All-dielectric Nanomechanical Metamaterials

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We report on experimental demonstrations of both electrostatically and all-optically actuated, free-standing, all-dielectric nanomechanical metasurfaces. These subwavelength-thickness devices manufactured in CMOS-compatible media, provide in the former case reflectivity changes of up to 20% at applied biases of only a few volts, and in the latter a large optomechanical nonlinearity, operating at intensities of only a few µW per unit cell and MHz modulation frequencies.

Non-metallic metamaterial nanostructures have attracted considerable attention of late as a means of circumventing the losses and costs associated with the noble metals employed in plasmonic architectures, with high-Q resonant metamaterials being demonstrated on a variety of material platforms including oxides and nitrides, graphene, topological insulators, and high-index dielectrics. At the same time, in the plasmonic domain, nanomechanical reconfiguration has been established as a powerful paradigm for dynamic, electrically/thermally/magnetically/optically-driven, high-contrast switching and tuning of metasurface optical response. We now experimentally demonstrate all-dielectric metamaterials with resonant reflection and transmission characteristics that can be manipulated via the spatial reconfiguration of the constituent elements under the action of electrostatic and optical forces.

Electrostatically actuated subwavelength grating metasurfaces are manufactured, by focused ion beam milling, in a bilayer membrane of 100 nm polycrystalline silicon and 70 nm indium tin oxide (ITO), the latter being structured such that alternate pairs of elements may be placed under alternately positive and negative bias. The in-plane spacing of elements is modified under the action of the resultant attractive/repulsive electrostatic forces, substantially changing the optical properties of the metasurface array over a spectral band set by design – in the present case 20% change in near-infrared reflectivity is achieved under an applied bias of 3V.

Optomechanically actuated metasurfaces are fabricated as an array of nano-cantilevers in a 100 nm thick free-standing polycrystalline silicon membrane. Illumination at a pump wavelength of 1550 nm generates optical forces within the structure which act to tilt the cantilever arms out-of-plane, bringing about a change in the transmission of the array at a probe wavelength of 1310 nm. With the nano-cantilever arms driven to oscillate at a mechanical eigenfrequency of 152 MHz, metasurface provides an extremely large optomechanical nonlinearity (an effective susceptibility $Im\{\chi^{(3)}\}/n_2 \sim 3.9\times10^{-14}$ m^2V^{-2}) at intensities of only a few tens of $\mu W/\mu m^2$.

Ultrathin all-dielectric nanomechanically reconfigurable photonic metasurfaces exploit the unique technological and manufacturing opportunities provided by dielectric/semiconductor membrane platforms and offer a compact, energy efficient and fast active optoelectronic platform potentially suited to practical application in high-speed photonic applications.