Title: Multiphoton polymerization of volumetric microscale gradient refractive index lenses and waveguides for ultra-dense 3D optics

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Abstract: Here, we present Subsurface Controllable Refractive Index via Beam Exposure (SCRIBE), a direct-write lithographic approach that enables the fabrication of volumetric microscale gradient refractive index lenses and waveguides. The basis of SCRIBE is multiphoton polymerization inside monomer-filled nanoporous silicon and silica scaffolds. Adjusting the laser exposure during printing enables 3D submicron control of the polymer infilling and thus the refractive index over a range of greater than 0.3 and chromatic dispersion tuning. Combining SCRIBE's unprecedented index range and 3D writing accuracy has realized the world's smallest (15 μm diameter) spherical Luneburg lens operating at visible wavelengths. SCRIBE's ability to tune the chromatic dispersion alongside the refractive index was leveraged to render achromatic doublets in a single printing step, eliminating the need for multiple photoresins and writing sequences. SCRIBE also has the potential to form multicomponent optics by cascading optical elements within a scaffold. As a demonstration, stacked focusing structures that generate photonic nanojets were fabricated inside porous silicon. Finally, an all-pass ring resonator was coupled to a subsurface 3D waveguide. The measured quality factor of 4600 at 1550 nm suggests the possibility of compact photonic systems with optical interconnects that traverse multiple planes. SCRIBE is uniquely suited for constructing such photonic integrated circuits due to its ability to integrate multiple optical components, including lenses and waveguides, without additional printed supports and compatible with almost any nanostructured host as long as the host does not strongly absorb the writing laser (~800 nm) and the structure can be filled with monomer.

Bio: Prof. Paul V. Braun is the Director of the Materials Research Laboratory, the Grainger Distinguished Chair in Engineering, and Professor of Materials Science and Engineering. He also has a co-appointment as a Professor in Chemistry and is affiliated with the Department of Mechanical Sciences and Engineering and the Beckman Institute for Advanced Science and Technology. The Braun group focuses on the synthesis of materials with carefully crafted 3D nano- and mesoscale architectures which lead to emergence of new optical, electrochemical, and thermal functionalities. Recent priority research areas include materials for energy storage, advanced optics, chemical sensing, and the control of heat. Prof. Braun received his B.S. degree with distinction from Cornell University, and his Ph.D. in Materials Science and Engineering from the University of Illinois. Following a postdoctoral appointment at Bell Labs, Lucent Technologies, he joined the faculty of the University of Illinois. Prof. Braun has co-authored a book, about 300 peer-reviewed publications, been awarded over 20 patents, and has co-founded three companies. Prof. Braun is a Fellow of the Materials Research Society and AAAS.