Playing the metamaterial guitar with light and ultrasound

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The ultimate goal of metamaterials research may be described as arbitrary control over material properties at any point in time and space. Fundamentally, this requires the ability to modify a metamaterial structure with sub-wavelength spatial resolution. Here we demonstrate dynamic control over metamaterial properties beyond the diffraction limit based on acoustic resonances and electromagnetic resonances of nanomechanical metamaterials.

Our nanomechanical metamaterials consist of coupled electromagnetic resonators supported by mechanical resonators, such that relative motion of the electromagnetic resonators changes the optical properties of the metamaterial array. The metamaterials have a thickness of 100 nm, with electromagnetic resonators consisting of gold nanorods arranged in a 700 nm x 700 nm unit cell, and supporting mechanical resonators consisting of silicon nitride strings of 200-300 nm width and 19-28 µm length. Thus, the structures exhibit near-infrared optical resonances (controlled by the gold nanorods) and mechanical resonances (controlled by the silicon nitride strings) at ultrasound frequencies of 100s of kHz to few MHz, where the resonance frequency is inversely proportional to the string length. The optical properties of the metamaterial arrays are modulated by nanostring displacement driven by (i) ultrasound, (ii) optical heating and (iii) optical forces. As efficient actuation of the nanostrings occurs only at their mechanical resonance frequencies, strings of different length can be addressed individually using ultrasound or light modulated at a string’s resonant frequency. Our experimental demonstrations include modulation of light by ultrasound as well as selective actuation of individual metamaterial strings spaced by 700 nm by modulated light of 1550 nm wavelength. Importantly, mechanical resonances allow us to control metamaterials with light and sound with the same spatial resolution as the string spacing, i.e. the resolution of our approach is set by nanofabrication, not diffraction.

In analogy with a guitar, use of optical and acoustic control signals to selectively excite vibration of individual strings at their different resonant frequencies may be thought of as playing a “metamaterial guitar” with light and ultrasound. In contrast to a conventional guitar, our vibrating metamaterial strings generate moving pictures by modulating light in time and space.

In summary, dynamic control of the addressable nanomechanical metamaterials enables simultaneous spatial and temporal modulation of metamaterial properties, taking metamaterials to the next level of functionality. Further development of this concept could lead to superresolution spatial light modulators, transformation optics/acoustics devices, reconfigurable optical/acoustic components, parallel optomechanical sensor arrays, superresolution imaging devices and miniaturized spectrometers.