Nano-structured Phoxonic Crystals for MWIR Sensing

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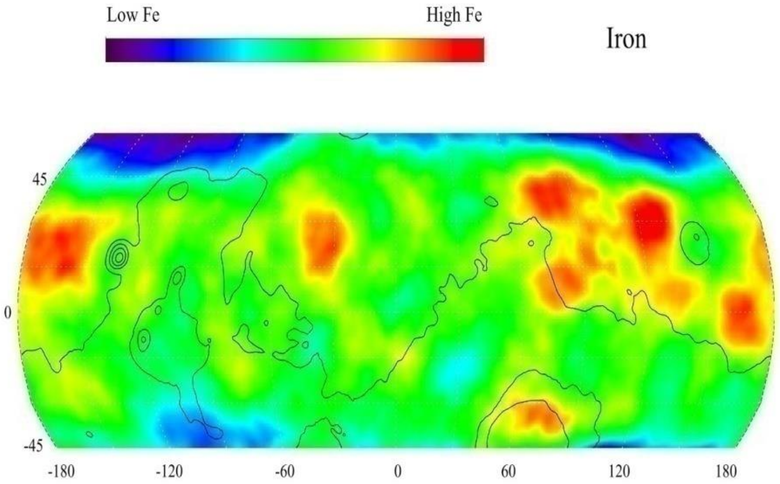
MWIR Sensing

- The **low power and multispectral on-chip sensing devices** are **need of the hour** for having maximum utilization of photonic integrated circuits.
    - Detecting Thermal Infrared radiations of objects at room temperature and above **(≥300 K)** have wavelength spectral peaks **≥ 3µm.**



THE BIG PICTURE

MWIR Sensors

Need to have a low-power and multispectral operation

Solutions to control nonlinearities

Suspended waveguide structures, Brillouin Nanophotonics with Phoxonic crystals

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Advanced 2D-Materials :

very tedious to synthesize

PhoXonic Crystals

(engineering electromagnetic + Elastic waves)

Brillouin Power Gain

$$\Theta_{sbs} = \frac{Q_m}{k_{eff}} \left(\frac{1}{c} \frac{d\, n_{eff}}{dx} \right)^2$$

Single photon brillouin coupling gain

$$g_o^2 = v_g{}^2 \frac{\hbar \omega_o \Omega_m}{4 L_m} \frac{\Theta_{sbs}}{Q_m}$$

$$k_{eff} = m_{eff} \Omega_m^2$$

Zero point fluctuation

$$x_{zpf} = \sqrt{\frac{\hbar}{2 m_{eff} L_m \Omega_m}}$$

Fundamental mechanical frequency

$$f_m = 1.03 \frac{t}{W_m{}^2} \sqrt{\frac{E_y}{\rho}}$$

Q_m	Quality factor
k_{eff}	Stiffness per unit length
n_{eff}	Effective refractive index
v_g	Group velocity of optical mode
Ω_m	Angular frequency of mechanical resonator
L_m	Length of the resonator
m_{eff}	Effective mass per unit length
f_m	Fundamental mechanical frequency
t_m	Material thickness
E_y	Young’s Modulus
ρ	Poisson's Ratio
Wm	Width of the resonator

Starting Point

Energy and momentum conservation

Coupled mode equations

For Optical Mode

$$\nabla \times \nabla \times E = \mu_o \varepsilon\, \partial_t{}^2 E \; - \mu_o\, \partial_t{}^2\, (\delta P)$$

For Mechanical Mode

$$\nabla \cdot (c\colon S) - \rho \partial_t{}^2 U = -\mathcal{F}$$

$$\omega_s = \omega_p \pm \Omega$$

$$\beta_s(\omega_s) = \beta_p(\omega_p) \pm \beta_m(\Omega)$$

$$m_s(\omega_s) = m_p(\omega_p) \pm M_m(\Omega)$$

$$(\partial_t + (i\Delta_p + \kappa_p/2))a_p = -ig_o a_s b + \sqrt{\kappa_{ep}}\, s_p$$

$$(\partial_t + (i\Delta_p + \kappa_p/2))a_s = -ig_o{}^* b^* a_p + + \sqrt{\kappa_{es}}\, s_s$$

$$(\partial_t + (i\Delta_m + \gamma/2))b = -ig_o{}^* a_s{}^* a_p$$

Photo-elastic and moving-boundary Gain contributions

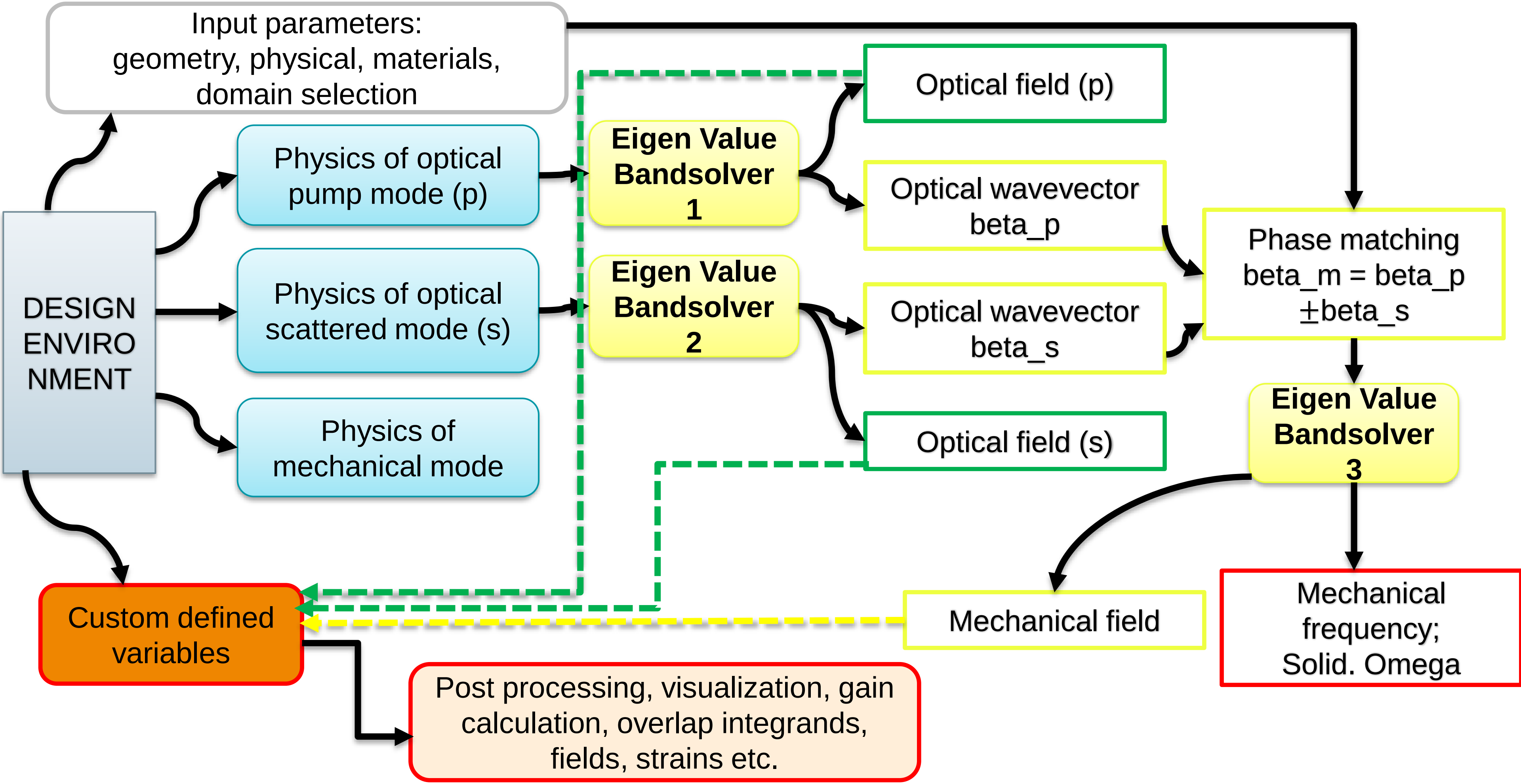
This is an attempt to grasp the nature of photo-elastic component used in coupling equations:

$$g_{pe} = {g_{om}}^{pe} * x_{zpf}$$

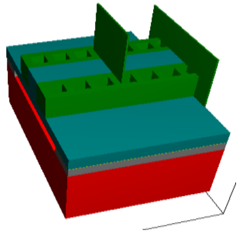
$$g_{mb} = {g_{om}}^{mb} * x_{zpf}$$

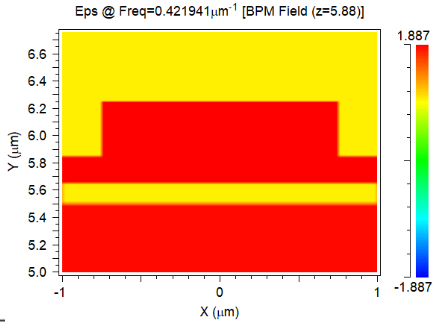
$$x_{zpf} = \sqrt{\frac{\hbar}{2m_{eff}L_m\Omega_m}}$$

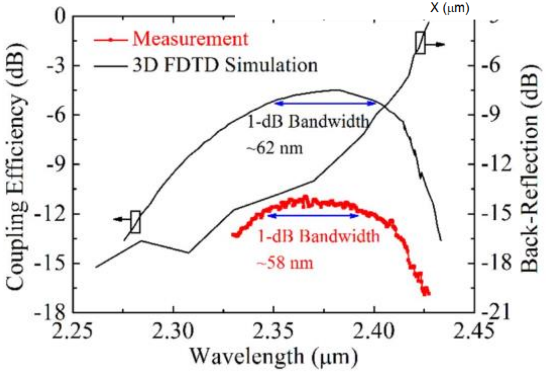
Atomistic Simulation Model For Phoxonic Structure

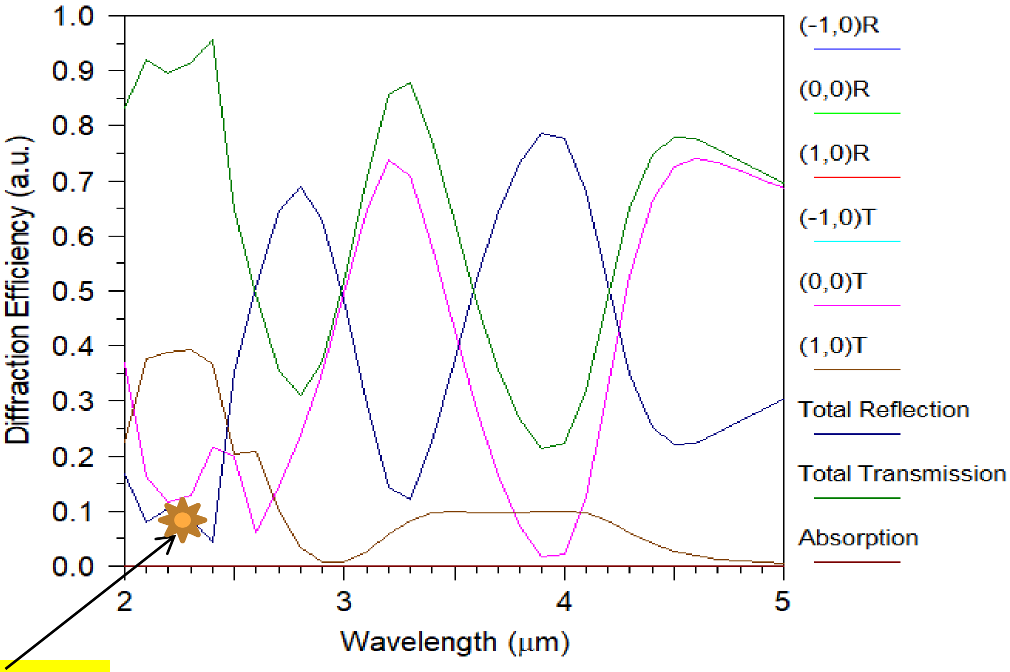


Kang, J. *et al.* Focusing subwavelength grating coupler for mid-infrared suspended membrane germanium waveguides. *Opt. Lett.* **42**, 2094 (2017).



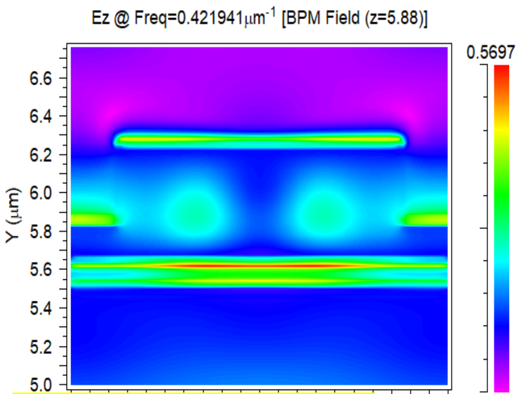




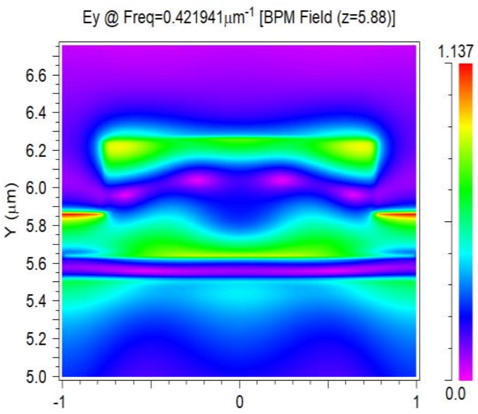


The simulated back-reflection is lower than −10 dB from the wavelength of 2.26 μm to the wavelength of 2.4 μm.

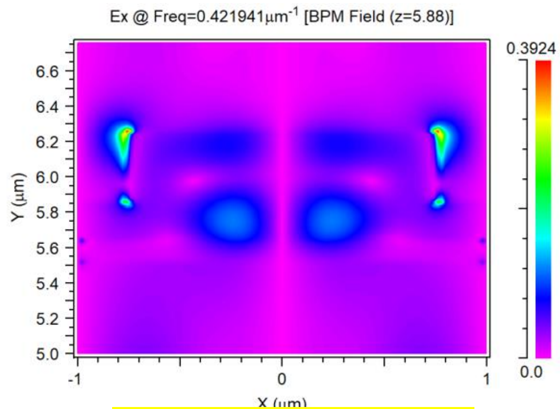
Analysing the mechanical mode variation due to thermo-optic effect



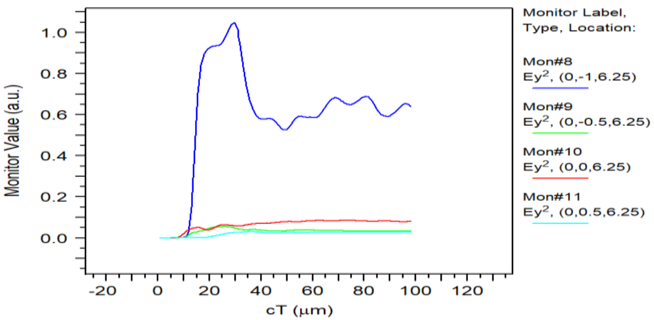
Whispering gallery mode

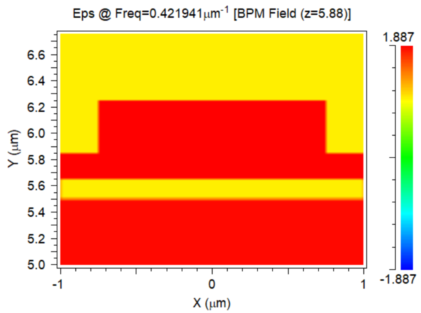


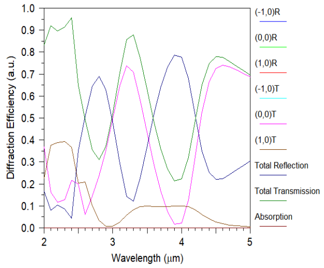
Flexural mode

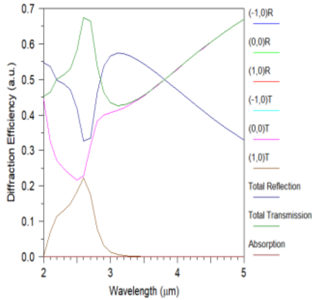


Dilational mode









Current Work in Progress:

- The idea is to simulate Brillouin scattering using a single integrated platform
  - To create a python based Machine learning model for this purpose, which could be integrated with available simulators.