Low Temperature Molding for High Space Coverage Microlens Arrays

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Abstract

This paper presents SF_6/O_2 plasma lens-mold-etching and low-temperature-molding to produce 100% coverage microlens arrays. The methods can successfully fabricate microlenses with different focal lengths (432.7-826.5µm) on a substrate in batch processes.

Introduction

Microlens arrays have played important roles in the field of telecommunications and display systems [1]. There are various methods that can produce microlens arrays [1-9]. For these methods, one of the biggest challenges is to produce a microlens array with high surface-coverage ratio. The coverage ratio is defined as the total lens coverage area vs. total array area. A higher surface coverage area implies lower optical loss and higher focusing efficiency. We use plasma-etched micromirrors [10] as master-molds. Then, we present low-temperature direct and indirect microlens-molding processes, shown in Fig. 1, to replicate flexible and stiff lenses from the master-molds respectively. Microlenses with spacing at 200µm, which are arranged into 70×70 arrays, have been successfully produced on a substrate in batch processes. Presented are the materials, methods, and testing and analysis results.

Materials and Methods

The master-molds are made from time-multiplexed plasma silicon etching which yield paraboloidal cavities [11]. By setting the origins at the lowest points on these symmetric cavities, one can characterize them by a second order polynomial, $Y = A_iX^2$. Three different master-molds (A_1=0.0021, A_2=0.0016 and A_3=0.0011) have been tested to reproduce microlens arrays. The selection of lens materials is critical in both direct and indirect molding processes. For example, a slight change of refractive index can induce a significant variation in focus for a lens. As shown in Fig. 1, direct molding creates flexible microlenses directly from master-molds with transparent material (PDMS). Indirect molding needs two flexible transfer-molds (Reprorubber) to transfer the lens shape from the original master-mold to produce stiff and UV cured microlenses. The selection of master-mold and

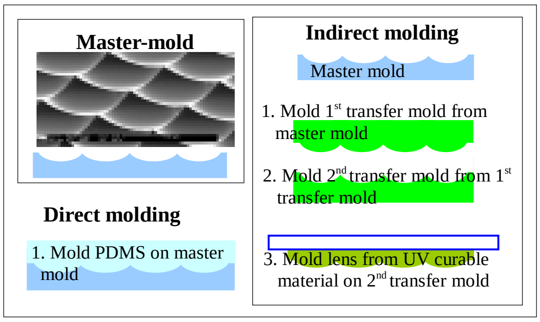

Figure 1: SEM picture of a master-mold, and the direct/indirect molding method.

transfer-mold materials is also important to achieve metrology-grade molding and lens reproduction without shrinkage. A comparison of optical properties of generally used lens and a comparison of mold materials is listed in Table 1. Overall, Norland 68 has best optical stability among the lens materials tested here.

Table 1: List of lens- and mold-materials used

Lens materials	Optical index	Hardness Shore D	Applicability
PDMS	1.40-1.60	28	Direct molding
SU8	1.60-1.80	78	Indirect molding
Norland 68	1.54-1.56	60	Indirect molding
Mold materials	**Shaping method**		**Applicability**
Si	Plasma etching		Master-mold
Reprorubber	Molding		Transfer-mold

Testing and Analysis

To check the imaging quality of the lens, condensed LED images are directly observed

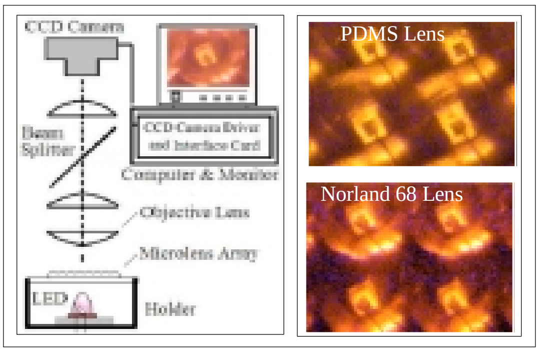

Figure 2: Experiment setup and condensed LED images on PDMS and Norland 68 Microlens arrays.

under an optical microscope setup shown in Fig. 2. Because the incident side of the lenses is a planar surface, paraxial optics is chosen for the ray tracing in Fig. 3 while considering only collimated light in a centered optical system. It is used to estimate the focal length and numerical aperture for microfabricated lens arrays (Table 2). However, the ray tracing method ignores the wave-like nature of light. After consider light as a vector wave, the diffraction limited spot sizes (Fig. 3), Seidel aberrations (Table 2) and distortions (Fig. 4) are analyzed by OSLO v6.1.

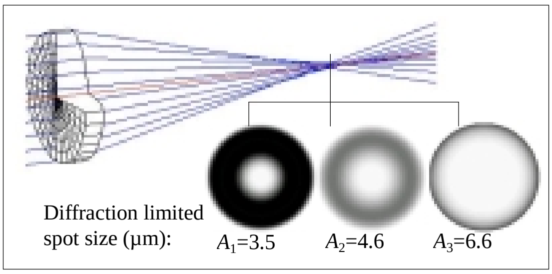

Figure 3: Ray tracing, diffraction spot size and interferogram plots for tested lens.

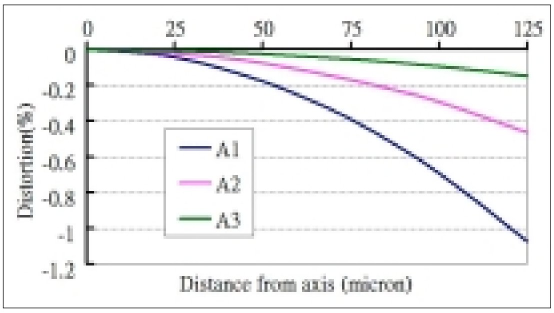

Figure 4: Distortion plot of these three molded microlenses

Table 2: Lens NA, focal length and aberration

Master mold	Approx. radius of the lens	NA	Aberration	Effective focal length
A_1	119.0	0.231	-12.37	432.7
A_2	156.3	0.176	-7.18	568.3
A_3	227.3	0.121	-3.39	862.5

Length unit: μm

The distortion is defined as the aberration of the chief ray, which can be expressed as the difference (in percent) between the actual mapping image and the ideal image. These molded microlenses have negligible image distortions. In the worst case, A_1, the distortion is only -1.25% (the negative sign is referred to as barrel distortion). It makes these lenses ideal for microscopic imaging.

Summary

This paper presents a series of processes to produce various microlens arrays with virtually 100% surface coverage in a cost-effective batch-process. The low temperature direct and indirect molding replicates microlenses with selected optical materials from plasma etched paraboloid-shaped master-molds. According to the optical observation, SEM and SPM examination, both experimental and analysis results proved that a paraboloidal microlens array can be produced by these methods with good focusing and imaging quality.

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