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Multiresonant Metasurfaces for Broadband Quadratic Spectral Phase Manipulations

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Metasurfaces (MSs) are being investigated for a broad range of applications. However, they have found limited use in broadband dispersion engineering and the temporal shaping of short pulses. This is because conventional, singly-resonant MSs are inherently narrowband and exhibit a specific spectral phase profile dictated by the resonance dispersion [$\varphi(\omega) \propto \text{atan}(\gamma(\omega - \Omega))$ for a single Lorentzian resonance centered at Ω]. The first example of a broadband, specifically-engineered spectral phase concerned a linear profile (spectrally-constant group delay) utilized to delay broadband pulses without distortion [1] and applied to achromatic wavefront manipulation [2]. A wider class of important applications requires a quadratic phase profile, namely, dispersion compensation, chirped pulse amplification, and in general any application requiring control over the instantaneous frequency (chirp) and temporal duration of a broadband pulse through pulse chirping/de-chirping.

Thus far, the approaches to dispersion compensation with MSs are either narrowband or do not guarantee pulse integrity [3,4]. Here, we present a solution to this problem by constructing multiresonant MSs that implement a purely quadratic phase profile which is both arbitrarily strong (despite the ultrathin nature) and (almost) arbitrarily broadband, as controlled by the spacing and number of the implemented resonances, respectively. The main elements of our approach are illustrated in Fig. 1. A specific configuration of Lorentzian resonances in the electric and magnetic surface conductivities with decreasing(increasing) frequency spacing can lead to a purely quadratic phase [$\varphi(\omega) = \Phi_2(\omega - \Omega)^2 + \Phi_1(\omega - \Omega) + \Phi_0$] with positive(negative) group delay dispersion Φ_2 [Fig. 1(a),(b)]. This can be used e.g. for dispersion compensation of chirped signals [Fig. 1(c),(d)]. For operation in transmission(reflection) electric and magnetic conductivities have to be spectrally overlapping(interleaved). In the example of Fig. 1(c),(d) the output pulse is completely de-chirped and compressed by a factor of $\sqrt{2}$, as intended. In practice, the resonance trains need to be truncated. Figure 1(e) investigates this scenario keeping seven resonances. The compression is only slightly affected and the residual output chirp is negligible along the duration of the output pulse [Fig. 1(f)].

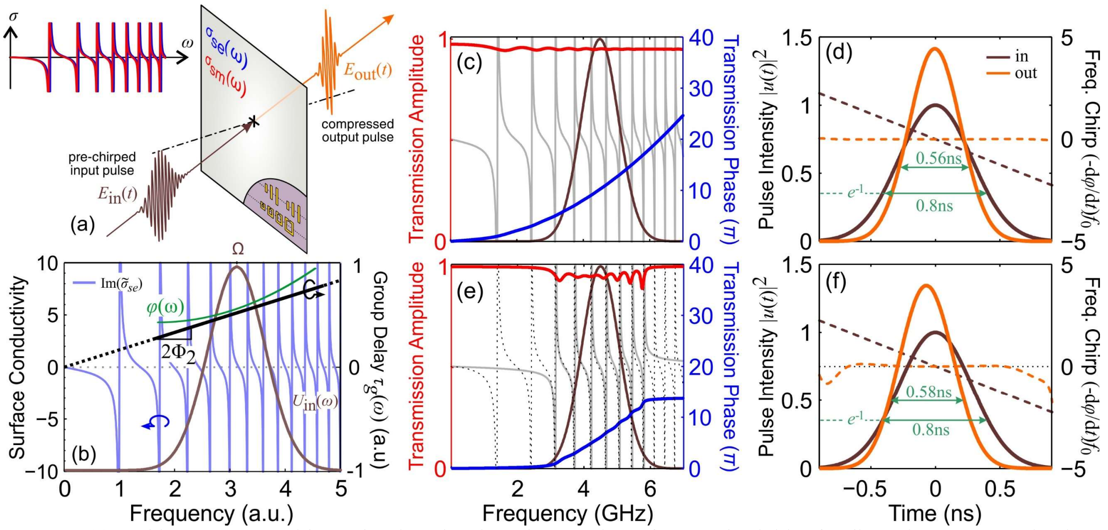

Fig. 1. (a) Multiresonant MS with overlapping electric and magnetic surface conductivities for dispersion compensation in transmission. (b) The decreasing frequency spacing leads to positive group delay dispersion. (c,d) Dispersion compensation example with an infinite Lorentzian resonance train. (e.f) The resonance train is truncated to seven resonances.

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