FABRICATION OF AZ4562 REFRACTIVE MICROLENSES ARRAY FOR LIGHT ENHANCEMENT ON OPTICAL MICROSYSTEMS

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***Abstract* — This paper presents the fabrication of an array of high aspect ratio photoresist based refractive microlenses (ML) using photolithography and thermal reflow. First, and in order to evaluate and predict the MLs optical properties and physical dimensions, finite element analysis was done. These simulations helped to design the super high resolution chrome on soda lime glass photomask as well as the parameters for the lithographic processes. Then, an array of high aspect ratio structures (length 4.9 mm, width 30 µm and 5 µm spacing between adjacent structures) with 5 µm thickness were fabricated. The thermal reflow technique (using a hotplate) was applied and an array of MLs measuring 5 and 32 µm at the vertex and radius, respectively, was achieved. When the photoresist (PR) is heated up above its glass transition temperature, it melts and the surface tension effect causes the fabricated microstructure to obtain the spherical lens profile. The hotplate thermal reflow is simple and easy to control, thus permitting the fabrication of smooth and homogeneous surfaces essential for good quality refractive microlenses.**

***Keywords :* Microlenses array, Photolithography, Photoresist, Thermal Reflow**

I - Introduction

Standard microfabrication processes (*i.e.* photolithography and photoresist thermal reflow) were used to fabricate an array of refractive microlenses. By using these technologies, it is possible to fabricate three dimensional microstructures that are reproducible to customize high-quality and cost effective optical microcomponents. Microlenses (ML) were first fabricated in 1988 by [1] and opened a large number of new applications for such optical structures and at the same time reducing the mechanical and electrical complexity of the existing systems. Basically, refractive MLs are used for collimation, focusing or imaging and are an appealing alternative for applications where miniaturization and alignment simplicity are requirements. Examples of these applications include imaging [2], biomedical instruments [3], lab-on-a-chip systems [4] and in optical communications [5]. The fabrication processes have been through various changes and improvements along this time period as well as the materials selected to fabricate refractive MLs. The two main materials used are glass and polymers and the current fabrication technologies for the latter are the microjet technique, photoresist reflow, ultraviolet curing, hydrophobic effect, LIGA and the soft replica molding methods [6]. The never stopping improvements observed in the polymeric based material properties and continuous process technology enhancements justify the focus given to this material when fabricating MLs. The main contribution presented in this paper is to report on the fabrication of micro-sized, high aspect ratio arrays of MLs to be used in light acquisition enhancement for image sensors. Photolithographic processes were used to accomplish such optical microdevices in the 35 and 5 µm width and thickness sizes, respectively. The thermal reflow was applied to obtain the actual lens profile based on the surface tension phenomenon [7]. This technique allows the fabrication of high quality spherical and parabolic shaped MLs by heating up the photoresist (PR) above its glass transition temperature. Once this temperature is reached, the photoresist starts to melt with the surface tension effect causing the fabricated microstructure to gain the desired lens profile. The entire process is relatively simple to perform and the thermal reflow specifically is very well controlled without the need for high-technology equipment guaranteeing good dimensional control and a smooth homogeneous surface. Moreover, this is an important topic because it provides the fabrication of MLs arrays in a reproducible way and at low-cost. The actual values of the several process parameters will obviously depend on the desired final size, requirements and applications of the micro-optical device. In the presented case the purpose is having the fabrication being done directly on top of an image sensor and the main contributions are the geometric sizes, the aspect ratio achieved and the quick reflow time when compared to other works [8].

II – Microlenses array design and fabrication

A. Microlenses array design

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

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

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

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 [9]. The equations representing the focal length *f*, and radius of curvature *R*, are shown in (2) [10] assuming their cross-section to be spherical. The simulated dimensions of the microlens are 5 and 32 µm for the sag and width, respectively, for an impinging wavelength λ=580 nm (center 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. The light is being irradiated parallel to the surface of the substrate and it is clearly seen that the simulations are in agreement with the theoretical focal length of 48.6 µm.

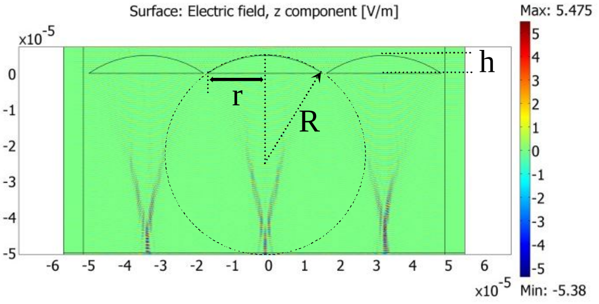

Figure 1*: FEM simulations showing the light concentration for microlenses measuring 5 and 32 µm for the vertex h and width 2r, respectively.*

B. Microlenses array fabrication

There are several different materials available for fabricating microlenses arrays such as the BCB, PDMS, SU-8/2, AZ9260 and AZ4562 photoresists, for example. These polymers allow the microlenses array fabrication by thermally reflowing the three dimensional structure achieved through the photolithographic process. The selected photoresist was the AZ4562 due to the fabrication requirements, *i.e.*, this 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 AZ [11]. The processing steps overview of the ML array fabrication process is presented in Figure 2.

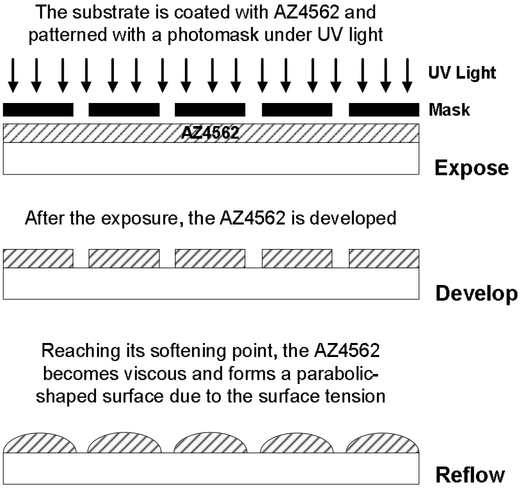

Figure 2: *Microlenses array fabrication steps.*

This process permits the production of an array containing 142 microlenses. The rectangles that compose the mask array measure 4.9 mm in length, width of 30 µm and 5 µm spacing between adjacent rectangles. This setup allows the fabrication of good optical quality in just a few minutes and with high degree of reproducibility of their characteristics. To the author's knowledge, this is the first time that such a geometry, with the presented dimensions and aspect ratio, is used to fabricate an array of MLs. 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, as seen in Figure 3. The rectangles are coated with chromium making them opaque to light and the spacing between rectangles is transparent allowing the photoresist under it to be later exposed to the UV light. The fabrication process of the microlenses array requires several steps and process parameters summarized in Table 1. First, it is necessary to spin coat the AZ4562 at 6000 r.pm. during 20 seconds, in a previously cleaned glass substrate, to achieve the desired 5 µm thickness.

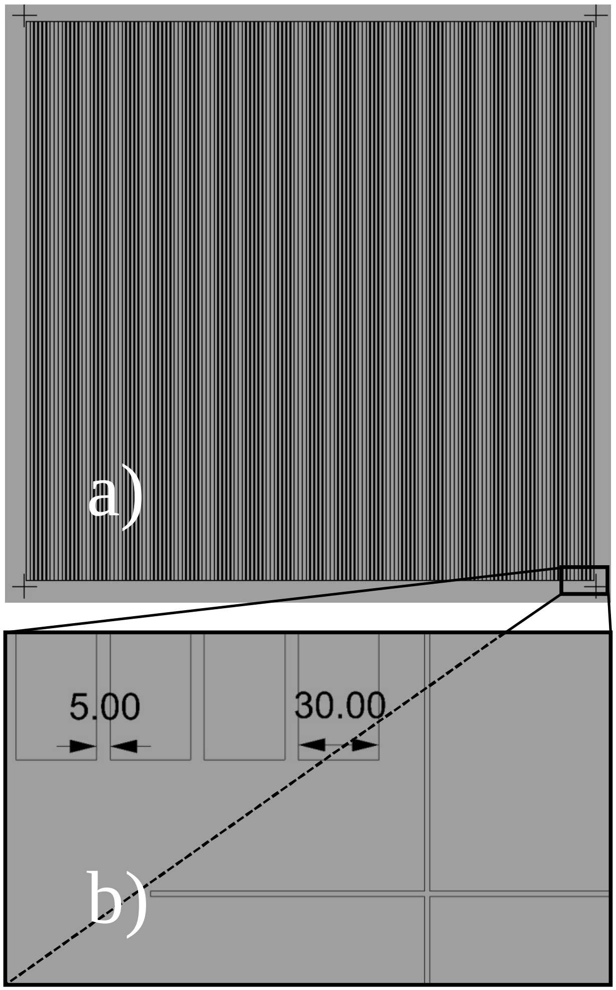

Figure 3: *In a) a whole picture of the array mask and in b) a detailed zoom-in with the chromium rectangle width (30) and spacing (5) is expressed in µm.*

After the coating, a prebake phase, using a computer controlled hot plate at 100º C for 5 minutes, is necessary to evaporate the solvents present in the photoresist. Next, to obtain the required array-like structure, the mask with the correspondent geometry is placed on top, directly contacting with the coated photoresist and exposed to UV light (365 nm) using a mask aligner. The AZ4562 being under a 134 W exposure during 30 seconds makes the unexposed material insoluble. Afterwards, the developing phase is achieved by either the AZ400K or the AZ351B developers in a 1:4 concentration with distilled water. To accomplish it, the substrate is immersed into two developer baths for 2 minutes and 15 seconds each, in a magnetic stirrer plate. This is required to leave just the unexposed photoresist in the substrate. The photolithographic process ends with the structures being rinsed with distilled water and dried out with a nitrogen flow. Finally, to obtain the lens profiles, the thermal reflow technique is applied so the substrate holding the array containing the fabricated structures is placed on a hotplate at 130º C for 5 minutes.

Table 1: Fabrication Process steps and parameters

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

III - Results and Discussion

A. Pre-thermal reflow array

After coating the photoresist one should guarantee that, if not all, at least most of the solvent is cleared off. To evaporate the solvent, a hotplate or an oven could be used. If this is not accomplished the trapped solvent may form bubbles and lift the resist film causing adhesion failure. In the process presented in this paper, the hotplate was used due to its better ability to evaporate the solvent as it ramps up to the final selected prebake temperature. By considerably reducing the existing bulk solvent concentration a better resist profile is achieved as well as a decrease of the developer etch to the unexposed resist. Figure 4 shows SEM images of the fabricated structure after the photolithographic process. 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.

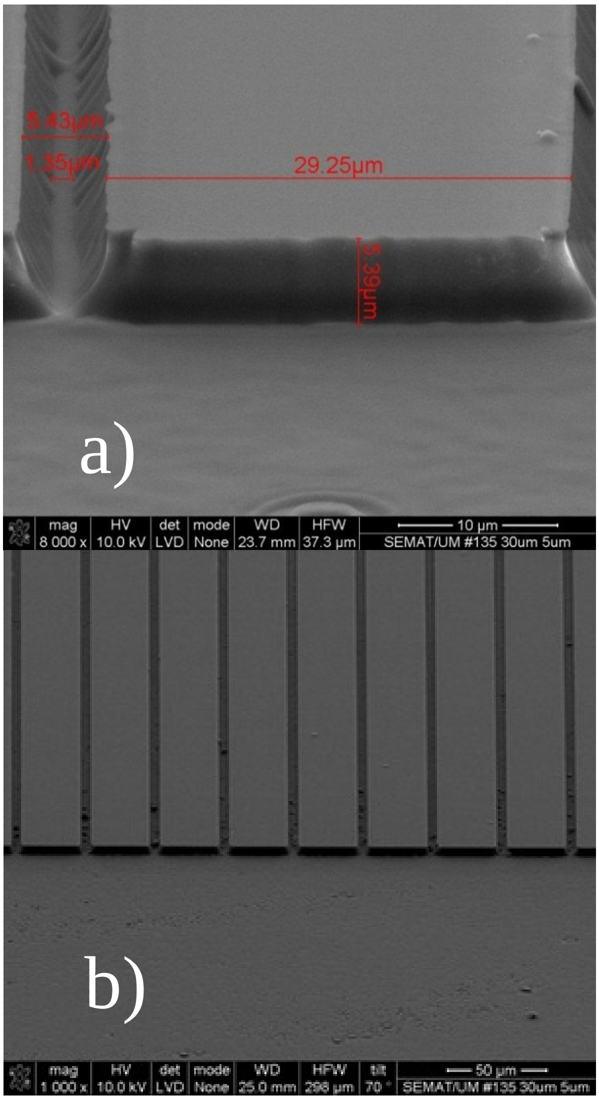

Figure 4: *In a) and b) SEM images of a single element of the array and an overview of the array, respectively.*

B. Post-thermal reflow array

The PRs that do not cross-link have a given softening point that can be used to thermally reflow the fabricated three dimensional structures. The AZ4562, being a positive photoresist, is one of these PR and its softening point is around 110 ºC [9]. During the fabrication optimization, it was realized that the best reflow conditions were using a hotplate in a temperature range between 130–140 ºC during 5 to 10 minutes depending on the thermal coefficient and thickness of the substrate. After applying the designated temperature the PR's viscosity decreases and the consequent flow occurs due to surface tension thus achieving the desired ML profiles. In Figure 5 are represented SEM images of one lens and a part of the entire ML array showing the obtained consistent result. It is clear from the figures that the thermal reflow process using a hotplate allows obtaining the desired microlens profiles necessary to refract the incident light.

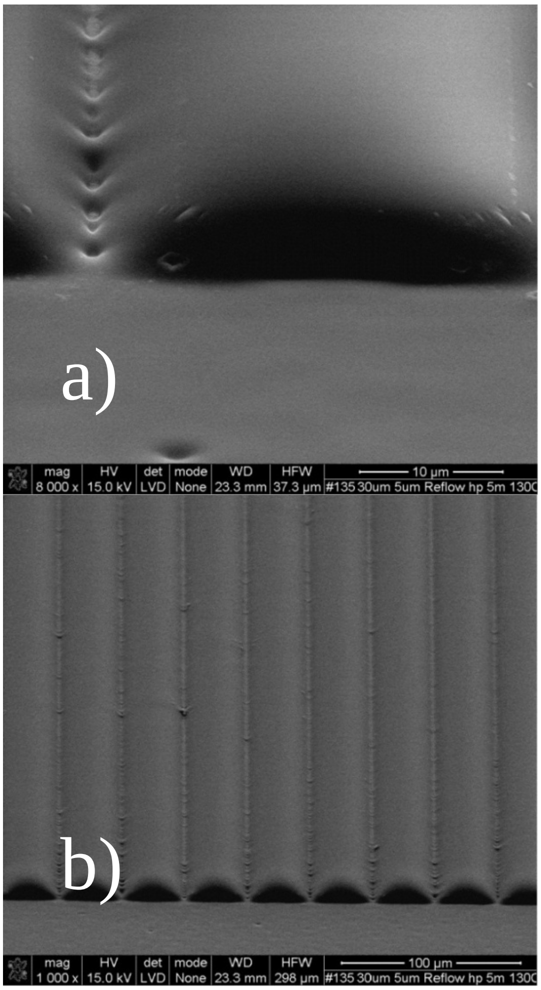

Figure 5: *In a) and b) SEM images of a single microlens an overview of the ML array, respectively.*

IV - Conclusions

This paper presented the fabrication process of an array of refractive spherical microlenses for light acquisition enhancement in image sensors. The microlenses design started with the FEM simulations to set and evaluate some parameters needed to fulfill the desired objectives. These objectives included the microlenses' purpose of enhancing the light capture on optical microsystems. The complete fabrication process was explained and the initial and final structures obtained were measured using SEM photographs. The several steps that comprise the photolithographic process were explained and justified and are flexible enough to be changed according to the desired final size, requirements and applications of the micro-optical device. It was also shown that the thermal reflow technique is ideal to obtain lens profiles in polymer based microstructures due to the surface tension effect. Moreover, the thermal reflow is an easy process to control and the results obtained are very smooth. This is an important requirement for obtaining microlenses with good quality. The direct fabrication of such an array of MLs on top of image sensors allows new approaches and applications for optical microsystems.

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