Reduced Model of Nanoscale Photonic Resonators for Inverse Design

Francesco Rinaldo Talenti[1], Stefan Wabnitz[1], Inès Ghorbel[2], Sylvain Combrié[2], Luca Aimone-Giggio[2], and Alfredo De Rossi[2]
[1] *DIET, Sapienza University of Rome, 00184 Rome, Italy.*
[2] *Thales Research and Technology, Campus Polytechnique, 91767 Palaiseau, France.*
*Corresponding author: *francescorinaldo.talenti@uniroma1.it*

In optics, the purpose of Inverse Design (ID) is to create a structure corresponding to a prescribed response to an excitation, a difficult and computing-intensive task. Yet, ID is extremely promising in harnessing modern nanofabrication technologies to achieve original functionalities or to maximize figures of merit[1,2,3].The bottleneck is the calculation of the response of the structure, needed to compute the error to be minimized. For complex 3D structures such as photonic crystals (PhC), approximated physical models[3] are used in place of standard Finite Differences in Time Domain (FDTD) or Finite Element Method (FEM) solvers, which are computationally expensive hence useless for optimization algorithms. Here we consider the case of a photonic crystal cavity to be engineered such that eigenmodes are strictly equi-spaced in frequency, starting from the fundamental. This enables optical parametric oscillations[4] and possibly mode-locking[5] in the smallest possible resonator. The task is difficult because the relative spacing of the modes need to be computed with accuracy. The main idea here is to use a reduced model of the photonic crystal which describes it as an equivalent Distributed Feedback (DFB) mirror, with parameters adjusted to reproduce the dispersion of a strictly periodic PhC within a spectral range of interest. We consider a class of nanoscale resonators which are obtained by adiabatic modification of a periodic structure and, as an example, the 1D parabolic beam PhC[6] shown in Fig.1(a), where the width $w(x)$ of the beam follows a parabolic rule. Our model describes the structure as a tapered DFB with

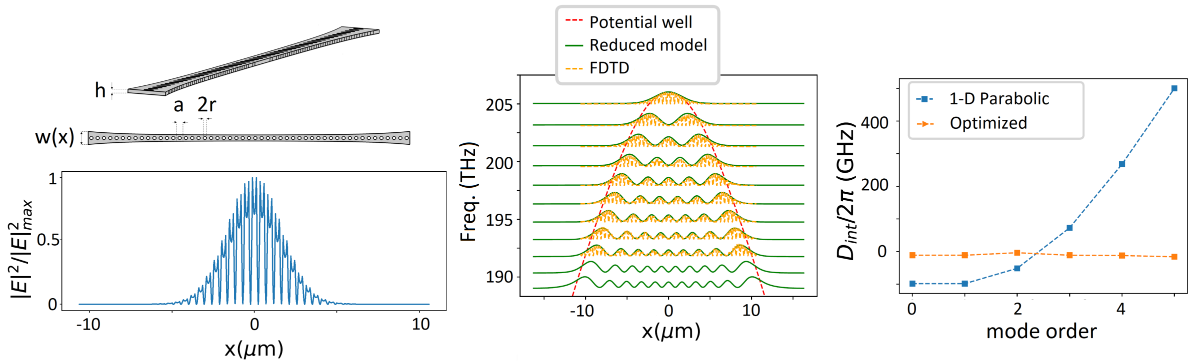

Figure 1: (a) parabolic-beam PhC and field intensity $|E_y|^2$ of the fundamental order mode; (b) eigenmodes calculated by the model (green, envelopes) and FDTD (orange, normalized field $|E_y|^2$) with vertical offset corresponding to the eigenfrequency. (c) Integrated dispersion of the parabolic beam and of the optimized structure (FDTD).

parameters extracted by assuming each section of the width-modulated beam to be periodic and invoking the adiabatic approximation. A posteriori justification is given by the comparison of the predicted eigenmodes with the FDTD calculation (Fig. 1(b)), with deviation within the estimated accuracy of the FDTD (about 30 GHz). Finally, the steepest gradient optimization is used to adjust the profile $w(x)$ such that the integrated dispersion is flattened, as veryfied by FDTD (Fig. 1(c)).
In conclusion, we have shown that a reduced model can be used for the modal engineering of a certain class of PhC cavities, with applications in the context of nanolasers and parametric sources for quantum-technologies. This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under the Marie Skłodowska-Curie grant agreement No 814147.

References

[1] Molesky et al.,Nat. Phot.,12, 659–670 (2018).
[2] L. H. Frandsen et al., Opt. Exp. 12, 5916 (2004).
[3] M. Minkov et al., ACS Photonics, 7, 1729–1741, (2020).
[4] G. Marty et al. Nat. Photonics, 15, 53-58 (2021).
[5] Y. Sun et al, Phys Rev Lett.123, 233901 (2019).
[6] Byeong-Hyeon Ahn et al., Opt. Expr., 18, 5654, (2010)