

High-Precision 3D Printed Micro-Optics for Next-Generation Optical Sensor Integration

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Summary:

Recent advances in optical sensing require compact, high-performance, and application-specific photonic architectures. We demonstrate how two-photon polymerization enables fabrication of high-resolution micro-optical components directly on substrates, fibers, and photonic interfaces for sensing applications. Additive microfabrication enables rapid prototyping of freeform optical elements while reducing assembly complexity. The presented approach highlights the potential of 3D printed micro-optics for next-generation optical sensors and integrated photonic systems.

Keywords: Two-photon polymerization, micro-optics, optical sensors, integrated photonics, additive manufacturing.

Recent advances in optical sensing require increasingly compact, high-performance, and application-specific photonic architectures. Conventional fabrication methods often limit the realization of complex optical interfaces, particularly when optical-quality freeform surfaces, 3D geometries, and precise alignment to existing photonic components are required simultaneously. As optical sensors continue to evolve toward higher integration density and miniaturized form factors, new fabrication approaches are needed to overcome the limitations of planar manufacturing and conventional assembly processes.

In this talk we demonstrate how two-photon polymerization enables fabrication of high-resolution micro-optical components directly on substrates, optical fibers, and photonic interfaces based on Two-Photon Grayscale Lithography (2GL®) and Aligned Two-Photon Lithography (A2PL®) for the fabrication and integration of high-resolution freeform micro-optics for sensing applications. Our approach allows the realization of complex 3D geometries with high spatial resolution and design freedom, enabling rapid prototyping and customization of optical functionality for application-specific sensor architectures.

2GL® enables the fabrication 2.5D and truly 3D microstructures by locally controlling the exposure dose during the printing process. In contrast to conventional layer-by-layer approaches, 2GL® allows continuous surface profiles and fabrication of complex freeform optical structures with smooth surfaces ($R_a < 5 \text{ nm}$) and advanced

geometries that are difficult or impossible to realize using conventional planar manufacturing technologies. Importantly, optical-quality freeform structures can be fabricated without significantly increasing printing time, enabling efficient prototyping and production of sophisticated 3D micro-optical components for integrated photonics and optical sensing applications.

A2PL® enables direct fabrication of micro-optics onto optical fibers, photonic chips, and other functional substrates with sub-micron alignment accuracy. By aligning printed optical structures directly to pre-existing optical interfaces, the technology enables highly compact and assembly-efficient photonic integration. This approach reduces packaging complexity, improves coupling efficiency, and enables rapid realization of application-specific optical interfaces for fiber-optic sensing, integrated photonics, spectroscopy, and miniaturized analytical instrumentation.

The presented approaches highlight the potential of additive micro-optics as a scalable enabling technology for next-generation optical sensors and integrated photonic systems. By combining high-resolution 3D design freedom, optical-quality finish with precise aligned integration, advanced two-photon lithography technologies open new opportunities for highly integrated and application-specific photonic sensor architectures.