HIGH-QUALITY SURFACE MICROLENSES BASED ON REHYDRATION

R. P. Rocha¹, M. J. Maciel¹, J. P. Carmo¹, J. H. Correia¹

¹University of Minho ; School of Engineering ; Department of Industrial Electronics ; Guimarães, Portugal

Abstract — This paper reports on the fundamental step needed for guaranteeing high-quality microsized, high-aspect ratio arrays of lenticular microlenses (MLs) fabricated with the AZ4562 photoresist (PR). The MLs were fabricated for a length of (but not restricted to) 4.9 mm and a width×thickness (at the apex) product of 24×5 μm. It is shown that during the fabrication process, the PR has to be rehydrated in order to obtain excellent results by preventing structural damages in the MLs crucial for achieving efficient optical properties.

Keywords : Microlenses, Rehydration, Thermal Reflow, Photore sist, Microfabrication.

I - Introduction

Microlenses (MLs) have been applied in different industrial fields which require concentration of light in a compact and efficient way [1]. The MLs can be fabricated using different methods [2–4] such as hot embossing, e-beam lithography, reactive ion etching, photore sist (PR) reflow method and LIGA. The most used fabrication technique is the thermal reflow due to fast process speed, its simplicity and low cost. The main objective of this paper is presenting an optimized fabrication method, based on rehydration, for guaranteeing MLs with excellent profile with very smooth and homogeneous structures which are essential for good optical quality microlenses. On a previous work, the AZ4562 ML fabrication process was demonstrated using the thermal reflow method [5]. Basically, only photolithography and a heating process (thermal reflow) are required for fabricating MLs. The photolithography is used for patterning the PR and then, a simple method consisting in heating the PR above its glass transition temperature (Tg) is applied. This temperature higher then Tg induces the surface tension phenomenon, causing the material to acquire a spherical profile [5],[6]. The precise form of the microlens, and hence their focal properties are determined also by the effects of the surface tension.

II – Microlenses Fabrication

A. Photolithography

The selected photoresist is the AZ4562 due to the fabrication requirements, i.e., this positive PR is appropriate for coating thicknesses of about 5 μm without having to increase the exposure energy considerably and still providing enough energy down to the substrate. Nevertheless, the prebake has the drawback of also evaporating the AZ’s water content producing results with less quality as demonstrated in Figure 4. The following phase, i.e., U.V. exposure, includes the correct position and alignment of a photo-mask in contact mode on top of the PR and the consequent exposure to UV light (237 nJ/mm²). This is achieved using a 128k dpi super high-resolution chrome on soda lime glass 3×3–0.060” photomask composed of 24 μm width rectangles spaced apart by 5 μm. A developing phase with the appropriate developer (AZ351B) and
The actual lens profile is highly dependent on these quantities. In these cases, it is assumed that the volume of the microstructure before and after thermal reflow is the same and that the interface with the substrate remains static. Moreover, above the material’s $T_g$ its viscosity decreases thus flowing under the influence of the surface tension. In this flowing condition, the AZ4562 obeys the Navier-Stokes equation [9]:

$$
\rho \left( \frac{\partial \mathbf{V}}{\partial t} + \mathbf{V} \cdot \nabla \mathbf{V} \right) = -\nabla p + \mu \nabla^2 \mathbf{V} + \mathbf{f}
$$

(2)

where $\sigma$, $\sigma_d$, and $\sigma_s$ are liquid surface tension, the solid and liquid boundary tension and the solid surface tension, respectively, and $\theta$ is the contact angle before reaching equilibrium.

Figure 2: Contact angle between the microfabricated structure and the substrate.

The entire process is relatively simple to perform and the TR specifically is very well controlled without the need for high-technology equipment guaranteeing good dimensional control and a smooth homogeneous surface as is demonstrated in the results section.

### Table 1: The MLs fabrication process steps and parameters.

<table>
<thead>
<tr>
<th>Process steps</th>
<th>Process parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spin coating</td>
<td>20 seconds @ 6000 rpm</td>
</tr>
<tr>
<td>Prebake (hotplate)</td>
<td>10 minutes @ 100 °C</td>
</tr>
<tr>
<td>Exposure in contact mode (Mask aligner)</td>
<td>237 mJ/mm²</td>
</tr>
<tr>
<td>Developing</td>
<td>AZ351B developer in a 1:4 concentration with distilled water (2’15”)x2</td>
</tr>
<tr>
<td>Cleaning</td>
<td>Rinse with distilled water and dry with N₂ flow</td>
</tr>
<tr>
<td>Thermal reflow (hotplate)</td>
<td>10 minutes above glass transition temperature</td>
</tr>
</tbody>
</table>

Since the prebake besides removing the solvents also removes the water from the PR, it is required to rehydrate it. The comparison between results of the fabrication process with and without rehydration can be seen in section III.

### B. Thermal reflow

For obtaining the desired lens profile, it is necessary to apply a thermal treatment to the fabricated microstructures. When the photoresist is submitted to a temperature higher than its glass transition temperature $T_g$, it softens allowing the shape transformation to occur. The external forces acting during this process are the surface tension (associated with the contact angle [7] and gravity, being the latter more significant in lenses with more volume [8]. This positive PR has a given softening point, around 110 °C [5], that can be used to thermally reflow the fabricated three dimensional microstructures. Immediately before the TR is applied, tensions are acting between the AZ4562 and the solid substrate, as is represented in Figure 2. As soon as the photoresist starts flowing, due to the surface tension, it starts gaining a lens profile until the system reaches equilibrium. In particular the contact angle of the softened resist with the surface of the substrate will strongly influence the shape of the microlens. The relation between these acting forces is described by [2]:

$$
\sigma_s = \sigma \cos \theta + \sigma_{sl}
$$

(1)
Figure 3: Reflow temperature profile used in the hotplate. It should be noted that the actual reflow time starts when the temperature reaches 100 °C. A continuous and linear distribution of heat across the substrate and the PR is highly desirable.

III - Results and discussion

A. Fabrication results without rehydration

In Figure 4a) and b) are presented the pre-TR structure and the post-TR finished microlens, respectively. The rough edges and wrinkles are obvious and occur due to the lack of water in the photoresist. This non-homogeneous surface will increase the non-desirable light scattering and reflection thus reducing the light transmission through the lens.

Figure 4: SEM images showing the fabrication results without rehydration. In a) is the pre-thermal reflow microstructure and in b) is the post-thermal reflow microlens. As is clearly seen, the lack of water produces visible cracks and surface protuberances.

B. Fabrication results with rehydration

The optimized fabrication process of geometrically and dimensionally consistent microlenses arrays with excellent optical properties requires the addition of a new process step between pre-bake and exposure (see Table 1). This consists on a new period of 10 minutes at room temperature so that the PR can absorb water from the air humidity, somewhere between 40–45%. The new procedure prevents the non-uniformity in polymer based MLs prejudicing their optical properties [10] and is of utmost importance. The rehydration step serves mainly to guarantee a sufficient amount of water in the PR during the UV exposure to allow a reasonably high development rate and contrast. It also prevents the development time to increase due to insufficient water and for obtaining very good results as shown in Figure 5 (with just the addition of the rehydration time period).

Figure 5: SEM images showing the fabrication results with rehydration. In a) is a zoom-in of the pre-thermal reflow microstructure. In b) is an overview of the array for demonstrating fabrication consistency.

The rehydration facilitates the fabrication of pre-TR structures with a profile closer to the theoretical parallelepipedal shape rather than a trapezoidal one, compare Figure 4a) and Figure 5a). A great advantage of the proposed procedure is the improvement of well-established standard microfabrication processes (photolithography) combined with photoresist thermal reflow. In Figure 6 are shown the results obtained after the thermal reflow is applied. The microlens plano-convex profile is very clear and the surface is very smooth thus
facilitating the light convergence across the ML.

Therefore the rehydration is the key factor for obtaining the very smooth and homogeneous structures seen in the pictures.

IV – Conclusion

The fabrication process for photoresist based microlenses was optimized. The typical fabrication includes the material’s prebake which has the unwanted consequence of causing its dehydration. This lack of humidity produces microlenses with rough edges and protuberances hence decreasing their optical properties. Therefore, it was demonstrated that a rehydration step is crucial for obtaining MLs with an excellent smooth and homogeneous profile. This optimization facilitates the fabrication of pre-thermal reflow structures with a profile closer to the theoretical parallelepipedic shape rather than a trapezoidal one thus making the post-thermal reflow results closer to a perfectly spherical profile. So, the rehydration is the key factor for obtaining microlenses with excellent optical properties.

Acknowledgements

Rui Pedro Rocha was fully supported by the Doctoral MIT-Portugal scholarship SFRH/BD/33733/2009 granted by the Portuguese Foundation for Science and Technology (FCT). The scholarship of Marino Jesus Maciel was fully supported by the FCT project PTDC/EEA-ELC/109936/2009. The authors also acknowledge to Dr. Ing Christian Koch from the company MicroChemicals GmbH for the technical support.

References