On chip micro-thin lens for coupling single-mode optical waveguide

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We are investigating a new technique to relax the tolerance in the alignment between an input beam and a single mode channel waveguide. We propose the use of an on-chip 3D printed lens. 3D printing permits to adjust in a flexible way the radius of curvature of the lens to adapt to different waveguide core dimensions and alignment errors. In this work we will present the current microlens design together with preliminary fabrication results.

Abstract

3D printed microlenses overcome the limitation of micro-ball lenses, permitting to design the required curvature of the lens in order to optimize it for a given optical waveguide cross-section and alignment tolerance. In this work, OrmoComp [1] microlenses were 3D printed using a Nanoscribe multiphoton polymerization printer. Details on the design, fabrication and preliminary characterization of the proposed microlenses will be presented.

Introduction

Typical waveguide systems usually need coupling between the integrated optical chip and free space. At the end facets of the waveguide, there is a strong divergence of the output beam [2]. Through integrating micrometer-sized lenses within the optical waveguide chip, the out-coupled light of the optical waveguide can be efficiently coupled in both the horizontal and vertical directions.

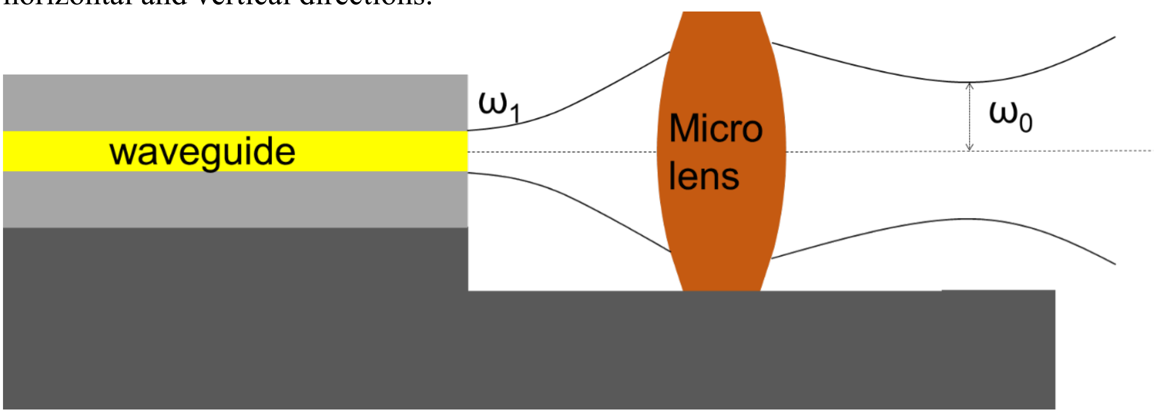


Figure 1. The model of the waveguide coupling system with micro-thin lens

At present, the micro-ball lens array produced by reflow cannot achieve a large radius of curvature due to volume limitation. This leads to a large spherical aberration, which is very obvious in the waveguide coupling device. On the other hand, with traditional lithography it is difficult to achieve a curved surface in the vertical direction. The two-photon polymerization (TPP) 3D printing technology provides an alternative solution [3]. Using 3D TPP, the radius of curvature and the size of the lens can be adjusted according to the optical waveguide system, achieving an optimized focusing effect.

In this paper, we propose the design of a micro-thin lens produced by Nanoscribe Photonic Professional GT. This printer has two working modes shown in Figure 2. In the immersion mode, a 63x lens is immersed into the IP-Dip resist. Due to the very high numerical aperture of the 63x lens, the edges of the lens might not be smooth enough. In the non-immersion method, a layer of i-line photoresist is spun on the substrate. Different lenses can be used for the printing process. A 20x lens has the best printing speed.

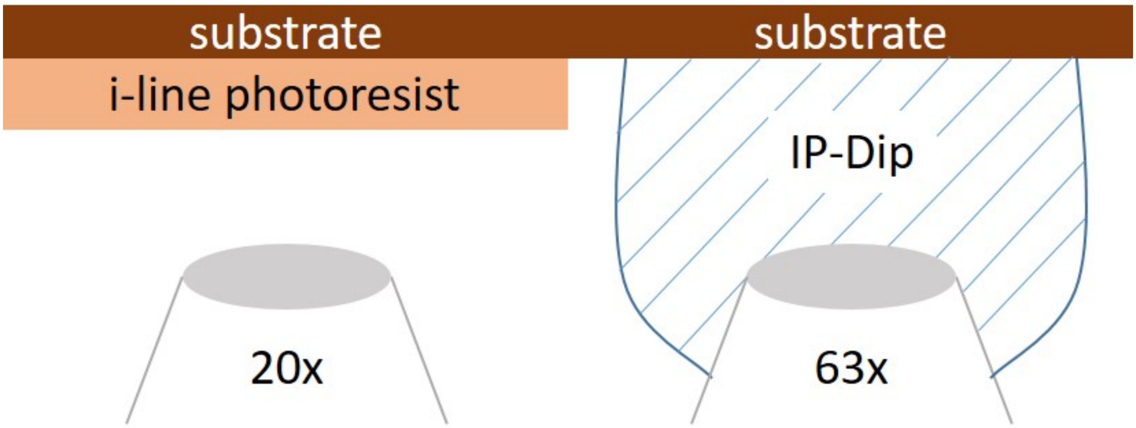


Figure 2. The two models of the printer.

Processing and result

Firstly, a 3D model is made in CAD software. The lens size is 100*100*40 μm^3 with a 300 µm radius of curvature. Then the STL file would be converted into GWL-file to use in the processing (Figure 3). A non-negligible step is that the refractive indices of the air and the photoresist are different, so in practice, the height of the model should be reduced according to the refractive index of the photoresist. The reason is that there is an air interface between the objective lens and the photoresist. When the objective lens moves a distance, the voxel in the photoresist will move by n (refractive index) times. The fabrication is only one step without subsequent assembly; however, the challenge is that the range of optimal parameters is very narrow and requires a lot of experimentation before the target design is completed.

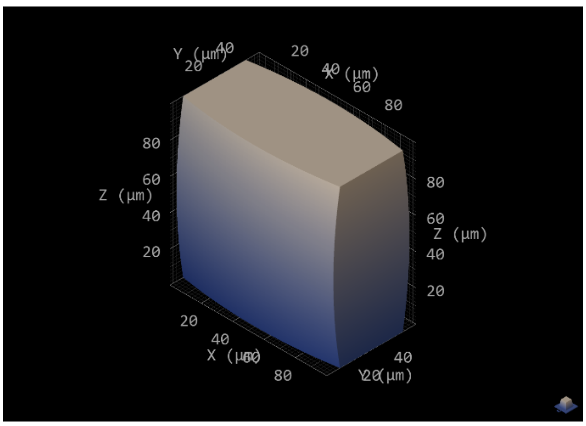
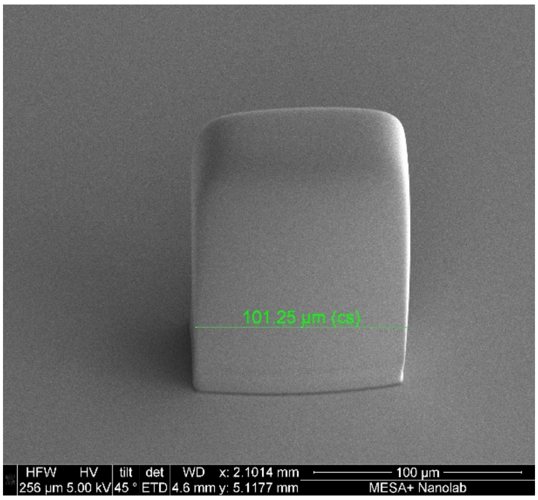
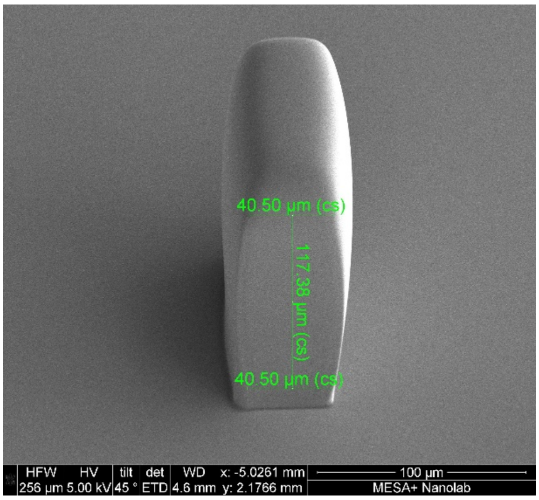


Figure 3.The 3D model of the lens in the Describe CAD software.

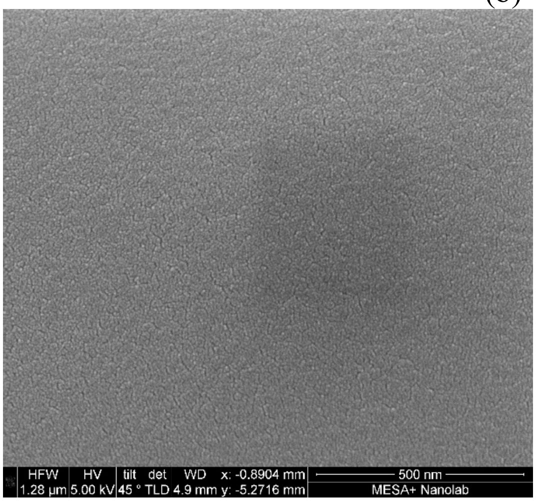
Figure 4 shows the SEM image of a 3D-printed micro-thin lens. We can see that the top of the lens is higher than the design height due to the excessive exposure dose. It is about 18 µm higher than the design height. This is also a drawback of low numerical aperture lenses. Insufficient light-gathering ability of the 20x objective lens will result in a long voxel in the vertical space. Above the printer scan area, the dose received by the photoresist cannot be ignored. However, the smoothness of the lens produced using this process is sufficient for the needs of the application. Figure 4(c) shows the surface structure of the front side of the lens. At the 100kx magnification, the surface of the lens is uniform enough.



(a)



(b)



(c)

Figure 4. The sample lens in the SEM

Conclusion

Our work demonstrates the design and fabrication of a thin lens. The manufacturing method is based on two-photon polymerization printing technology with the feasibility of large-scale manufacturing. With the 3D TPP instrument available in our lab, fabrication times are 10-15 minutes for one lens. This time is acceptable in an experimental environment. For scalability, a 3D TPP machine with higher throughput should be utilized. In the next experiment we will test the optical properties of the lens. If necessary to reduce aberrations, a combination of multiple lenses could be designed or different coatings could be investigated.

References

[1] A. Schleunitz, J. Klein, R. Houbertz, M. Vogler, and G. Gruetzner, "Towards high precision manufacturing of 3D optical components using UV-curable hybrid polymers," in *Optical Interconnects XV*, 2015, vol. 9368: International Society for Optics and Photonics, p. 93680E.

[2] L. Chang et al., "Waveguide-coupled micro-ball lens array suitable for mass fabrication," Opt. Express, vol. 23, no. 17, pp. 22414-22423, 2015/08/24 2015.

[3] S. Thiele, K. Arzenbacher, T. Gissibl, H. Giessen, and A. M. Herkommer, "3D-printed eagle eye: Compound microlens system for foveated imaging," (in eng), Science advances, vol. 3, no. 2, pp. e1602655-e1602655, 2017.