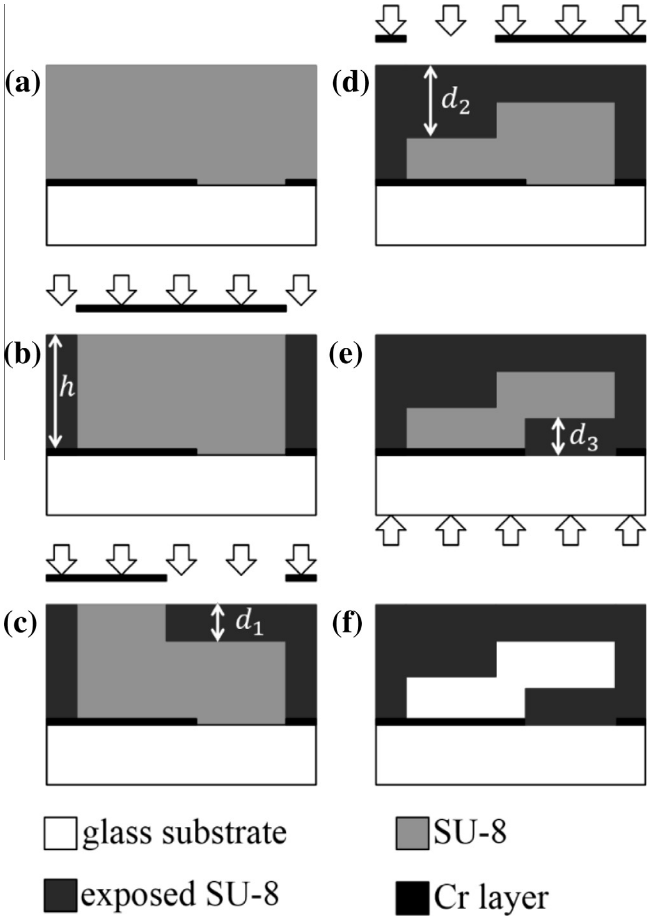

Fig. 1. Fabrication of an embedded SU-8 microstructure with asymmetric inside cross-section by DoMPE method. (a) Defining the metal layer as alignment keys, and coating negative photoresist. (b) Defining the supporting structures by front exposure. (c) Defining the thinner part of upper bridge structure at by front partial exposure. (d) Defining the thicker part of upper bridge structure by another front partial exposure. (e) Defining the bottom SU-8 structure by back-side partial exposure. (f) Development and release.

is then partially exposed by front partial exposure to define the thinner part of upper bridge structure (d_1). (d) Another front partial exposure is conducted to define the thicker part of the upper bridge structure (d_2). (e) SU-8 photoresist is then exposed by back-side partial exposure to create the bottom SU-8 structure (d_2). (f) After development, the embedded SU-8 microstructure with asymmetric inside cross section can be obtained.

3. Results and discussion

In this section, the relationships between developed thickness and exposure dosage in front exposure and back-side exposure are experimentally characterized first. Then, by combining front and back-side partial exposure with single-layer SU-8 coating, an embedded microstructure with an asymmetric inside cross-section is fabricated to demonstrate the capability of the proposed DoMPE method on negative photoresist.

3.1. Developed thickness by front partial exposure

Fabrications are carried out on soda lime glass substrates, and the commercially available negative thick photoresist (SU-8 2075, Microchem) is used here. After cleaning the glass substrate, the photoresist around 115 μm thick is spin-coated and then soft-baked at 65 °C for 10 min and at 95 °C for 30 min. After rehydration for over 30 min, the photoresist is exposed to different dosages and then PEB at 65 °C for 3 min and at 95 °C for 10 min. Final development is performed for 10 min with a Microchem SU-8 developer, followed by a second spray/wash with Isopropyl Alcohol (IPA) for another 10 s. Fig. 2 shows experimental results of developed thickness at different dosages by front partial exposure for photoresist SU-8 2075. The developed thickness becomes thicker with the increasing exposure dosage. Under UV exposure (365 nm) dosage of 30, 45, 60, 75, and 90 mJ/cm^2, average developed thicknesses (d_f) are found to be 13.6, 23.5, 44.8, 71.6, and 93.7 μm, respectively. It is also found that at exposure dosage of 105 mJ/cm^2, the photoresist is fully exposed. With multiple front partial exposures at two regions, a bridge microstructure with two different levels can be achieved, as shown in Fig. 3. The thickness of thinner part of bridge structure (d_{f_1}) is 16.8 μm at dosage of 30 mJ/cm^2, and the thickness of thicker part of bridge structure (d_{f_2}) is 77.2 μm at dosage of 75 mJ/cm^2, where the initial coated SU-8 thickness is about 105 μm.

3.2. Developed thickness by back-side partial exposure

In back-side partial exposure experiments, glass substrate, exposure system, SU-8 2075, coated thickness, soft-bake, PEB, and development solution are similar to those used in front partial exposure experiments, except exposure is performed from back side and an 100 nm thick Cr layer is deposited and patterned on the glass substrate to act as the mask. Experimental results of

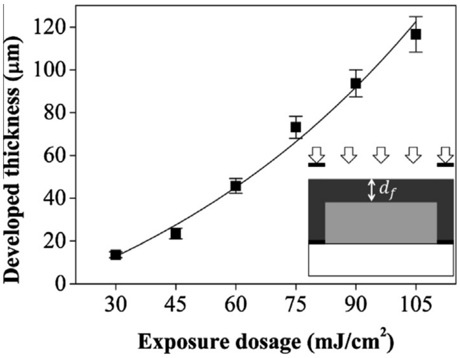

Fig. 2. Experimental results of developed thickness under different front partial exposure dosage on SU-8 2075.

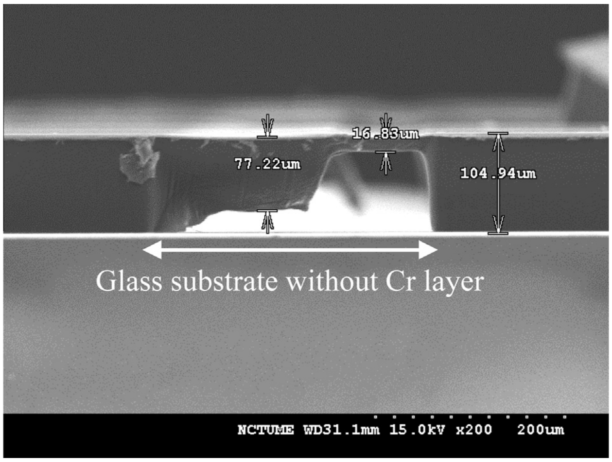

Fig. 3. SEM picture of a SU-8 bridge microstructure with two different thicknesses by two front partial exposures (30 mJ/cm^2 and 75 mJ/cm^2).

developed thickness at different back-side partial exposure dosages on SU-8 are shown in Fig. 4. Under exposure dosages of 30, 45, 60, 75, 90, and 105 mJ/cm^2, average developed thicknesses (d_b) are 9.1, 19.6, 39.5, 65.9, 90.1, and 115.3 µm, respectively. The photoresist is also fully exposed at exposure dose of 105 mJ/cm^2.

3.3. DoMPE process on SU-8

DoMPE method shown in Fig. 1 is proposed here to fabricate embedded SU-8 microstructure with asymmetric inside cross section. The Cr layer is deposited and patterned on glass substrate by lift-off to act as the mask for back-side partial exposure, and then the substrate is coated with SU-8 (Fig. 1(a)). After front exposure steps shown in Fig. 1(b and c), however, we found that reflection effect is a critical factor to the developed thickness of SU-8. Reflection from bottom Cr layer would provide extra exposure dosage on SU-8 to cause thicker developed thickness, comparing to developed thickness without reflection effect. For example, as shown in Fig. 5(a), the SU-8 bridge structures are fabricated by the same front partial exposure dose (45 mJ/cm^2) on the glass substrate where part of the bottom surface has Cr layer. The developed thickness d_w and $d_{w/0}$ (with and without Cr layer at the bottom surface) are 28.7 and 23.8 µm, respectively. Thickness deviation due to reflection is 5 µm. The difference becomes more evident with stronger reflected light. As shown in Fig. 5(b), at the exposure dose of 60 mJ/cm^2, the developed thickness d_w and $d_{w/0}$ are 56.4 and 41.6 µm, respectively. In our previous study [11], a simulation model with experimental results on developed thickness of SU8 with reflection effect was developed. It was found that the deviation of developed thickness with and without reflection effect increased steadily with increasing exposure dosages at the same coated SU-8 thickness. For the same exposure dosage, the deviation of developed thickness due to reflection effect became insignificant with increasing coated SU-8 thickness. The proposed simulation model and experimental results showed that the deviation of developed thickness due to reflection effect was less than 4% when coated thickness of SU-8 was above 350 µm [11]. In order to reduce this reflection effect, thicker SU-8 is coated on the glass substrate by pouring proper volume of photoresist into a hollow metal mold placed on the substrate. Fig. 6 shows SEM images of fabricated bridge structure after the same front partial exposure (90 mJ/cm^2) on glass substrate with and without Cr layer. The initial coated thickness of SU-8 is 383.9 µm, and developed thickness of the bridge structure is found to be around 187.0 µm, with or without Cr layer on glass substrate, which demonstrates that the reflection effect becomes insignificant at coated thickness of 383.9 µm.

After coating thicker SU-8, the processes shown in Fig. 1(c–f) can be performed to fabricate the embedded SU-8 microstructure with asymmetric inside cross section. It is found that a thicker SU-8 is also helpful to attenuate cross-link effect due to exposure dose accumulation on SU-8 from both front and back sides in DoMPE process. In addition, it usually needs longer development time to remove thicker photoresist. If the photoresist to be removed is hard to be reached by the developer, it will need longer develop-

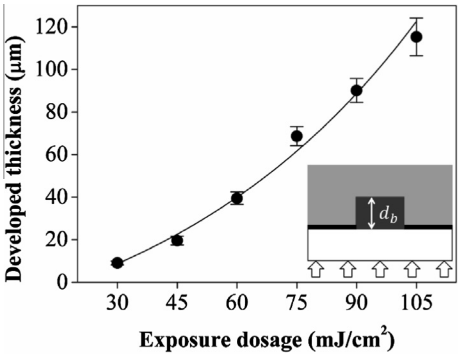

Fig. 4. Experimental results of developed thickness under different back-side partial exposure dosage on SU-8 2075.

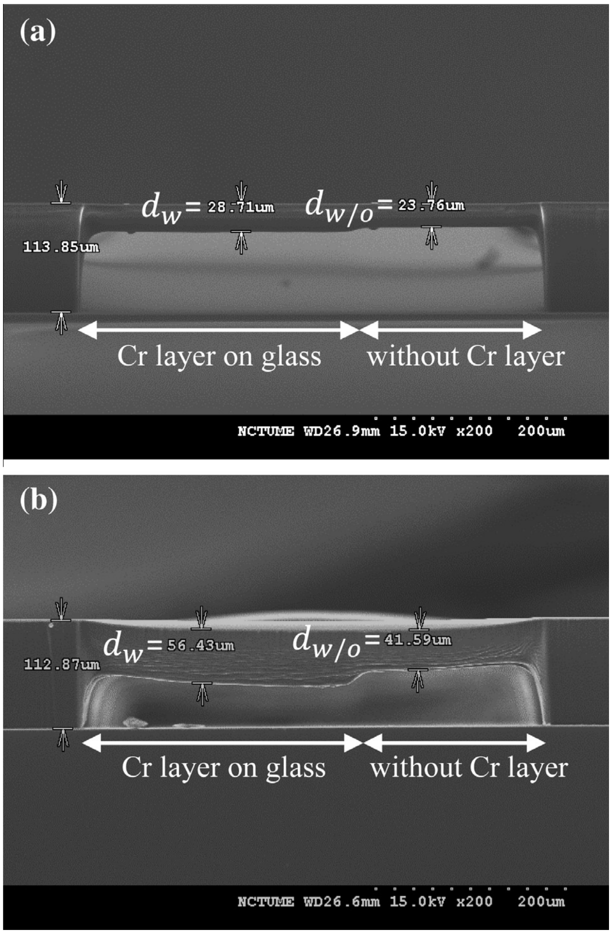

Fig. 5. Developed thickness of SU-8 bridge structures with and without Cr layer on glass substrate at different front exposure dosages; (a) at exposure dosage of 45 mJ/cm^2; (b) at exposure dosage of 60 mJ/cm^2.

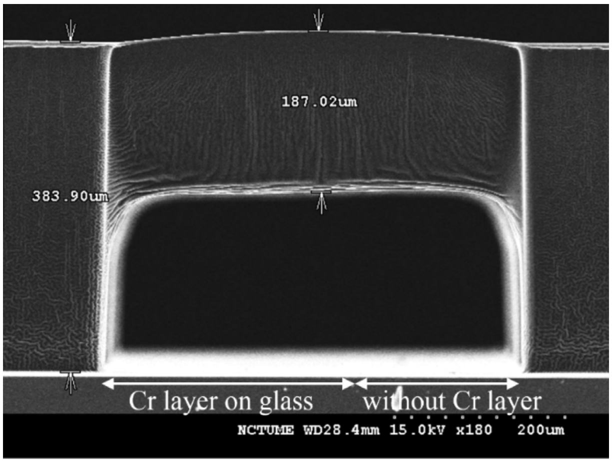

Fig. 6. Experimental results of developed thickness of SU-8 bridge structures with and without Cr layer on glass substrate at coated thickness of 383.9 µm for exposure dosage of 90 mJ/cm^2 by front partial exposure.

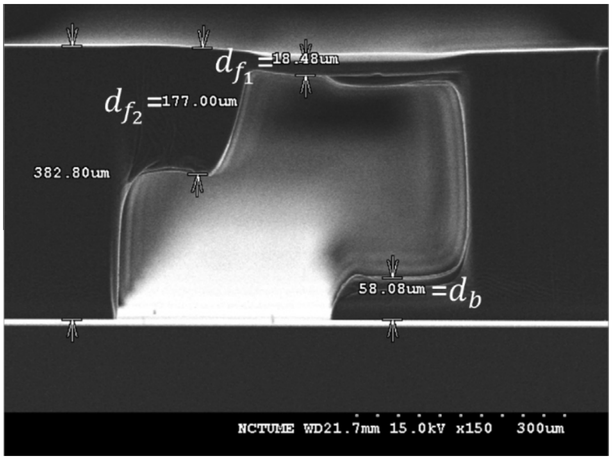

Fig. 7. An embedded SU-8 microstructure with asymmetric inside cross section by DoMPE process on negative photoresist SU-8.

ment time. For fabricating the embedded SU-8 microstructure, thickness of the bottom part is defined by back-side partial exposure dose. However, stronger dose leads to thicker developed thickness, and this may cause the space between upper bridge structure and bottom part is too narrow to be developed. Therefore, low back-side exposure dose (30 mJ/cm^2) is chosen here to define thickness of the bottom part. As shown in Fig. 7, different depths (d_{f_1} = 18.5 and (d_{f_2} = 177.0 μm) on SU-8 upper bridge structure are achieved with front exposure doses of 30 and 90 mJ/cm^2, respectively, where depth (d_b) at the part of bottom is 58.1 μm with the back-side exposure dose of 30 mJ/cm^2. This result verifies that the proposed DoMPE method needs only single-layer SU-8 coating to fabricate not just embedded microstructures, but also embedded microstructure with asymmetric inside cross section.

In further discussion, diffraction, refraction, and reflection [12,13] were found to significantly affect the SU-8 profile, specifically the taper angle. Zhang et al. [12] indicated that longer expose time resulted in smaller (i.e. less steep) side wall angle. Moreover, Zhou et al. [14] indicated that the swelling effect and the exposure dose, to some degree and in a certain range, could be balanced to achieve good sidewall angles. Therefore, these models could be helpful to explain why the embedded microstructure fabricated here by double-side multiple partial exposures having sloped sidewall profile.

4. Conclusions

By multiple front partial exposures, SU-8 bridge structure with multi levels can be fabricated. With patterned Cr layer on glass substrate as the mask, SU-8 at specified location can be developed at the bottom of substrate by back-side partial exposure. Combining both front and back-side multiple partial exposures with single-layer coating of negative photoresist SU-8 on glass substrate, an embedded SU-8 microstructure with complex inside cross section becomes possible by this double-side multiple partial exposure (DoMPE) method.

After experimentally characterizing process parameters, it is found that coating thicker SU-8 not only can reduce reflection effect from Cr layer, but also can attenuate cross-link effect due to exposure dose accumulation on SU-8 from both front and back sides. Finally, an embedded SU-8 microstructure is demonstrated to verify that the proposed DoMPE method needs only single-layer SU-8 coating to fabricate not just embedded microstructures, but also embedded microstructure with asymmetric inside cross section. The DoMPE method on negative photoresist proposed here can act as a fabrication platform to provide an affordable solution to construct more flexible features in three dimensional microstructures for MEMS applications.

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