Flat Optical Mach-Zehnder Interferometer based on Gradient Metasurfaces

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Metasurfaces —i.e. artificially designed two-dimensional structures— have been shown to be a powerful tool to successfully decrease the size of many optical elements and devices. Realization of flat lenses with thicknesses in the order of wavelength, ultrathin cloaking blankets, and flat polarizers and waveplates, are some of the most recent developments in this area (N. Mohammadi Estakhri and A. Alu, JOSA B 33, A21-A30, 2016). The intriguing characteristics of metasurfaces are rooted in their capability to locally control the phase, amplitude, and polarization state of the scattered wave. Frequently, to achieve a desired functionality, a non-uniform distribution of elements are required on the surface (usually referred to as gradient metasurfaces). In this work, we introduce a compact Mach-Zehnder (MZ) optical modulator based on two cascaded gradient metasurfaces. MZ modulators and interferometers (MZI) are essential elements in many optical devices such as highly sensitive sensors. Recently, Miller proposed the MZI system based on the coupled waveguide scenarios to implement reconfigurable beam couplers (D. A. Miller, Optics Express 21, 6360-6370, 2013). The role of the MZI is to translate the local variations of a parameter (e.g. phase) into the modulation of the amplitude of the output signal. In free-space, MZIs are realized with combination of beam splitters and mirrors in an optically large setup. Our idea of flat MZ modulator is to use two cascaded metasurfaces. The input signals to the unit are two oblique plane waves with incidence angles of $\pm\theta$ degrees. The first gradient metasurface is designed to imprint a constant momentum on the incident waves and therefore, the two beams experience deflection on the first interface. The second interface, instead, is designed to imprint the exact opposite momentum, thus, restoring the initial direction of both waves. Due to the difference between the angles of the two incoming waves inside the gap, the output beams experience a phase difference directly proportional to the gap length. Combined with two flat beam-splitters on the input and output ports, this structure is a MZI, controlling the amplitude of the output beams based on the relative distance of the two gradient metasurfaces. As a proof of concept, we have designed MZ elements with two dielectric metasurfaces at 633 nm for incidence angles of ± 10 degrees. Our studies indicate around 85% modulation efficiency in an interferometric setup, assuming ideal flat beam splitters. In our presentation, we will discuss advantages and potential applications of this setup in various optical applications including free-space signal processing and pulse compression.