Combining UV-replication techniques with injection moulded polymer optics

J. Mutanen[1], J. Väyrynen[2], S. Siitonen[3], A. Kauppila[3], A. Partanen[1], P. Pääkkönen[1], H. Tuovinen[1], T. Itkonen[1], M. Kuittinen[1], J. Niemi[2], and K.Mönkkönen[2]
[1]*University of Eastern Finland, Finland*
[2]*North Karelia University of Applied Science, Finland*
[3]*Nanocomp Oy Ltd, Lehmo, Finland*

Jarkko.Mutanen@uef.fi

Abstract

In this paper a new approach to improve the accuracy of injection moulded plano convex acrylic lens by UV-curing process is introduced. It is shown that by UV-curing a layer on the planar side of the lens the optical performance was enhanced. The surface roughness and shape variations of the injection moulded lens and corrected lens were measured and a clear improvement on the optical performance and reduced surface roughness and reduced shape variations were observed.

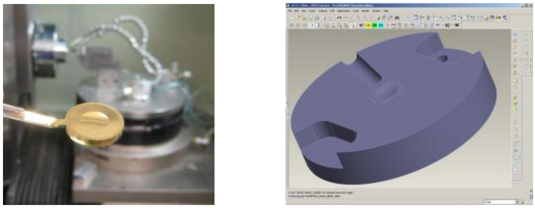
1 Introduction

Manufacturing affordable lenses with high optical quality is challenging. Glass lenses have high optical quality, but the manufacturing is expensive. On the other hand plastic lenses made for example by injection moulding are more affordable but the quality of the lens is limited by distortions due to the injection molding process. Various techniques can be applied while trying to improve the shape accuracy, alignment and the roughness of moulded plastic optic parts. These techniques usually concentrate on improving the molding process by tuning the mold insert or manufacturing a better mold. With these techniques the shape accuracy of the injection moulded parts will be in micrometer level at the best. The same applies to surface roughness which is typically at a micron level. [1]

We have investigated methods to improve the accuracy of moulded plastic optics by combining UV-curing process with an injection moulded plastic part. The optical and surface properties of the corrected lenses are measured and analysed.

2 Design and fabrication of the lens

A plano convex acrylic lens (f = 120 mm, r = 58.95 mm) with thickness of 3 mm, and diameter of 9.5 mm and overall diameter of 20 mm was designed in Light Tools ray tracing program. Two plate single cavity aluminum mould with two separate inserts was designed in the Pro/Engineering software (Fig. 1). The two separate round inserts contained the planar and concave surfaces.



(a) (b)

Figure 1: (a) Injection moulded part and (b) the lens cavity insert.

The mould frame was machined from 7075 aluminum and the optical inserts were made from fine grain sized RSP Technologies RSA-905 aluminum. The frame parts were machined with Mikron XSM 400 and the optical parts were turned with Moore 350FG diamond machine tool using a 1.5 mm controlled waviness diamond tool. Tool path programming for the lens was done with Diffsys software. For the lens cavity a constant angle spiral toolpath was programmed with 4 µm sidestep and 0.05 degrees angular increment. Finishing depth of cut of 5 µm was used to machine the entire insert (diameter 43 mm). The cutting of the inserts was done in off-axis mode. The cutting strategy used would give an estimated Ra value of 4-6 nm for the part. Injection molding of the part shown in Fig. 1 was done with Engel ES 75/200 HL injection moulding machine on PMMA Altuglas® material.

3 Correcting shape distortions of lens by UV curing

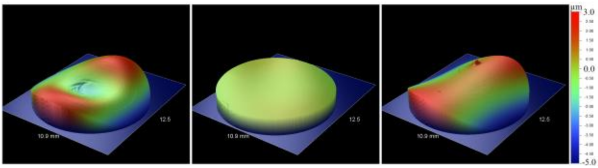
The process of correcting the shape distortions of the planar side of the lens involved placing an acrylate based UV curable liquid (NALAX3) on the planar surface of the lens and placing a glass plate on it. Two approaches were tested. In the first method NALAX3 with a lens placed on top of a BK7 wafer was used. Then the UV curing was done with XL-1000 UV Crosslinker (Spectronics corp.) with 2.2 mW/cm^2 irradiance. During the first step of a 60 s UV curing the NALAX3 was hardened, and firmly attached to the lens due to the adhesion. At this point the lens was detached from the BK7 wafer and NALAX3 further hardened with a 500 s UV curing.

In second method the lens was placed face down onto a suitable mold, NALAX3 was applied on the top and a quartz wafer was carefully placed on top of it. The whole package was then stacked to the nanoimprinter machine (NIL Eitre 3) and processed at a pressure of 10 bar at 25°C. The UV curing process was run for 40 s.

4 Results and discussion

4.1 Lens profile measurements

The shape distortion corrected, planarized lenses were measured with Wyko NT9300 optical profilometer. The uncorrected lens, the lens planarized with a face down method, and the lens planarized with NIL are presented in Fig. 2.



(a) (b) (c)

Figure 2: (a) The original, uncorrected lens, (b) the lens corrected with the face down method, and (c) the lens corrected with the NIL method.

Fig. 2 shows that the face down method gives the best lens planarization results. The uncorrected lens has approximately 7 µm difference in height and the face down corrected lens has only about 600 nm difference in height. We managed to decrease the variations in the “saddle shape” height by factor of 10. The lens corrected with the NIL method has the height difference of almost 7 µm with a slightly altered backside shape distribution. It seems that using too high processing pressure leads to a saddle shape being copied to the NALAX3 film. In addition, the surface roughness of both methods was measured. Surface roughness was measured with 5 × magnification on 1.3 mm × 0.95 mm measurement area. The original non-planarized lens had a surface roughness Rq of 50.7 nm, the face down planarized lens a surface roughness Rq of 5.52 nm, and the NIL corrected lens a surface roughness Rq of 34.61 nm. Again the best results were obtained by using the face down method.

4.2 Optical quality of lenses

The beam focusing ability of the lenses both before and after the planarization of the flat surface was measured. Measurement system consists of a HeNe laser, injection molded acrylic lenses, beam profiler camera and a precision travelling stage. The measured parameters were minimum beam waists and focal lengths of the lenses. It was shown that after the UV curing planarization the minimum beam waist was reduced 5.8 % in horizontal direction and 3 % in vertical direction. Also focal lengths were reduced 3.5 % in horizontal and 3.8 % in vertical direction, respectively. After the planarization the average focal length of the lenses was within 1.6 % of the designed focal length (120 mm) of the lenses. Smaller beam waists indicate better focusing ability of the lenses.

5 Conclusions and future work

With the method described affordable plastic lenses with excellent optical quality can be mass-produced by combining injection molding and UV-curing. A clear improvement on the optical performance of the lens and reduced surface roughness and shape variations were observed. Using a simple face down method gives the best lens shape distortion correction results (10 × improvement). In addition, correction of the convex side of the lens with suitable mould to further improve the accuracy of UV corrected lens will be studied in the near future.

Acknowledgements

The work in this paper was supported by TEKES/European Union-European Regional Development Fund.

Reference:

[1] ”The Handbook of Plastic optics“ 2nd Ed, Corning Precision Lens Inc., Cincinnati (OH), (2000).