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A two-state phononic crystal using highly dissipative polymeric material interface

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Abstract: Periodic structures exhibit very specific properties in terms of wave propagation. In this paper, some numerical tools for dispersion analysis of periodic structures are presented, with a focus on the ability of the methods to deal with the dissipative behavior of the components. An example of design of a two-state phononic crystal using a highly dissipative polymeric interface is finally shown.

A periodic medium is a material or a structural system that exhibits spatial periodicity. The study of periodic structures has a long history in the field of vibrations and acoustics [1]. The methods currently used are most of the time based on those derived from wave propagation in crystals [2], where almost no dissipation occurs. Reaching the upper scale for structural dynamics implies that damping effects have to be included in the analyses which are performed. The system consists in an infinite periodic bidirectional waveguide shown in Fig 1. It is a 1 mm thick plate with periodic cylindrical pillars. Due to the periodicity, the unit cell is used and the corresponding first Brillouin zone is described in Fig. 2.

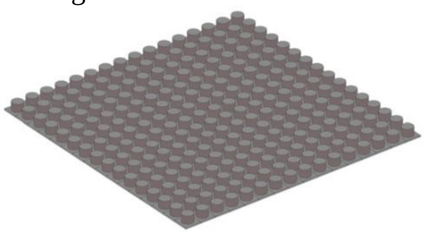

Figure 1 Infinite plate

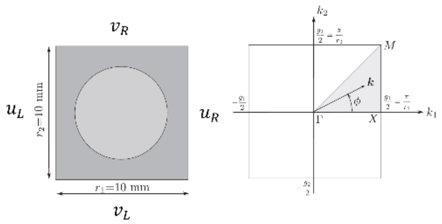

Figure 2 Real and reciprocal lattices

In order to design a two-state phononic crystal, a polymeric base is included in the pillar (Fig 3). The base plate is made of isotropic Aluminium 6063-T83 ($\nu_{alu} = 0.33$; $E_{alu} = 69e9\,[Pa]$ and $\rho_{alu} = 2700\,[kg/m^3]$). Pillars are made of combination between a highly dissipative polymer tBA/PEGDMA ($\nu_{poly} = 0.37$; E_{poly} and $\rho_{poly} = 1004\,[kg/m^3]$) [3] and Aluminum.

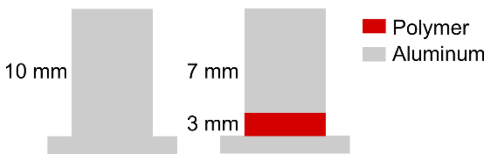

Figure 3 Reference and two-state structure

A suitable model is required for the description of the frequency-dependent behavior of the polymer. Here a fractional derivative Zener model is used. Moreover this material exhibits a strong temperature dependency that will be used to obtain the two-state phononic crystal. The expression of the elastic complex modulus is

$$E^*_{poly}(\omega) = \frac{E_{0_{poly}} + E_{\infty_{poly}}(i\omega\tau)^\alpha}{1 + (i\omega\tau)^\alpha}, \tag{1}$$

where $E_{0_{poly}}$ and $E_{\infty_{poly}}$ are respectively the static elastic modulus and the high-frequency limit value of the dynamical modulus, τ is the relaxation time and α is the order of fractional derivative. An estimation of the four parameters $E_{0_{poly}}$, $E_{\infty_{poly}}$, α and τ is obtained by experimental measurements [3].

The ”Shifted-Cell Operator” technique consists in a reformulation of the PDE problem by ”shifting” in terms of wave number the space derivatives appearing in the mechanical behavior operator inside the cell, while imposing continuity boundary conditions on the borders of the domain. The formulation leads to the following eigenvalue problem [4]

$$\left[(K-\omega^2 M)+\lambda_i(L-L^T)-\lambda_i^2 H\right]\phi_i^r=0, \quad (2)$$

where $\lambda_i = jk_i$ is the i-th eigen value, ϕ_i^r denotes the right eigenvector associated to λ_i, M and K are respectively the standard symmetric definite mass and symmetric semi-definite stiffness matrices, L is a skew-symmetric matrix and H is a symmetric semi-definite positive matrix. In this formulation, all matrices can depend on ω. A parametric eigenvalue analysis is then performed where the pulsation ω is fixed as real parameter, allowing introduction of damping effects. The wavenumbers $\lambda_i = jk_i$ and the associated right eigenvectors ϕ_i^r are computed by solving the quadratic eigenvalue problem.
For frequency-dependent systems, the estimation of the group velocity is not trivial [5, 6]. We focus on homogeneous cases where the frequency dependency is characterized by a Young’s modulus such that $E = f(\omega)E_0$ and a constant Poisson’s ratio. Hence $K = f(\omega)K_0$, $H = f(\omega)H_0$ and $L = f(\omega)L_0$. In this case we obtain

$$C_g = real\left(\frac{\partial\omega}{\partial k_i}\right) = real\left(\frac{j\phi_i^{l^T}\left[f(\omega)(-L_0+L_0^T+2\lambda_i H_0)\right]\phi_i^r}{\phi_i^{l^T}\left[\omega^2\frac{\partial f}{\partial\omega}-2\omega\right]M\phi_i^r}\right). \quad (3)$$

The height of the polymeric interface has been chosen such that the resonance of the pillar occurs between 15 kHz to 45 kHz. A comparison between the results obtained using the reference structure and the tunable structure is presented on Fig 4. The two states are obtained by changing the temperature of the polymeric interface: at $50°C$, the band gap is visible around the selected frequency. Above the glass transition, the phononic crystal tends to behave as an homogeneous plate.

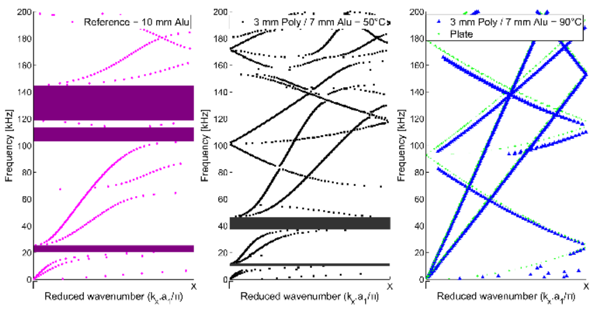

Figure 4 Dispersion curves of the various configurations

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