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# Acousto-optic scanning multi-photon lithography with high printing rate

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Acousto-optic scanning and spatial switching methods have revolutionized printing rate improvements for multi-photon lithography.

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As a manufacturing method that is focused on end-users, 3D printing has gained a lot of attention in recent years due to its unique advantages in fabricating complex three-dimensional structures. Various new micro-nano 3D printing methods have been developed to meet the demand for high-precision and high-yield manufacturing[1–9]. Among them, multi-photon-photon lithography (MPL) is a promising 3D nanofabrication technology due to its capability of true 3D digital processing and nanoscale processing resolution beyond the diffraction limit. It has been widely used to fabricate micro-optics[10,11], photonic crystals[12], microfluidics[13], meta-surfaces[14], and mechanical metamaterials[15]. However, its slower processing and manufacturing efficiency have been a challenge for wider industrial production applications. Researchers have been working on achieving high-efficiency processing while ensuring high precision and high design freedom, which is the core issue of multi-photon polymerization 3D printing technology.

In a recent paper published in the *International Journal of Extreme Manufacturing*[16], Prof. Wei Xiong and Prof. Hui Gao's group from Wuhan National Laboratory for Optoelectronics proposed a multi-photon polymerization lithography method based on acousto-optic scanning and spatial switching, which realizes a high-precision and high-yield nano-3D printing method. This method achieves a record 3D printing rate of $7.6 \times 10^7$ voxel/s, which is nearly an order of magnitude higher than the highest printing rate of previously reported scanning multi-photon lithography method[17]. It provides a feasible technological route for the realization of large-scale multi-photon polymerization 3D printing methods.

Figure 1 demonstrates the schematic of acousto-optic scanning multi-photon lithography based on the spatial optical switch (AOSS) method. The AOSS method contains two main modules: an inertia-free acousto-optic scanning module and a multi-foci spatial optical switching module. On the one hand, the inertia-free acousto-optic scanning module realizes high-speed continuous acousto-optic scanning with nearly no wavefront aberration. On the other hand, the spatial optical switching method overcomes the problem of processing resolution degradation due to insufficient switching frequency of optical switches in high-speed scanning. The inertia-free acousto-optic scanning module contains a two-axis AOD to realize raster scanning. The AOSS method uses the aforementioned nonlinear sweeping to drive the AODy, significantly reducing the wavefront aberration of the deflected beam at the edge of the swept field. The multi-foci spatial switching module contains diffracted optical

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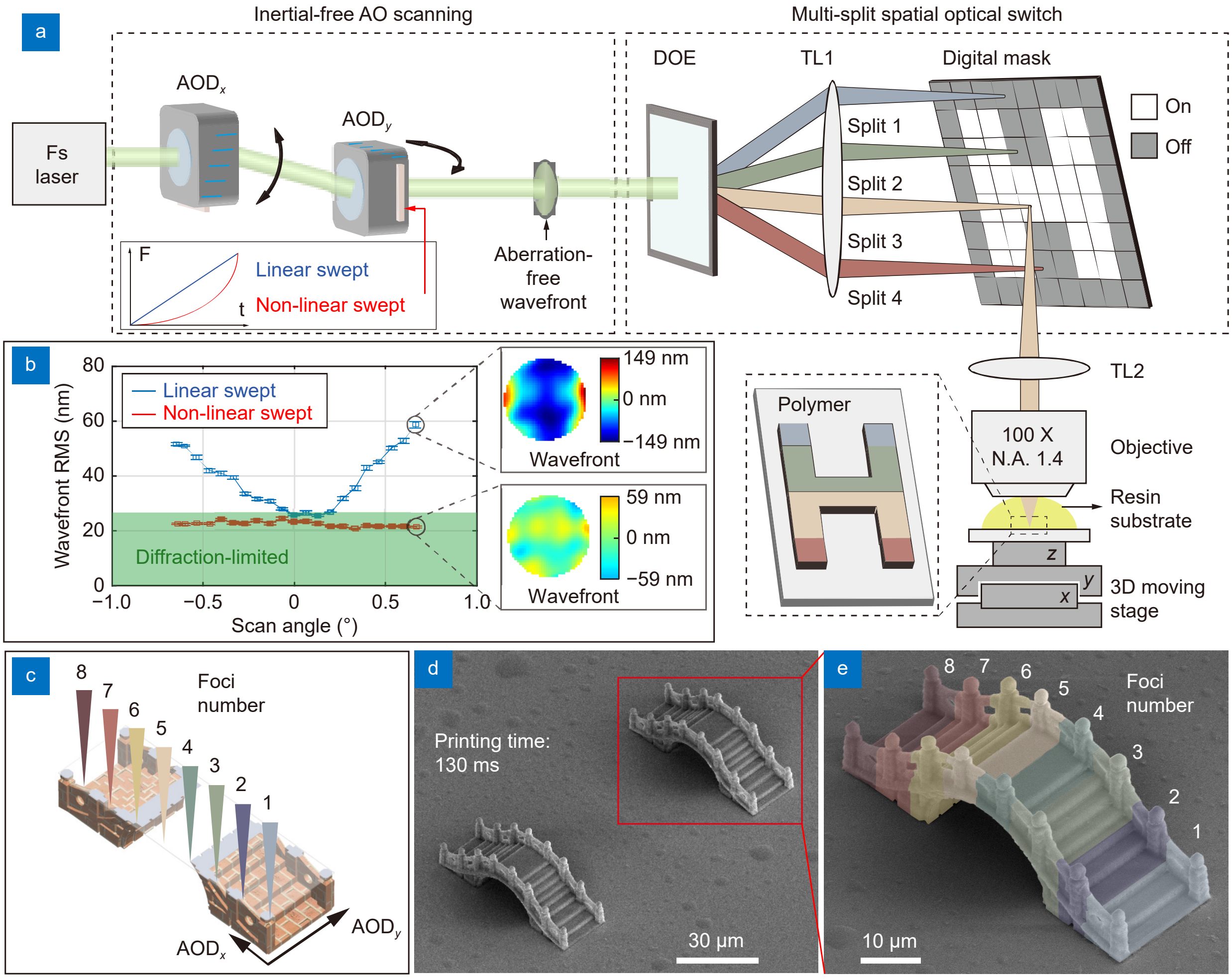


**Fig. 1 | The schematic of acousto-optic scanning multi-photon lithography based on spatial optical switch[16].**

elements (DOE) to divide the scanning laser into multiple beams. The digital mask and the DOE exhibit object-image conjugation, so that the laser beams with different scanning angles are focused at different positions on the surface of the digital mask. The digital mask controls the optical switching of the laser beams by switching each of the pixels to control the optical switching of the laser beam. Whether the beam is allowed to pass or not is independent of the moment it reaches the specified angle. Therefore, the resolution is not limited by the frequency of temporal optical switching. In addition, each focal point is scanned in a different region of the digital mask, and the switching of each focal point is independently controlled by the respective region of the mask pattern, allowing the print of non-periodic structures. A stone bridge model was fabricated by the 8-foci AOSS method in 130 ms, which demonstrates the high throughput manufacturing capability of the AOSS method.

The AOSS method reported in this work shows leading performance in scanning multi-photon lithography and also has a great potential for further development, in which the acousto-optic scanning range can be increased by increasing the scanning angle of acousto-optic scanning[18], and the processing throughput can be further improved by increasing the number of multi-foci. For example, it has been reported that hundreds or even thousands of focuses can be independently controlled by spatial light modulators and digital micromirrors[19,20]. In summary, the AOSS method demonstrated in the article has high throughput, high resolution, and high design flexibility, providing a promising technical route for the realization of large-scale 3D printing fabrication of many micro-nano applications (e.g. metasurfaces, metamaterials, micro-mechanics, micro opto-electronics) in the future.

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