# 3D Printed Freeform Lenses with Nanoimprinted Moth-Eye Antireflective Structures

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Several studies point out the challenge to produce controlled patterned nanostructures on the surface of complex 3D fabricated objects. Micromolding and soft lithography have been used to generate micro and nanoscale topographical features on planar and non-planer substrates. Some developments aim at structuring nanoscale features directly on the surface of 3D printed objects (e.g. chemical etching or plasma surface modification). Incorporating the Moth-Eye structures for Anti-Reflection (AR) [1] effect on optical elements like 3D printed lenses, using Nanoimprint lithography [2] can be an advantageous combination and is potentially cheap in the fabrication. Compared to conventional AR-coatings, AR Moth-Eye structures has a broad-spectrum range. However, structuring such features on a curved surface lens is rather challenging. In this work, we describe an effective and simple method for lens fabrication using 3D printing and also surface patterning of the lens via soft UV Nano Imprint Lithography (UV-NIL) [3].
A precision Stratasys Polyjet$^{TM}$ printer [4] Objet500 was used for 3D printing of a lens core part, which produces smooth and accurate parts with microscopic layer resolution and accuracy down to 16 µm. During the fabrication process, a liquid photopolymer is jetted onto the build tray, and tiny droplets are instantly cured by UV light (a process similar to inkjet printing can be seen in figure 1. Fine layers are accumulated on the build tray to create a precise 3D model of the lens. Figure 2 shows a general 3D model of a plano-convex lens shape with a diameter of 54 mm and height of 6 mm was printed out of a standard transparent UV curable acrylic polymer.
The 3D printed lens was post-processed by structuring nanofeatures using nanoimprint lithography. A flexible stamp, exhibiting AR Moth-Eye structures, is used to achieve a conformal contact with the surface to perform an imprint on both front and backside simultaneously. Process feasibility has been investigated on several 3D objects with curvature in one or more direction. Figure 3 and Figure 4 shows the photographs of the printed lens with and without AR Moth-Eye structures. Atomic Force Microscopy measurements at different positions on the 3D lens proves the replication fidelity of the imprinted nanostructures. The potential of this simple and effective process for nanostructuring of 3D-printed lens using UV-NIL will be presented.

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References:
[1] E. A. Favret und N. O. Fuentes, Functional Properties of Bio-inspired Surfaces: Characterization and Technological Applica-tions. World Scientific, 2009.
[2] H. Schift, Nanoimprint lithography, J Vac Sci Technol B 26 (2008) 458.
[3] T. Köpplmayr, L. Häusler, I. Bergmair, und M. Mühlberger, „Nanoimprint Lithography on curved surfaces prepared by fused deposition modelling“, Surf. Topogr. Metrol. Prop., Bd. 3, Nr. 2, S. 024003, Juni 2015.
[4] Stratasys PolyjetTM, http://www.stratasys.com/polyjet-technology

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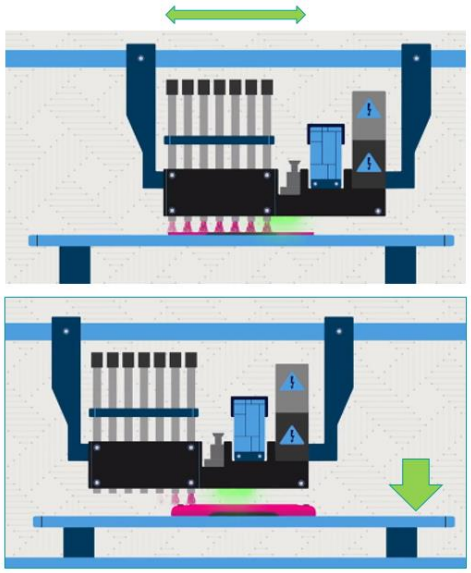

**Figure 1.** 3D printing process illustration for lens fabrication with Polyjet™

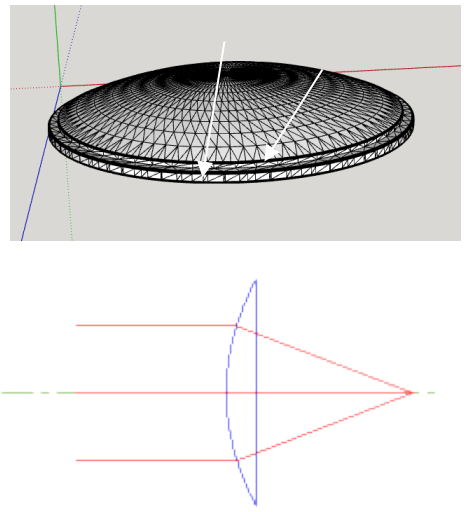

**Figure 2.** 3D model of a Plano-convex lens with a diameter of 54 mm and 6 mm height.

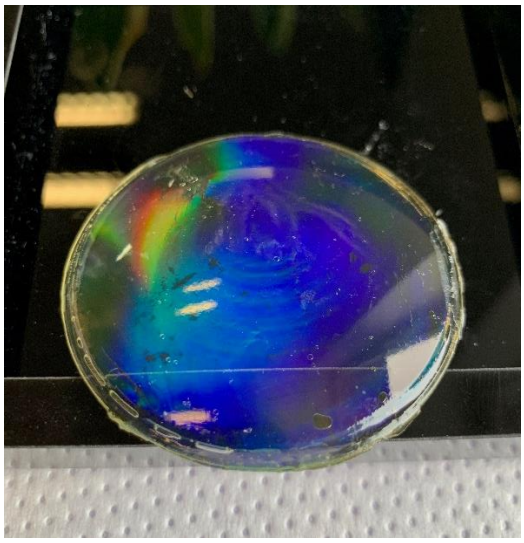

**Figure 3.** AR-Moth-Eye structure demonstrated on a 3D printed lens. The front and backside of the lens is imprinted with AR-Moth Eyes. The homogeneous imprint and coverage is shown by illuminating at a very flat angle of incidence.

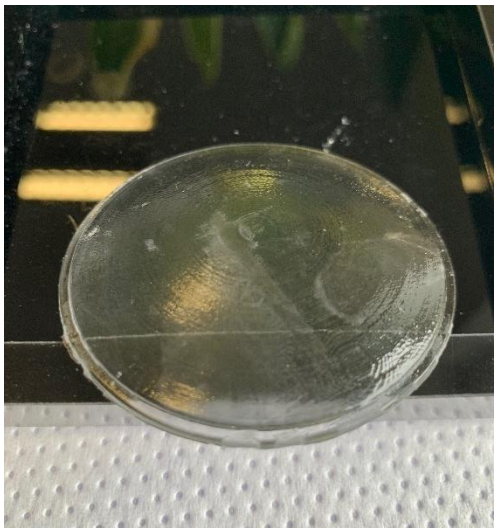

**Figure 4.** Photographs of 3D printed lens before post processing without AR-Moth Eyes structures.