Replication of Refractive and Diffractive Micro Opto-mechanical Components via Vacuum Casting and Hot Embossing

Patrik Tuteleers, M. Heckele*, Alex Hermanne and Hugo Thienpont**
Department of Applied Physics and Photonics (TW-TONA),
Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium
tel.: ++ 32 2 629 3613, fax: ++ 32 2 629 3450, Patrik.Tuteleers@vub.ac.be
**Forschungszentrum Karlsruhe, Institut für Mikrostrukturtechnik,*
Postfach 3640, 6021 Karlsruhe (Germany)
***Cyclotron Department VUB, Laarbeeklaan 103, 1090 Brussels, Belgium*

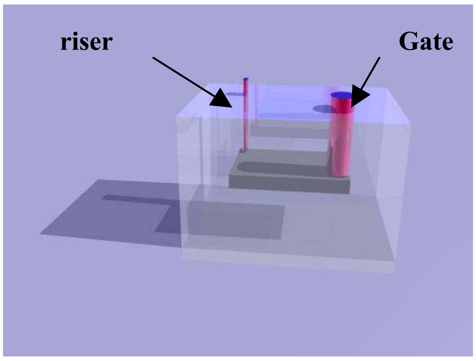
In this paper we assess the replication of micro-optical structures through vacuum casting and hot embossing technology. For the vacuumcasting we have replicated, besides optical components and structures fabricated with DLP a variety of other optical components: micro-jet lenses, glass gratings, glass lenses and hybrid integrated systems. Next we report on the hot embossing of DLP-fabricated structures that we have done in collaboration with FZK on a machine specially designed to replicate micro-structures.

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, hot embossing and through vacuumcasting [3]. In this paper we will focus on the vacuumcasting and hot embossing technology.

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 and placed inside a vacuum 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 a two-component resin is poured inside the prepared mold under vacuum conditions. After curing the resin, it is demolded, resulting in a copy of the original part.



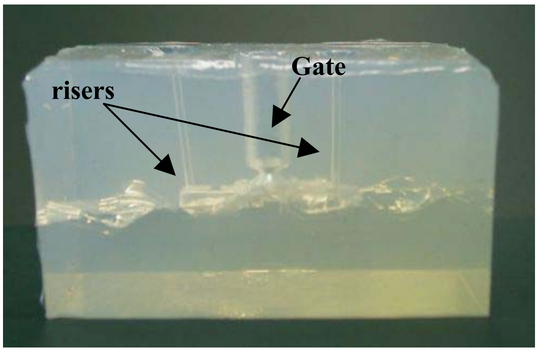
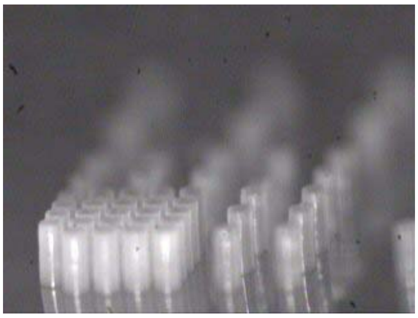


Figure 1 Rubber mold configuration: a. Drawing, b. Image with two risers and one gate in the middle

Despite the flexibility of the rubber it is possible to copy very accurately micro-optical components. Fragile mold-structures will not break or bend, as with metal molds, due to the elastic (elongation of max. 380%) property of the rubber. Figure 2a shows an image of rubber pins with a height of 500 µm and a diameter of 200 µm.



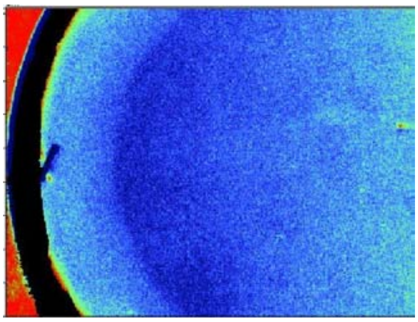


Figure 2 a. Rubber pins (500µm height, 200µm diameter), b. Height profile of an oxide-confined teststructure for vcsel fabrication

As an example of the accuracy, we copied in rubber an oxide confined teststructure for vcsel fabrication to study the height profile of the oxide-layer, where we measured a height of 6 nm. Our study showed that we have a linear shrinkage of 0.1% when the rubber is cured at controlled room temperature (25°C) and it increases slightly when the temperature is raised. The curing time decreases when the temperature is increased (24h / 25°C and 2h / 60°C). To make a copy, the filling of the mold can be done with a wide range of polyurethanes (PU). The polyurethane, used for the replication has an index of refraction n=1.515, a transmission efficiency of 93.7%in the visible range 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. For replicated microlenses, the shrinkage can be controlled between +2.4% and –1.4% with aberrations that are almost the same as the original lenses. We can also apply a smoothing effect to improve optical surfaces by changing some parameters

Hot embossing

In collaboration with FZK, hot embossing of DLP-fabricated structures were studied on a machine specially designed to replicate micro-structures. With this technology an inverse of an electroplated master is created in a polymer through heat and pressure. A thermoplastic polymer is heated above the glass transition and a pressure is applied, pressing the master into the polymer. Then the master and the polymer are cooled below the glass transition temperature and pulled apart. When the polymer cools below its glass transition temperature, it solidifies again and the micro-structures are permanently formed.

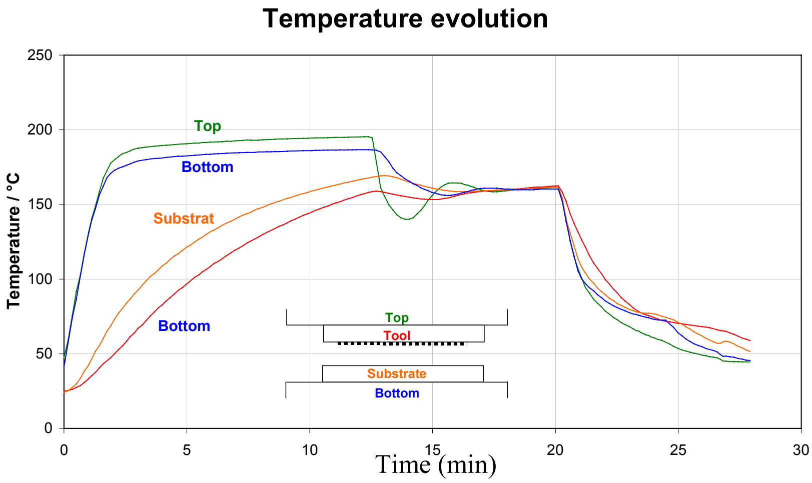


Figure 3 Heating cycle of hot embossing

Figure 3 shows a typical heating cycle of a hot embossing machine. After the setup is stabilized (17 min), a controlled pressure is applied. The embossing process is performed under a vacuum to achieve a good filling of the mold. After a few minutes, the system is cooled down and the pressure released. To achieve a good replication, the two major parameters that can be changed are the temperature and the embossing force.

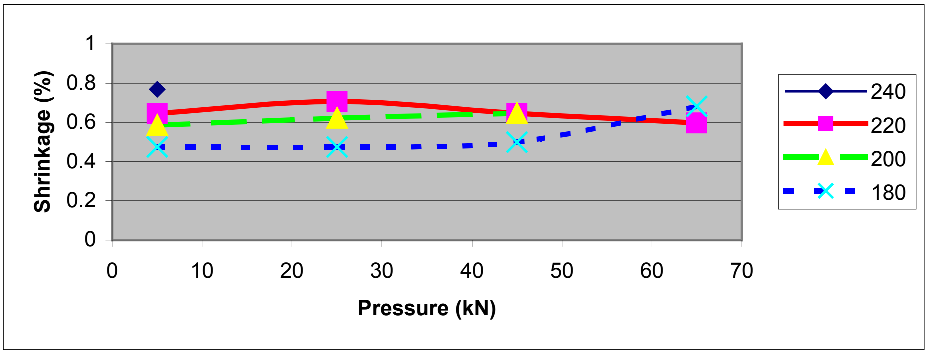


Figure 4 Shrinkage at different pressures and temperatures

Figure 4 shows that the lowest shrinkage can be achieved at 180°C, but in that case the optical walls are deformed due to the low temperature during the embossing. Deformation effects can also be observed at high pressures (>50kN), which explains the bending of the curves. The only usable region for replication of this component is between 200 and 220°C and pressures between 20 and 40 kN.

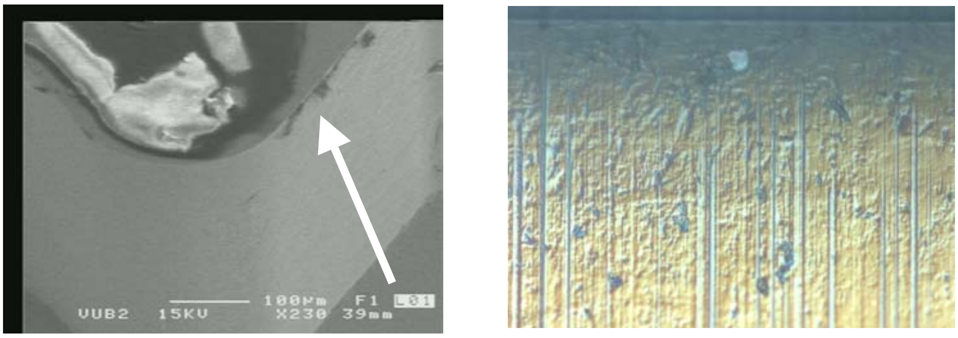


Figure 5 a. SEM image of small metal particles on the edge of the moldinsert, b. colored interference measurement of replica to show scratches on the surface

Due to some small metal particles on the moldinsert (Figure 5), the optical surface of the replica is scratched (small lines from to bottom) during the demolding. This can be avoided by better polishing the top surface or different mold design.

Conclusion

In this paper we have shown how Deep Lithography with Protons can be made compatible with vacuum casting and hot embossing, thus allowing for the mass-replication of high-quality micro-optical modules. We applied the same technique with success to other technologies to combine them in micro-optical modules and systems. However, due to a change in optical material properties between the master and the replicated element, optical properties can change. The different process parameters must be tuned for every design to obtain an accurate replication. We also showed that it is possible to make metal moldinserts and use them for hot embossing. These replications have scratches on their optical surface due to metal particles on the edges of the moldinsert. Shrinkage effects are always present in both replication methods and must be compensated in the master element to acquire the desired final dimensions.

Acknowledgement

The work reported here is funded by DWTC IAP, FWO, GOA, IWT-ITA II GBO and the OZR of the VUB. The authors thank P. Vynck, B. Volckaerts, H. Ottevaere, C. Debaes and M. Vervaeke for their contributions and support during this work.

References

1. K.-H. Brenner et al, *H^+-Lithography for 3-D integration of optical circuits*, Appl. Optics 29 (26), 3723-3724, 1990.

2. B. Volckaerts, H. Ottevaere, P. Vynck, C. Debaes, P. Tuteleers, A. Hermanne, I. Veretennicoff and H. Thienpont, *Deep lithography with protons: a generic fabrication technology for refractive micro-optical components and modules,* Asian Journal of Physics, Vol. 10, No. 2, pp. 195-214, 2001

3. P. Tuteleers, P. Vynck, B. Volckaerts, H. Ottevaere, V. Baukens, C. Debaes, A. Hermanne, I. Veretennicoff and H. Thienpont, *Replication of refractive micro opto-mechanical components made with Deep lithography with protons*, Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS (DTIP2001), Cannes, France, pp. 329-337, April 2001.