8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

TOPOLOGY OPTIMIZATION OF OPTICAL BAND GAP EFFECTS IN SLAB STRUCTURES MODULATED BY PERIODIC RAYLEIGH WAVES

*** Allan Roulund Gersborg and Ole Sigmund**

Department of Mechanical Engineering (Solid Mechanics)
Technical University of Denmark, DK-2800 Lyngby, Denmark
E-mail/Home page: arg@mek.dtu.dk/www.topopt.dtu.dk

Key Words: *Topology optimization, Band gap, Rayleigh waves, Opto-mechanical coupling.*

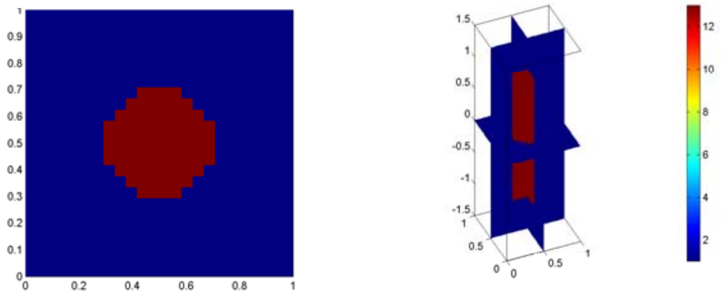
ABSTRACT

The present talk is concerned with topology optimization of a coupled optical and mechanical wave propagation problem in a photonic crystal slab. It is motivated by the potential gain in functionality of optical devices where Rayleigh waves (travelling in the surface of the material) play a leading role. The practical applications cover novel optical modulators and frequency shifters.

The unique feature of photonic crystals is that a band gap can form – meaning that eigenstates within a limited band of frequencies do not exist, see e.g. [1]. A requirement for the existence is that an optical contrast is present in the structure, e.g., in 1D as a Bragg grating and in 2D as an arrangement of circular inclusions. Computationally a unit cell analysis is often employed, motivated by the periodicity of the structure. Typically the relevant material parameter (dielectric constant) is taken to be cell periodic where as the state variables are represented using a time-periodic Floquet-Bloch solution, see e.g. [1]. In this contribution we focus exclusively on the special case of band gaps between *guided modes* in a photonic crystal slab being a structure which is in-plane periodic with a finite out-of-plane height, see figure 1. A guided optical mode is simply a localized eigenstate in the slab analogous to total internal reflection of light ray, see figure 1(c). Furthermore we assume linear constitutive relations and non-magnetic materials which allow us to compute the physical state by a 3D eigenvalue problem formulation of Maxwell's equations.

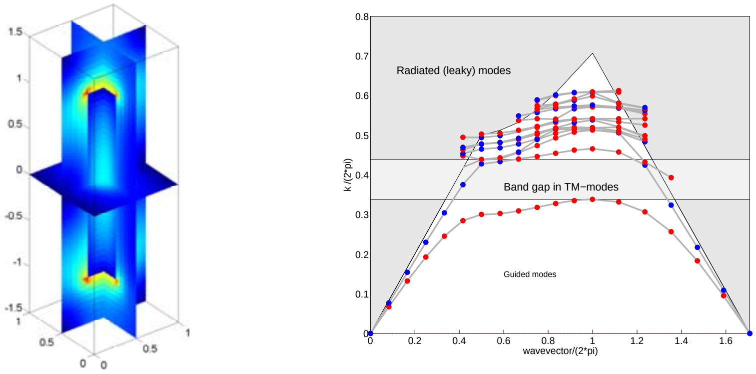
The modelling of the *guided modes* in the optical slab relies on two subtle arguments as explained in [2]. When computing the band diagram, the guided modes appear under the light line l being defined as $l = |k_w|/2\pi$ where $|k_w|$ is the length of the wave vector, see figure 1(d). Secondly, to avoid the computation with a large volume of surrounding air and non-reflecting boundary conditions, we use the trick of periodicity in the z-direction. This is acceptable since our focus is on the guided modes which have a rapidly decaying amplitude outside the slab where this trick changes the response significantly.

Using the computational procedure described in [3] we introduce topology optimization of photonic crystal slabs by comparing the band gaps of topology optimized slabs to the literature [2]. This we



(a) Planar view of the unit cell with the normalized size $a = 1$. The circular inclusion has a radius of $r = 0.2a$.

(b) 3D view of the unit cell. The dielectric rod has a finite height of $h = 2a$. The color bar depicts the dielectric constantϵ_r.



(c) Slice plot of $|\mathbf{E}|$ of a guided mode. The electric field amplitude decays outside the slab.

(d) The relative band gap in TM modes is 26%. Based on the spatial energy distribution TM/TE modes are identified (red/blue dots, respectively).

Figure 1: (a)-(b) the unit cell which models a photonic crystal slab composed by finite sized rods suspended in air, (c) a guided mode and (d) band diagram for the guided modes of the slab.

extend by applying topology optimization to the coupled problem where a periodic model of a Rayleigh wave is introduced in optical slab model. Here we consider the (typical) case where the mechanical wave is unaffected by the optical wave, i.e. there is a one-way coupling. We model the opto-mechanical interaction geometrically based on the amplitude field of the Rayleigh wave. From an optical point of view the physical state is computed using the eigenvalue formulation but now with a geometrically distorted unit cell.

REFERENCES

[1] K. Busch et al.“Periodic nanostructures for photonics”. *Physics Reports*, Vol. **444**, 101-202, 2007.

[2] S. G. Johnson, et al. “Guided modes in photonic crystal slabs”. *Physical Review B*, Vol. **60**(8), 5751-5758, 1999.

[3] J.S. Jensen and O.Sigmund “Systematic Design of Photonic Crystal Structures using Topology Optimization: Low-loss Waveguide Bends”. *APL*, Vol. **84**(12), 2022–2024, 2004.