Design of a r-θ Projection Micro Stereolithography System for Large Area Optics Fabrication

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Abstract

Additive manufacturing of large area parabolic/spherical mirrors requiring little to no figuring or modification is difficult to achieve due to the accuracy, surface roughness and print speed required to make these optics viable for applications such as the manufacturing of telescopes. Therefore, the objective of this system is to develop techniques/technologies to enable the 3D printing of such structures with the figuring accuracy typically required of wavelength/10 or better and print speeds such that a 300 mm optic can be printed within 24 hours. Previously, we have successfully demonstrated the printing of PMMA layers with average surface roughness, Sa, of ~29 nm in a 2” by 2” printed area by systematically investigating and improving the constrain-surface-based 3D printing tool and process parameters (Figure 1). This paper presents the design of a custom-built 3D printing tool to fabricate 300 mm diameter parabolic mirrors with surface roughness better than 40 nm.

The 3D printer system works on the same physics as a typical stereolithography printer has a long travel and high-resolution r-θ stage to achieve the high resolution of Sa < 40 nm and part size > 30 cm in diameter. This new system will allow us to scan a projected image over the entire 30 cm by 30 cm area in order to combine the accuracy of the scanning stages with the throughput of building with over 4 million pixels. The custom-designed scanning optics for this project incorporate two spatial light modulators, one to achieve the high resolution needed to precisely define the edge of a layer and a second large area spatial light modulator to achieve the throughput needed to complete the large area 3D printing in a reasonable time. A z-axis positioning stage with 10 nm resolution is used to control accurate layer heights of less than 100 nm. Ultra flat and precise build plates and surfaces (Sa < 10 nm) are also incorporated into the machine in order to achieve the desired part surface roughness.

The new projection micro stereolithography system that has been custom designed for this optics fabrication operation (Figure 2) works by projecting two separate images from each of the spatial light modulators: (1) A high resolution, 2.5mm by 1.5mm image that precisely defines the edge of the layer with better than 1 µm accuracy and (2) a large area, 192mm by 108mm image that exposes the bulk of the part far away from the layer edge to increase the part fabrication throughput where high lateral precision is not needed. These two light engines are placed on a linear stage with better than 100nm repeatability and 10 nm resolution so that the edge of each layer can be precisely set. This linear stage is mounted on a precision rotary stage that rotates the optics in order to cure the full circular part. The radial position of the linear stage is adjusted between each layer such that the edge of each subsequent layer fabricated is precisely defined. Thanks to this r-θ setup stage setup, the full part can be scanned and cured in less than 250 ms while still maintaining better that 1 μm lateral resolution at the edge of the layer.

After a layer has been cured, a high-resolution z-stage is used to pull the build plate with the part on it out of the resin and reposition it with 1 nm accuracy so that layer heights as small as 100 nm can be precisely and repeatably achieved. With 100 nm layer heights and the 29 nm within layer surface roughness, we estimate that an average surface roughness of the final part to be approximately 37 nm.

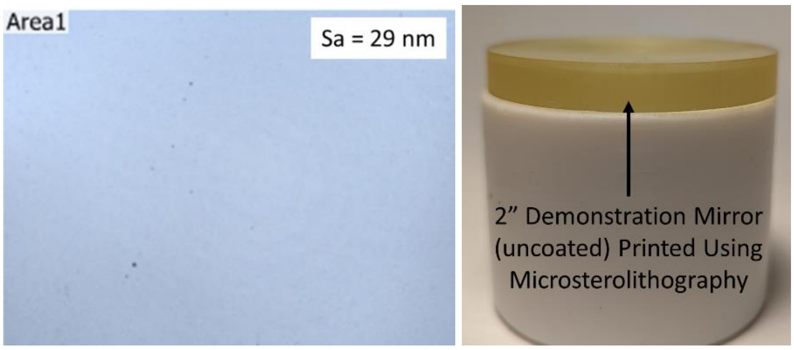

Figure 1: (Left) Optical Proifilometry image of 3D printed PMMA surface with 29 nm average surface roughness, (Right) 2” demonstration mirror profile that was printed using microsterolithography

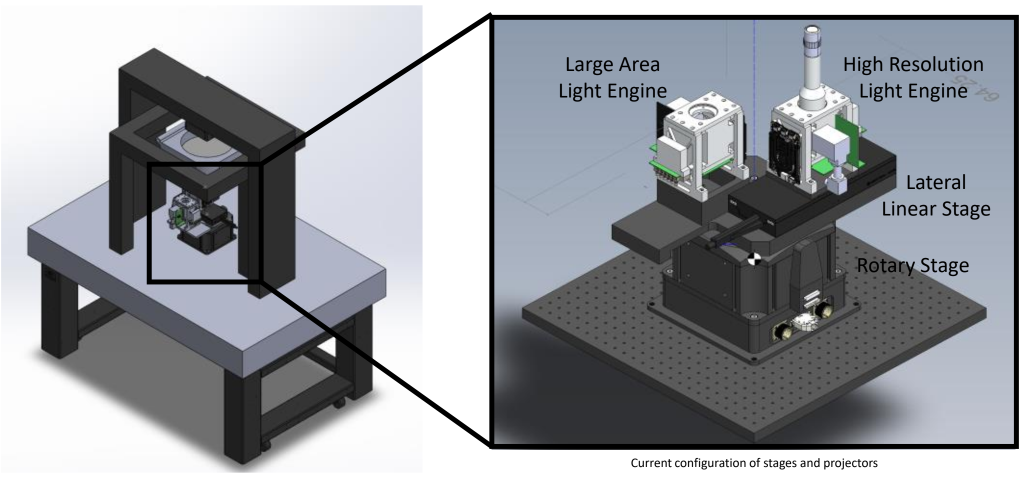

Figure 2. Proposed printing platform with a precision linear stage affixed to a precision rotary stage for moving the optics and a counterbalanced vertical linear stage for pulling the part out of the resin bath and changing the layer height