Light-Crafted Landscapes: Maskless Photosculpting of Hydrogels

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Introduction: Engineering physiologically relevant cell culture substrates requires decoupling multiple environmental cues, such as substrate stiffness and surface topography. Existing hydrogel patterning approaches are limited by complex fabrication, inflexible design space, and feature collapse on soft substrates. Here, we introduce a **maskless, contact-free UV-sculpting technique** that enables fully programmable microscale topographies (from 2 µm to DMD dimensions) directly onto a wide range of hydrogels both synthetic (e.g. pAA, pNIPAM, PEG) and natural (GelMA, gelatin) with tunable resolution and topographical amplitude using digital designs and adjustable UV exposure or photoinitiator concentration.

Method: This approach leverages a digital micromirror device (DMD) to project any grayscale mask pattern onto hydrogel surfaces pre-treated with a photoactivator. Within minutes, spatially defined chemical modifications induce sculpting with micrometric fidelity. Feature height or depth (z-scale) can be precisely controlled by varying technique parameters, enabling rapid exploration of design structure relationships across hydrogels properties and physical cues.

Conclusions: This technology provides a fast (< 5 min fabrication), digital, versatile, and high-throughput platform for generating multi-cue hydrogel substrates. The ability to independently tune mechanical and topographical parameters enables systematic studies in more physiologically relevant microenvironments. Future applications could extend to dynamic platforms, further enhancing spatiotemporal control over cell material interactions.