A semi-analytical model for unidirectional guided resonances based on multimodal interference

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1 - Introduction

Recently, optical bound states in the continuum (**BICs**) have been produced in photonic crystal slabs. A variation, unidirectional guided resonances (**UGRs**), has been reported, where the symmetry is broken, leading to leakage in a specific direction [1]. We explore a microscopic semi-analytical model to understand these resonances, by extending a multimodal interference approach of BICs.

The multimodal approach consists of searching for vertically propagating guided modes in a waveguide that has the same dimensions as our geometry. Then by injecting these modes in the upper and lower half of our structure we construct de reflection matrices of two halves of our cell. These matrices gives us information about the way the guided modes interfere in the structure.

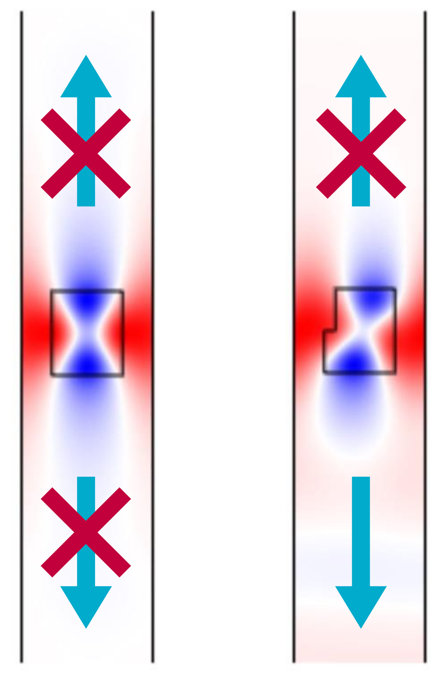

Figure 1 – Out-of-plane electric field for a **BIC** (left) and a **UGR** (right).

2 - Search of guided modes

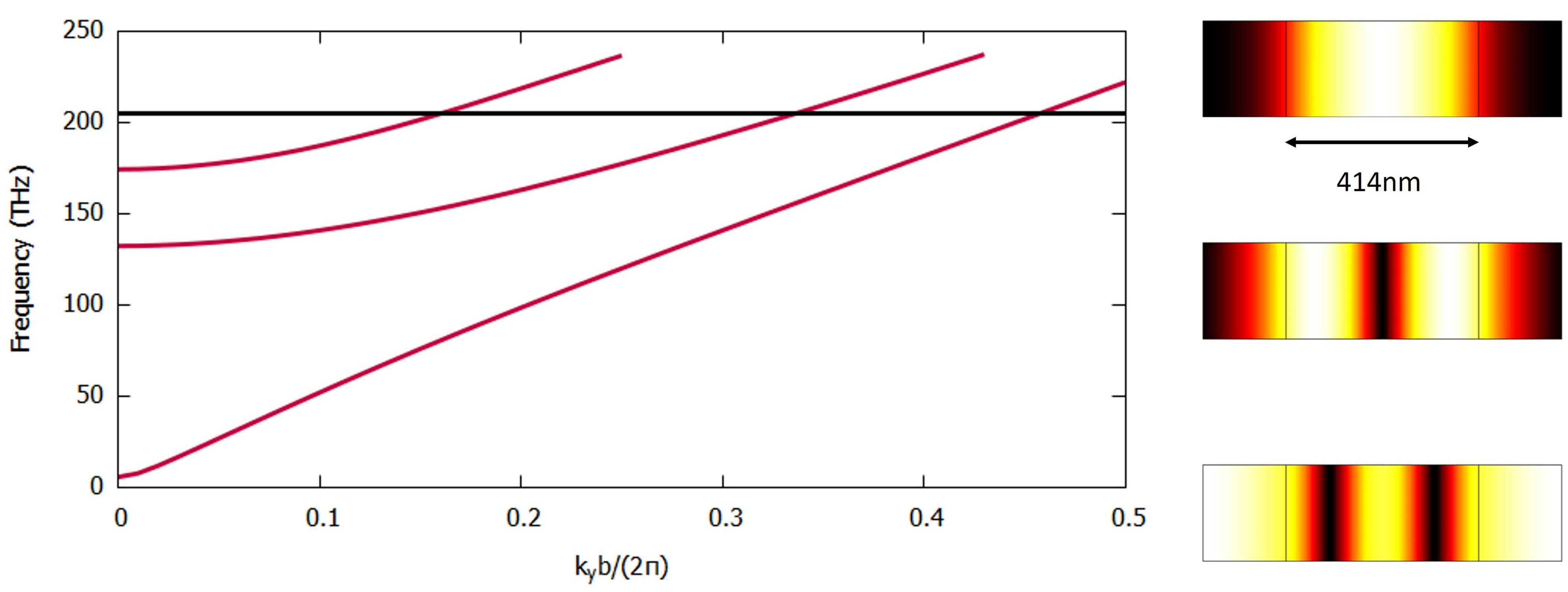

Figure 2 – *Left*: Dispersion curve of a waveguide with same dimensions as our structure. The black line shows the frequency of the **UGR**. *Right:* Electric field norm of the three guided modes used for interference.

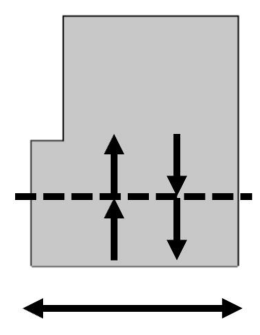

Figure 3 – Inner geometry used for the **UGR**. The dashed line shows the separation between the upper and lower half.

How we proceed:

➔ Using an eigenmode solver, 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** R_u (up) and R_d (down).

3 - Model

$$R_d R_u v_u = \lambda v_u$$

$$R_u R_d v_d = \lambda v_d$$

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.**

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

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

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

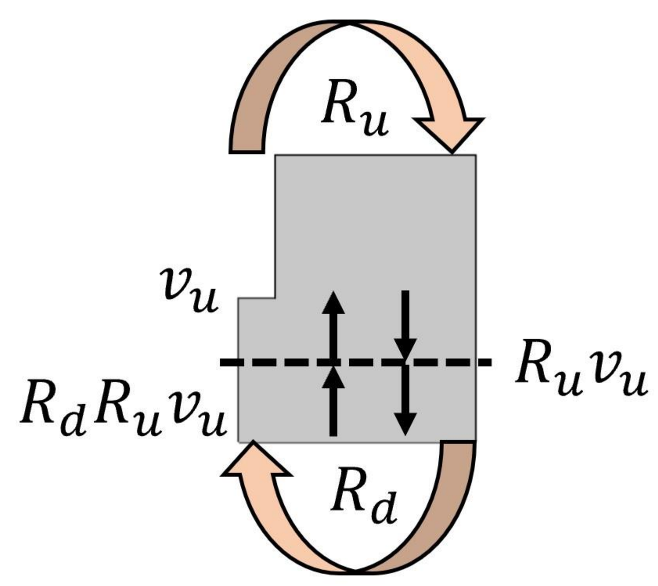

Figure 4 – We construct the round trip by combining the **eigenvectors** and **reflection matrices**.

4 - Results

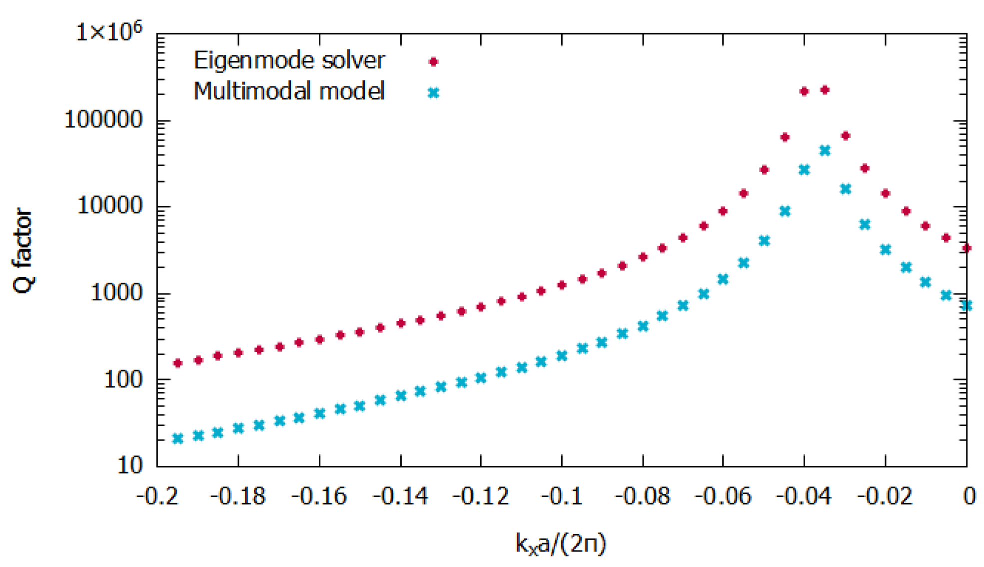

Figure 5 – Comparison between the **Q factor** given by our model and an eigenmode solver.

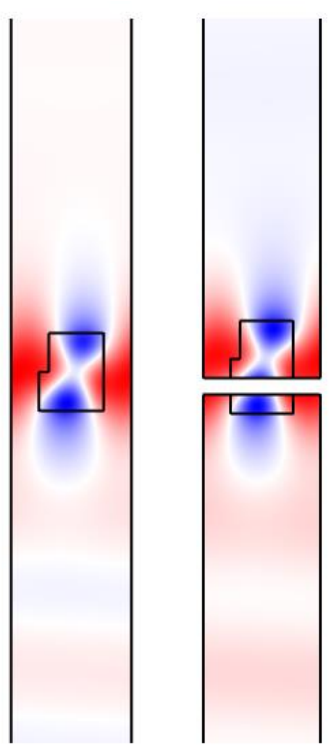

Figure 6 – Comparison of the out-of-plane electrical field profile given by an eigenmode solver (left) and the mode mixing of our method (right).

As we can see, the profile of the two methods are similar. Showing that the mode mix given by the **eigenvectors** reproduces the **UGR**.

5 - Conclusion and perspectives

As shown on **figure 5**, our model gives good results in comparison to an eigenmode solver. Meaning that we can describe **BICs** and **UGRs** as interferences between fundamental modes. However more investigation are needed to construct a more precise formula for the **Q factor**.

Perspectives:

- Extending the model to more elaborate structures
- Using the multimodal interference to find BICs and UGRs in new geometries
- Connecting our near-field approach with the far-field description of UGRs [1]

References

[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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