Investigation of the replication quality of plastic micro-optical interconnection components.

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The technology of Deep Lithography with Protons (DLP) is a high-precision rapid prototyping technology for the fabrication of 3D monolithic micro-optical elements and micro-mechanical structures in PMMA. We report on our investigation on how to adapt this DLP process to be compatible with LIGA-based injection molding techniques and with vacuum casting replication technologies for the mass fabrication of 3D plastic micro-optical components. We highlight the progress made to optimize the vacuum casting technology to obtain optical quality. The examples we present are replicas of optical interconnection modules consisting of components such as microlenses and microprisms.

Introduction

The technology of DLP [1,2] is a high-precision rapid prototyping technology for the fabrication of 3D micro-optical elements and micro-mechanical structures in PMMA. With this technology different optical components can be structured in one block to form monolithic micro-optical modules. In addition mechanical positioning and support structures can be integrated. This approach however is unpractical for mass-fabrication because an irradiation session, to obtain a single component, can take several hours. We therefore investigated whether we could mass replicate the DLP micro-optical components. We showed that, using the DLP elements as a master element, it is possible to obtain replicas via different methods: with a LIGA-adapted injection molding technique and through vacuumcasting. In this paper we will focus on the vacuumcasting technology. We will show that this technology is suitable for elements that are not made by DLP.

Vacuum casting: the technology

Vacuum Cast Molding, a relatively new development in polyurethane prototyping, uses familiar principles with new materials to further enhance the accuracy of prototypes. The original part is embedded in a vulcanizing silicone (Figure 1c) and placed inside a vacuum chamber (Figure 1a) to de-aerate the silicone. This results in a very accurate replication of the part features. After curing, the mold is cut apart and the master element is removed. The master component will remain intact, which is an important advantage, and can be reused for other replications. The mold is then taped together and inside a vacuum chamber a two- component resin is poured inside the prepared mold. After curing the resin, it is demolded, resulting in a copy of the original part.(Figure 1d)

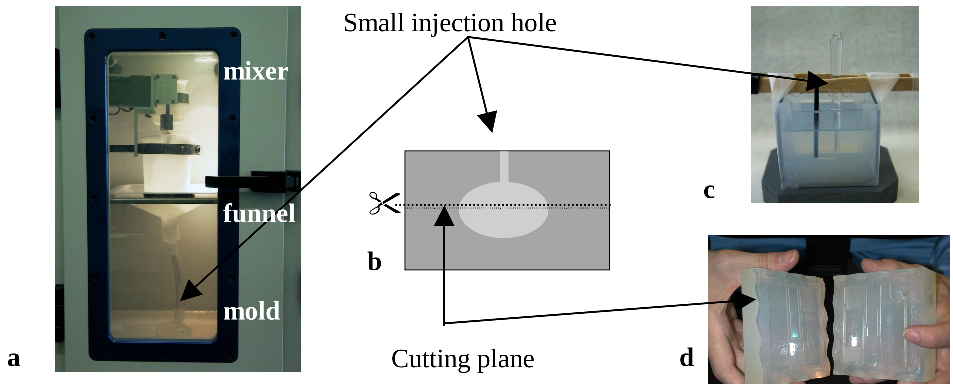

Figure 1a. Vacuum casting machine, b. Drawing of silicone mold, c. Embedding of the master component in silicone rubber, d. opening of the mold to remove the replicated part in polyurethane

The polyurethane, used for the replication has an index of refraction n=1.515, a transmission efficiency of 93.7% and a thermal conductivity k=0.208 W/mK. It is important however to correctly choose the process parameters to obtain predictable shrinkage conditions so it can be implemented in the original design.

Vacuumcasting of a DLP micro lens array

We will now present the results on the replication of a micro lens array, which was made using the DLP technique [3]. A micro lens array, featuring micro lenses with a diameter of 200 µm and different sags, were copied with the vacuum casting technique (Figure 2a).

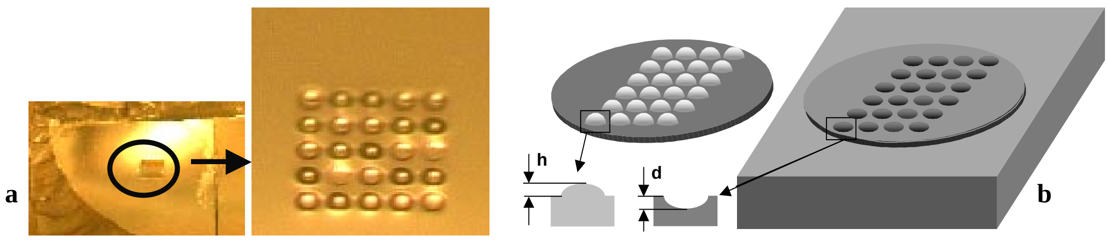

Figure 2 : a. Picture of the rubber mold with a 5x5 micro lens array, b. Master of the micro lens array and the fabricated rubber mold

Measurements reveal that the depth d of the micro lens is 0.2% higher than the sag h of the lenses on the master. This corresponds with the expected shrinkage of the silicone rubber. After replication, the sag of the replicated lenses is 1.25% higher than the original ones on the master. The process parameters of the replication process have to be investigated further to reduce the difference between the original and the replicated micro lenses.

Vacuumcasting of a micro optical intra-chip interconnection module.

The optical pathway block (Figure 3a) that we describe in this section of the paper is an optical bridge consisting of two components [4]. The first one is a base plate featuring two arrays of spherical micro-lenses, which were discussed in the previous section, and a pair of alignment holes. The second component integrates the counterpart mounting features and two micro-mirrors. Both components were made with DLP and after assembling copied via vacuumcasting. The first advantage that can be mentioned is that the interface between the two components, which is filled with glue, is not present in the copy.

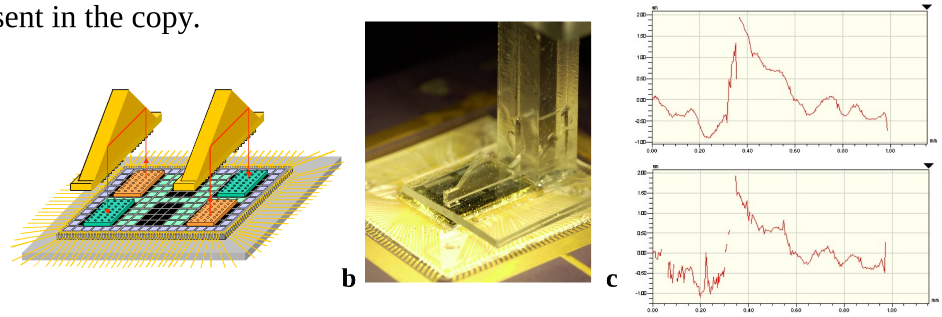

Figure 3 a. Drawing of optical bridge above the oiic chip, b. Image of optical bridge mounted with holder above oiic chip, c. Optical surface measurement (roughness of 3 µm over 1 mm length) of a bad mirror of original (lower) and copy (upper).

Another advantage of the copying is that the optical surface becomes smoother, without loosing the finest details (Figure 3c). To demonstrate this, we took a measurement of the worst part of the mirror surface: details remain but the surface roughness is better.

Vacuumcasting of a glass relay module.

To test the vacuumcasting on other elements than those fabricated with DLP, a glass relay module (Figure 4a) with different etched structures(Fresnel lenses, linear and circular diffraction gratings) was tested.

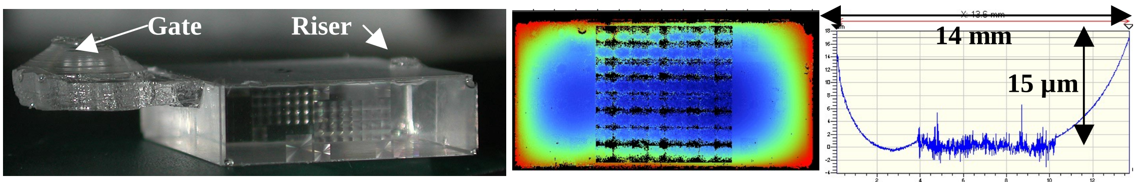

Figure 4 a. Copy of module with lenses on front and back, b. Measurement on surface of relay module, c. Horizontal surface profile of relay module.

All resins shrink when they change from liquid to solid and all generate heat as they polymerize (an exothermic reaction). Because heat accelerates chemical reactions, all resins cure from the inside out. As the setting resin generates heat, the center of the mass gets hot faster than the surface, which is transferring its heat to the mold. As a result, the center hardens and shrinks first, while the last area to harden is the area in contact with the mold. This effect can be seen in Figure 4b where edges are 15 µm higher than the center. The large shrinkage is only present on the edges. By placing the optical elements in the center, most of the curvature can be avoided due to its exponential behavior. Measurements show that the copies of the microstructures are almost identical to the originals(Figure 5).

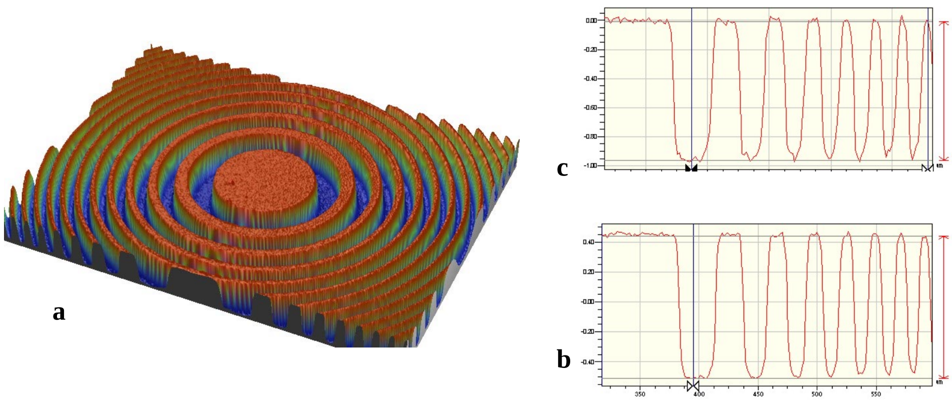

Figure 5 a. Binary Fresnel lens, b. Original lens profile, c. Copy lens profile

Conclusion

In this paper we have shown how Deep Lithography with Protons can be made compatible with vacuum casting, thus allowing for the mass-replication of high-quality micro-optical modules. The combination of the rapid prototyping approach of DLP and vacuum casting techniques makes it now possible to advance very quickly from an idea to a demonstrator-component and finally to mass-production. However, due to a change in optical material properties between the master and the replicated element, optical properties can change. A change in the refractive index, for example, will directly affect the focal length of the replicated element. This fact must be taken into account in the design of a micro-optical element. Furthermore, shrinkage is present and must be compensated in the master element to acquire the desired final dimensions.

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