HIGH-ASPECT-RATIO c-Si METASURFACES FOR ULTRA-FAST PULSE LASERS

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Dielectric metasurfaces offer a transformative approach to wavefront engineering, yet their deployment in the ultrafast regime is frequently constrained by the complexities of managing group delay dispersion (GDD). While crystalline silicon (c-Si) is a premier platform due to its high refractive index and CMOS-compatible fabrication, its application with femtosecond pulses requires sophisticated strategies to balance phase accumulation against two-photon absorption (TPA) and nonlinear losses [1].

In this work, we demonstrate the fabrication and characterization of monolithic c-Si metasurfaces specifically engineered for low-power, ultrafast beam shaping. By utilizing monolithic integration, we realize exceptionally tall meta-atom geometries that significantly expand the parameter space for temporal and spatial optimization. To circumvent the limitations of aspect-ratio-dependent etching (ARDE), we employ a Pancharatnam–Berry (PB) phase design, ensuring a uniform local pattern density that is critical for high-fidelity fabrication [2].

Our fabrication process leverages deep reactive ion etching (DRIE) to achieve aspect ratios up to 15:1. This structural depth may enable substantial GDD tuning via propagation phase accumulation, a mechanism that operates independently of the geometric phase modulation provided by the PB orientation [3]. We experimentally validate our design by characterizing the transmitted pulse duration and evaluating the laser-induced damage threshold (LIDT). Our results demonstrate efficient spatial modulation with negligible temporal distortion, positioning high-aspect-ratio silicon metasurfaces as a robust, passive architecture for next-generation integrated ultrafast systems.

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Keywords: Dielectric Metasurfaces, Monolithic Crystalline Silicon, Ultrafast optics, Pancharatnam–Berry, High-aspect-ratio

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