

PROCEEDINGS

# Precision 3D Printing of Bioinspired Hydrogels via Spatio-Temporal Femtosecond Laser Engineering

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## ABSTRACT

Hydrogels are widely recognized as excellent biocompatible materials owing to their high water content and favorable cell-interactive characteristics. However, their inherently low viscosity and high fluidity often lead to uncontrolled spreading, slumping, and structural deformation during additive manufacturing, which severely compromise the fabrication resolution and fidelity of complex, multilayer biofunctional structures. To solve this problem, we present a femtosecond laser processing system based on simultaneous spatial and temporal focusing (SSTF). This system employs blazed gratings to induce controllable temporal pulse stretching and concurrently generates spatial energy gradients, collectively producing a super-Gaussian optical field at the focal plane. Optical simulations and experimental characterizations reveal that this super-Gaussian energy distribution creates a steep radial gradient that effectively counteracts material flow and homogenizes polymerization dynamics—a critical advantage over conventional Gaussian profiles. Comparative studies show that our SSTF technique markedly improves surface smoothness and interlayer bonding quality, with interlayer thickness variation confined to within  $\pm 0.5 \mu\text{m}$ , thus enabling the successful fabrication of diverse biofunctionalized microstructures with high structural integrity. In vitro biological validation further reveals that the printed constructs not only support cell adhesion and maintain high cell viability but also significantly enhance cell proliferation throughout the culture period. Therefore, this three-dimensional, controllable polymerization process, which relies on radial energy gradients to inhibit material flow and control axial localization, offers a high-fidelity, biosafe, and versatile manufacturing route for medical applications, including tissue-engineering scaffolds, organ-on-a-chip platforms, and implantable biosensors.

## KEYWORDS

Simultaneous spatio-temporal femtosecond laser focusing; soft hydrogels; bio-inspired functional structures; precision processing

**Funding Statement:** This work was supported by the National Key R&D Program of China (2023YFB4603203) and the National Natural Science Foundation of China (52475424).

**Conflicts of Interest:** The authors declare no conflicts of interest to report regarding the present study.



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