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***Research***

# A COMPARATIVE STUDY ON THE PHOTORESIST PATTERNING OF GLASS AND SILICON WITH MICROHOLES VIA MASKLESS PHOTOLITHOGRAPHY

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## ABSTRACT

Maskless photolithography, a useful tool used in patterning the photoresist which acts as a mask prior to the actual etching process of substrate, has attracted attention mainly due to the taking advantage of reducing cost because of not requiring a preprepared mask and freedom in creating the desired pattern on any kind of substrate. In this study, we performed the positive photoresist patterning with microstructures on both glass and silicon substrates via maskless photolithography. Specifically, we examined the discrepancies between the transparent (glass) and reflective (silicon) substrates even though the photolithographic process has been carried out under the same conditions. Since the positive photoresist patterning was the subject of this study, we could successfully produce the microholes with almost circular shapes and properly placed in squarely packed on both substrates as confirmed by optical microscopy and profilometer mapping measurements. We observed additional rings around the holes when silicon was used as substrate while very clear microholes were obtained for glass. Besides, the number of the rings increased when the writing speed of laser (velocity) reduced. We claim that these important findings can be attributed to the standing wave effect phenomenon which results from the multiple reflections through the semi-transparent photoresist coated on the reflective surface of the polished silicon. In brief, we reveal an important conclusion, in this study, based on the differences in formation of the microholes only due to the substate preference while all the photolithographic process parameters are kept the same.

**Keywords:** Maskless photolithography, Positive photoresist, Microholes, Glass, Silicon, Standing wave effect

## 1. INTRODUCTION

Minimizing the reflection caused by the interaction of incident light with the material surface and thus maximizing the absorption has been intensely studied in literature to improve the performance of optoelectronic devices especially such as photodetectors [1, 2] and solar cells [3, 4]. Surface patterning is one of the most preferred methods regarding in reducing reflection from sample surface. The microstructures with different shapes and physical properties are mainly preferred to pattern the substrates specifically glass and silicon via etching. The etching process to conduct the patterning of the substrate can be classified mainly as wet [5, 6] and dry [7, 8] based on either physical or chemical interactions subjected. Prior to the etching process, the usage of an appropriate patterning mask with well-defined structures in micro-scale is vital to carry out a successful patterning. Photolithography is one of the most efficient, versatile, and practical methods to obtain a well-prepared mask.

Photolithography is operated to perform the photoresist delineation with microstructures for a more controllable surface patterning prior to the actual etching. Therefore, a well-defined complete etching is mainly dependent on a successful lithographic process. The photolithography can be operated via with and without a mask. In the masked photolithography [9], exposing process occurs faster since the laser shines on the whole substrate at the same time through a mask. Contrary to this advantage, the price of the mask is the main factor that reduces the interest in masked photolithography. In the maskless lithography, on the other hand [10], an extraordinary parameter called laser velocity (writing speed, mm/s) has an important role in determining the exposing process as the maskless lithography is like directly writing with a laser pen. Another advantage of the direct laser writer system is that it can be performed for patterning in different shapes without using any additional masks unlike the masked photolithography.

Photolithography is generally carried out by three steps called coating of photoresist, laser exposure and development. For the photoresist, a light-sensitive and polymer-structured material, homogenous coating with desirable thickness is important. To achieve a homogenous photoresist coating, the process of spin coating parameters such as temperature and speed of rotation should be tuned accordingly [11]. The second step is the laser exposure onto the photoresist. There are two types of photoresists; positive [12, 13] and negative [14, 15]. When the positive photoresist is used, the laser exposed areas of the photoresist are weakened and cleared off during the development step. Whereas, the parts exposed to the laser of photoresist are strengthened

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and the remaining parts are removed by development in negative photoresist process. The wavelength and power of the laser are important parameters for the exposing step. In the development step, the duration of the chemical bath and the solution temperature [16] are two effective parameters. Through the photolithographic steps, the following facts such as photoresist uniformity, alignment, overexposing, pattern resolution and standing wave effect [17] need to be evaluated carefully.

In this study, we used soda lime glass (SLG) and polished float zone (FZ) silicon substrates to carry out the positive photoresist patterning via maskless photolithography. We spin coated the photoresist onto the substrates under the same conditions and then, the laser exposition with the same parameters onto the photoresist on the substrates has been carried out. Finally, the development step of both substrates was conducted simultaneously. We mainly conducted a study based on the formation of microholes on the photoresist on two different substrates. Furthermore, whether the physical properties of the microholes differ or not according to the preferred substrate has been investigated.

## 2. MATERIAL AND METHOD

Soda lime glass (SLG) and polished (FZ) silicon used as substrates in this study to observe the difference in photolithographic process for transparent and reflective materials, respectively. Two different processes were applied for two different substrates for the cleaning procedure. The glass substrate was cleaned with acetone for 5 minutes, isopropyl alcohol for 5 minutes and deionized water for 10 minutes, respectively, by ultrasonic bath and then dried with nitrogen gas. The RCA (Radio Corporation of America) cleaned silicon was additionally cleaned with hydrofluoric acid for 90 seconds and then washed with distilled water for 30 seconds to remove the natural oxide layer on its surface.

Both clean glass and silicon substrates were then heated up to 200 $^{0}$C on hot plate to remove possible residues. Then, the substrates were placed onto spin coating and rotated at 4000 rpm for photoresist coating. A positive type of photoresist, Shipley S1805 was used as photoresist material. Figure 1 represents the hot plate device, spin coating system and the schematic representation of the photoresist coating onto substrate.

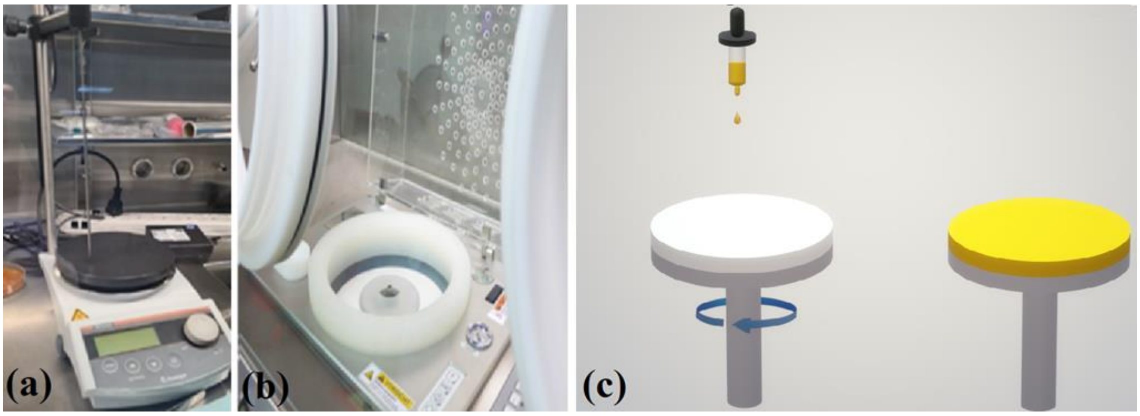


**Figure 1.** Hot plate device (a), spin coating system (b) and schematic representation of the photoresist coating (c).

**Table 1.** Sample names obtained by only contouring & contouring and filling with different laser velocities.

| **Sample Name** | **Contour & Filling** | | **Velocity (**mm/s**)** | |
|---|---|---|---|---|
| | **Contour** | **Filling** | **Contour** | **Filling** |
| **G-CF** | ✓ | ✓ | 0.3 | 10 |
| **S1-CF** | ✓ | ✓ | 0.3 | 10 |
| **S2-C** | ✓ | **X** | 0.4 | **X** |
| **S2-CF** | ✓ | ✓ | 0.4 | 13 |
| **S3-C** | ✓ | **X** | 0.6 | **X** |
| **S3-CF** | ✓ | ✓ | 0.6 | 13 |

A maskless photolithography instrument, Kloe Dilase 650, was operated for the exposure process. The wavelength of the laser used during the process was 375 nm (Ultraviolet). The microstructures with desired diameters in squarely packed construction that constitute the pattern were first defined by the device's software and then the pattern was transferred onto the photoresist via laser exposure. During the defining of microstructures prior to the laser operation, the two parameters called "contour" and "filling" to outline the circles and to fill in the circles, respectively, should be applied. We have produced the patterns of microstructures with contour only and contour and filling for comparison in terms of structural formation. Additionally, the laser parameter of velocity (writing speed, mm/s) has been differed as well during the contour and filling formation of the circles. As the velocity decreases, the larger area of photoresist is affected since the photoresist is exposed by the laser for a longer time, and vice versa. The samples obtained with only contour & contour and filling under different velocities are summarized in Table I.

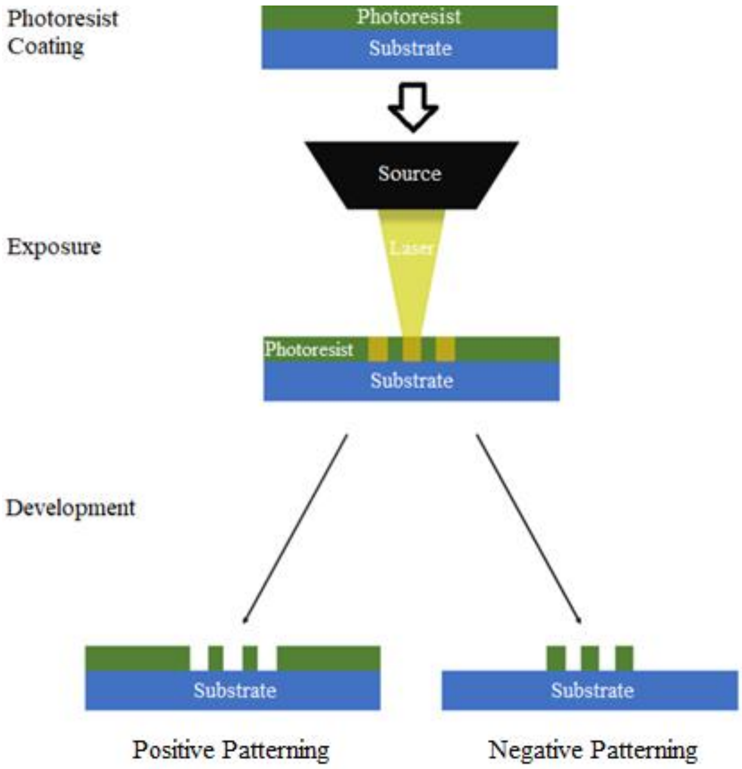


**Figure 2.** Schematic illustration of positive and negative patterning process steps via maskless photolithography.

Microposit MF-319 was used in the development process for positive photoresist. The substrates coated with photoresist with the patterns of microstructures were immersed into the developer solution for a few seconds. Then, the substrates were washed with deionized water and dried with nitrogen gas, respectively. After the development process, the substrates were heated and stayed at 100 $^{0}$C for 1 min on hot plate for the evaporation of any unwanted chemicals that could possibly remain. The three main steps for the photolithography process to obtain positive or negative patterning is schematically demonstrated in Figure 2.

In this study, we performed the positive photoresist patterning. Thus, we obtained the microholes on photoresist for both substrates because of photoresist delineation. The top view images of microholes were captured by optical microscopy of photolithography device. The angled images and dept profiles of the patterns were obtained by profilometer (Bruker DektakXT).

## 3. RESULTS AND DISCUSSION

Top view and angled images of SLG and silicon with microstructures obtained by optical microscopy and profilometer, respectively, are demonstrated in Figure 3 (a-d). The regarding depth profiles of the patterns measured by a line laterally drawn through the microholes can be seen in Figure 3 (e-f). Since the same procedure has been applied for the depth profile measurement for both samples, the line was added only to the SLG image.

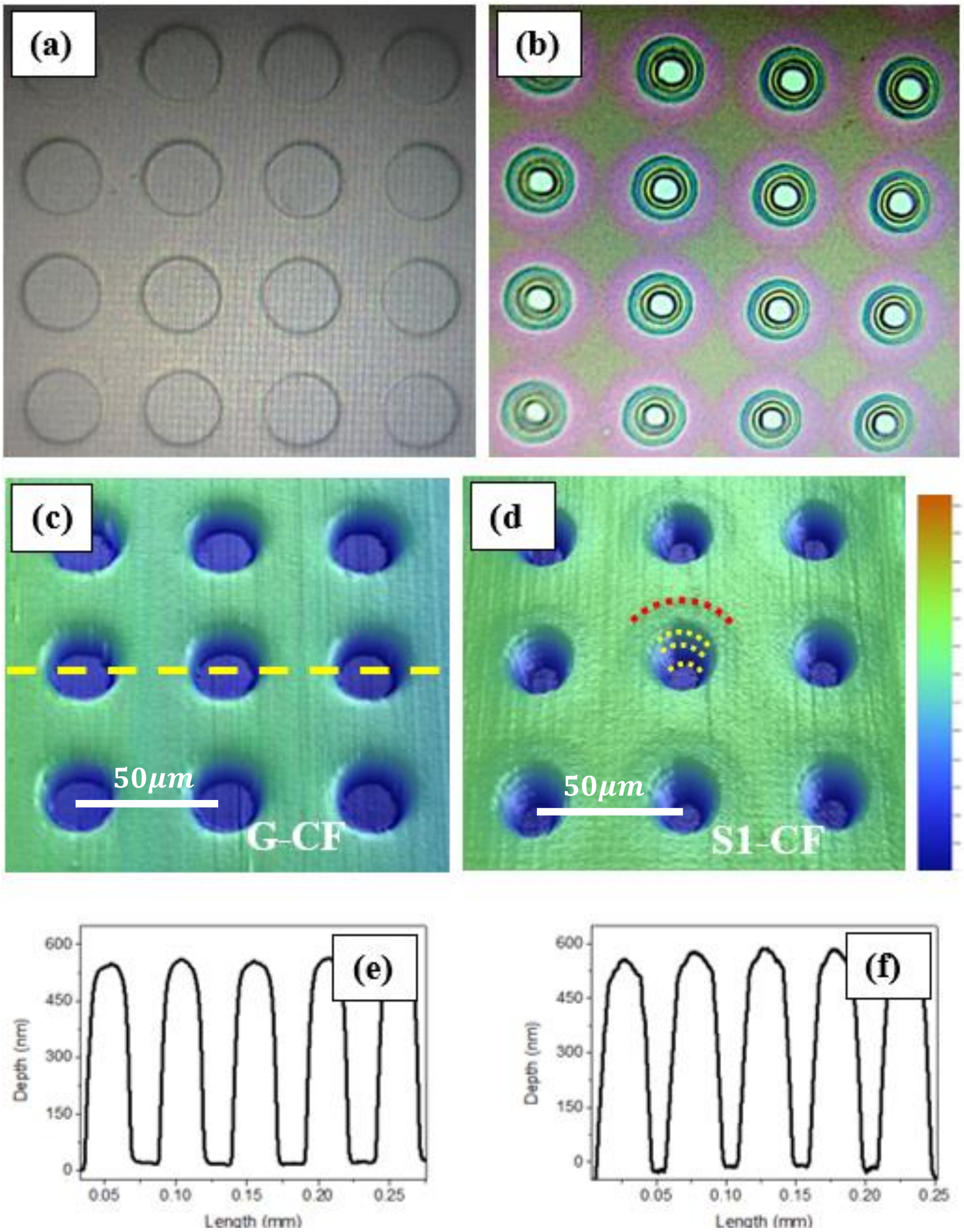


**Figure 3.** The top (optical microscopy) and angled (profilometer) images of microholes delineated on photoresit coated on SLG (a & c) and silicon (b & d), respectively; the regarding depth profiles of SLG and silicon obtained by laterally drawn line through microholes.

The most significant difference between the performed patterns made up of microholes on glass and silicon is the formation of the rings when the silicon is used as substrate while no ring is observed for glass. Since the photoresist patterning process is the same for both substrates, the main reason behind this important finding is probably due to the optical reflection properties of the substrates. Since glass is quite transparent in UV-Vis range [18], the laser passes through both semi-transparent photoresist and glass. Therefore, one-directional trajectory of the laser results in formation of almost perfectly circular microholes. On the other hand, silicon with a polished surface has approximately 30-40 % reflectance of light in UV-Vis range [19]. As a result, the laser has been subjected to the multiple reflections from the silicon surface which produces the standing wave effect and thus, the circles along with the microholes are formed on photoresist coated silicon. Standing wave effect is a phenomenon that generally observed when a substrate with reflective surface is used. The meeting of the incident light with the reflected light results in the formation of constructive and destructive interference creates the standing waves [20].

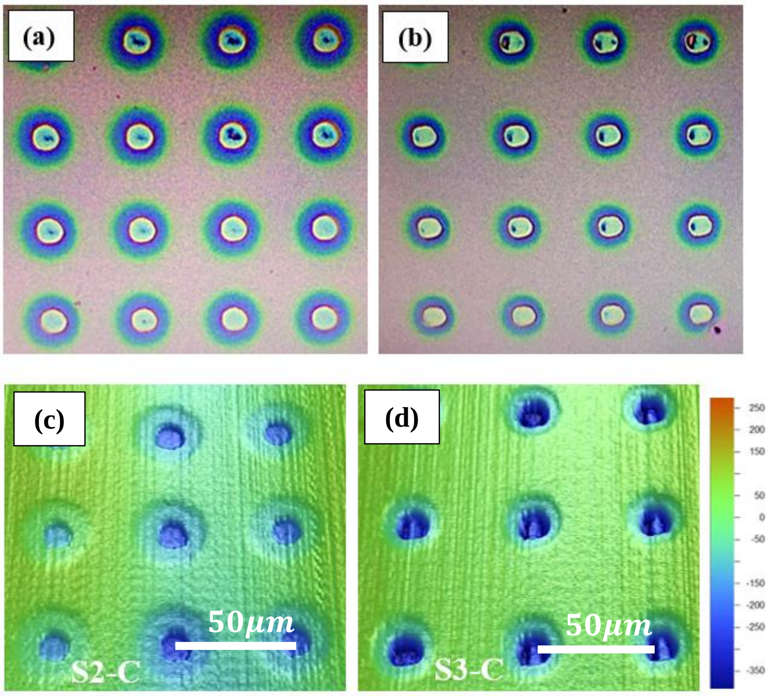


**Figure 4.** The top (optical microscopy) and angled (profilometer) images of microholes delineated on silicon only by contour formation under different velocities; samples of S2-C (a & c) and S3-C (b & d), respectively.

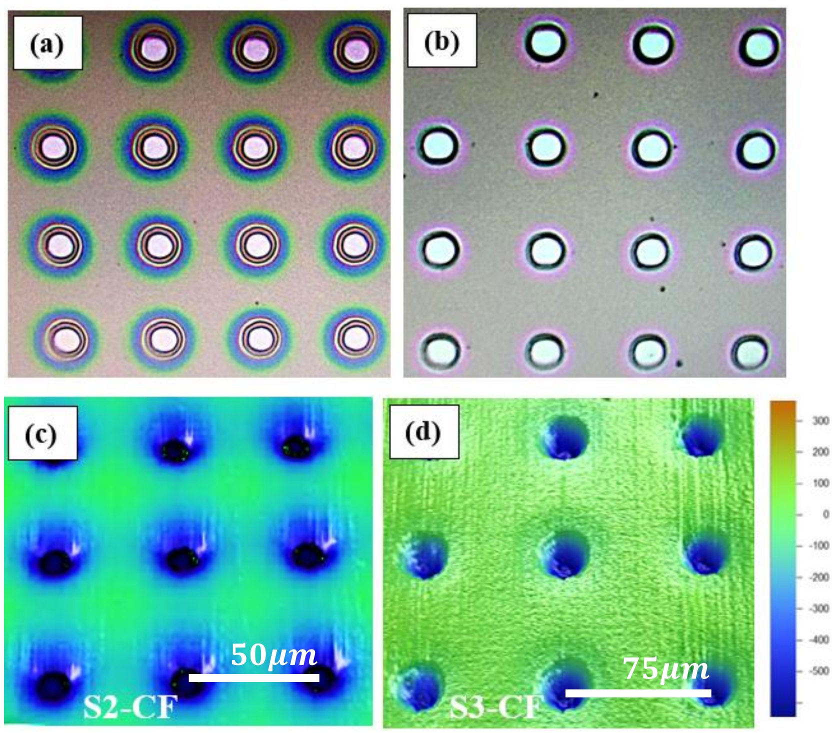


**Figure 5.** The top (optical microscopy) and angled (profilometer) images of microholes delineated on silicon by both application of contour and filling under different velocities; samples of S2-CF (a & c) and S3-CF (b & d), respectively.

To further investigate the origin of the rings observed around the microholes when silicon is used as substrate, the patterning process of microholes were performed by only countering and both contouring and filling at various laser writing speeds. The details of the samples are given in Table I. The most direct conclusion can be interpreted from Figures 4 & 5 is that the outermost ring is due to the contour application regardless of speed of laser. Indeed, the ring with the purplish color in Figure 3b as labeled by a red semi-circle in Figure 3d has the similarity with the samples demonstrated in Figures 4 & 5. As can be predicted, all blurry purplish rings around the microholes seen in optical microscopy images can be attributed to the reflection of light from the shiny surface of silicon during the contouring process. Moreover, another important interpretation is that the number of rings increases by decreasing of the laser writing speed during contouring of the circles. This is due to the higher duration of laser on photoresist for the lower speed.

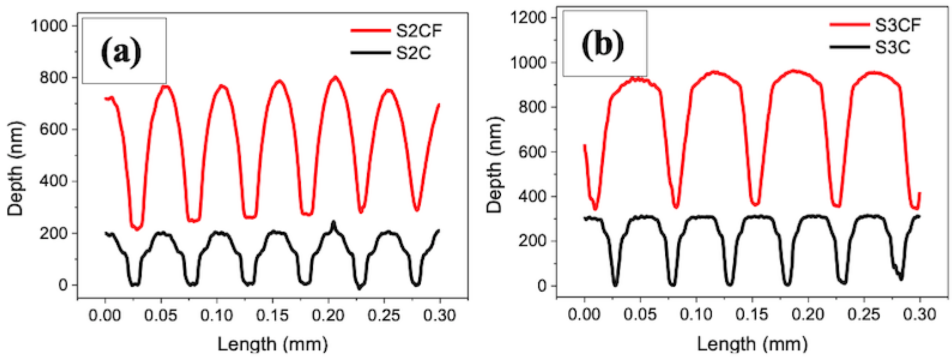


**Figure 6.** The depth profiles of the samples obtained by only contouring and both contouring and filling. S2C-S2CF and S3C-S3CF depth profiles are given in (a) and (b), respectively.

The depth profiles of the samples named S2C-S2CF & S3-S3CF obtained under different laser speeds of contouring are given in Figure 6 (a & b). It is apparent that the depth of the photoresist can be etched only up to 200-300 nm for both samples when only contouring is carried out. While the measured depth for the samples of S2CF & S3CF (when both contouring and filling applied) is about ~ 500-600 nm which is equal to the coated thickness of the photoresist itself. The more and less deep microholes shown in the profilometer images in Figures 4 & 5, respectively, are correlated with the depth profiles. In addition, since the contour velocity of the laser in the S3C and S3CF samples are higher than S2C and S2CF, Figure 6a represents sharper curve. Accordingly, there are fewer microholes in the S3CF curve in the equal scanning line (0.3 mm) and this resulted in the S3C and S3CF curves not being aligned. Indeed, this situation can be even understood when the scale bars of the Figure 5c and 5d are compared, as the distance between the microholes is bigger in Figure 5d.

## 4. CONCLUSION

In summary, patterning the positive photoresist coated on glass and silicon substrates with microholes via maskless laser writer photolithography was successfully carried out in this study. It was confirmed by both optical and profilometer images that well-defined, organized and almost perfectly circular microholes could be produced regardless of process parameters. Besides, the penetration depths of the circles obtained for only contouring and contouring & filling can be determined approximately ~ 200-300 nm and ~ 500-600 nm, respectively, from depth profiles. The homogenous coating of photoresist interpreted from the images and depth profiles is another important finding that is revealed in this study. On the other hand, the formation of the rings around the microholes when silicon is used as substrate while no ring is observed for glass is quite important observation that should be considered. Moreover, the number of rings increases by the lower laser speed. The most possible reason for these findings can be attributed to the transparency and reflectivity properties of glass and silicon, respectively. The laser is subjected to multiple reflections from the shiny surface of silicon while the laser is passes through the glass. Therefore, the phenomenon called standing wave effect arises for silicon which results in the rings. Since the laser stays more on the photoresist when the laser speed is low, the standing effect becomes more apparent thus the number of rings increases. On the contrary, very clear and smooth microholes without any ring are obtained for glass. To sum up, we revealed a successful study on the formation of patterns made up of microholes on the positive photoresist on two different substrates. The differences on the patterns due to the reflectivity properties of substrates are explained and demonstrated. In this regard, we believe the results shared in this study would make a contribution to the literature especially in photolithographic area.

## SIMILARTY RATE: 2%

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