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MICRO LENS ARRAY FABRICATION BY PHOTOLITHOGRAPHY AND THERMAL REFLOW PROCESS

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Abstract

Photolithography and thermal reflow methods were two standard microfabrication technologies to fabricate plano-convex refractive micro lens array. Optical lithography is chosen because of its accuracy to obtain fine features along with good resolution in the structures. Thermal reflow method is preferred to provide high quality and cost effective solution for fabrication of optical micro components. This process was specially optimized for positive photoresist AZ4903. Experiments was conducted with the aim of obtaining dimensions in the range of 50 μm, 15 μm, and 50 μm diameter, thickness of micro lens and spacing between the lens respectively. The morphological characterization is done by using optical microscope in transmission/reflection geometry.

Introduction

Micro lens Array is one of the most commonly used element in the family of refractive micro-optics. It consists of series of small sized lenses which is used to refract and focus the incident light beam. Due to these features, array of micro lens have been used in imaging, integral photography, astronomy, optical interconnects and other engineering applications. There are various ways of fabricating the micro lens array. The fabrication of micro lens array is not as straight forward as single lens fabrication. It requires more process steps. Generally it involves a pattern generation and transfer through various micro fabrication techniques. The alignment precision of the micro lenses, control of the lens dimensions accuracy such as radius of curvature, diameter, focal length as well as surface quality are important issues that should be keep in mind while fabricating micro lens array. Numerous researches have been done and it draws attention from researchers from all over the world. Popovic.et.al first explained the formation of micro lens array by thermal reflow method in 1988. Flexibility and low cost production are basically the reasons for choosing thermal reflow process for fabricating the micro lens array. The foremost step in this method is the creation of cylindrical shaped photoresist structure on a glass substrate by photolithography. Secondly, photoresist microstructure is heated above the glass transition temperature of photoresist. When this temperature reaches, photoresist microstructure starts melting and it causes the resist to reflow into hemispherical shaped micro lens array. This technique enables the micro lens array with good surface finish quality. The profile of micro lens array is influenced by surface tension and gravity and it affects its optical properties. It have been studied that that aspect ratio is affected by the action of gravity and interfacial tension. As the effect of gravity and interfacial tension increases, aspect ratio decreases.

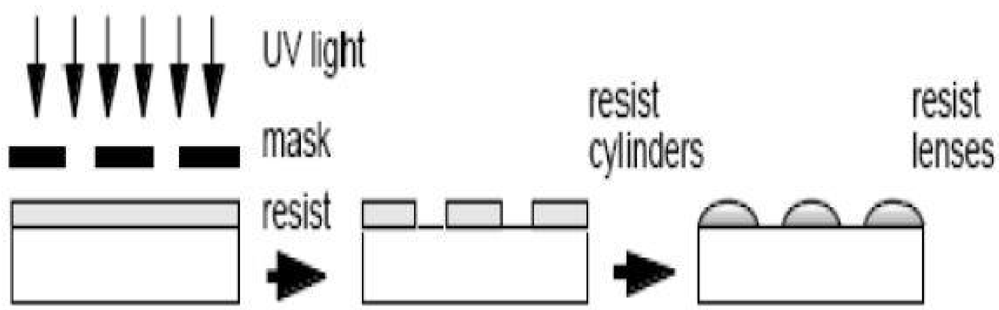

Figure 1: Demonstrates the formation of Micro lens Array by the combination of photolithography and thermal reflow process.

In this paper, we have reported photolithography process to fabricate micro lens array with 50 µm diameter, 50 µm spacing and 15 µm height. After that thermal reflow is done on a hot plate at a certain temperature and surface tension causes resist polymer to transit fro rubbery state into glass state. This technique allows the microstructure to have desired lens profile. Long focal length and high NA microstructure are fabricated by this method. High NA properties leads to excellent optical properties of micro lens array, which are highly required in high resolution. Significant features of this method is low cost production, simple without any use of high technology equipment.

Experimental Process

Micro lens array fabrication requires two processes which includes photolithography and thermal reflow process.

PhotolithographyMaterial used was glass with dimensions of 25 mm * 25 mm and thickness 1.35 mm. We cleaned the sample in ultrasonic bath using deionized water and acetone to remove any contamination. Next step is spin coating, various photoresist are available to fabricate micro lens array such as AZ4903, AZ4562, SU8 etc. The chosen photoresist is AZ4903 as it offers various benefits. It provides good adhesion on a wide variety of substrates; sensitive to g-, h-, and i- line wavelengths; achieve maximum thickness up to 60 µm and also it is sensitive to all popular exposure tools. The sample was coated with AZ4903 positive tone photoresist. Spin coater (Spin NXG-P2) is used to accomplish photoresist coating. The coater's spin speed determines the thickness of the photoresist coated over the substrate. Spin coating is done at 1800 rpm to obtain uniformity. It corresponds to resist thickness of 15 µm. The coated sample is prebake at 115 ° C on a hot plate for 5 minutes to remove the moisture and to harden the photoresist.

Experimental Setup for Exposure:

The system includes UV-LED exposure system, lens system for collimation and substrate holding system. The LED used was UV LED with a wavelength of 405 nm. This UV-LED has a radial power of 5 W and thermal resistance of 4.2 °C/W. For collimation, plano-convex lens was used. UV exposure was carried out by using dark field mask positioned over photoresist coated substrate and fixed in substrate holding system. It results in the generation of patterned structure on the photoresist. After a single exposure, pattern structure is formed. The optimized exposure time is 60 seconds. The exposed glass substrate is developed in AZ4903 developer for approximately 2 minutes and developing time allowing the exposed resist to be dissolve completely. The rinsing with DI water is done followed by drying with nitrogen. This procedure generated cylindrical islands of photoresist structure.

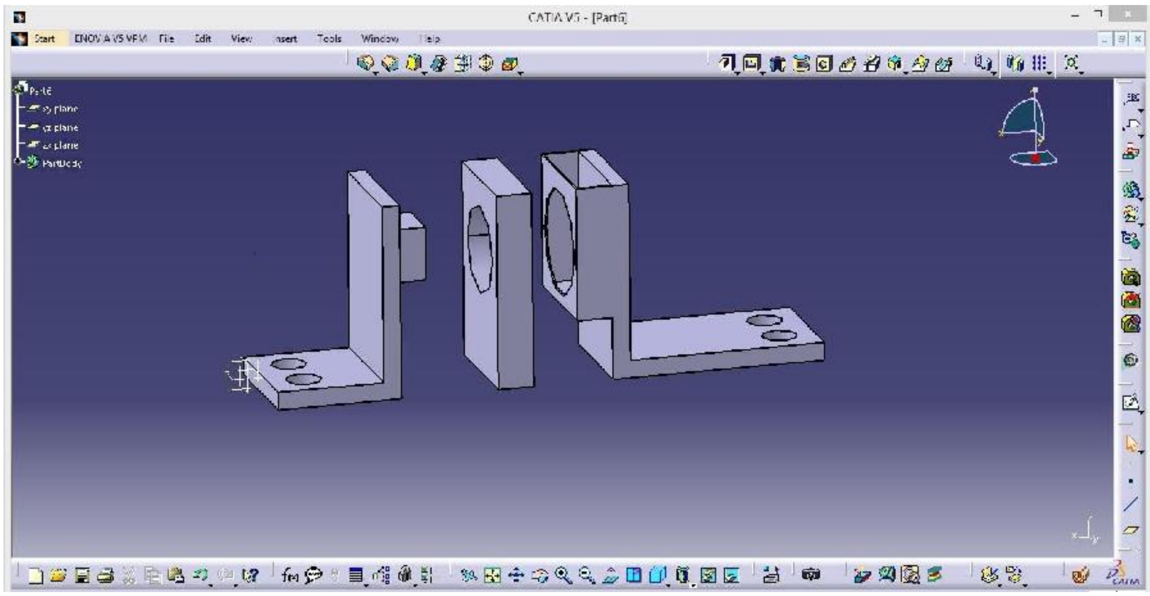

Figure 2: CAD model of UV Exposure System

Resist Reflow

The sample was then heated on a contact hot plate at a temperature at 120˚C for 30 seconds, 60 seconds, 90 seconds, 120 seconds, 150 seconds and 180 seconds. The heating of the photoresist pillars at a high temperature causes the resist to melt. Due to the surface tension among the melted resist, sample surface and surrounding air, the resist pillar changes its shape into hemispherical to minimize the surface energy. The dynamic mechanism of the resist reflow can be explained and modeled by the Navier-Stoke
equation [1]:

$$\rho\frac{\partial u}{\partial t} \quad \Delta P \rho g + \quad \Delta u \quad (1)$$

where *ρ* is resist mass density, *u* flow speed, *P* external pressure, *g* dynamic viscosity and *g* gravitational acceleration. The gravity effect is negligible (*ρg* ~ 0) so the external force applied on the fluid is the external pressure exerted on the surface and is resulted from Laplace' law, thus Eq. 2 is obtained:

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$$\Delta P = (\text{Pint-Pext}) = \frac{2\gamma}{R} \qquad (2)$$

Whereby γ is the resist surface tension and *R* the surface curvature radius.

By proper control of the heating parameters such as time and temperature, the large area of resist pillars forms into microlens arrays on the quartz surface.

Measurements

For measurements of micro lens arrays, various methods are used. In our discussion, optical microscope is used to examine the uniformity of the photoresist patterns before and after the thermal reflow. It is also used to measure the dimension of the patterns, such as the periods of the structure as well as the size of the pattern. The LEICA MICROSYSTEM optical microscope was used in this experiment. It is equipped with up to 1000× magnifications and connected to a CCD camera fed to image acquisition software for accurate measurement. The optical microscope illuminates the sample either through the top light or backlight, which makes the characterization more versatile.

For determination of thickness of the photoresist, stylus profilometer is used. It determines the height of structure before and after reflow.

For designing the Microlens array the following design parameters are to be calculated which includes width of the lens (W), spacing between the lens (S), height of the lens (H), contact angle (α), focal length (f), radius of curvature (R), and others.

Mathematical calculations for MLA

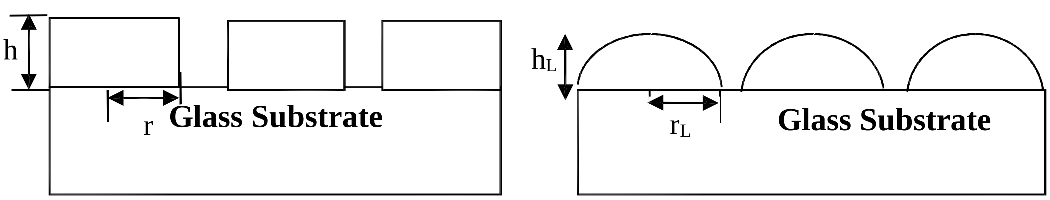

Figure 3: Situation before and after of micro lens array

Before Reflow **After**

Reflow Parameters Obtained before and after reflow Before reflow AfterReflow

1. Height - 15 µm 1. Height- 6 µm
2. Diameter- 50 µm 2. Diameter- 70 µm
3. Spacing- 50 µm 3. Spacing- 30 µm

Radius of Curvature before Reflow:

As we know radius of curvature of plano-convex lens is given by:

$R = r^2+h^2/2h$ (a)

Where r = radius and h is height before reflow

By putting the values of r and h in (a), we get

R = 28.33 µm

Radius of Curvature after reflow

$R = r_L^2+h_L^2/2h_L$ (b)

Where r_L = radius and h_L is sag height after reflow

By putting the values of r_L and h_L in (b), we get

R = 105.08 µm

Therefore, it is concluded that after thermal reflow, curvature increases. After a certain reflow, it becomes flat.

Focal length of the lens is given by:

$f = R/n – 1$

On the basis of above equations, the focal length of the lens is about

f = 210.16 μm (or 0.2 mm)

Focal length of the lens depends upon radius of curvature and refractive index of the lens.

As radius of curvature of the lens increases , so the focal length of the lens also increases.

Contact angle of the lens is given by:

$\text{Sin } \alpha = 2r_L h_L / h_L^2 + r_L^2$

By putting the values of r_L and h_L, we get

$\alpha = 19.2^\circ$

Numerical aperture of the of the lens will be

$NA = n\sin\alpha$

Where n is refractive index of the lens

Value of n is 1.5, put the value in above equation, we get

$NA = 1.5 * 0.33$

$= 0.495$

High-NA properties leads to excellent optical performance of the MLAs, which are highly required in high-resolution.

Results and discussion

Before reflow

Figure 4 shows the cylindrical shaped photoresist structure images after photolithography obtained through optical microscope. This structure is designed with 50 μm diameter, 50 μm spacing between the structure. The dimension accuracy is same as mask dimensions.

Height of the photoresist structure obtained through stylus profilometer is 15 μm. Resist thickness should be high enough so that after reflow microlens doesn't face deviations from spherical shape. .

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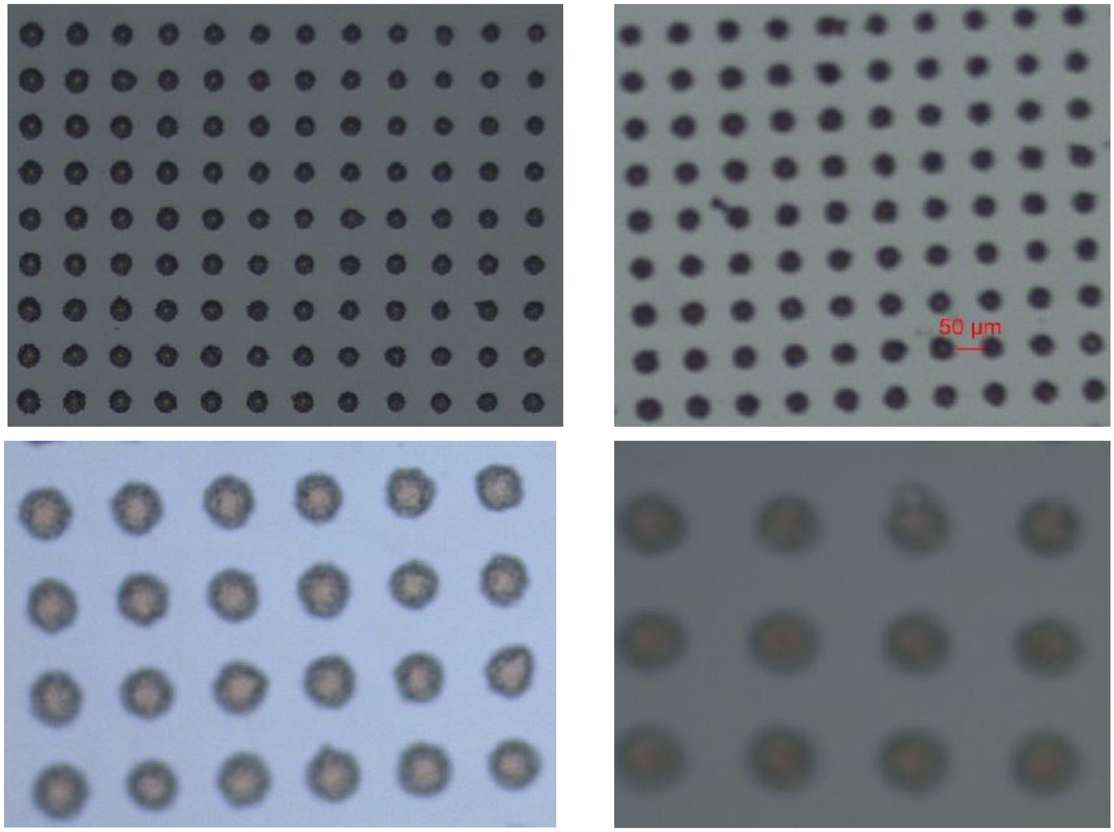


Figure 4: Optical microscope images of dot arrays on photoresist with 50 µm diameter and 50 µm spacing between the circle at different magnification. These are the images before photoresist reflow.

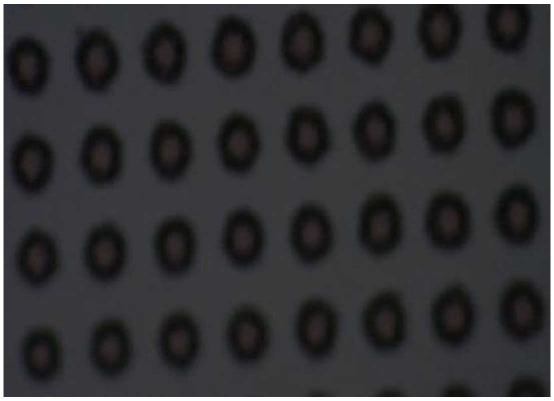
After Reflow

Optical Microscope images of microlens after reflow is shown in figure 5. It have been observed that Thermal reflow process allows the photoresist structures to melt and reflow to form cylindrical or hemispherical micro lenses due to the surface tension of the melted resist. Several changes have been observed. Firstly, the period of the photoresist structures and the arrangement of rectangular packed structures are not affected by the thermal reflow process. It was found that the periods before and after reflow are almost the same when random measurement was done across the sample.

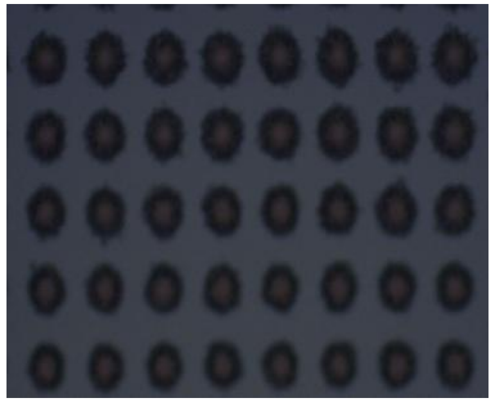
	Diameter (μm)	**Spacing (μm)**	**Height (μm)**	**Pitch (μm)**
Before Reflow	50	50	15	100
After Reflow	70	30	6	100

Table 5: Comparison of the micro lenses before and after the reflow

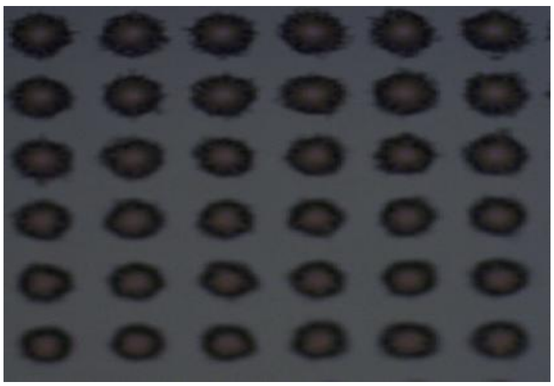
It was also noticed that after the reflow, the height of the photoresist structures was reduced. This is because when the photoresist structures reflow to form hemispherical structure, the resist tends to pull together to reduce the surface energy while maintain a constant volume to reduce the height of the micro lenses. The heating of photoresist also causes the resist to vaporize slightly from the resist surface in some extend; therefore the height becomes lower. As the reflow temperature increases, the micro lenses width becomes larger. The same phenomenon was observed for increasing the reflow time. This could be because the increase of temperature or heating time reduces the viscosity of the resist during the melting; thus the resist becomes wider. Temperature increase also reduces the surface tension.



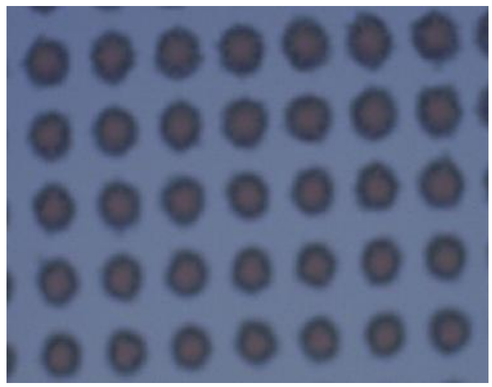
30 seconds



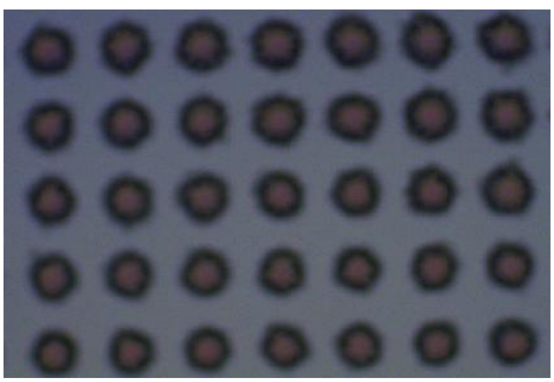
60seconds



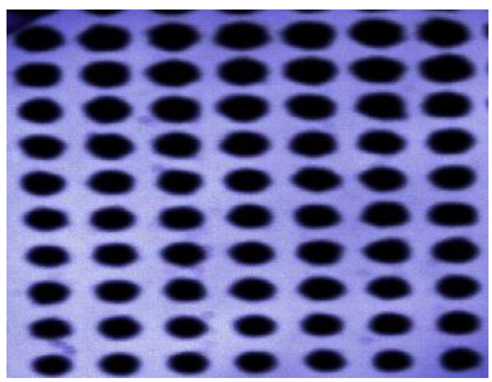
90 seconds



120 seconds



150 seconds



180 seconds

Figure 6: Optical microscope image of dot arrays on photoresist with 77 µm diameter and 20 µm spacing between the circle at different magnification. These are the images after photoresist reflow at 30 seconds, 60 seconds, 90 seconds, 120 seconds, 150 seconds, 180 seconds

Sag height of the micro lens array after reflow is shown in figure 7:

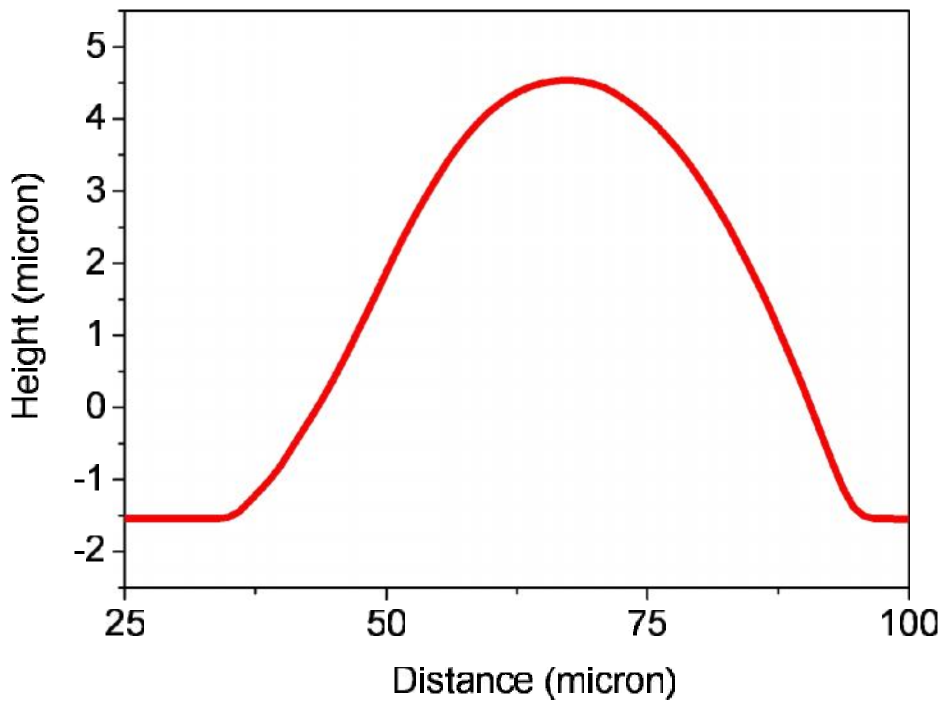


Figure 7: Sag height after thermal reflow

Conclusion

In this paper the Novel techniques of microlens array fabrication are demonstrated. Firstly, the feasibility to fabricate microlens arrays (MLA) by the combination of Thermal Reflow Method and Photolithography. With optical lithography the production of identical photoresist structure can be made possible. The structure were formed on the photoresist by exposure through the UV-LED Exposure System. These were further reflowed into MLA by a surface tension between photoresist and the substrate surface. Experimental results show that plano-convex microlens arrays of diameters 50 µm were successfully fabricated. Optical Microscope shows the lens surface can be obtained. It also demonstrates the curvature of the lens, diameter of lens and spacing between the lens.

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