Large Area Electrically Tunable Metasurface Lens

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Abstract:
Our tunable optics technology enables dynamic tuning with voltage-resolved precision. We have demonstrated electrically controlled focal length tuning of over 100% with a metasurface lens 2 cm in diameter.

Summary of Research:
Introduction. Planar optical elements control the wavefront of light by using arrays of fixed optical phase shifters, amplitude modulators, or polarization changing elements, which are patterned on a surface to introduce a desired spatial distribution of optical phase, amplitude, and/or polarization. By tailoring the properties of each element of the array, one can spatially control these properties of the transmitted, reflected, or scattered light and consequently mold the wavefront [1]. Based on this concept, various functionalities have been demonstrated including lenses, axicons, blazed gratings, vortex plates and wave plates [2]. These devices are thin and lightweight. Recently, a new class of optical components based on metasurfaces has been developed that are based on subwavelength-spaced phase shifters. We introduce a new technology in which metasurface lenses are made tunable by an applied voltage.

Lens Description. Requirements for practical devices include high efficiency, controllability, repeatability, and ruggedness. A practical device should also be readily extendable for large-area fabrication. The lens we have constructed is a transmission-based, polarization-independent, infinity-corrected spherical lens. The design is based on pillars in the material amorphous silicon for the wavelength of 1550 nm and focal length of 50 mm (Figure 1). The lens diameter is 2 cm (Figure 2), giving a large diameter to metasurface unit cell ratio greater than 10,000.

Tuning Description. The lens was designed with an initial focal length of 50 mm and in experiment displayed a focal length tuning range from 52 mm to 107 mm (Δf/f=106%) when the applied voltage
was increased (Figure 3). With this method, focal length tuning of the metasurface lens maintains a good focus. Spherical aberration can be quantified as the deviation of the resulting phase profile from the ideal hyperbolic phase function. Our calculations reveal that increasing the focal length introduces a built-in suppression of spherical aberration. The magnitude of spherical aberration can be mathematically expressed to follow an inverse quartic function to the applied voltage. This allows for flat, highly tunable lens devices with excellent immunity to aberration.

**Applications.** This technology enables long sought-after applications, in which dynamic and high-speed tuning can be done with voltage-resolved precision in an analog or digital manner. It brings into focus embedded optical zoom for chip-scale image sensors (e.g. cell phone cameras) as well as optical zoom and adaptive focus with lightweight form factors for head mounted optics, such as everyday eyeglasses, virtual reality and augmented reality hardware, heads-up displays, projectors, and optical disc drives. In other applications, it allows for optical zoom and focal plane scanning for cameras, telescopes, and microscopes without the need for motorized parts. Furthermore, its flat construction and inherently lateral actuation allows for highly-stackable systems, such as compound optics.

**References:**
