Abstract for NANOMAN2024(500 words) Fused silica cylindrical microlens array fabrication by multi-focus ultrafast laser with precise CO_2 laser polishing

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The fused silica cylindrical microlens array is extensively used for homogeneous top-hat light modulation due to its excellent transmission and high-power durability. However, surface structuring and precise polishing remain challenging due to the material's high hardness and brittleness. Grayscale lithography and high-temperature molding are commonly used for production but are limited by cost, flexibility, and efficiency. Here, we propose a systematic laser fabrication strategy to produce glass cylindrical microlens arrays with high scale accuracy and a mirror-like surface. A modulated picosecond laser beam, featuring multiple focus points arranged in a curve, is employed to rapidly ablate continuous cracks in the glass bulk, creating an initial cylindrical surface with ~500 nm roughness after alkaline chemical etching. The laser beam is modulated using superimposed phase diagrams of Fresnel lenses and blaze gratings on a spatial light modulator. An algorithmic 3D coordinate correction addresses scale errors caused by the refractive index mismatch between glass and air, and spherical aberration of multiple foci distant from the objective's original focus. Positional randomization along the designed trajectory enhances energy distribution uniformity, resulting in lower surface roughness and higher scale precision. Subsequent CO2 polishing, guided by a galvanometer, smooths the microlens array surface to a mirror finish. Initially, a high-power laser beam focuses on the original surface and scans it to reduce surface roughness to 90 nm with minimal shape change, which can be adjusted with precise multi-focus laser modulation. This is followed by low-power laser polishing to eliminate shallow surface grooves caused by the Marangoni effect during thermal treatment from high-power polishing, reducing roughness to 20 nm. Finally, defocusing laser polishing with lower energy intensity and a larger focus is used to achieve a mirror surface with roughness less than 5 nm. The final two precise polishing processes only impact shape accuracy on the micrometer scale due to their low energy intensity. We further demonstrate the effectiveness of this technique with cylindrical microlens arrays of various sizes and a double-sided cylindrical lens array, both showing excellent performance in top-hat light modulation.

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