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Mechancial Transduction in Periodically Patterned Media

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Mechanical Transduction

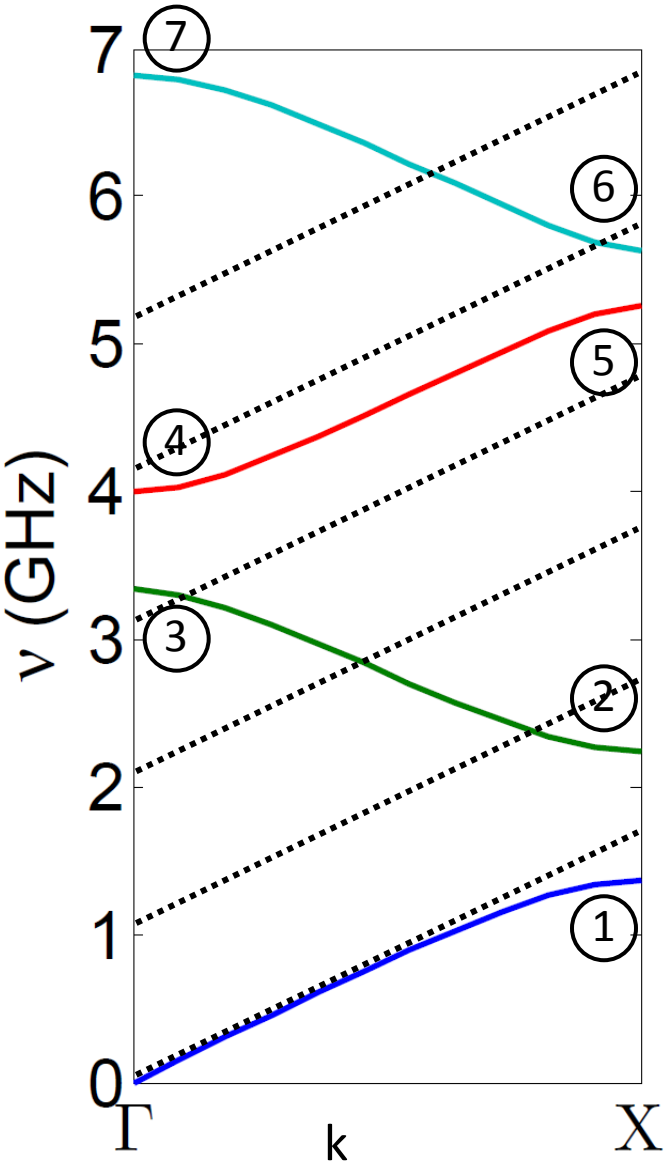
- Convert Electromagnetic/Thermal/Optical Energy to Mechanical energy
- Need to do it efficiently over large bandwidth
- Applications:
  - Sensing
  - Energy Harvesting
  - Signal encoding / receiving
  - Memory

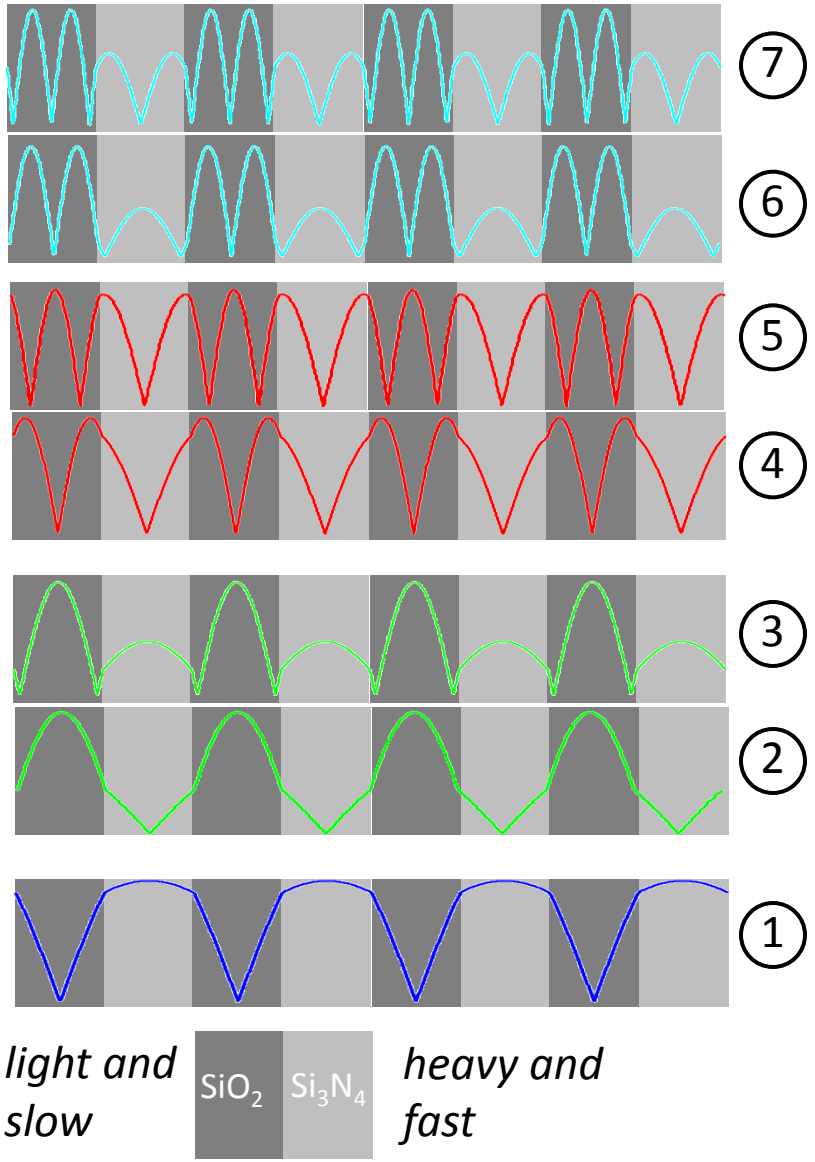
A Simple Phononic Bragg Stack

Material	Elastic Properties	
	density	phase velocity
light and slow SiO_2	$\rho \approx 2200\ {}^{\mathrm{kg}}/_{\mathrm{m}^3}$	$v_p \approx 5600\ {}^{\mathrm{m}}/_{\mathrm{s}}$
heavy and fast Si_3N_4	$\rho \approx 3100\ {}^{\mathrm{kg}}/_{\mathrm{m}^3}$	$v_p \approx 9000\ {}^{\mathrm{m}}/_{\mathrm{s}}$

Question: How does mechanical energy flow in this system?

Energy density in phononic Bragg stack





Mechanical power flow

Question: how much power flows through structure?

Power depends on impedance

$$P \propto \frac{1}{Z} \longrightarrow Z_0 = \rho v_p$$

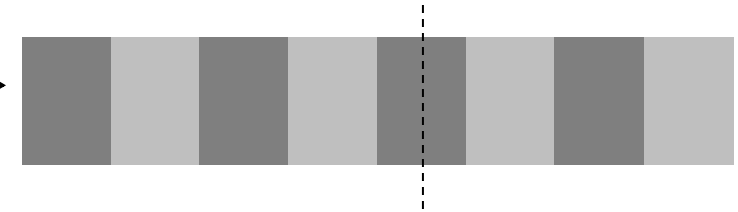
$$Z_0 \approx 12 \frac{\text{Pa} \cdot \text{s}}{\mu\text{m}}$$

$$Z_0 \approx 28 \frac{\text{Pa} \cdot \text{s}}{\mu\text{m}}$$

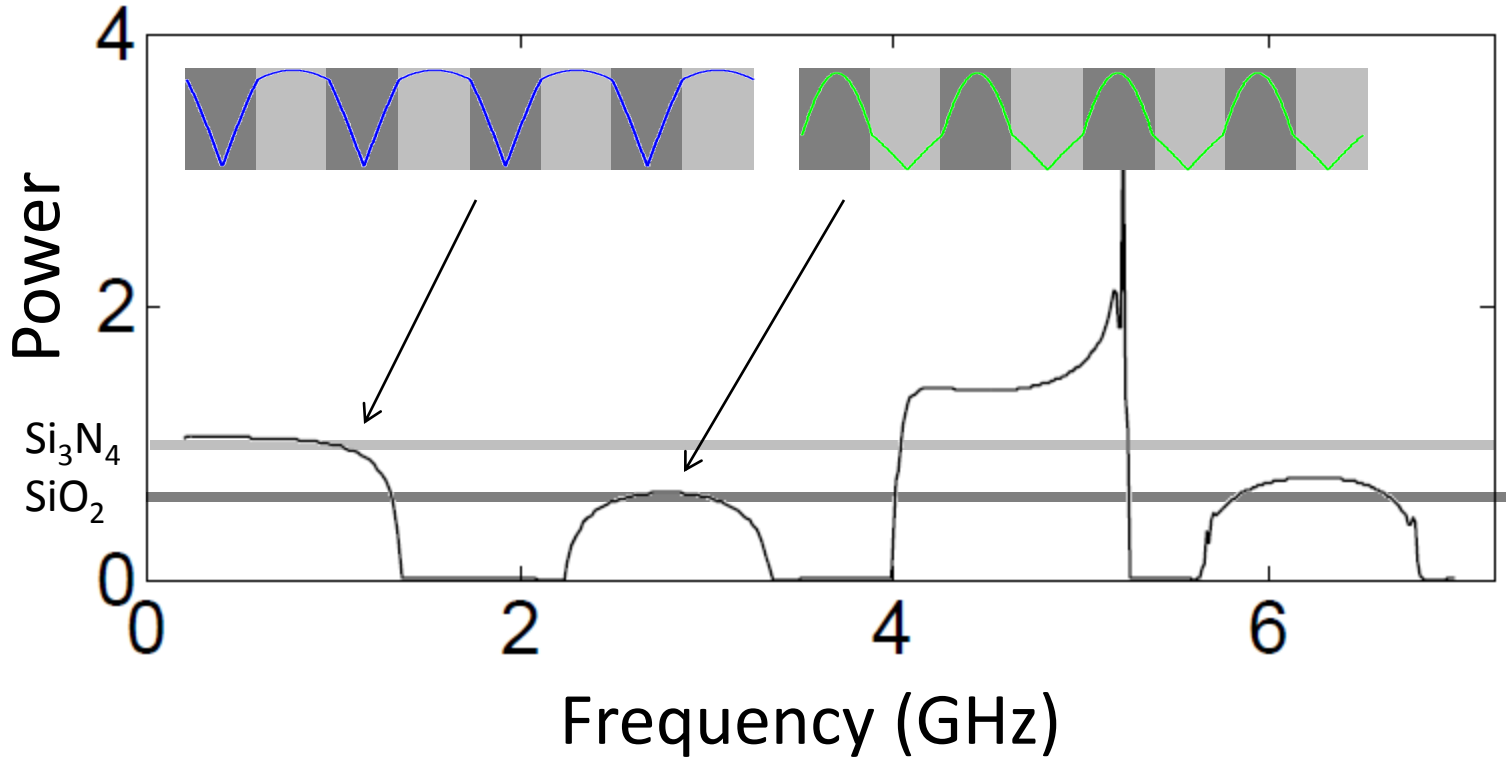
Impedance in periodic media

Apply Force

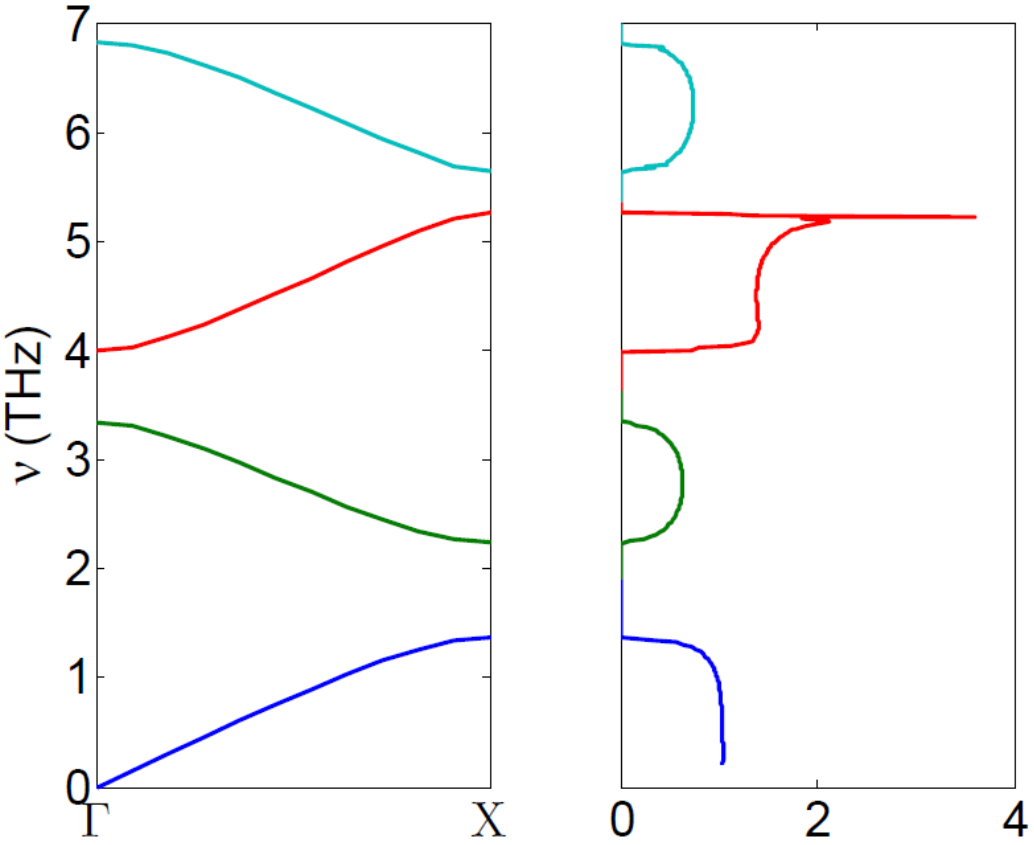
$$F = F_0 \sin(\omega t)$$



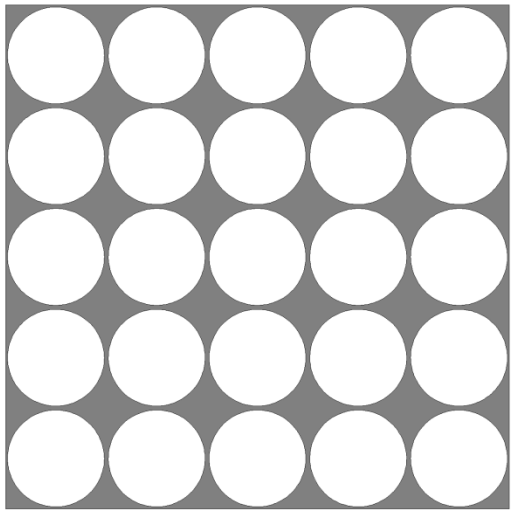
Measure power flow through structure

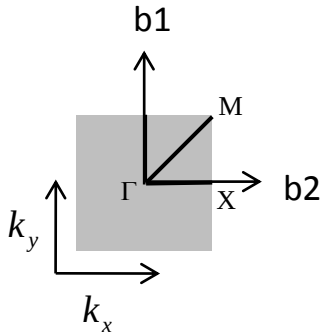


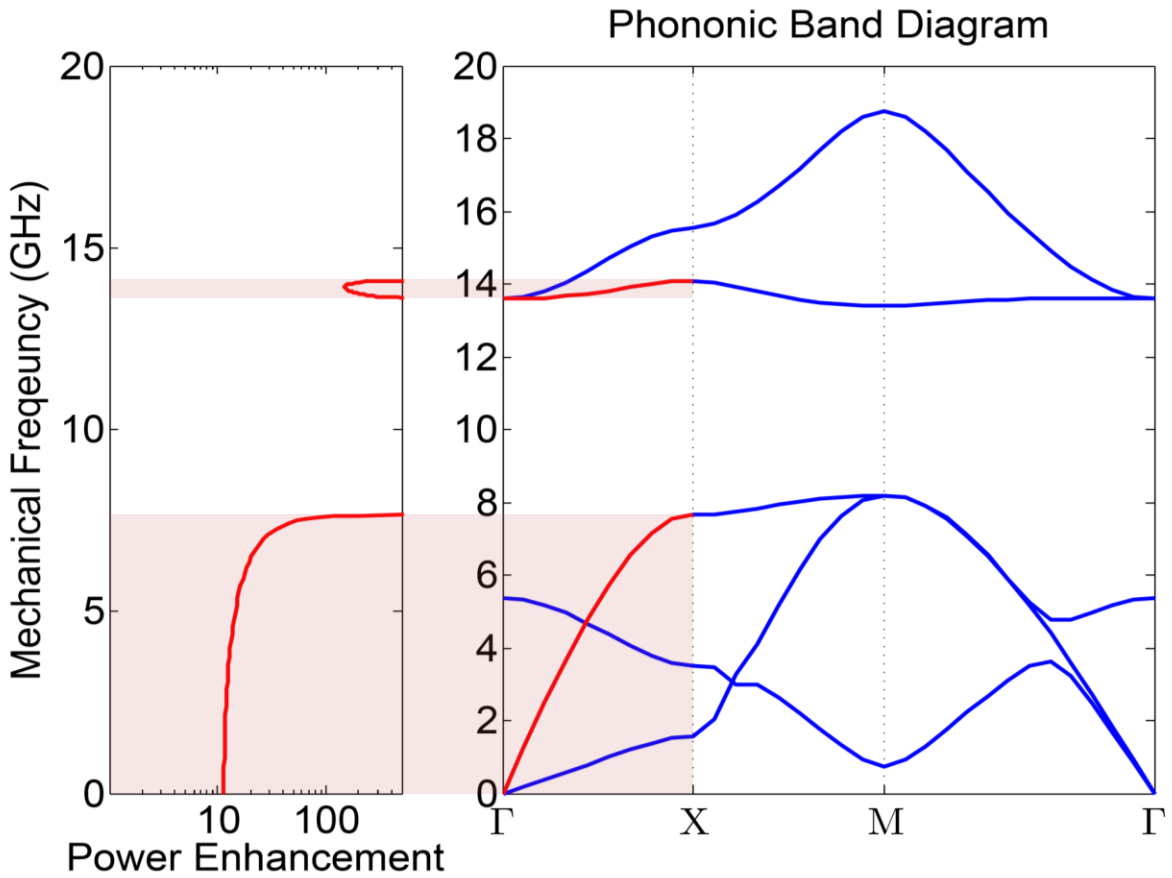
Dispersion and Power Flow



Power enhancement in a 2D periodic structure

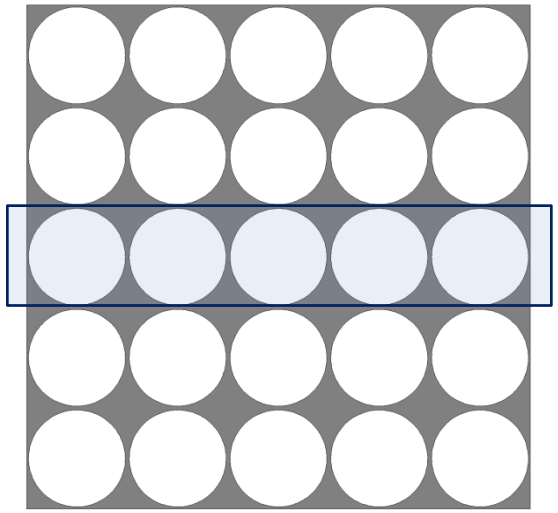


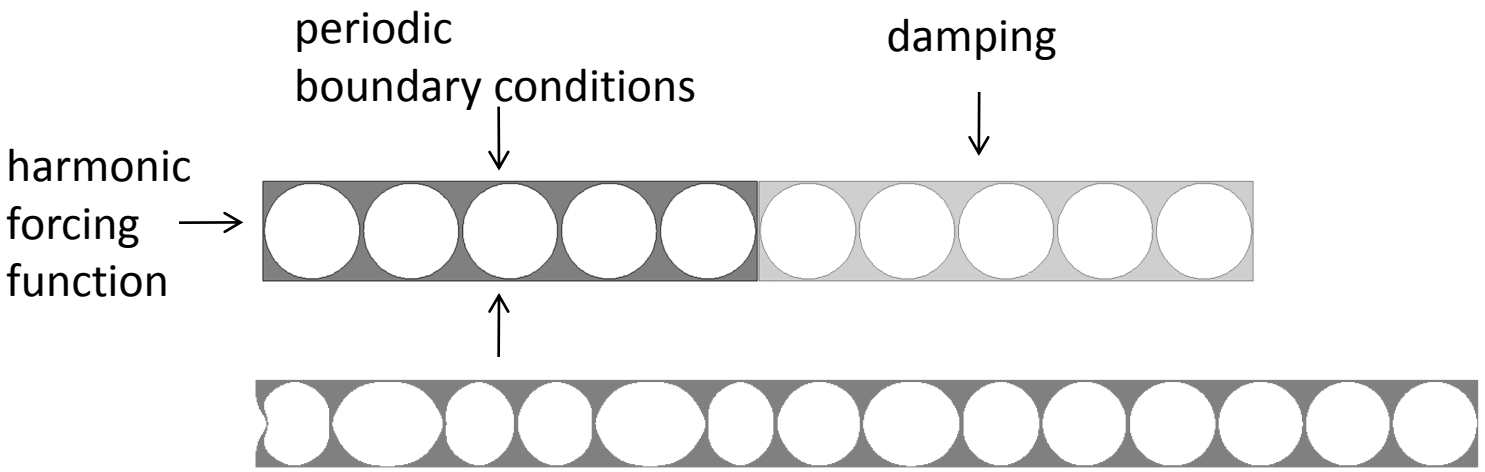




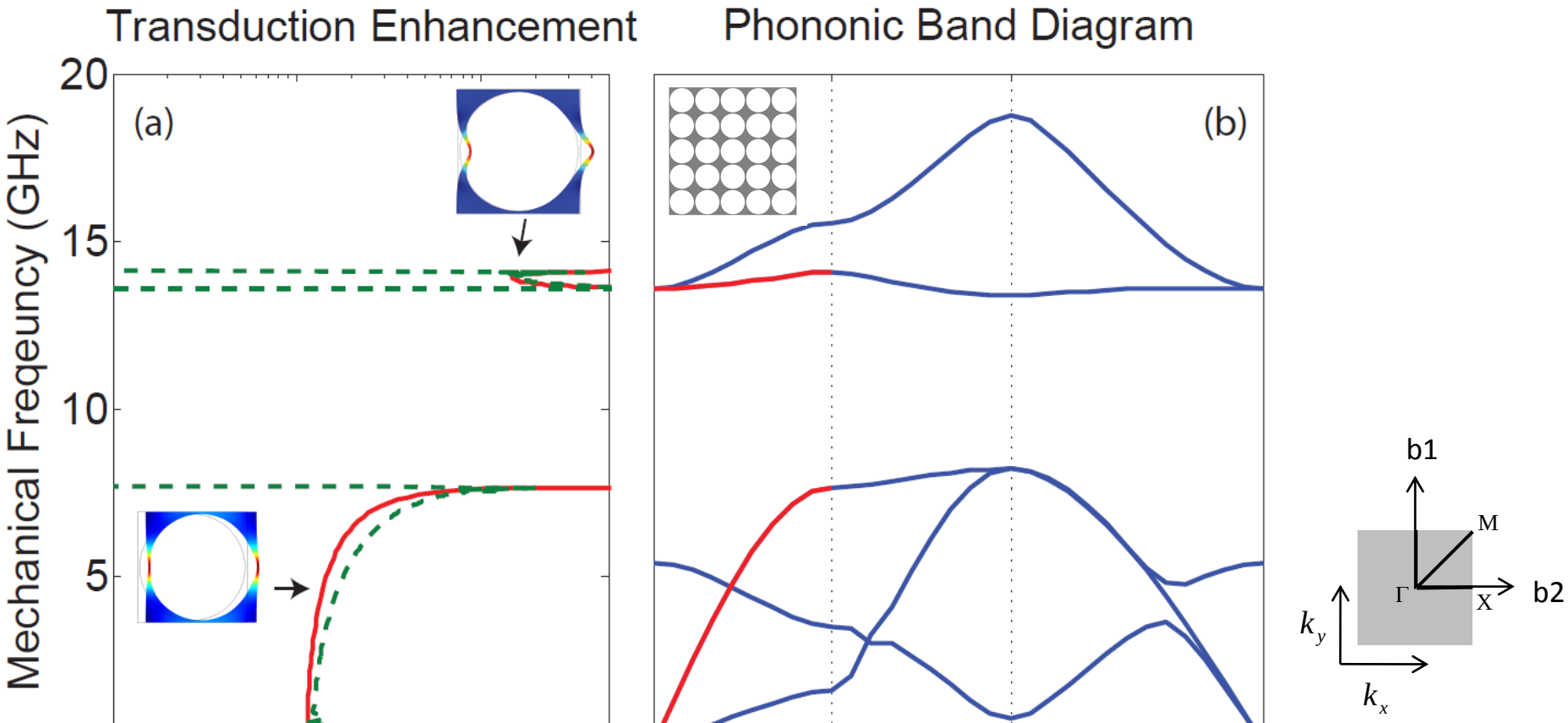
Harmonic Forcing

2D periodic structure

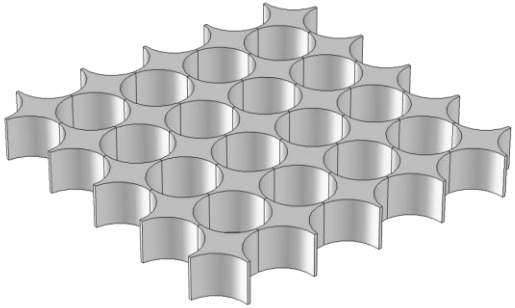


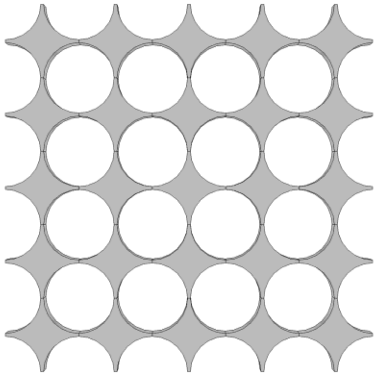


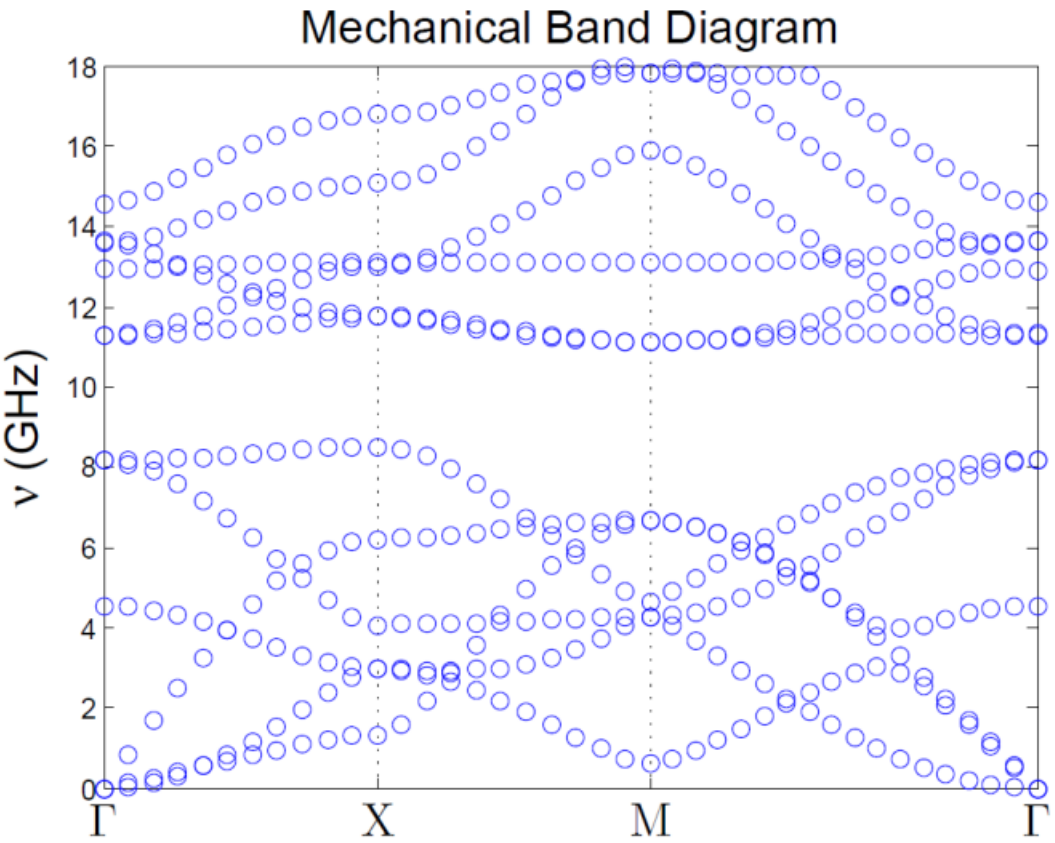
Density of states / harmonic forcing comparison

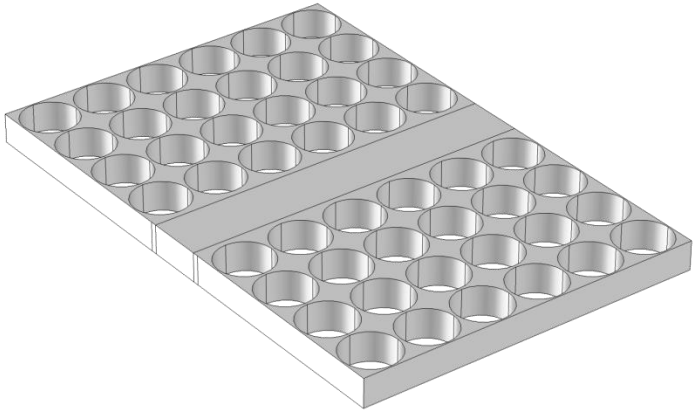


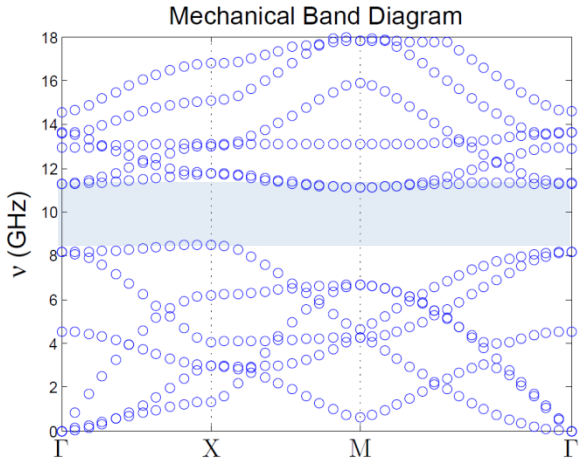
3D Square Lattice of Holes

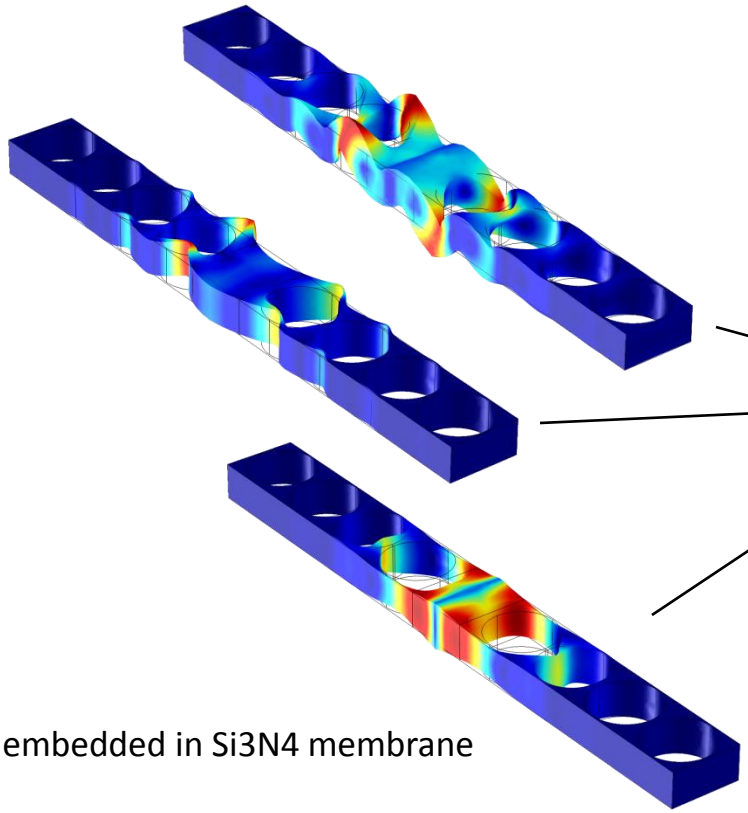


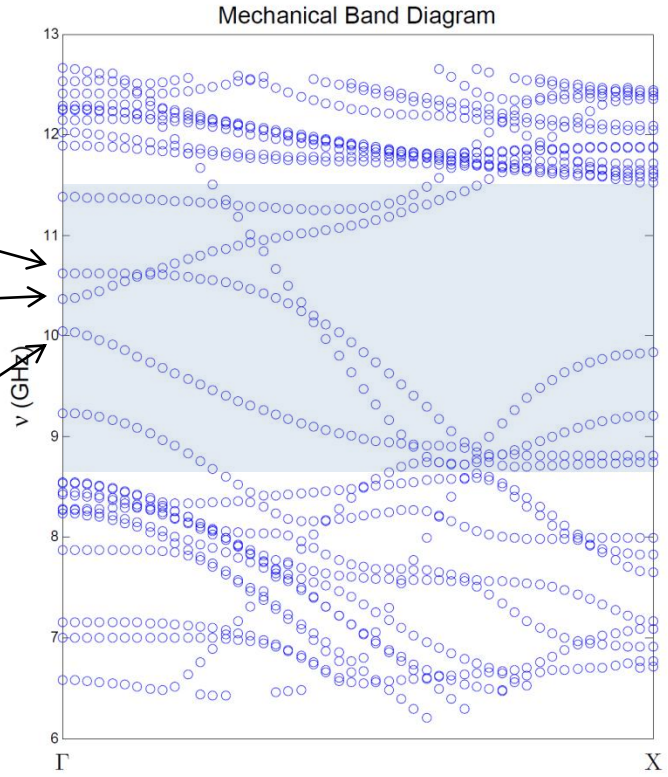






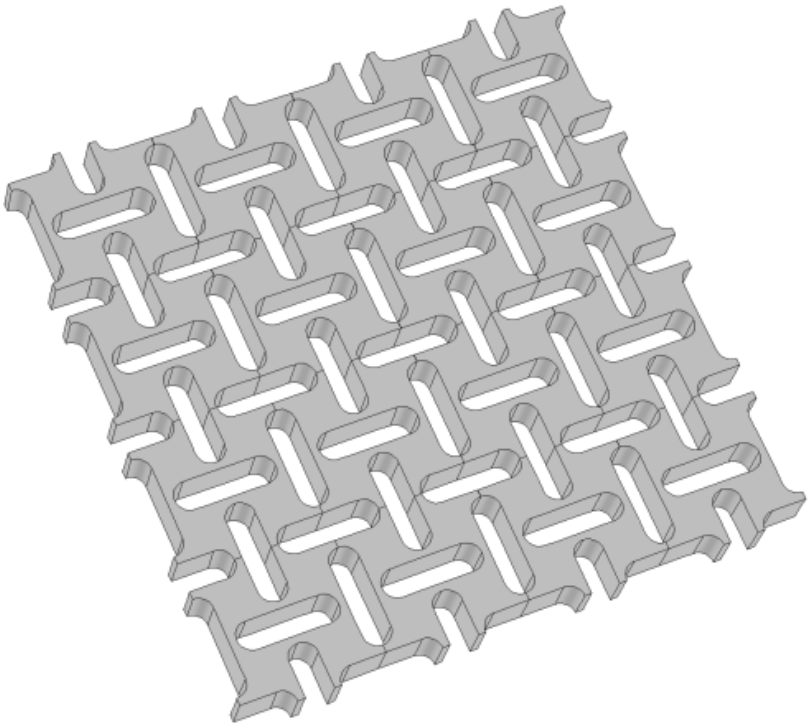


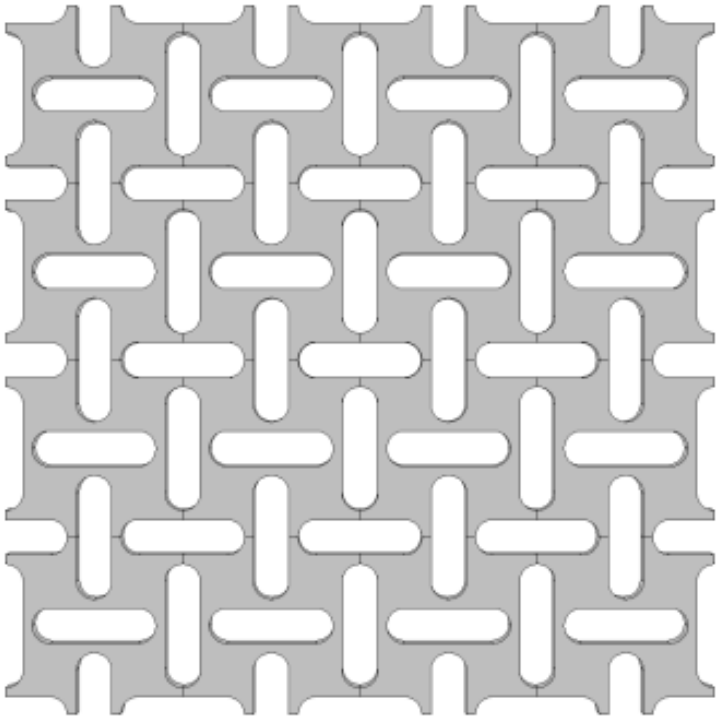




Si Waveguide embedded in Si3N4 membrane
a= 300 nm
r = 0.48*a
t = 0.5*a
W = -20 nm

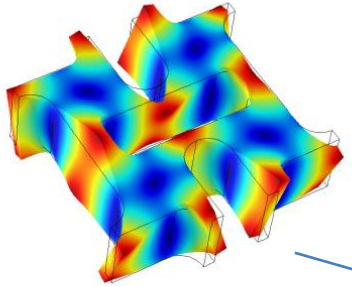
3D “Pillbox” Phononic Crystal

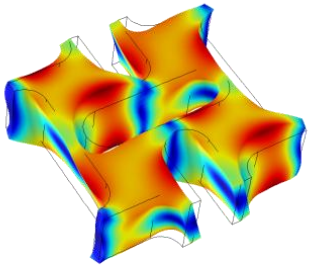




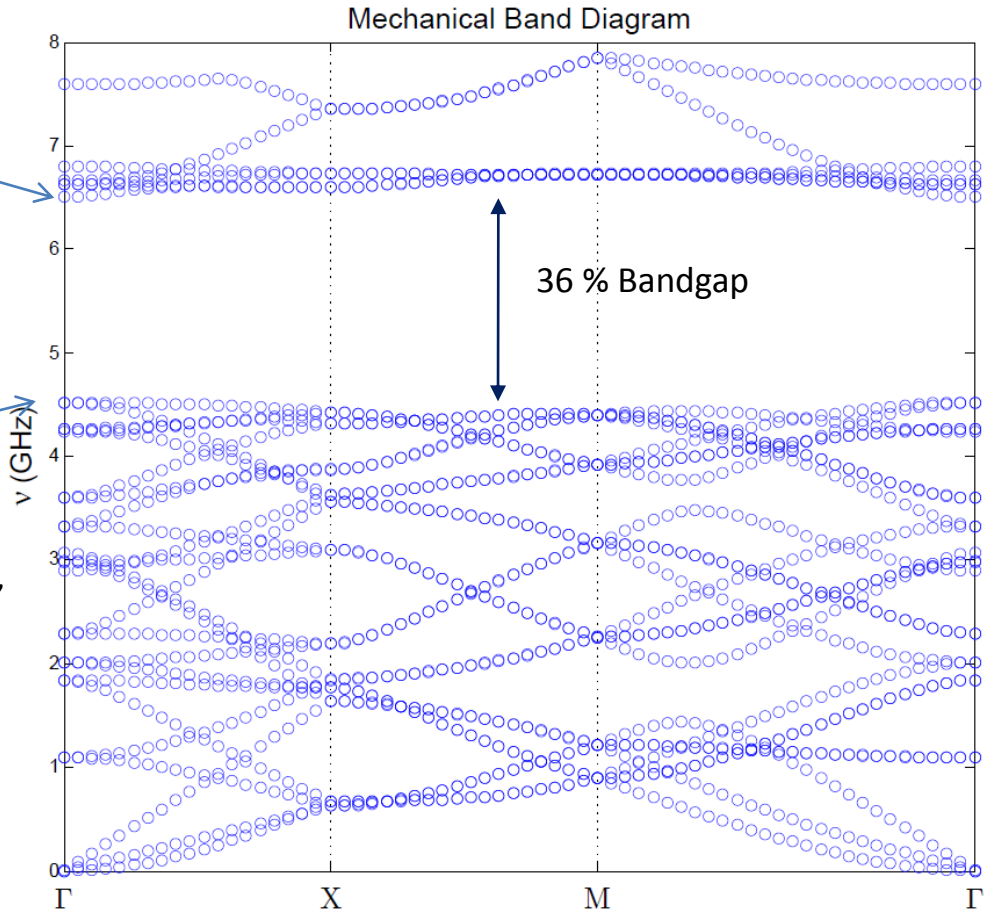
3D “Pillbox” Phononic Crystal

6.5 GHz Mode: “small” mass twists

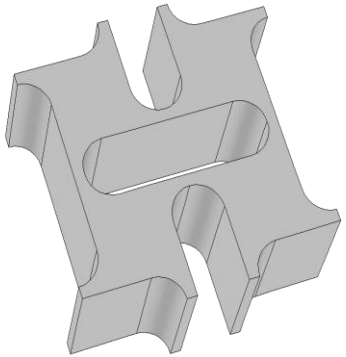


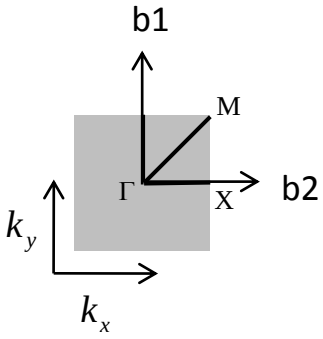


4.5 GHz Mode: “large” mass twists

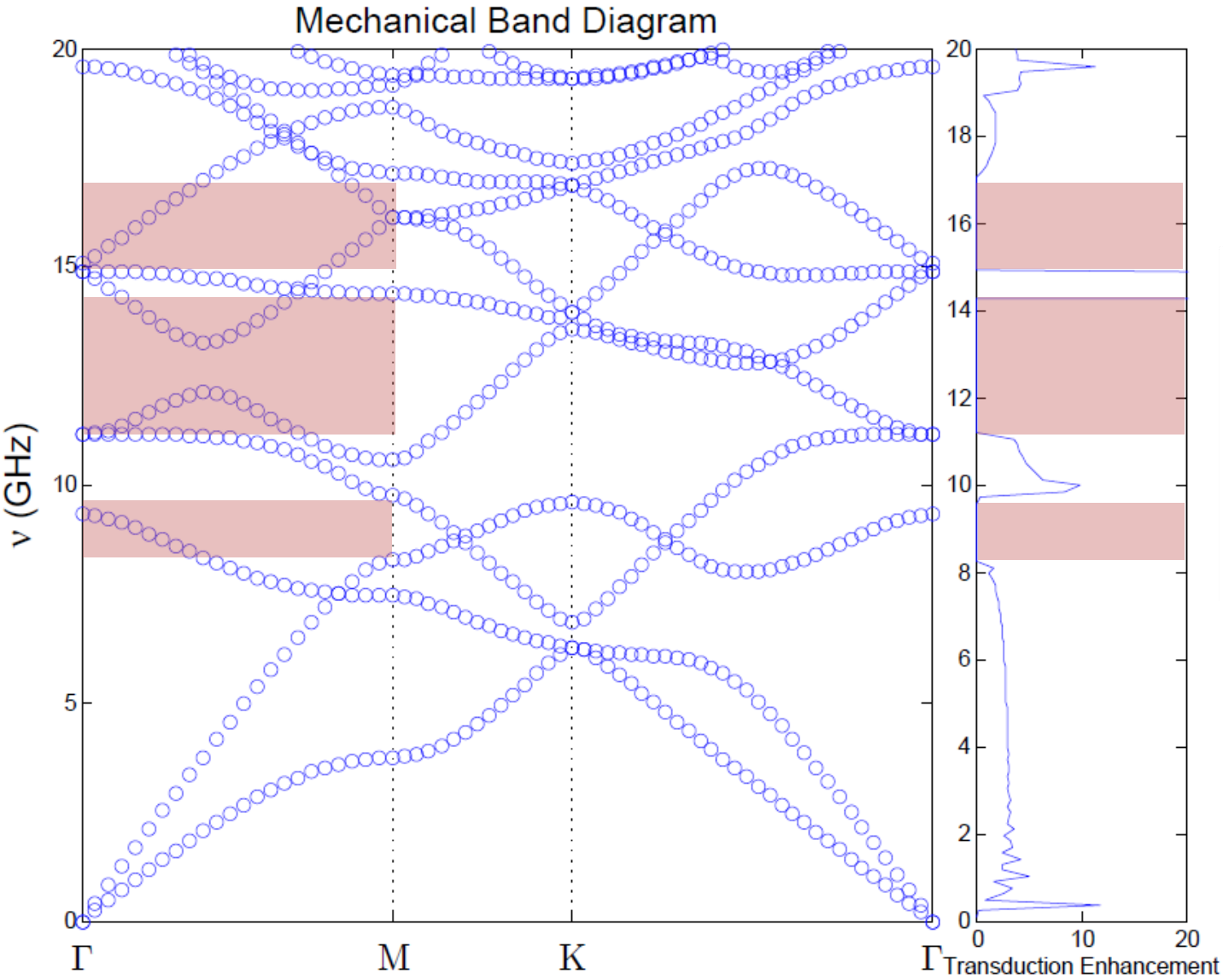


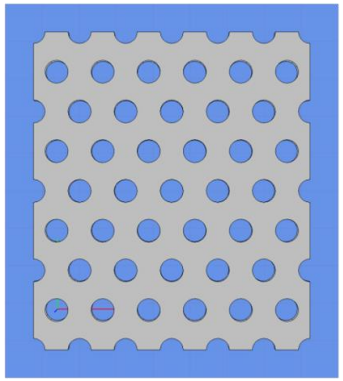
Unit Cell



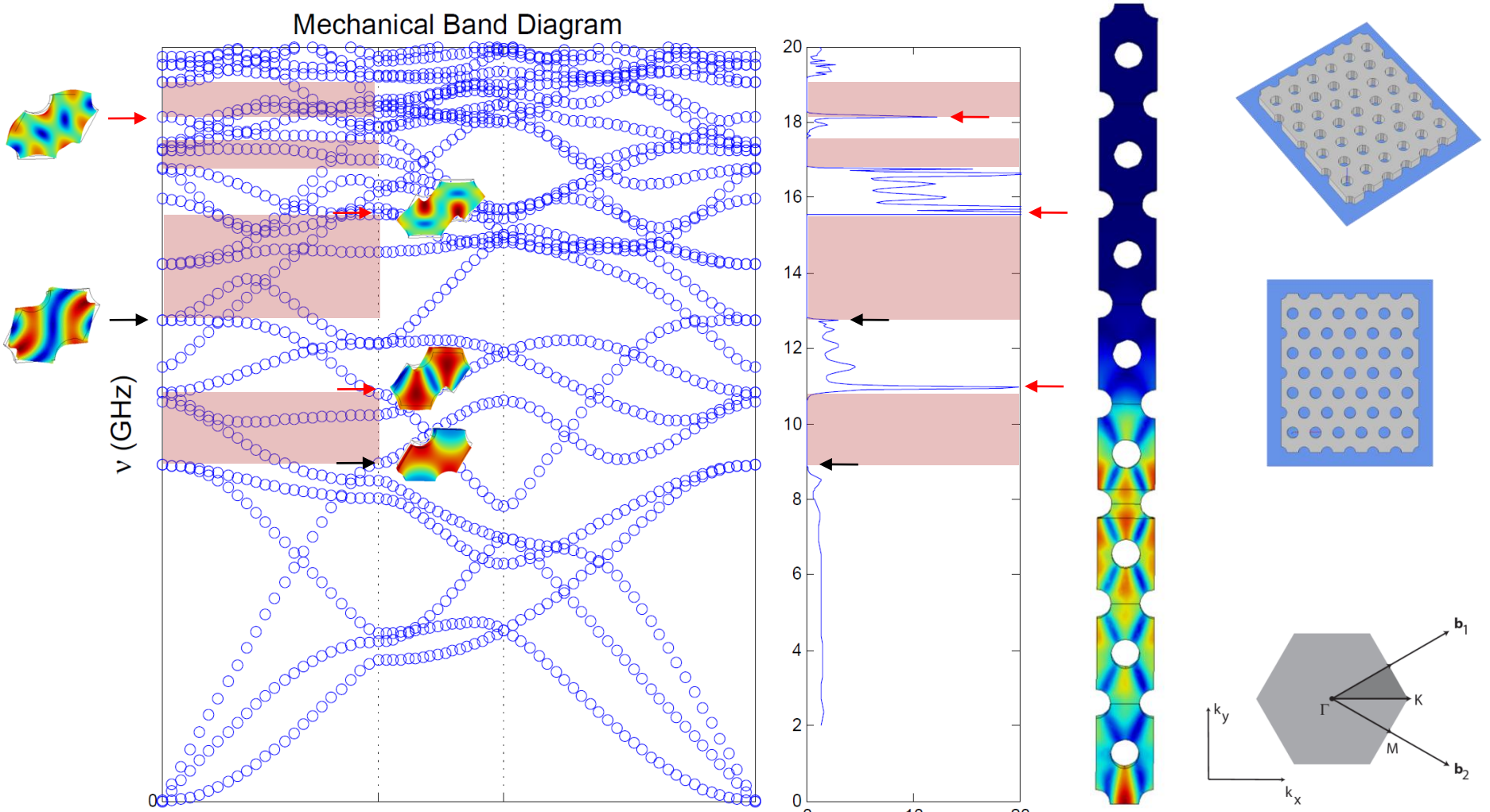


Hexagonal Lattice of Holes 2D





Hexagonal Lattice of Holes 3D

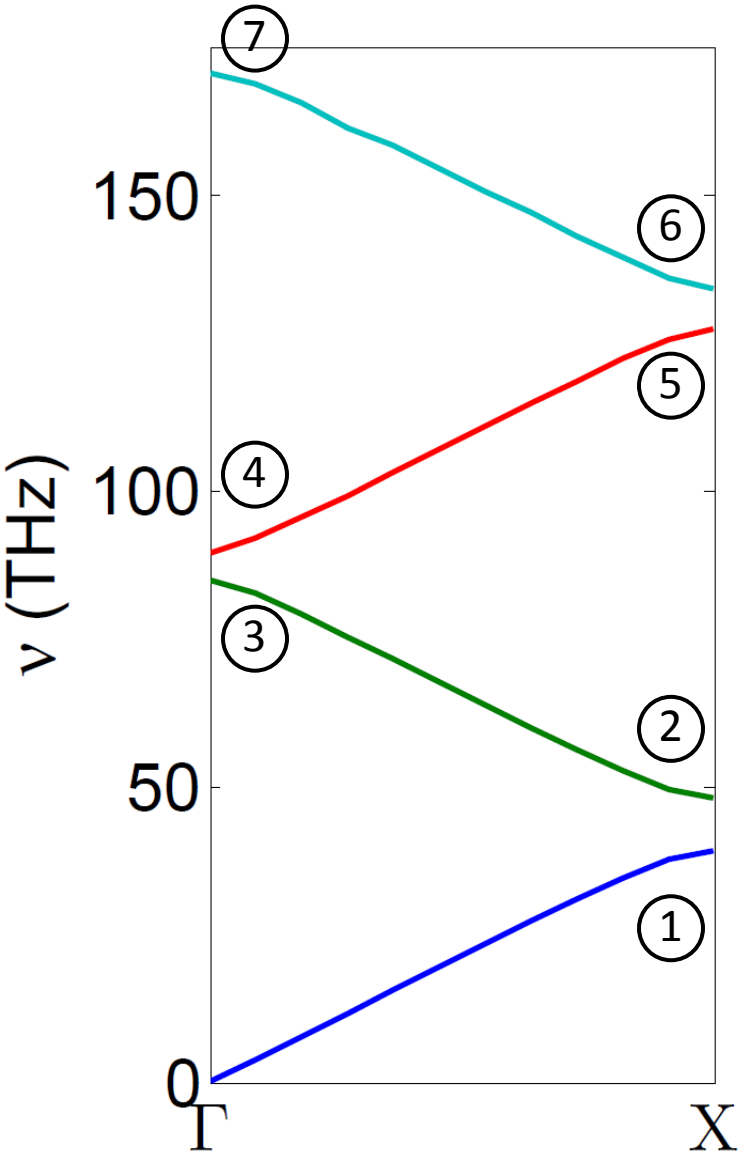


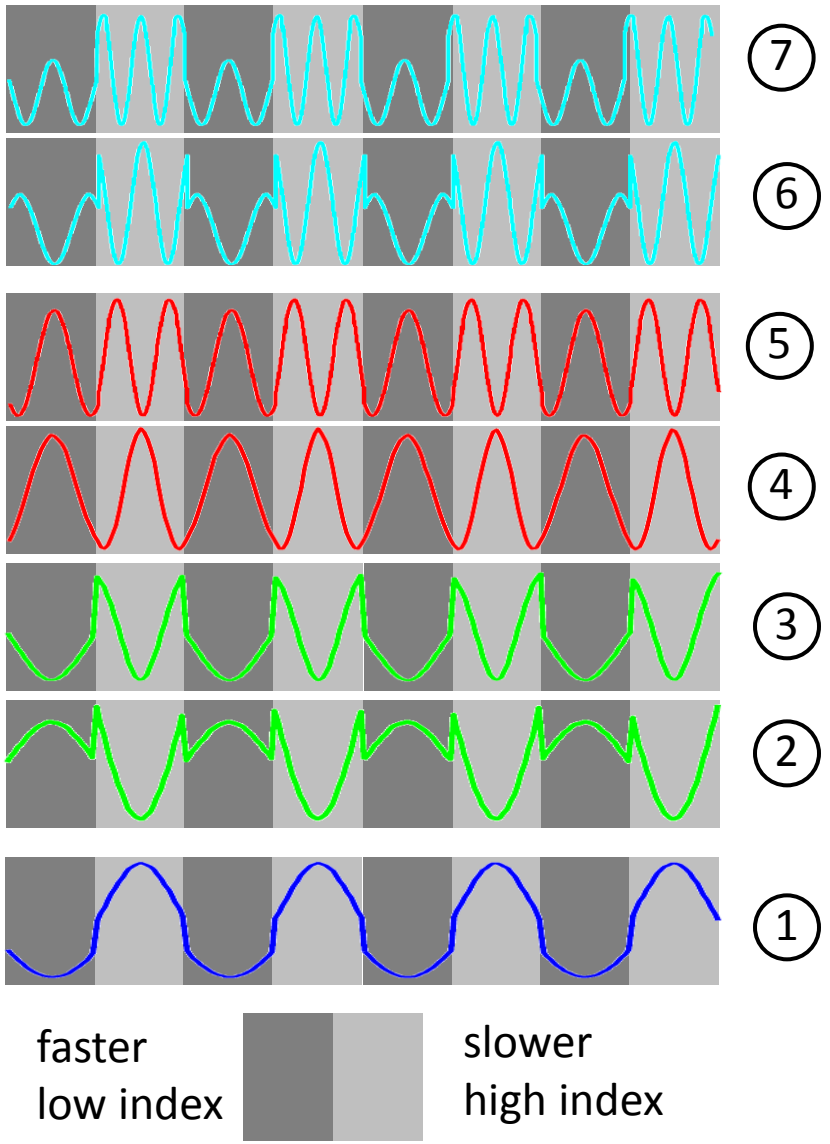
What about optical properties

Material	Elastic Properties	
	refractive index	phase velocity
light and slow SiO_2	$n \approx 1.45$	$v_p \approx 2\times10^8\ \mathrm{m/s}$
heavy and fast Si_3N_4	$n \approx 2.0$	$v_p \approx 1.5\times10^8\ \mathrm{m/s}$

Question: How does optical energy flow in this system?

Photonic Bragg Stack





Conclusions

- Mechanical impedance may be dramatically enhanced in periodic media
- Simple systems can yield powerful intuition on how to harness low Z media
- Examples include the old but revisted hexagonal lattice of holes and the novel “pillbox” structure.

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