

# 3D laser writing and high-density holography as dual photonic approaches

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Recent developments in three-dimensional (3D) lithography and analogous 3D printing approaches, such as additive/subtractive manufacturing, is rapidly capturing the imagination of scientific community. While the excitement was originally centred around 3D laser fabrication in glasses, polymers or plastics, the picture is now evolving, in particular with the introduction of 3D laser writing in semiconductors [1]. Here I will first summarize the first 3D laser writing approach in silicon, followed by the introduction of the first “in-chip” photonic devices created deep inside the wafer [1]. A subset of these photonic devices, i.e, holograms can be developed to establish a dual 3D optical technology.

I will introduce this novel 3D optical projection capability, which is based on holography [2]. Holography is considered to be the most promising route to true-to-life 3D projections, but the incorporation of complex images with full depth control remains elusive. We demonstrate 3D holograms that form on-axis with full depth control without any crosstalk, producing large-volume, high-density, dynamic 3D projections with 1,000 image planes simultaneously, improving the state-of-the-art for the number of simultaneously created planes by two orders of magnitude [2].

These dual 3D approaches [1,2] are poised to establish a new photonic toolbox, where the strong 3D control on the laser light is expected to enable new 3D laser fabrication capabilities. I will finish with an outlook on the convergence of these approaches.

[1] O. Tokel†, A. Turnalı†, G. Makey, P. Elahi, S. Ilday, T. Çolakoğlu, E. Ergeçen, Ö. Yavuz, R. Hübner, M. Z. Borra, I. Pavlov, A. Bek, R. Turan, S. Tozburun, F. Ö. Ilday., “In-chip microstructures and photonic devices fabricated by nonlinear laser lithography deep inside silicon”, *Nature Photonics*, 11, 639–645 (2017).

[2] G. Makey, Ö. Yavuz, D. K. Kesim, A. Turnalı, P. Elahi, S. Ilday, O. Tokel†, F. Ö. Ilday†, “Breaking crosstalk limits to dynamic holography using orthogonality of high-dimensional random vectors”, *Nature Photonics*, 13, 251, 2019.