TWO NEW METHODS TO IMPROVE THE LITHOGRAPHY PRECISION FOR SU-8 PHOTORESIST ON GLASS SUBSTRATE

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ABSTRACT

This paper introduces two novel approaches to effectively eliminate the influence of the scattering light from the wafer chuck and enhance the lithography precision of the SU-8 photoresist on a glass substrate. The first method is based on the complete reflection of light from Si substrate, and the second one employs materials which has low optical transparency and can achieve complete absorption of the near ultraviolet light transmitted from the SU-8 photoresist and the glass substrate. The SU-8 structures produced by these two methods have much better profiles than those made by the conventional process, and the line width deviation is smaller than 1 µm. These two routines have advantages of simplicity, low cost, therefore are applicable to batch fabrication and can significantly enhance the performance of MEMS devices.

INTRODUCTION

SU-8 photoresist is becoming a popular structural material for micro-electro-mechanical system (MEMS) devices due to its attractive properties: biocompatible, high thermal and chemical stability, and so on [1-5]. Normally SU-8 photoresist is patterned on Si or glass substrate by lithography process. For biomedical MEMS application, the glass substrate is more often used due to its optical transparence, which allows the biochemical activities in the channels to be easily detected and monitored. However, the exposure precision of SU-8 photoresist on the glass substrate is limited by the aperture edge diffraction or the scattering light from the chuck. Y. J. Chuang et al. [6] reduced the UV light diffraction utilizing glycerol as a compensator to bridge out the air gap between the mask and the resist, and fabricate high aspect-ratio photoresist structures with straight sidewalls. However, till now no effective solution has been reported to minimize the influence of the scattering light from the wafer chuck.

Figure 1 depicts the wavelength dependence of absorbance for different SU-8 films [7], it can be seen that the SU-8 photoresist has high optical transmission for the lights with wavelengths above 360 nm. Thus it is ideally suitable for fabricating the thick vertical structure with straight sidewall (thickness: >200 µm). However, fabricating fine SU-8 structures with high precision on transparent substrates, e.g. glass, has some limitations, since the near ultraviolet light penetrates through the SU-8 photoresist and the glass substrate, reaches the chuck of the exposure system, and is reflected and scattered by the V-groove on the chuck, as shown in Figure 2. The reflected and scattered lights go through the glass substrate back to the SU-8 photoresist, expose the SU-8 photoresist in an uncontrollable way. Finally some locations originally protected by the mask are exposed, and the structure is broadened more than 40 µm, as can be seen in Figure 3 for the patterns made by the conventional lithography process, this deviation is not acceptable for fabricating high-end devices.

This work developed two simple and reliable routines to eliminate the influence of the scattering light from the chuck and dramatically improve the lithography precision of SU-8 photoresist via achieving either complete reflection of the normally incident light from Si substrate or complete absorption of the penetrated light by photoresist, respectively.

EXPERIMENTS AND RESULTS

Conventional lithography

The SU-8 photoresist on a glass substrate is usually exposed with the conventional lithography process, that is, the SU-8 photoresist with a thickness about tens of micrometer is spin-coated on a glass substrate, then exposed under a 365 nm UV light. The patterned structures are given in Figure 3. It can be seen that the lithography precision is poor for the structures located in the wafer area corresponding to the V-groove region of the chuck, while much better resolution is achieved in the area above the open window of the chuck. This phenomenon mainly results from the following reasons. Firstly, the SU-8 photoresist has a relatively small absorption coefficient for the lights with wavelengths above 340 nm, its transmittance is higher than 80%, as shown in Figure 1. For the 10 µm thick SU-8 photoresist, the transmittance at a wavelength of 365 nm is larger than 90%. Secondly, the Pyrex glass also has high transmittance, that is, more than 90% for the UV light, thus the UV light transmitting the SU-8 photoresist and the Pyrex glass is more than 81%. Thirdly, the transmitting light is incident to the chuck and scattered from the V-grooves of the chuck, as shown in Figure 2.

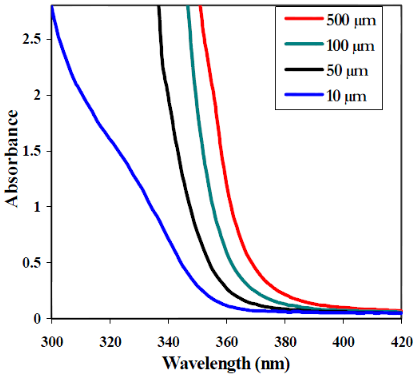
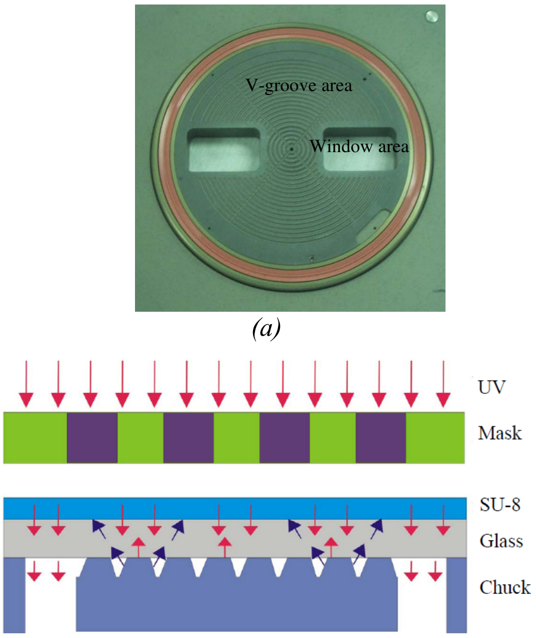


Figure 1: The wavelength dependence of absorption for SU-8 photoresist with various thicknesses

Figure 2(b) shows the principle of the conventional lithography process for the SU-8 photoresist on a Pyrex



(a)

(b)

Figure 2: (a) The chuck of the exposure system; (b) The schematic drawing for the conventional lithography of the SU-8 photoresist on the glass substrate, the scattering light from the chuck exposes some locations originally protected by the mask.

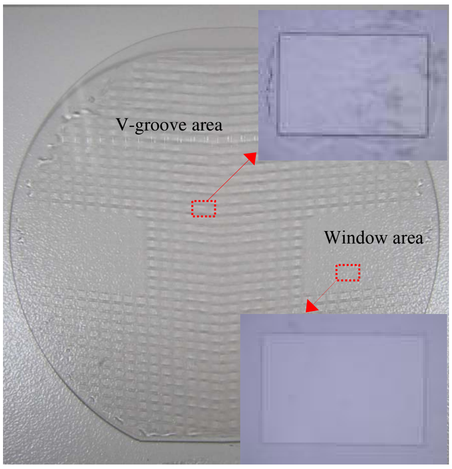


Figure 3: The 10 µm thick SU-8 structures made by the conventional lithography process.

glass. The 365 nm UV light successively penetrates through the mask, the SU-8 photoresist, the glass substrate, and reaches the chuck. The light incident to the window area of the chuck will be transmitted away; while the light arriving at the V-groove area of the chuck is randomly reflected back, penetrates through the glass substrate again, and exposes the unexpected area of the SU-8 photoresist. As a result, the lithography precision is not controllable on the whole wafer, as depicted in Figure 3. Figures 4 and 5 give the 2D and 3D profiles of the 10 µm thick patterned SU-8 structures located in the V-groove and window area, respectively. The SU-8 structure in the window area has a steep side-wall and the unexposed area is free of the photoresist; while the SU-8 structure in the V-groove area has severe deformation, there is no clear boundary between the exposed and unexposed area, and the inclining sidewall is longer than 100 µm, which results in a poor lithography precision. Therefore, an effective solution to improve the lithography precision of the SU-8 photoresist on the transparent substrates at wafer level is highly desired for producing high-end SU-8 based devices. This work developed two routines to significantly enhance the lithography precision of SU-8 photoresist, that is, the complete reflection of the normally incident light from Si substrate and the complete absorption of the penetrated light by photoresist to prevent the transmitting light from reaching the chuck.

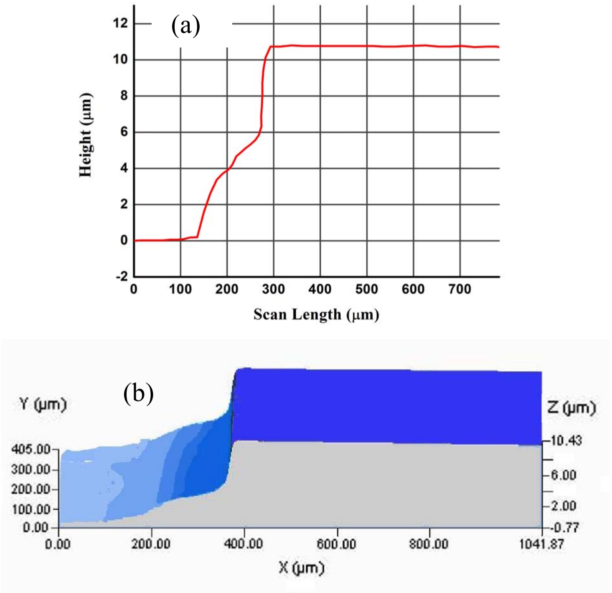


Figure 4: 2D and 3D profiles of the SU-8 photoresist structures located in the V-groove area.

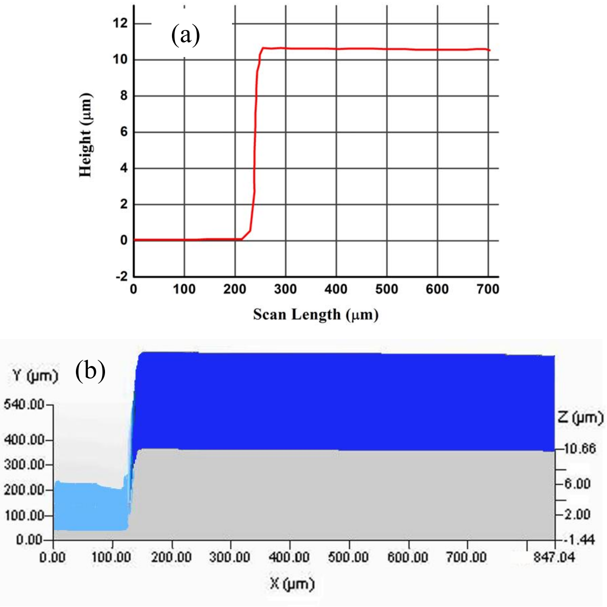


Figure 5: 2D and 3D profiles of the SU-8 photoresist structures located in the window area.

The complete reflection method

Figure 6 describes the working principle of the complete reflection of the normally incident light from a Si substrate. The process includes the following steps. Firstly, A 10 µm thick SU-8 photoresist is spin-coated on the Pyrex glass wafer and pre-baked. Subsequently, a polished Si wafer is attached to the backside of the glass wafer with deionized (DI) water. Then, the exposure of the SU-8 photoresist is done with 365 nm UV light for 90 s. The ultraviolet light penetrates through the mask, the glass substrate, reaches the Si wafer, and is fully reflected by the polished Si substrate in a perpendicular direction, thus no light could reach the chuck. The reflected light transmits the glass substrate and exposes the SU-8 photoresist once again. Therefore, this new process needs relatively short exposure time due to the extra exposure by the reflected light. Finally, the polished Si and Pyrex 7740 wafers are separated, the exposed SU-8 photoresist is post-baked and developed successively.

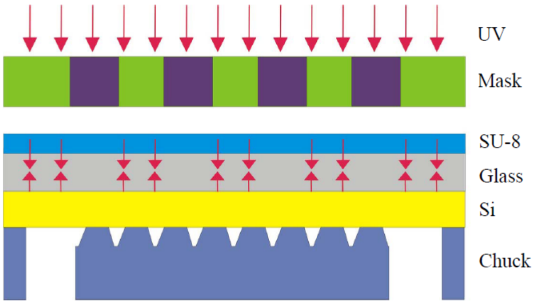
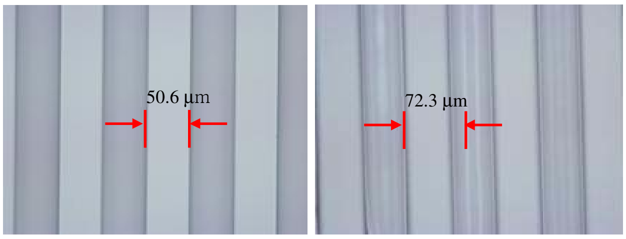


Figure 6: The sketch explaining the working principle of the complete reflection by Si substrate.

The patterned SU-8 structures fabricated by this proposed method are given in Figure 7 in comparison with that exposed for 120 s by the conventional lithography process. The line profile is very clear and much better than the structure made by the conventional process, and the line width deviation is smaller than 0.6 µm. Contrastively, in the same structure made by the conventional lithography process, the residual photoresist exists between the lines.



Complete reflection *Conventional lithography*

Figure 7: The SU-8 structures fabricated by the complete reflection method and the conventional lithography process, respectively.

There are several advantages for the complete reflection method: (1) clearly improving the lithography precision; (2) reducing the exposure time; (3) simple and easy to be implemented, therefore suitable for mass-production process; (4) reliable process with low cost.

The complete absorption method

Another alternative uses materials which has low optical transparency and can completely absorb the near ultraviolet light. In this work, a 5 µm thick L-300 photoresist with high absorption to the UV light is chosen for achieving complete absorption of the transmitting light. The working principle of the complete absorption of the penetrated light by photoresist is shown in Figure 8.

The new lithography process is carried out according to the following steps. Firstly, A 10 µm thick SU-8 photoresist is spin-coated on the 1st Pyrex glass substrate and pre-baked, and L-300 photoresist is spin-coated on the 3rd Pyrex glass wafer. Subsequently, the 3rd Pyrex glass is combined with the 2nd Pyrex glass via L-300 photoresist. Then, the backside of the 2nd Pyrex glass is attached to the backside of the 1st Pyrex glass with DI water, and the SU-8 photoresist is exposed for 120 s with 365 nm UV light. During exposure, the UV light successively goes through the mask, the SU-8 photoresist, the 1st Pyrex glass substrate, the 2nd Pyrex glass, reach the L-300 photoresist and is fully absorbed by the photoresist, therefore, could not reach the 3rd Pyrex glass and the chuck. After exposure, the 1st and 2nd Pyrex glass substrate are separated; the SU-8 photoresist is post-baked and developed. For comparison, the same SU-8 photoresist on a glass substrate is exposed for 120 s by the conventional lithography process.

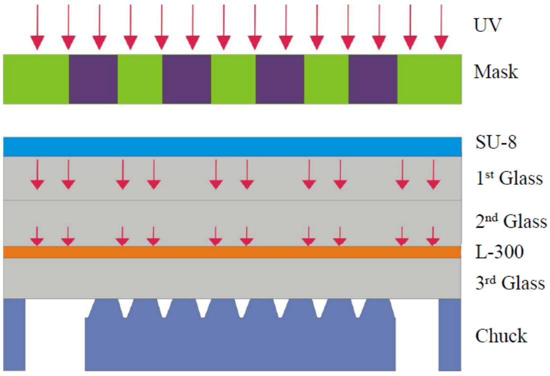
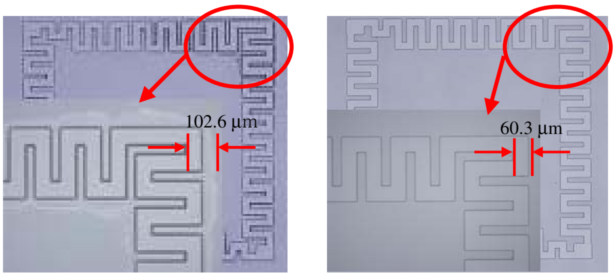


Figure 8: The sketch describing the working principle of the complete absorption by L-300 photoresist.

The feasibility of this approach is testified. The SU-8 structures produced by the complete absorption method and the conventional lithography process are shown in Figure 9. For the line structures of 60 µm wide in the designed mask, the patterned SU-8 lines are broadened more than 40 µm after the conventional lithography process, this deviation is not acceptable for fabricating fine structure. But a line width deviation less than 0.3 µm for the 60 µm wide SU-8 structure is obtained by the complete absorption method at wafer level.

There are several advantages of the complete absorption method: (1) enhancing the lithography precision; (2) simple and easy to be implemented, therefore suitable for mass-production process; (3) reliable process with low cost.



Conventional lithography *Complete absorption*

Figure 9: The SU-8 structures produced by the complete absorption method and the conventional lithography process, respectively.

CONCLUSION

Two approaches provide perfect solutions to effectively eliminate the influence of the scattering light from the chuck and dramatically improve the lithography precision of SU-8 photoresist on a transparent substrate.

The first method is based on the complete reflection of light by a Si substrate. Another alternative uses materials with low optical transparency to achieve complete absorption of near ultraviolet light. These two routines have advantages of simplicity, low cost, therefore are applicable to batch fabrication and can significantly enhance the performance of MEMS devices.

The feasibility of these two approaches is testified, the 60 µm wide SU-8 line structure is perfectly fabricated with a width deviation less than 1 µm. These two methods dramatically enhance the lithography precision for SU-8 photoresist on the glass substrate at wafer level. The same principle could be extended to improve the photolithography resolution for the transparent photoresists on the transparent substrates. This technique improvement is significant for developing high-end MEMS devices, specifically for the biomedical devices.

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