A novel fabrication method of embedded micro-channels by using SU-8 thick-film photoresists

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Abstract

This paper proposes a novel method to fabricate multi-layers, embedded micro fluidic structures by simply employing dosage-controlled UV exposure on thick SU-8 resist and anti-reflection coating on the bottom surface to prevent the reflection UV-light from inducing exposure. Experimental results show the top wall thickness of the embedded micro-channels can be well controlled in a resolution of 2 μm for the UV dosage from 120 to 190 mL/cm². Stacked micro-channels have also been successfully realized and showed no interference on the bottom structures when the top structures are being exposed. Numerical simulation of the top wall thickness by UV exposure dosage control has also been conducted, and the comparison between the calculated and experimental results showed similarity in trend. This simple and inexpensive method can be applied to fabricate multi-layers of complex fluidic systems for the applications of μTAS (MicroTotal Analysis System), inkjet printhead, capillary electrophoresis, and micro PCR (Polymerase Chain Reaction).

Keywords: Embedded micro-channels; 3-D micro structures; SU-8 resist; UV dosage control

1. Introduction

There have been many micromachining processes to fabricate buried micro-channels, such as wafer bonding after bulk micromachining [1], sacrificial etching by surface micromachining [2], and through mold plating [3], etc. Besides, LIGA or micro stereolithography can also realize micro channel structures. However, those processes either are complex, expansive, require high temperature/electrical field, or need special equipments for fabrication, not as easy as the use of photopolymers such as SU-8 resist [4].

For simple and low cost fabrication, the SU-8 thick film photoresists has been employed to fabricate micro-channels due to its outstanding mechanical properties [5]. There are at least four major methods which have been reported by using SU-8 resist to fabricate buried channel structures, including: (1) SU-8 plus filling materials to form channel spaces [6], (2) metal mask used to protect from second exposure for forming channel space [6], (3) laminated SU-8 and Riston® film to form channel space [4] and (4) proton beam used to partially expose SU-8 to form buried channel [7], as shown in Fig. 1(a) and (d), respectively. The first method must apply two materials to form the buried micro-channels, and the filling materials may induce steps affecting successive processes, not mention the troublesome material compatibility problem between filling materials and SU-8 photoresists. The second method employed metal as masks for UV light protection, but the crack of metal thin film during elevated temperature by evaporation process or the later SU-8 baking process may potentially fail the stacking process; besides, the metal removal process could pose undesired damage to SU-8 resists. The third, Laminating process, may cause the adhesion uniformity problem between laminating materials and SU-8 resists. In the fourth method, although proton beam can achieve good dosage control, it is not a popular source for common use.

All these methods described above use either more than two materials and tedious process, or costly facility like proton beam, which are not simple enough for the fabrication of stacked channels. In this paper, we developed a simple fabrication process of embedded micro-channels by using UV dosage control and anti-reflection coating on SU-8 resists.

2. Concepts and fabrication processes

The reason for the aforementioned tedious methods to fabricate buried channels by SU-8 photoresist is the high UV
transmission of the resist in the UV range of 320–380 nm, as shown in Fig. 2 [8]. When partial UV light exposure is used to obtain desired top wall thickness, the bottom of the micro-channel is usually exposed by the reflected UV light from the interface between photoresist and silicon wafer, as shown in Fig. 3(a), and the channel height is very hard to control by partial exposure. As a result, the fabrication of channels encounters serious problem such as collapse from insufficient exposure dosage or fill-up from the reflection UV light with normal exposure dosage. The process window for channel formation is very narrow and difficult to control and repeat.

In this paper, we propose a novel approach, as shown in Fig. 3(b), employing an anti-reflection layer on the resist-wafer interface to absorb UV light and prevent it from reflecting, thus thoroughly eliminating the reflection problem. Due to the absorption of the extra UV light by the anti-reflection layer, we can get wide process window and control the UV exposure depth accurately.

The detailed SU-8 micro-channels fabrication processes are shown in Fig. 4. It starts from the spin-on of CK-6020L resist (FujiFilm Olin Inc., Japan), the anti-reflection coating,
and channel structure. Fig. 5 shows six different channel top-wall thicknesses of 14, 23.2, 27.2, 31, 45.2, and 61.4 μm, which are under UV exposure (365 nm) for 122.5, 161.7, 176.4, 191.1, 196, and 200.9 mJ/cm², respectively. The relationship between thickness and exposure dosage is shown in Fig. 6, bi-linearly related for 120-200 mJ/cm². A double-stacked micro-channel has also been successfully fabricated by repeating the process, and the result is shown in Fig. 7. The channels are well defined without interference, which suggests the possibility of the fabrication of complex fluidic systems with multi-layers.

4. Calculation of SU-8 thickness by exposure dosage controlled

To find out the SU-8 thickness by exposure dosage control, the UV light intensity pattern in SU-8 resists is defined where total incident exposure energy matches the threshold energy required by the resist. In the calculation of SU-8 thickness by exposure dosage, we have to find out the attenuation of UV light intensity in the SU-8 resists along the vertical direction first. The UV transmission rate for layers varying from 50 to 660 μm has been measured experimentally; the results are shown in Fig. 2. From these experimental results, we can obtain the attenuation function of 320–380 nm UV-light intensity in SU-8 resist, B(r), with the following form:

\[ B(r) = a - \beta r + \gamma \times 10^{-6} \times r^2 \] (1)

where \( r \) is the depth in resist from resist surface and its unit is μm. The constant \( a, \beta \) and \( \gamma \) in Eq. (1) are 0.7446576673, 0.001642391082 and 1.037896453, respectively.

Therefore, the relationship between exposure dosage and induced thickness can be described by [8]

\[ E(r) = k E_{inc} B(r) \] (2)

where \( E_{inc} \) is the incident exposure dosage on the resist surface and \( k \) is a parameter related to the inverse product of exposure dosage and exposure sensitivity [8]. With a given photoresist, choosing a proper exposure time yields a corresponding parameter \( k \). Since lacking of the knowledge of the exposure sensitivity and photochemistry for SU-8 resist, the proper \( k \) value was selected in a way to fit the experimental data for the exposure thickness of 14 μm, and this value was employed for all exposure thickness and dosage. As a result, the minimum exposure light intensity was decided as 89.4 mJ/cm² for the cross link of SU-8 resist, and the \( k \) value was also determined as 1.371. This intensity was used as a threshold for the estimation of incident dosage need for a specific resist thickness. The calculated curve by Eq. (2) was shown in Fig. 6 in a dot line, and demonstrated a well agreement in UV incident exposure dosage for the resist thickness below 31 μm, but with a larger slop for the rest curve. This suggested that the employed \( k \) value was too

3. Experimental results

This simple process has been routinely employed to fabricate micro-channels with accurate top wall thickness for UV light absorption, and then spins coating the SU-8 resist with desired thickness (Fig. 4(a)). After the first UV exposure to define the channel wall (Fig. 4(b)), a partial second exposure is then taken to define the channel top wall (Fig. 4(c)). The PEB (post exposure bake) process is required before the fabrication of the successive stacking layers to ensure good structure-definition and to stop the bottom SU-8 from mixing with the upper layer. The second anti-reflection layer is then applied for the partial exposure of the next layer (Fig. 4(d)). Multi-layers of micro-channels can be fabricated simply by repeating the processes (Fig. 4(e)). After the fabrication of all layers, channel structures can be released by final developing process (Fig. 4(f)).
Fig. 5. Top wall thickness controlled by different UV dosages.

Fig. 6. Wall thickness vs. UV exposure dosage by calculation, experiments, and vendor suggested average data.
large in the region of resist thickness above 31 μm, and could be adjusted back to fit the right side of the curve.

5. Discussions

From the calculated exposure thickness of SU-8, the bilinear relationship is obtained as it can be seen in the experiments. The calculated curve shows linear relationship because of the sharp decay in Fig. 2 for the thickness ranging from 14–61 μm, approaching a straight line with negative slope.

In addition to the calculation, the transition point can also be observed from the suggested average exposure data by Microchem corporation [9], and the suggested exposure dosage is redrawn as the third curve in Fig. 6. Although there is a difference in the relationship between resists exposure thickness and incident exposure dosage, the transition point of the Microchem curve at 195 mJ/cm² is very close to that of the experimental result at 190 mJ/cm². The causes of this transition phenomenon are not known and require more investigations.

The experiments demonstrate that the anti-reflection coating effectively eliminates the reflection of UV light from the SU-8 resists/wafer interface and makes the fabrication of SU-8 embedded micro-channels possible. In the experimental results, the relationship between thickness and exposure dosage is bi-linearly related to resist thickness from 120 to 200 mJ/cm². Due to this linear relationship, embedded micro-channels can be fabricated with desired top wall thickness easily. However, when the exposure thickness is over 31 μm, the resist seems to become more sensitive to the UV dose and the thickness control is not as accurate as those below this critical value. The wall thickness in the lower dosage range can be controlled in 2 μm increment, while 12 μm in the higher dosage range.

6. Conclusions

A novel fabrication method of embedded micro-channels employing simple UV dosage control and anti-reflection coating has been proposed and successfully demonstrated. Different from other SU-8 processes reported for buried channel fabrication, this new and simple method employs UV dosage to control exposure depth while using anti-reflection coating to absorb the reflection UV light to prevent the bottom of micro-channel from getting exposure. The calculations are in well agreement with the experimental results. A double-stacked micro-channel has also been successfully fabricated and is well defined without interference. This fabrication method shows very good control of channel top wall thickness, and is potentially applicable to complex micro fluidic systems and Bio-MEMS.

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References


Biographies

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Jen-Ju Chuang was born in 1974 in Taoyuan, Taiwan, ROC. He received the BS degree in nuclear engineering and engineering physics in 1996, and the MS degree in engineering and system science in 1998, both from National Tsing-Hua University, Taiwan, ROC. He has been studying for PhD degree in engineering and system science department in Tsing-Hua University since 1998. His current researches focus on the development of a novel micro droplet injector system and IC chip cooling by MEMS device.

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