3D optical manipulation of photopolymers

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Inorganic photorefractive materials have been extensively studied in diverse applications due to their ability to efficiently translate optical intensity patterns into index of refraction gradients with ~100 nm resolution. Similarly, focused femto-second nonlinear absorption has recently received significant attention as a 3D nanofabrication method for index structures in inorganic glass. In this talk, I will describe how one-photon absorption processes in solid photopolymers held above their glass transition temperature results in complex 3D meso-structured index of refraction with resolution well below 100 nm in cm-thick volumes. This enables large-area index control via mask or holographic lithography as well as local patterning via 3D direct-write lithogrpahy. In the latter technique, demonstrated CW power levels are below 1 microwatt at mm/s write speeds and milliwatts at write speeds of 20 m/s. This combination of high resolution and high throughput has inspired diverse applications of industrial relevance. The materials are inexpensive, easy to fabricate and their properties can be simply modified by selection of monomers, initiators or inhibitors.

The study of this soft-matter/optical interaction requires several new tools. The dynamics of photo-activated polymers are typically studied on cm-scale areas with lamps emitting milliwatts of total power in a broad wavelength band. Conversely, optical intensity, reaction rates and diffusion speeds can change by 10 orders of magnitude or more when a narrowband laser is focused to submicron spot. Particularly in liquid or solid materials above their glass transition temperature, mass-transport of small molecules plays a dominant role in the development process. Thus, an understanding this coupled evolution of nonlinear optical propagation, mass transport and polymer chemistry is critical in harnessing these reactions. I will introduce lithographic tools for creating 3D structures, quantitative microscopy tools for measuring the results and compare these to diffraction/reaction/diffusion models. As an example of how this physics can be exploited to reach new performance regimes, I will describe a two-color, single-photon lithography method which exploits opposing interactions in the polymer to create material structure whose scale is not constrained by the optical diffraction limit.