

Stimulated Brillouin Scattering with a twist

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We propose a bulk material comprising thin silicon and silica layers with strong Stimulated Brillouin Scattering performance. In this material, strong enhancement is observed when the optical field interacts with a shear (transverse) acoustic mode, as opposed to a longitudinal acoustic mode, giving both a strain and rotation contribution to the electrostrictive overlap.

In a conventional stimulated Brillouin scattering (SBS) process, an electromagnetic field generates an elastic deformation in the medium which modulates the dielectric properties of the material and acts as a source for a secondary light wave [1]. Amplification can then be achieved when this secondary light wave is resonantly excited with an additional electromagnetic field at the Stokes frequency. In a cubic or isotropic material the only acoustic modes that can be used in an SBS process are longitudinal acoustic waves, however in materials with lower symmetry, SBS can in fact be driven by acoustic shear waves. In this event, a maximum of 12 combinations of Pump, Stokes, and Acoustic fields are available to contribute to an SBS process. Furthermore, photoelasticity does not describe light-sound interactions entirely for shear waves. An additional contribution arises due to a local material lattice rotation caused by the acoustic field which is known as the roto-optic effect [2]. This effect is proportional to the optical anisotropy and exists in uniform material of sufficiently low symmetry. Subsequently, the change in permittivity ϵ_{ij} for a non-piezoelectric dielectric material is described by

$$\Delta(\epsilon^{-1})_{ij} = p_{ijkl}s_{kl} + r_{ijkl}r_{kl}$$

where p_{ijkl} is the photoelastic tensor, r_{ijkl} is the roto-optic tensor, s_{kl} is the strain tensor, and r_{kl} is the infinitesimal rotation tensor. To exploit the roto-optic contribution to SBS we consider a layered material (Figure 1a) with optically isotropic constituents which gives rise to a composite with tetragonal symmetry.

Existing work on structured materials has been confined to composites possessing cubic symmetry [3], which have $r_{ijkl} = 0$. For a layered medium, even with isotropic constituents, the structure is immediately anisotropic and thus $r_{ijkl} \neq 0$. Using rigorous effective medium treatments for all materials tensors we compute the gain coefficient for the layered medium under an optimal frame rotation. For the transverse acoustic mode combination, we achieve a maximum gain value of $g_P = 4.2 \times 10^{-11} [\text{m} \cdot \text{W}^{-1}]$ at $f = 40\%$ when the roto-optic effect is omitted, and a maximum value of $g_P = 2.3 \times 10^{-10} [\text{m} \cdot \text{W}^{-1}]$ at a filling fraction of $f = 46\%$ when the roto-optic effect is included. This is considerably higher than values in silicon ($g_P = 2.7 \times 10^{-12} [\text{m} \cdot \text{W}^{-1}]$) and silica ($g_P = 4 \times 10^{-11} [\text{m} \cdot \text{W}^{-1}]$) alone.

This previously unexplored SBS mechanism, the coupling of light to acoustic shear waves in bulk materials, also opens new opportunities for device implementation as lower shear wave velocities permit acoustic confinement.

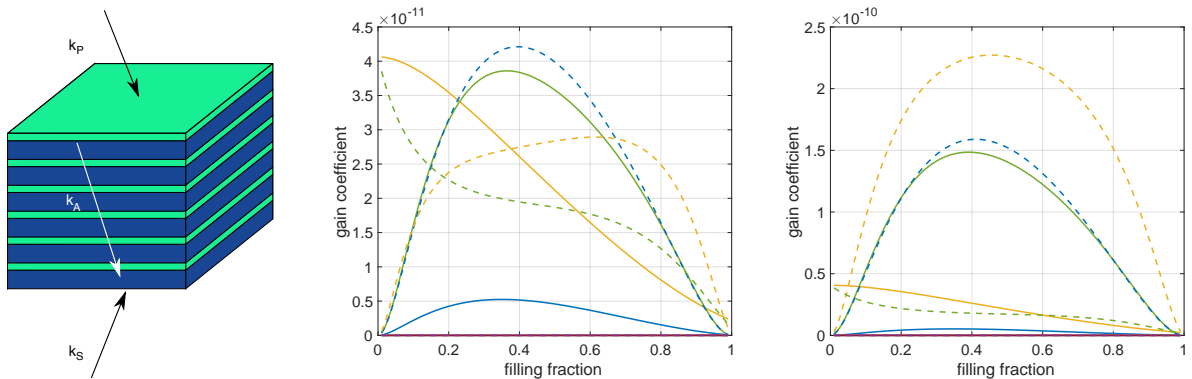


Fig. 1: (a) Schematic of layered material with Pump, Stokes, and Acoustic wave vectors labelled; (b) SBS gain coefficients $[\text{m} \cdot \text{W}^{-1}]$ versus filling fraction for all acoustic and electromagnetic mode combinations with $r_{ijkl} = 0$; (c) and with $r_{ijkl} \neq 0$.

References

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