Multimodal interference semi-analytical model for unidirectional guided resonances in a photonic crystal

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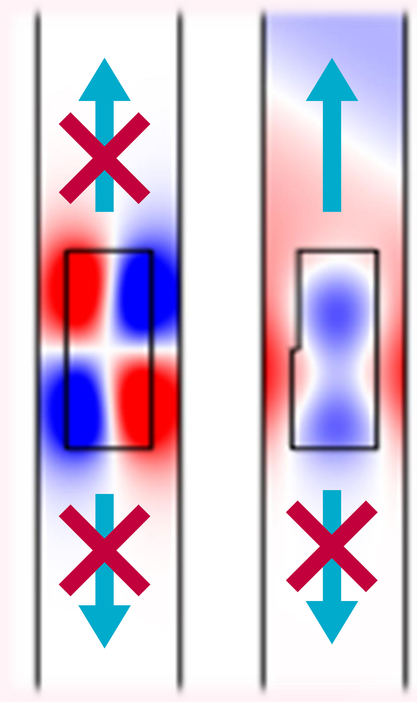
1 - Introduction

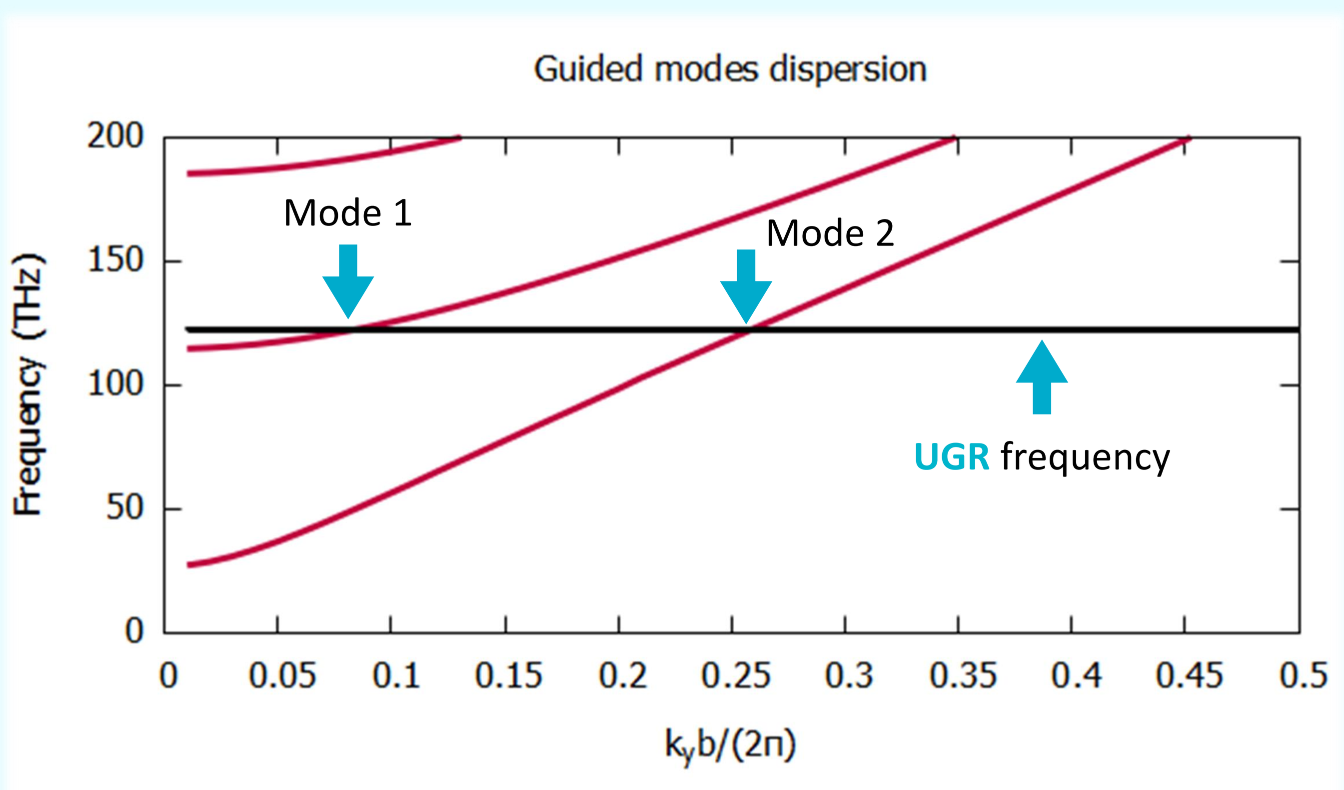
Lately, there have been notable advancements in generating optical bound states in the continuum (**BICs**) within photonic crystal slabs. A related phenomenon, known as unidirectional guided resonances (**UGRs**), has been reported. In **UGRs**, geometrical symmetry is intentionally disrupted, resulting in the controlled emission in a specific direction [1]. In order to comprehend these resonances, we built a microscopic semi-analytical model which is an expansion of the **multimodal** interference methodology employed for studying **BICs**.

The **multimodal** approach encompasses the identification of propagating guided modes within a waveguide possessing the same dimensions as our target geometry. Subsequently, these identified modes are introduced into both the upper and lower halves of our structure. By doing so, we construct reflection matrices for these two halves. These matrices provide valuable insights into the intricate interference patterns of guided modes within the structure.

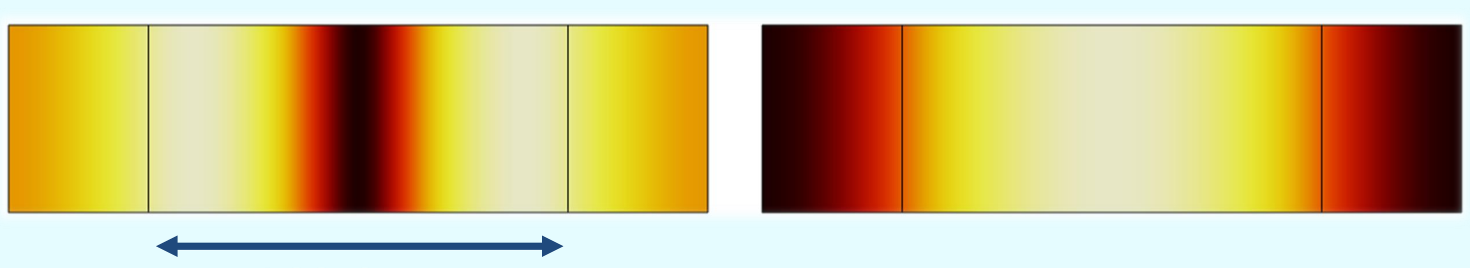


BIC vs **UGR** electric field profile

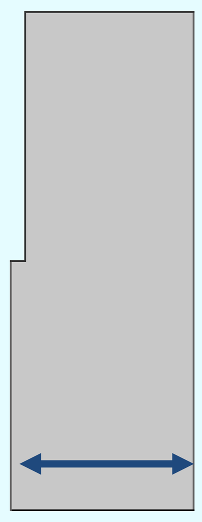
2 – Search of guided modes



Mode 1 Mode 2



463.2 nm



463.2 nm

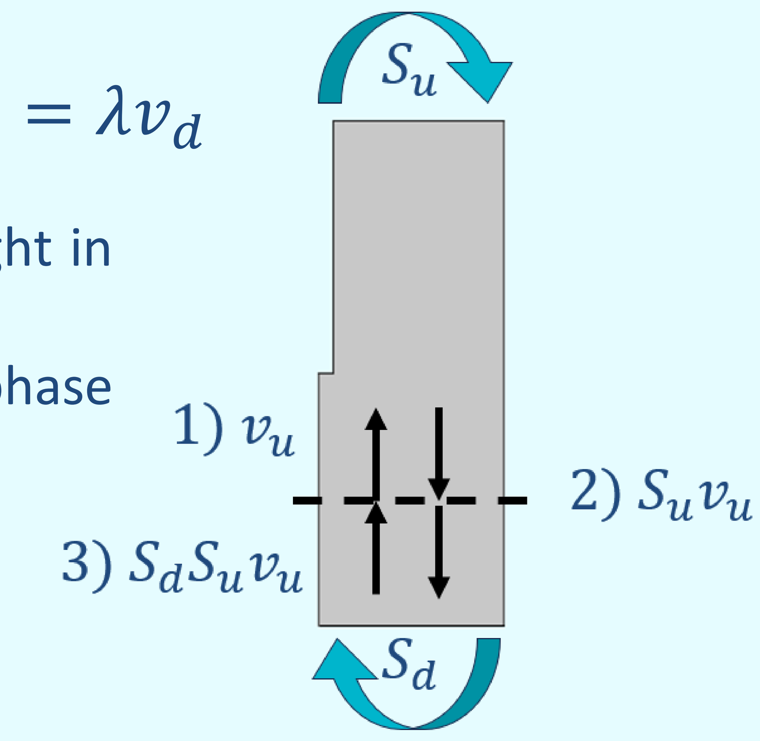
➔ We search for **guided modes** with the same horizontal wavenumber and frequency as the **UGR.**

➔ We inject these modes in the upper and lower half of the structure.

➔ We construct the **reflection matrices** S_u (up) and S_d (down).

3 - Model

$$S_d S_u v_u = \lambda v_u \qquad S_u S_d v_d = \lambda v_d$$



The **eigenvalue λ** gives us insight in the resonance:

- If $Im(\lambda) \to 0$ we have a phase resonance.
- If $|\lambda| \to 1$ losses go to zero.

Losses are computed with the **eigenvectors and reflection matrices**.

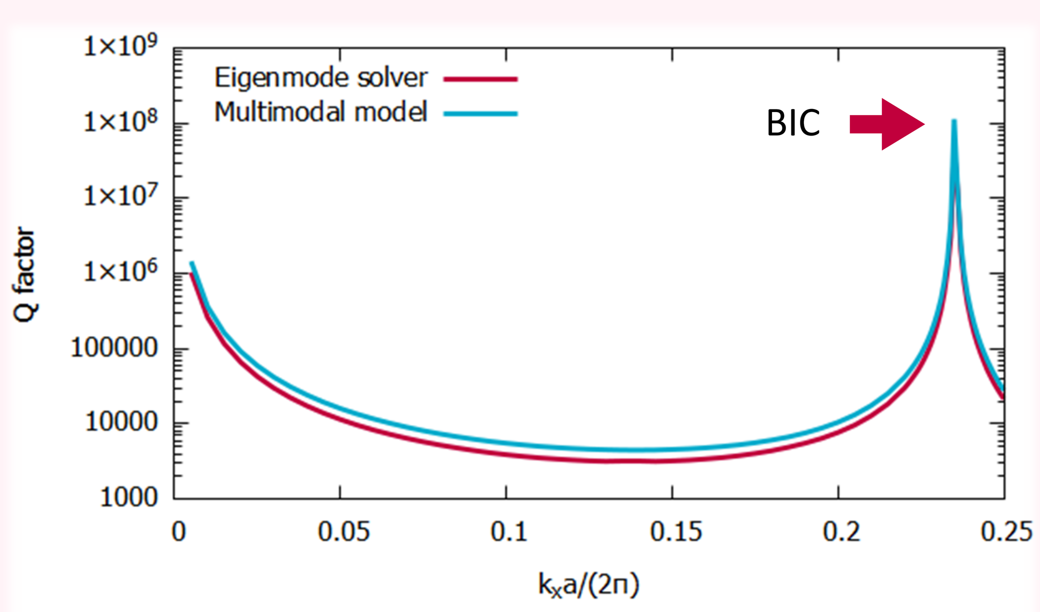
$$T_u = 1 - \frac{\sum_i |S_u v_{u_i}|^2}{\sum_i |v_{u_i}|^2} \qquad T_d = 1 - \frac{\sum_i |S_d S_u v_{u_i}|^2}{\sum_i |S_u v_{u_i}|^2}$$

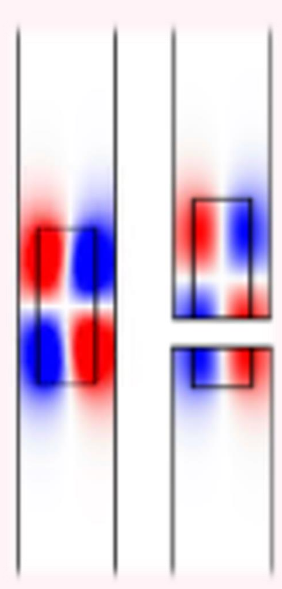
Based on [2] and [3] we constructed the **semi-analytical Q factor** for the two halves.

$$Q_u = \frac{2\omega_0 L}{|v_g| T_u} \qquad Q_d = \frac{2\omega_0 L}{|v_g| T_d}$$

4 - Results

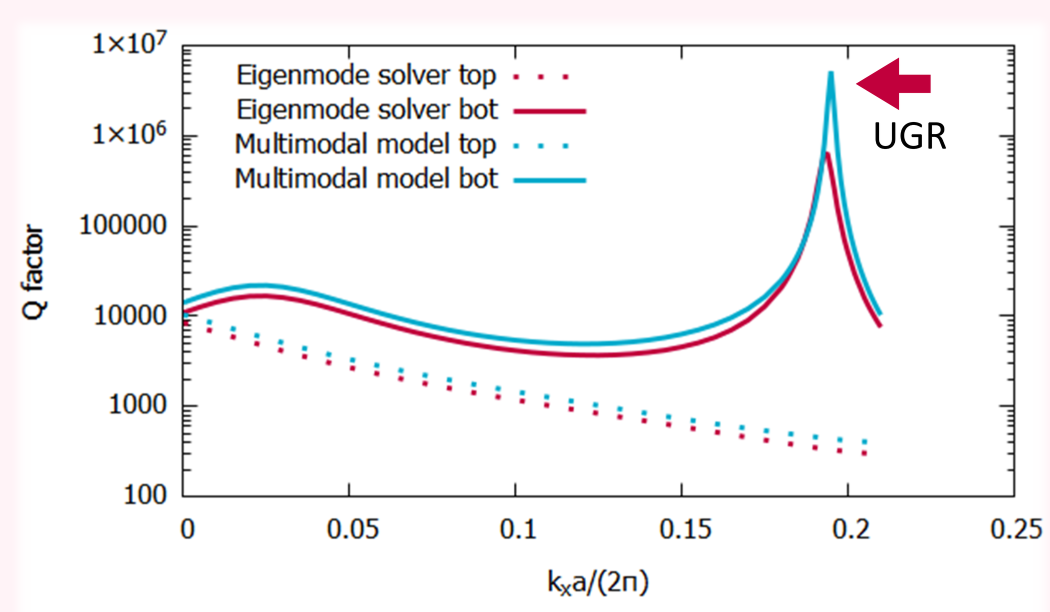
Result for a **BIC**

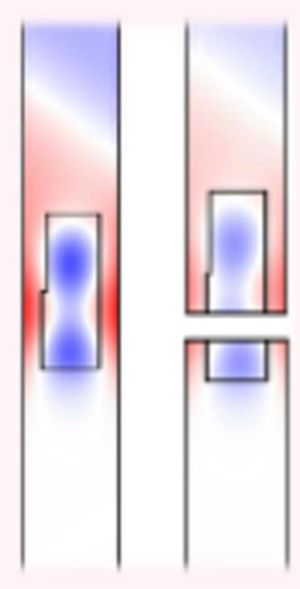




Out-of-plane E field for eigenmode solver (left) vs multimodal model (right)

Result for an **UGR**





Out-of-plane E field for eigenmode solver (left) vs multimodal model (right)

5 – conclusion and references

As shown on the figures above, our model gives good results in comparison to an eigenmode solver. Meaning that we can describe **BICs** and **UGRs** as interferences between fundamental modes.

Perspectives:

- Extending the model to more elaborate structures
- Connect our near-field approach to the far-field description of the UGR [1]

[1] X. Yin, J. Jin, , M. Soljačić, et al., Nature, vol. 580, 467–471 (2020)
[2] B. Maes, et al., Opt. Express , Vol. 15, Issue 10, 6268-6278 (2007)
[3] H.A. Haus, Waves and fields in optoelectronics (Prentice-Hall, 1984).
[4] A. I. Ovcharenko, et al., Phys. Rev. B, Vol. 101, Issue 15, 155303 (2020)

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