Aspheric Micro-DOEs Fabricated by Grayscale Direct Laser Writing and Nanoimprint for MicroLED Collimation

Rongchen Qin, Zijie Jiang, Wen-Di Li
Department of Mechanical Engineering, Univ. of Hong Kong, Hong Kong
liwd@hku.hk

Emerging optical elements with micro-structured patterns can spatially modulate the phase distribution of the light passing through and have been demonstrated in applications such as broadband collimation[1], holograms[2], and laser processing[3]. With the increasing interest in adopting micro-LEDs for display applications, microlenses with rationally designed surface profile are used to enhance display brightness and improve the display's angular emission performance. Traditional mass fabrication methods of spherical microlens, such as thermal reflow and machining, suffer from imprecise control of the light phase. Although some groups have demonstrated the ability of large-area fabrication of aspheric micro-devices[4], there are limited records of high-throughput manufacturing of aspherical microlenses for customized micro-LEDs.

In this work, we present the full design and fabrication flow for the production of such free-form microlens devices, which comprehends optical design, master fabrication by 4096-stage direct laser writing lithography patterning on 4-inch Si wafers, the pattern transfer by UV NIL lithography on glass substrates and the optical characterization of the final product. For the master design, and fabrication step, we explored the phase map for the collimation of the Lambertian-distribution light source, and the optimization of the fabricated master profile. For the NIL step, we developed imprintable recognizable alignment marker that enables alignment during NIL without metalizing the alignment marks. The monochromatic light intensity distribution above the aspherical microlenses is characterized with micrometer-precision in three-dimensional space using a custom-built setup.

The demonstration of the full fabrication process is shown in Figure 1a, 1b, and 1c. The 2cm x 4cm master is fabricated using a 405-nm laser writer. Combined with the nanoimprint method, this process provided both precise morphology and high throughput. It has the potential to be widely applied in the industrial production for the performance enhancement of mirolenses and other microsized optical elements.

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[1] Hu, Zhi-Yong, et al. "Broad-bandwidth micro-diffractive optical elements." *Laser & Photonics Reviews* 16.3 (2022): 2100537.

[2] Siegle, Leander, et al. "Diffractive microoptics in porous silicon oxide by grayscale lithography." *Optics Express* 32.20 (2024): 35678-35688.

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[4] Luan, Shiyi, et al. "High-speed, large-area and high-precision fabrication of aspheric micro-lens

array based on 12-bit direct laser writing lithography." *Light: Advanced Manufacturing* 3.4 (2022): 676-686.

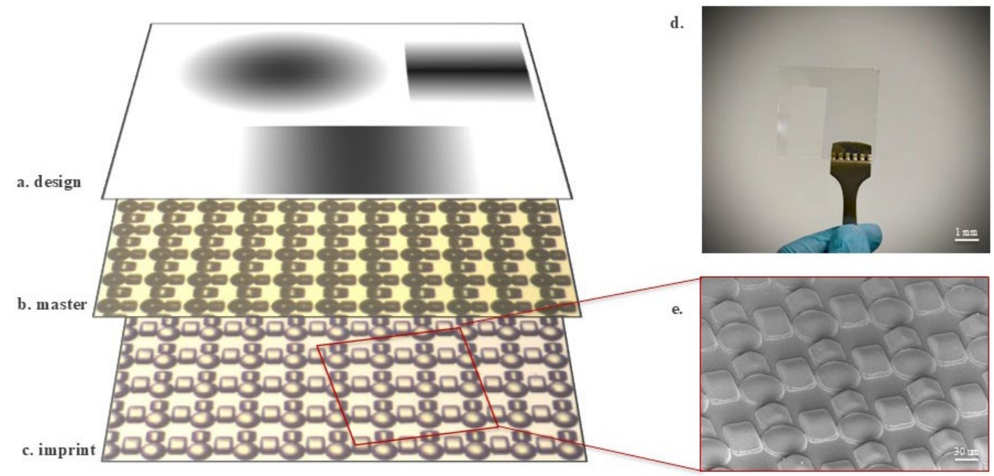

Fig. 1. Demonstration of the fabrication process. a. as designed; b. as produced on master (optical micrograph); c. as patterned on glass by soft-UV NIL using a high n-index resist (optical micrograph). d. Arrayed Micro-DOEs imprinted on the 4cm x 5cm glass substrate. e. SEM image of Micro-DOE arrays.