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Microlenses array made with AZ4562 photoresist for stereoscopic acquisition

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Abstract

In this paper is presented a fabrication process for obtaining refractive microlenses arrays with high reproducibility and low cost. This process was specifically optimized for the AZ4562 photoresist. Functional prototypes of microlenses arrays with dimensions in the range of 30 μm, 4.9 mm and 5 μm for width, length and thickness, respectively, were fabricated and tested. The pre-thermal reflow spacing between adjacent isosceles trapezoids is 1.35-5.43 μm, from bottom to top, respectively. This separation allows the photoresist to reflow and join the adjacent microlens creating a consistent and homogeneous array.

Keywords: Microlens; Thermal Reflow; Photoresist AZ4562; Stereocopic Image Formation.

1. Introduction

Standard microfabrication processes (*i.e.* photolithography and photoresist thermal reflow) were used to fabricate an array of microlenses (MLs). By using these technologies, the fabrication of three dimensional microstructures, that are reproducible to customize high-quality and cost effective optical microcomponents, is possible. MLs are used essentially for collimation, focusing or imaging and are an appealing alternative for applications where miniaturization and alignment simplicity are requirements. The main contribution presented in this work paper is to report on the fabrication of microsized, high aspect ratio arrays of MLs to be used in stereoscopic image formation for image sensors. Photolithographic processes were used to fabricate MLs with approximately 30 and 5 µm for width and thickness, respectively and length measuring 4.9 mm. The thermal reflow was applied for obtaining the actual lens profile based on the surface tension phenomenon [1] guaranteeing good dimensional control and a smooth homogeneous surface. The actual values of the several process parameters will obviously

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depend on the desired final size, requirements and applications for the MLs arrays. In the work presented in this paper, the purpose is having the fabrication steps being done directly on top of a micro optical device, illustrated in Figure 1 a), composed by CMOS image sensors and optical filters. This feature demonstrates the capability of light acquisition necessary for stereoscopic image formation with just a single image sensor, see also FEM simulation result in Figure 1 b).

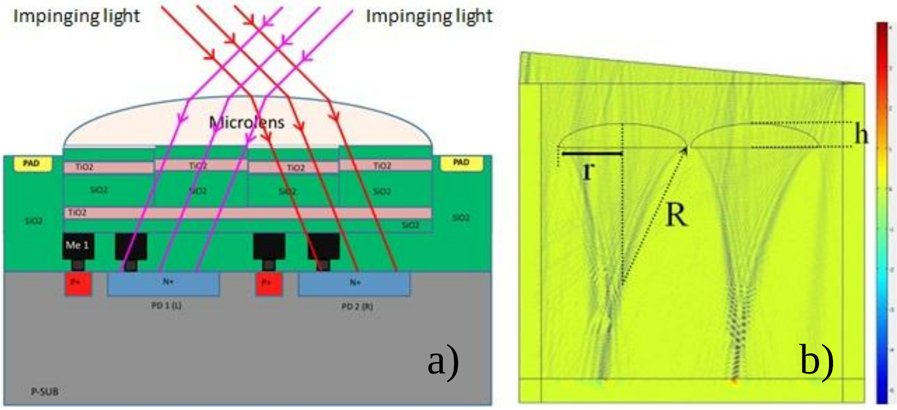


Figure 1 – In a) is the illustration of the concept for the MLs application, *i.e.*, stereoscopic acquisition with a single polychromatic CMOS image sensor (example with only 1 microlens and 2 photodiodes). In b) is the FEM simulation showing the light concentration for microlenses with a width (equal to 2*r) of W=32 μm and a sag height of h=5 μm

2. Microlenses array design and fabrication

2.1. Microlenses array design

The ML design started with finite element method (FEM) simulations, shown in Figure 1 b). The models used to evaluate and define the MLs characteristics are shown in the following equations:

$$n = N_1 + \frac{N_2}{\lambda^2} + \frac{N_3}{\lambda^4} + \ldots \tag{1}$$

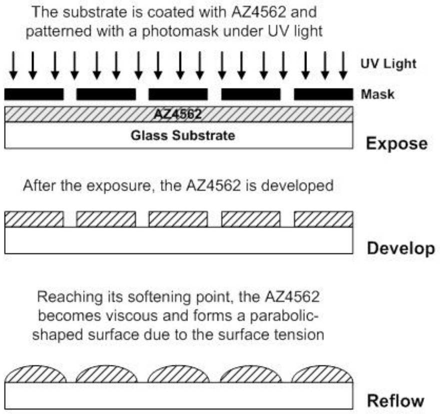
$$f = \frac{R}{n-1} \quad and \quad R = \frac{r^2 + h^2}{2h} \tag{2}$$

In (1) n is the refractive index for a given wavelength λ given by Cauchy's empirical equation where N_1, N_2 and N_3 are the photoresist's constants [2]. The equations representing the focal length f, and radius of curvature R, are shown in (2) [3] assuming their cross-section to be spherical, which is confirmed in SEM cross-sectional pictures. The simulated dimensions of the microlens are 5 and 32 μm for the sag and width, respectively, for an impinging wavelength λ=580 nm (centre of the visible spectrum), where r is half the line segment of the reflowed photoresist interfacing with the substrate and h is the maximum height, or vertex. It should be noted that the simulations are in agreement with the theoretical focal length of 48.6 μm. The simulation was done to steer the impinging light having an angle of 7.6º with the normal due to the assumption made, that the light was previously focused by a converging lens.

2.2. Microlenses array fabrication

As illustrated in Table 1, the microlenses array is fabricated as follows: arrays of rectangular strips with high aspect-ratios (strips with high length/width ratios) are patterned using photolithography. Different sized arrays were designed and printed into a 128k dpi super high resolution chrome on soda lima glass 3x3–0.060 inches mask with each array covering an area of 25 mm^2. Then, a thermal reflow process is applied to the AZ4562 strips. The reflow consists in heating up the MLs material until it becomes viscous and forms a surface with a desired shape due to the surface tension. The process steps and parameters to fabricate the MLs array are summarized in Table 1. Moreover, the AZ4562 positive photoresist is ideal for coating thicknesses above 3-5 µm without having to increase the exposure energy considerably and still providing enough energy down to the substrate of the photoresist [4].

Table 1. Fabrication process steps and parameters



Process steps	Process parameters
Spin coating	20 secs. @ 6000 rpm
Prebake (hotplate)	5 mins. @ 100º C
Exposure @ 365 nm (mask aligner)	30 secs./contact mode @ 134 W
Developing	AZ400K or AZ351B developers in a 1:4 concentration with distilled water (2*2 mins. 15 secs.)
Cleaning	Rinse with distilled water and dry with N_2 flow
Thermal reflow (hotplate)	5 mins. @ 130º C

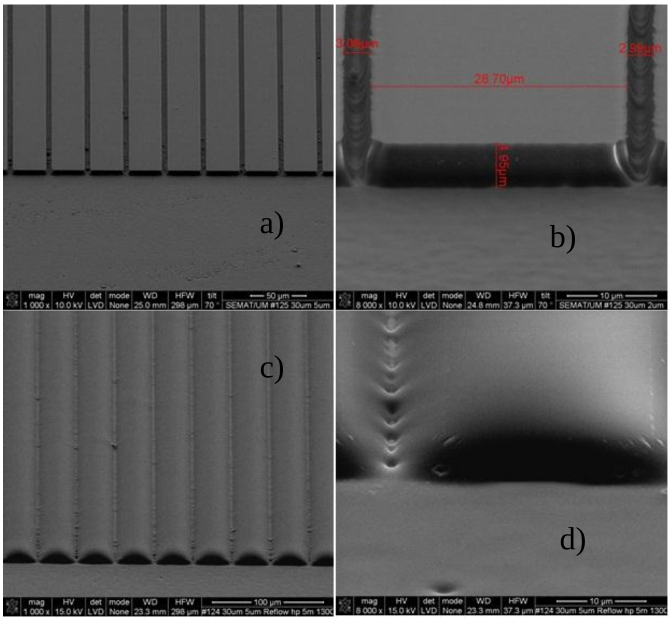


Figure 2 – SEM photographs the MLs array before and after the thermal reflow.

Figure 2 shows scanning electron microscope (SEM) photographs of the fabricated structures. It is possible to see in a) a general view and in b) a zoom in before the thermal reflow and in c) and d) the same perspectives are represented but after the thermal reflow. It should be noted that the physical dimensions of the array elements, *i.e.* width and pitch distance, are very close to the mask dimensions.

The volume of the AZ4562 before and after the reflow is assumed to be equal.

3. Results

Figure 3 shows the results of some experiments done with the prototype. The subjective evaluation made to the optical quality of microlenses and their structural integrity was done by impinging a laser beam, λ=632 nm (generated from a neon source) into the array and observing the diffraction pattern into a perpendicular plane. On the left bottom side of the picture below (in foreground), it is seen the laser dot (with a 1 mm diameter) hitting the MLs array with the following corresponding pattern seen in the background. The distance between the array and the plane is 1.6 m and the pitch between the smaller red dots, seen in Figure 3, is 3.5 cm. The subjective quality of the microlenses array is very good. It can also be observed in the picture that each microlens in the array spreads the laser beam into a specific direction. Moreover, it is possible to see the interaction between the spread beams. The structural and optical quality that were observed during the process optimization and during the characterization of the microlenses arrays open good perspectives for fabricating stereoscopic image sensors at low cost.

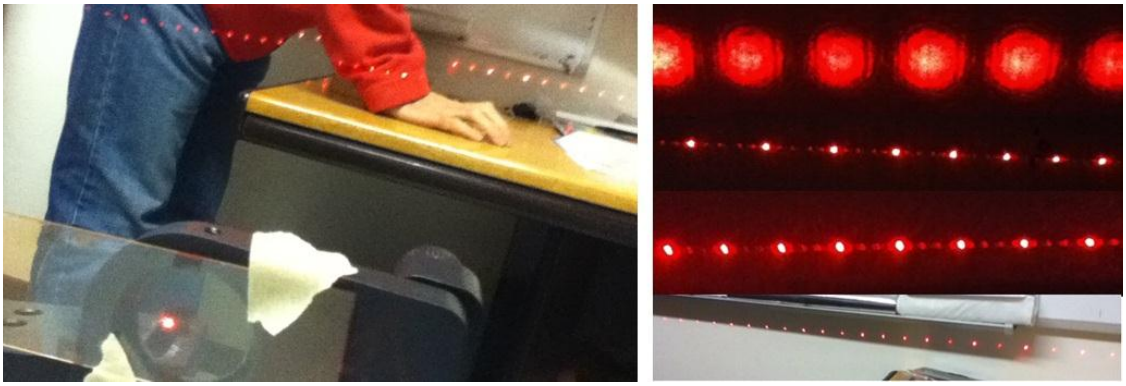


Figure 3 - Optical setup used for the quality evaluation of multibeams. This setup is composed by a selected array of microlenses, by a laser source and by a flat surface to project the spread beams. Photographs with projections of laser beams after being spread in the MLs array. It is possible to note interference patterns between the beams.

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