Femtosecond Pulse Shaping Using Metasurfaces

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Ultrafast optical science and technology depend on optical pulse shaping, which compliments pulse generation and characterization methods. Fourier-transform pulse shaping has emerged as the most successful and widely adopted technique, in which shaping is achieved by parallel modulation of spatially separated frequencies without requiring an ultrafast modulator.[1] Recently, dielectric metasurfaces have been developed as a powerful technology for arbitrary control over the amplitude, phase, or polarization of light in a single, compact optical element.[2] Here, we offer the first experimental demonstration of femtosecond pulse shaping using a centimeter-scale silicon metasurface acting as both amplitude and phase modulation mask. Masks of this type offer a lower cost, larger size, higher resolution, high diffraction efficiency, high damage threshold method for controlling ultrafast pulses.

Figure 1a shows the Fourier-transform pulse shaping apparatus. A dielectric metasurface mask positioned at the focal plane of the apparatus can introduce amplitude and phase modulation to each spectral component of the femtosecond optical pulse. Our metasurface masks are composed of an array of polycrystalline silicon pillars resting on a fused-silica substrate (Figure 1b). Polycrystalline silicon was selected for its large refractive index and low optical absorption within the spectral range of the femtosecond pulse. The pillars are 1µm tall with widths ranging from 110 nm to 180 nm. The total length (along the x-axis) of the metasurface, approximately 3 cm as shown in Figure 1a, corresponds to the spectral bandwidth of the incoming femtosecond pulse. The example metasurface shown in Figure 1b imparts a pure quadratic phase (as a function of frequency) to a near-infrared femtosecond pulse. This design would generate enough dispersion to stretch a pulse from 15 fs to 40 fs. The measured group delay dispersion agrees with the designed value, with slight deviations at the edges of the spectrum. We will discuss our recent results of independent amplitude (through polarization) and phase shaping using metasurfaces.

In summary, we have designed, fabricated and tested an optical pulse shaper that uses a metasurface for spectral and amplitude phase modulation. The high precision with which metasurfaces can control polarization, amplitude, and phase point toward new, previously unrealizable applications in optical pulse shaping.

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[1] A. M. Weiner, Rev. Sci. Instrum. 71, 1929 (2000).
[2] A. Arbabi, Y. Horie, M. Bagheri, and A. Faraon, Nat. Nanotechnol. 10, 937 (2015).

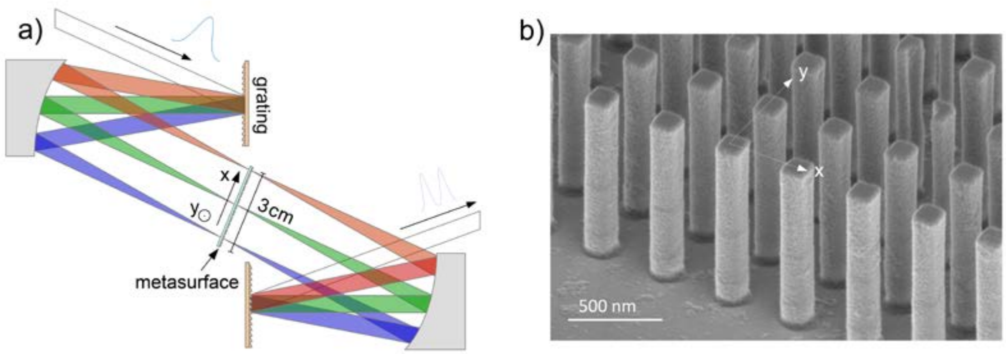

Figure 1: (a) A schematic diagram of the Fourier-transform pulse shaping setup (not to scale). (b) A representative scanning electron micrograph of the silicon pillars that comprise the metasurface.