Multimodal Insights on Bound States in the Continuum and Unidirectional Guided Resonances in Photonic Crystals

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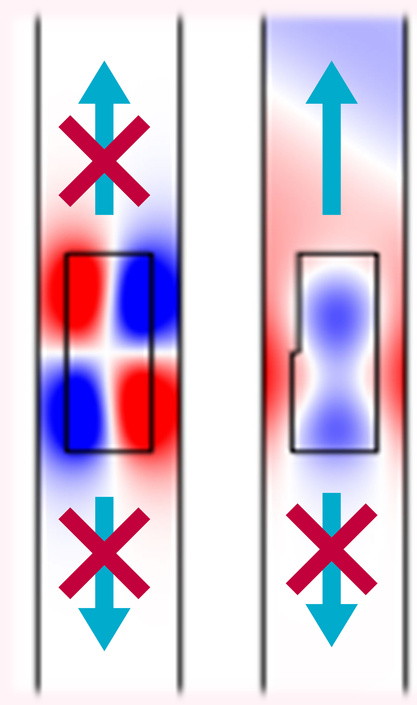
1 - Introduction

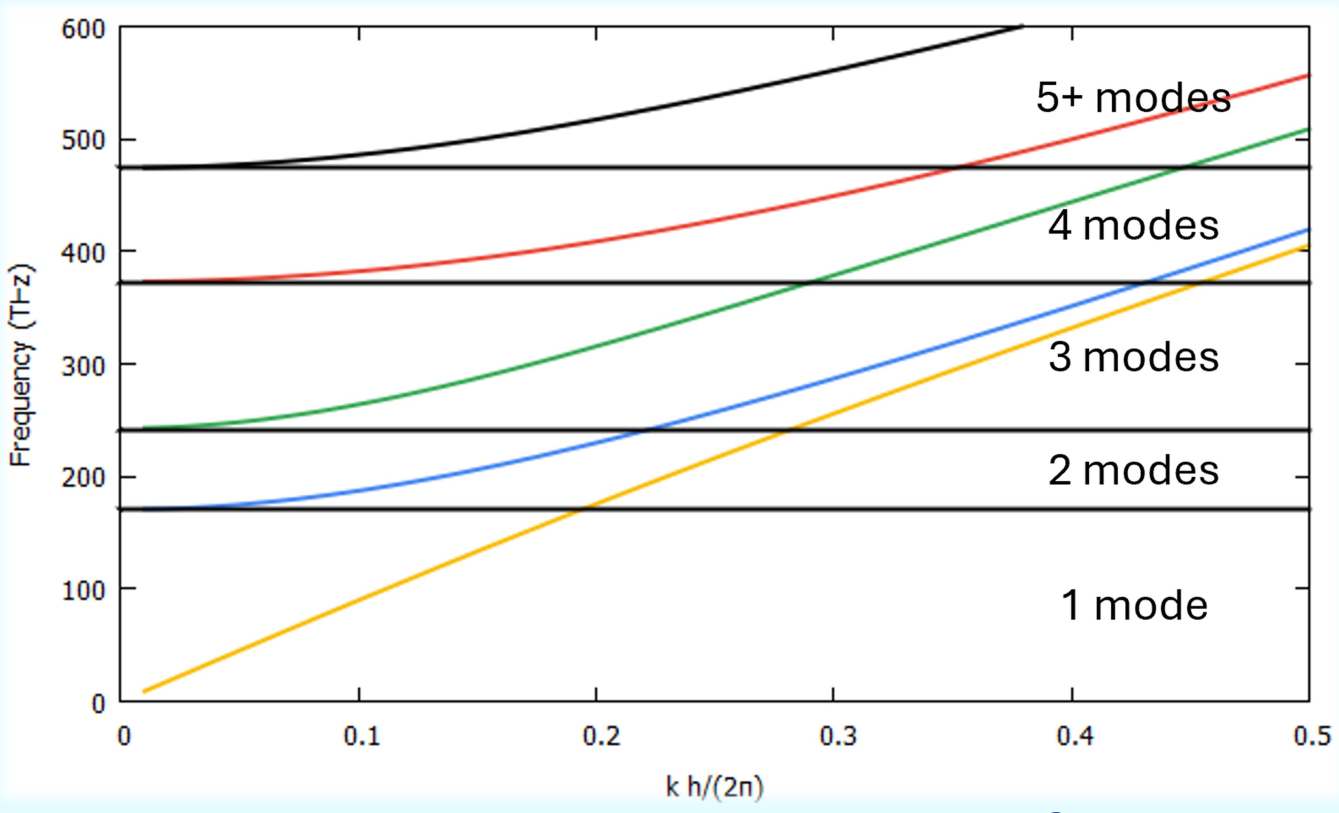
In recent years, bound states in the continuum (**BICs**) have attracted considerable attention due to their unique characteristics. Unlike typical confined modes, **BICs** coexist with the radiation continuum but remain decoupled from it, offering exciting applications in various fields. A newly examined resonance type, called unidirectional guided resonance (**UGR**), has also emerged in similar structures, but with an intriguing twist: **UGRs** exhibit broken symmetry, allowing energy to radiate in only one direction.

Various theories explain how **BICs** come about, with the **multimodal interference model** being one such approach. This model posits that BICs arise from the interference of multiple fundamental modes, leading to destructive interference outside the structure and creating a **BIC** under specific conditions. Our research extends this model to **UGRs**, providing a **semi-analytical** framework to understand these resonances. This model's flexibility allows for efficient analysis of different geometries, yielding valuable insights into the behavior of **UGRs** and their potential applications in photonic devices.



BIC vs **UGR** electric field profile

2 – The multimodal model

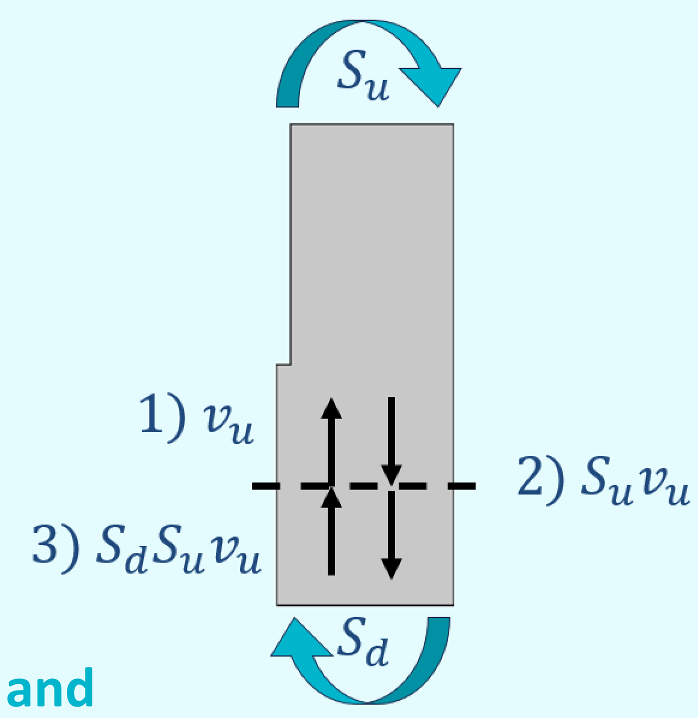


➔ We search for **guided modes** in the transverse direction.

➔ 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).

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



$$S_d S_u v_u = \lambda v_u$$

$$T_u = 1 - \frac{\sum_i |S_u v_{u_i}|^2}{\sum_i |v_{u_i}|^2} \qquad Q_u = \frac{2\omega_0 L}{|v_g| T_u}$$

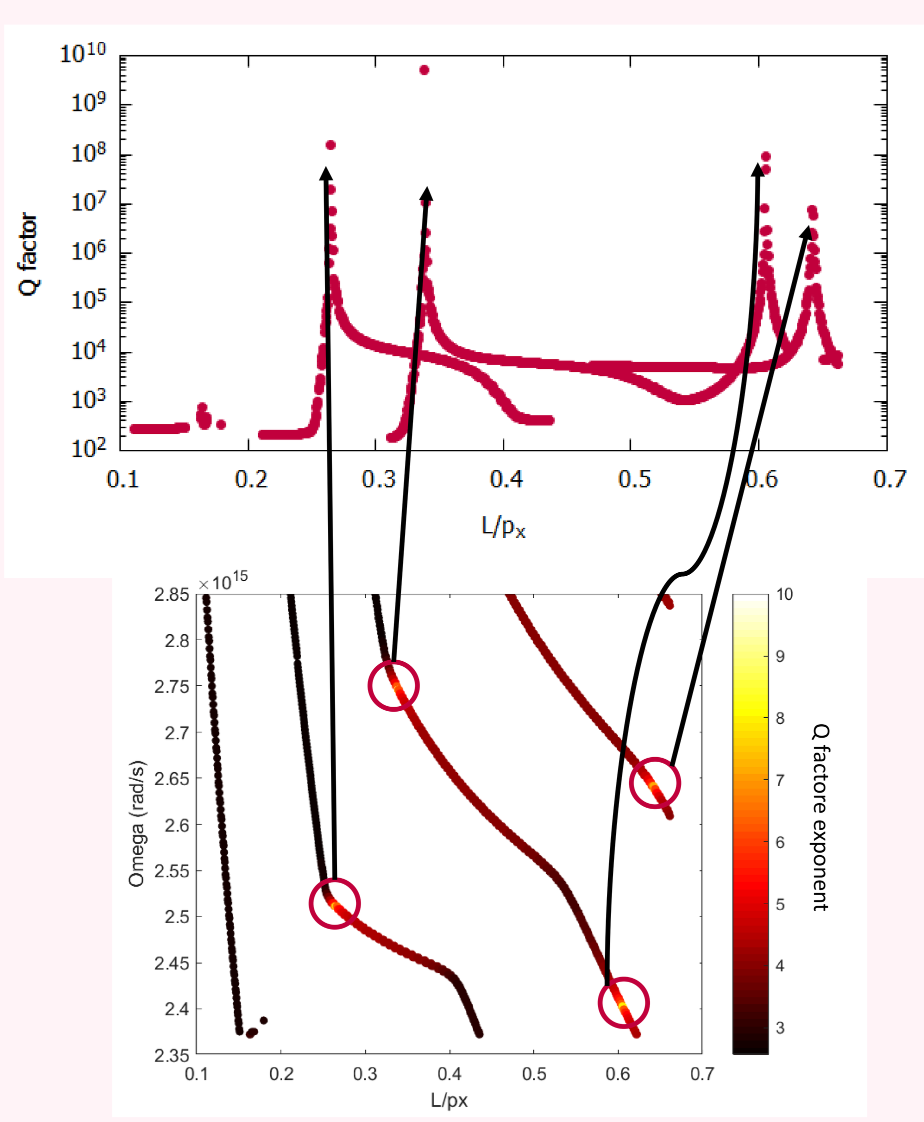
$$T_d = 1 - \frac{\sum_i |S_d S_u v_{u_i}|^2}{\sum_i |S_u v_{u_i}|^2} \qquad Q_d = \frac{2\omega_0 L}{|v_g| T_d}$$

➔ By imposing **Im(λ) = 0** and **Re(λ) > 0**, we can find the position of **BICs**, **Quasi-BICs** and **UGRs** in a parameter space.

➔ This allows to find the best parameters to optimize Q-factor.

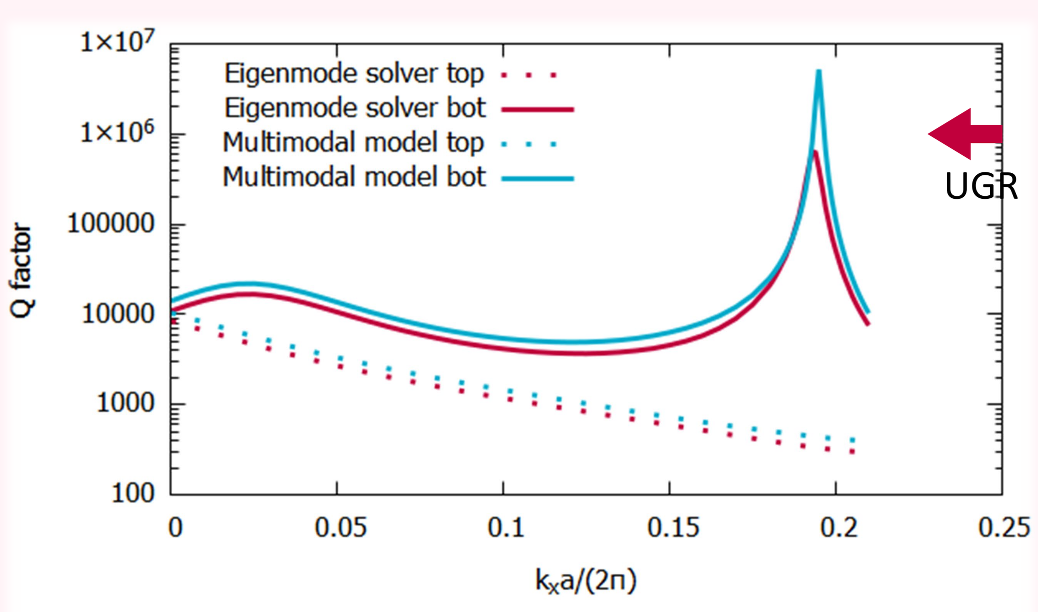
3 - Results

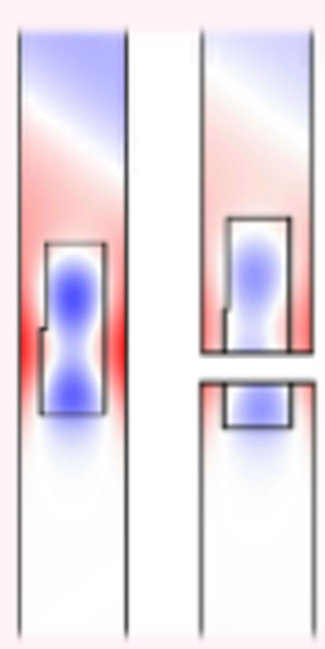
Result for a (quasi-)BIC



Conditions on λ allow us to find the position of the **Quasi BICs** in the parameters space.

Result for an UGR

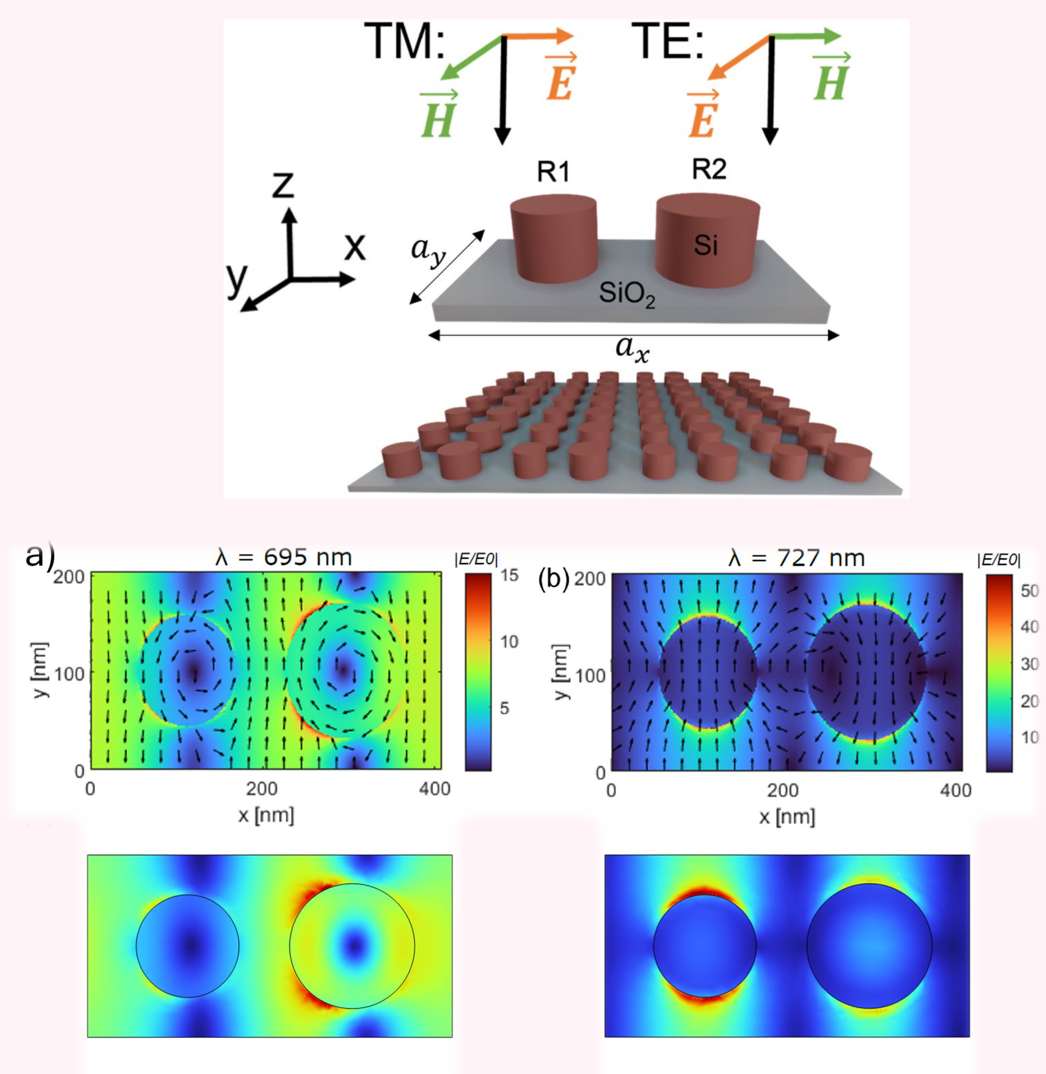




Out-of-plane E field for eigenmode solver (left) vs **multimodal** model (right).

We obtain the same electric profile showing that our method allows to reproduce the **UGR**.

Result for a 3D structure



E field norm from a scattering simulation (top) vs **multimodal** model (down).

4 – 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]

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