Single-exposure Millimeter-scale Volumetric Holographic Additive Manufacturing

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Abstract: We demonstrate a single-exposure volumetric holographic additive manufacturing. The millimeter-scale 3D hollow cube can be simultaneously polymerized in UV resin within 1 second exposure time.

Introduction: The conventional approach to 3D nanofabrication [1] is primarily bottom-up, but its fabrication speed is constrained by point-building and layer-building technologies. Addressing the need for fabrication efficiency while maintaining high resolution, we propose a novel approach: single-exposure volumetric lithography enhanced by an inverse-designed [2] 3D computer-generated holography. This innovative technology demonstrates the capability to polymerize all structures of a 3D object simultaneously within a short timeframe.

Results: We experimentally fabricated the hollow cube by using the digital hologram, the illustration is shown in Fig. 1. The hologram is designed with 2-mm width, 1-um pixel size and illuminated with 405 nm wavelength. The holographic images of the hologram in Fig. 1(a) show 'gradient' intensity patterns of the hollow cube in 3D space. The gradient hologram is designed based on the exponential attenuation model based on Beer-Lambert Law. The inverse exponential attenuation model $I_0 \exp(-530d)$ is multiplexing with the full 3D targets therefore intensity appears the nonlinear level at different planes. The hologram is inverse designed using gradient-assisted algorithm and performed in TensorFlow framework and fabricated using grayscale optical lithography (DWL66+, Heidelberg Instruments GmbH). The experimental fabrication process is illustrated in Fig. 1(d). In this setup, the hologram is positioned at the bottom, with a spacer arranged between the hologram substrate and the UV resin container. The objective is to project the complete 3D intensity pattern of a hollow cube into the resin while simultaneously compensating for solution absorption. Following a 1-second exposure, the resin undergoes polymerization in relatively large intensity areas and form a hollow cube. The resulting micrograph, captured using a microscope is depicted in Fig. 1(h). In conclusion, our work showcases an ultra-fast, single-exposure holographic lithography manufacturing technique in a single step. This method provides a viable solution for rapidly fabricating simple objects on a commercial scale.

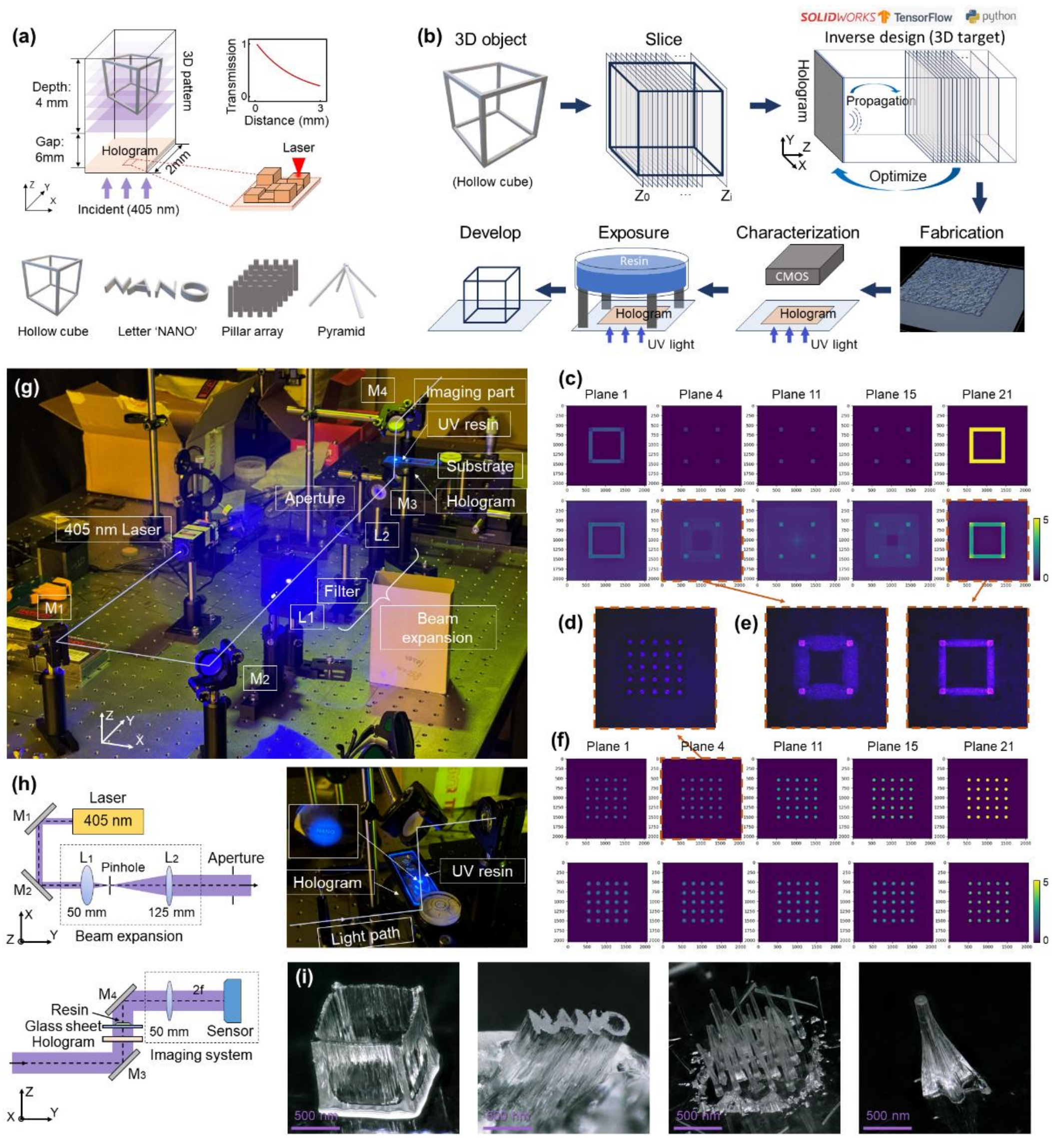

Figure 1. Illustration of the single-exposure holographic manufacturing. (a) Gradient hologram model with nonlinear intensity level. (b) Flowchart of the manufacturing of a 3D object. (c) Design result of a hollow cube and its measured image in (d). (f) Design result of a pillar array and its measured image in (e). (g) View of the experimental optical setup. (h) Illustration of optical setup. (i) Manufacturing results of cube, letter 'NANO', pillar array and pyramid.

Reference:

[1] Jia, Wei, et al. "Machine learning enables the design of a bidirectional focusing diffractive lens." Optics Letters 48.9 (2023): 2425-2428.

[2] Lin, Dajun, et al. "Inverse-Designed Multi-Level Diffractive Doublet for Wide Field-of-View Imaging." ACS Photonics (2023).