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

Thomas Delplace – Bjorn Maes
Micro- and Nanophotonic Materials Group, Research Institute for Materials Science and Engineering, University of Mons, Place du Parc, 20, 7000, Mons, Belgium

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.

2 – Search of guided modes

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

3 - Model

\[ S_d S_u v_u = \lambda v_u \quad S_u S_d v_d = \lambda v_d \]

The eigenvalue \( \lambda \) gives us insight in the resonance:
- If \( \text{Im}(\lambda) \to 0 \) we have a phase resonance.
- If \( |\lambda| \to 1 \) losses go to zero.

Losses are computed with the eigenvectors and reflection matrices.

\[ T_u = 1 - \frac{\sum_i |S_u v_{ui}|^2}{\sum_i |v_{ui}|^2} \quad T_d = 1 - \frac{\sum_i |S_d v_{di}|^2}{\sum_i |v_{di}|^2} \]

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

\[ Q_u = \frac{2\omega_0 L}{v_g |T_u|} \quad Q_d = \frac{2\omega_0 L}{v_g |T_d|} \]

4 - Results

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.

5 – conclusion and references

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

Contact: Thomas.Delplace@umons.ac.be

References: