Mechanically Tunable Bilayer Metasurface for Beam Modulation

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Metasurface is a flat optical device composed of artificially fabricated subwavelength nanostructures. Due to the ability to engineer the amplitude, phase, polarization, and other properties of light, it has attracted much interest as an emerging technique for miniaturized optics. Recently, active metasurfaces with multiple functionalities depending on external stimuli have been developed to be applied to advanced optical devices. Among various tuning mechanisms, mechanically tunable bilayer metasurfaces are used for their large tuning range and continuous tunability [1-3]. However, the complexity of designing the phase profile of the bilayer system limits the applicability to varifocal lens and optical beam steering. Here, the design method for modulating the characteristics of the one-dimensional (1D) optical beam described in the Cartesian coordinate is proposed.

The bilayer metasurface is composed of two parallel metasurface layers with nanopillars facing each other. The spacing between the layers should be minimized at the range of avoiding the interlayer coupling to describe the total phase profile of the system as a linear sum of the phase profiles of both layers. The mechanical actuation for the lateral shift affects the planar location of the layers while maintaining the spacing constant. The metasurfaces are orthogonal to the beam propagation direction, which is considered as z-axis. The phase function of x generates the target 1D optical beam. At the same time, the layers are shifted along the y-axis, which is independent of the beam generation. If the phase profile is written as $\varphi(x)$, the beam tuning metasurface is simply designed by multiplying $\pm y$ at $\varphi(x)$. The mechanical shift of displacement $d/2$ is applied to both layers in the opposite direction. The final phase profile of the bilayer system can be calculated as

$$\Phi_{fin}(x,y) = \Phi_{top}(x,y) + \Phi_{bot}(x,y) = \left(y + \frac{d}{2}\right)\varphi(x) - \left(y - \frac{d}{2}\right)\varphi(x) = d\,\varphi(x). \quad (1)$$

The multiplied term $\pm y$ functions as a coefficient on the target beam generating function, leaving the variable coefficient d multiplied by the term. The phase functions such, as the lens or the accelerating beams can be applied to eq. 1, leading to the modulation of their optical properties, including the focal length, the curvature of the trajectory, and the full-width at half maximum(FWHM) of the main lobe of the beam. The optical beams generated by the Fourier transform can also be applied to the system by including the additional phase profile of the Fresnel lens on the phase profile of the top layer. 1D Airy beam, for example, is generated by the Fourier transform of the 1D Airy packet [4]. The Fresnel lens term is independent of the tunable term d, leaving the initial point of the Airy beam constant, which is the focus of the Fresnel lens.

The design method of using a coordinate independent of the beam generation for continuous modulation on the optical beam is proposed in this paper. As the mechanical tuning mechanism of the system is compatible with micro-electromechanical systems, the design can provide further possibilities for various applications.

References

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