# Metamaterials for enhanced acousto-optic interactions

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Interactions between light and sound are described by processes such as piezoelectricity, electrostriction, and photoelasticity, and drive key technologies underpinning modern telecommunications systems, such as frequency filters, Brillouin lasers, and sensors [1]. However, the range of materials available for practical applications is small, as acousto-optic interactions are generally weak in technologically relevant materials, such as silicon [3]. Metamaterial structuring presents a new and unprecedented opportunity for enhancing light-sound interactions, ultimately reducing device sizes, and improving existing device performance for applications [4].

To this end, we investigate the photoelastic properties of structured materials with periodicities much smaller than all optical and acoustic wavelengths. Here we define photoelasticity via [2]

$$\Delta(\varepsilon^{-1})_{ij} = P_{ijkl}\,\frac{\partial u_l}{\partial x_k} = p_{ij(kl)}s_{kl} + p_{ij[kl]}r_{kl}, \tag{1}$$

where $\Delta(\varepsilon^{-1})_{ij}$ denotes an infinitesimal change in the inverse permittivity tensor, $P_{ijkl}$ is the full photoelastic tensor, and $\partial u_l/\partial x_k$ the gradient of the displacement from equilibrium. The full photoelastic tensor can be decomposed into symmetric $p_{ij(kl)}$ and anti-symmetric $p_{ij[kl]}$ tensors, acting on the linear strain $s_{kl}$ and infinitesimal rotation $r_{kl}$ tensors, respectively.

We show that metamaterial structuring can significantly enhance the symmetric photoelastic and antisymmetric photoelastic (or *roto-optic*) properties of conventional dielectric materials [4, 5]. Surprisingly, the photoelastic properties of metamaterials are not given by weighted averages of the constituent materials alone; they also include *artificial contributions*, and correspond to changes in permittivity arising purely from changes in filling fraction. This behaviour is not observed in the linear optical, acoustic, or thermal properties of metamaterials, and the contribution to the total photoelasticity can be significant [5]. We demonstrate this with a selection of metamaterial designs, including arrays of spheres and layered media.

## References

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