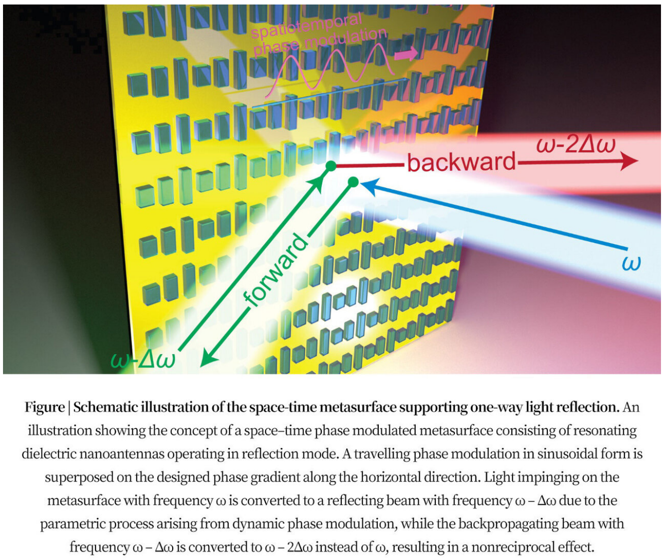
Space-time metasurface makes light reflect only in one direction

20 December 2019



An illustration showing the concept of a space-time phase modulated metasurface consisting of resonating dielectric nanoantennas operating in reflection mode. A travelling phase modulation in sinusoidal form is superposed on the designed phase gradient along the horizontal direction. Light impinging on the metasurface with frequency ? is converted to a reflecting beam with frequency ?-?? due to the parametric process arising from dynamic phase modulation, while the backpropagating beam with frequency ?-?? is converted to ? -2?? instead of ?, resulting in a nonreciprocal effect. Credit: by Xuexue Guo, Yimin Ding, Yao Duan, and Xingjie Ni

Light propagation is usually reciprocal, meaning that the trajectory of light travelling in one direction is identical to that of light travelling in the opposite direction. Breaking reciprocity can make light propagate only in one direction. Optical components that support such unidirectional flow of light, for example isolators and circulators, are indispensable building blocks in many modern laser and communication systems. They are currently almost exclusively based on the magneto-optic effect, making the devices bulky and difficult for integration. A magnetic-free route to achieve nonreciprocal light propagation in many optical applications is therefore in great demand.

Recently, scientists developed a new type of optical metasurface with which phase modulation in both space and time is imposed on the reflected light, leading to different paths for the forward and backward light propagation. For the first time, nonreciprocal light propagation in free space was realized experimentally at optical frequencies with an ultrathin component.

"This is the first optical metasurface with controllable ultrafast time-varying properties that is capable of breaking optical reciprocity without a bulky magnet," said Xingjie Ni, the Charles H. Fetter Assistant Professor in Department of Electrical Engineering at the Pennsylvania State University. The results were published this week in *Light: Science and Applications*.

The ultrathin metasurface consists of a silver back-reflector plate supporting block-shaped, silicon nanoantennas with a large nonlinear Kerr index at near-infrared wavelengths around 860 nm. Heterodyne interference between two laser lines that are closely spaced in frequency was used to create efficient travelling-wave refractive index modulation upon the nanoantennas, which leads to ultrafast space-time phase modulation with unprecedentedly large temporal modulation frequency of about 2.8 THz. This dynamic modulation technique exhibits great flexibility in tuning both spatial and temporal modulation frequencies. Completely asymmetric reflections in forward and backward light propagations were achieved experimentally with a wide bandwidth around 5.77 THz within a sub-wavelength interaction length of 150 nm.

Light reflected by the space-time metasurface acquires a momentum shift induced by the spatial phase gradient as well as a frequency shift arisen from the temporal modulation. It exhibits asymmetric photonic conversions between forward and backward reflections. In addition, by exploiting unidirectional momentum transfer provided by the metasurface geometry, selective photonic conversions can be freely controlled by designing an undesired output state to lie in the forbidden, i.e. non-propagative, region.

This approach exhibits excellent flexibility in controlling light both in momentum and energy space. It will provide a new platform for exploring interesting physics arisen from time-dependent material properties and will open a new paradigm in the development of scalable, integratable, magnet-free nonreciprocal devices.

More information: Xuexue Guo et al, Nonreciprocal metasurface with space–time phase modulation, *Light: Science & Applications* (2019). DOI: 10.1038/s41377-019-0225-z