Passive and bias-free nonreciprocal transmission based on nonlinear asymmetric dielectric metasurfaces

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The breaking of Lorentz reciprocity law is the fundamental mechanism behind several unidirectional devices, such as all-optical isolators, circulators, and optical diodes. Compared to other relevant nonreciprocal devices, asymmetric nonlinear metasurfaces are ultra-compact, totally passive (no active materials are required), and have the ability to generate nonreciprocity by the input light itself, a.k.a., self-induced nonreciprocity. No external biases are required to trigger nonreciprocity in these devices, such as magnets, currents, or other space and time modulation schemes, avoiding instabilities or other quantum noise problems and leading to more compact designs. Fano metasurfaces are commonly used due to their narrowband transmission spectra. However, it has been proven that the maximum obtained nonreciprocal transmission in a single Fano resonator is limited by its quality factor, input power, and nonreciprocal intensity range.

In this work, a new all-dielectric low-loss nonlinear bifacial metasurface design is demonstrated to achieve passive and bias-free strong self-induced nonreciprocity in transmission (B. Jin and C. Argyropoulos, Phys. Rev. Appl. 13, 054056, 2020). The presented metasurface is constructed by two layers composed of periodic silicon nanospheres that are embedded in a glass substrate and exhibit Fano and Lorentzian resonances, respectively. Strong nonreciprocal transmission arises from the highly asymmetric structure of the proposed nonlinear metasurface. The boosted local electric field along the metasuface enhances the nonlinear Kerr effect and reduces the required input intensity to achieve nonreciprocity to only a few megawatts per centimeter square. The required low input intensity is an intriguing property that can lead to the realization of the currently elusive single-photon or few-photon quantum optical nonreciprocal devices. To further improve the nonreciprocity capabilities, such as insertion loss, nonreciprocal intensity range, isolation ratio, and flatness of transmission band, we design more complex nonlinear bifacial metasurfaces composed by cascading two or more bifacial metasurfaces. The increased geometric asymmetry in these cascade systems further relaxes the trade-off limit between insertion loss and nonreciprocal intensity range. In addition, we demonstrate that the 'dynamic' reciprocity problem can also be relaxed by using the presented configurations and large nonreciprocal transmission is still preserved for some range of input intensity values of the two counterpropagating incident waves. Furthermore, it is demonstrated that the proposed metasurface is robust with regard to fabrication imperfections. This work can find a plethora of free-space-optics applications, such as nonreciprocal ultrathin coatings for the protection of sources or other sensitive equipment from external pulsed laser signals, circulators, and isolators.