Reconfiguring Photonic Metamaterials with Electromagnetic Forces

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Abstract: We show that reconfigurable photonic metamaterials provide a flexible platform for fast modulation and high-contrast switching of metamaterial optical properties in response to external stimuli such as electric voltages, optical excitation and magnetic fields.

Dynamic control over metamaterial optical properties is key for the use of metamaterials as active elements ranging from modulators and switches to tunable filters and programmable transformation optics devices.

Here we demonstrate that reconfigurable photonic metamaterials provide a flexible platform for dynamically controlling metamaterial optical properties. The properties of virtually any metamaterial structure strongly depend on the spatial arrangement of its components. By manufacturing plasmonic metamaterials on a grid of elastic dielectric bridges of nanoscale thickness, we are able to dynamically rearrange sub-micron sized plasmonic building blocks across the entire metamaterial array, see Fig. 1(a, c). We demonstrate that this approach allows tuning, modulation and switching of photonic metamaterials via electric, optical and magnetic control signals.

Fig. 1(a) shows a reconfigurable metamaterial nanostructure controlled by electrostatic fields. Here different electric potentials are alternatingly applied to pairs of flexible conducting bridge structures, leading to alternating attractive and repulsive electrostatic forces between the bridges. A control signal of a few volts gives access to regimes of MHz rate modulation, reversible tuning and non-volatile switching with up to 250% contrast [see Fig. 1(b)] of the metamaterial's optical properties. The metamaterial's effective electro-optic coefficient exceeds that of lithium niobate by about 5 orders of magnitude. With electric control at a few volts, microwatts power consumption and sub-picojoule switching energy, such reconfigurable structures integrate well with existing optoelectronic technology.

An optically controlled reconfigurable metamaterial is shown by Fig. 1(c). Here, structural deformation of the metamaterial lattice is driven by optical forces resulting from near field interactions of the optically excited plasmonic resonators. Simulations show that the optical forces between the bridge pairs are strongest at plasmonic resonances of the nanostructure and that they can be either attractive or repulsive [see Fig. 1(d)]. In the attractive regime, the narrowing gap will tend to increase the resonant attractive force, but it will also lead to a spectral shift of the resonance. This feedback between structural deformation and optical forces gives rise to nonlinear phenomena such as bistability.

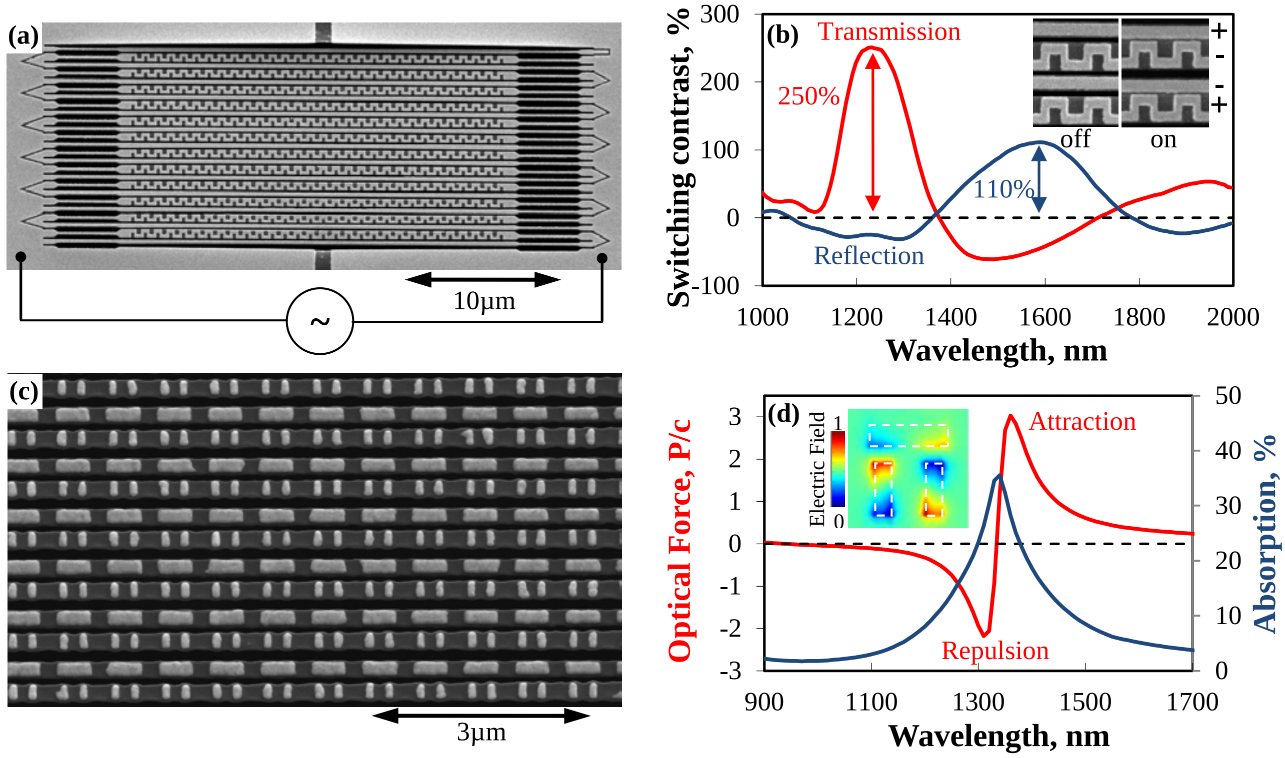

Fig. 1: (a) Electrostatically reconfigurable metamaterial and (b) measurements of its switching contrast in transmission ΔT/T and reflection ΔR/R. (c) Optically reconfigurable metamaterial and (d) corresponding simulations of optical forces (in units of light pressure, power/speed of light), absorption and resonant electric field distribution. The incident light is polarized parallel to the bridges in all cases.