Coupled optical defect cavities in finite 1-D photonic crystals and quasi-normal modes

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We analyze coupled optical defect cavities realized in finite one-dimensional Photonic-Crystals. Viewing these as open systems where waves are permitted to leave the structures, one obtains eigenvalue problems for complex frequencies (eigenvalues) and Quasi-Normal-Modes (eigenfunctions) [1-2]. QNMs are field profiles in which the leaky structure would oscillate after an initial excitation is revoked, representing damped oscillatory solutions of the wave equation. A variational principle permits to predict the field and the spectral transmission and Q-factor close to these resonances, using a template with the most relevant QNMs [2].

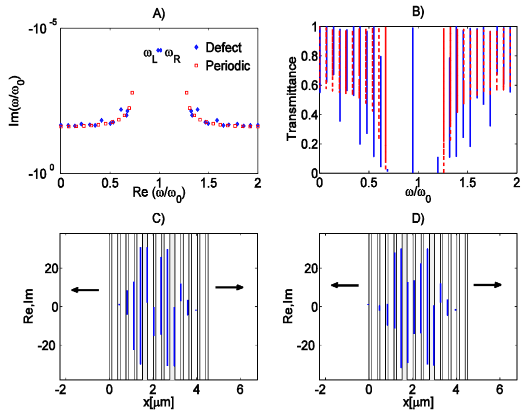

Fig. 1 *A) QNM (eigenvalue) spectrum B) Transmittance for periodic (dashed) and double cavity structure (continuous); QNMs corresponding to complex frequencies in the bandgap region C) QNM for ω_L D) QNM for ω_R. Parameters and layer arrangement are given in the text.*

Single defect structures (Photonic Crystal Atoms) can be viewed as elementary building blocks for multiple-defect structures (Photonic Crystal Molecules) with more complex functionality. The QNM description links the resonant behavior of individual PC atoms to the properties of the PC molecules via eigenfrequency splitting. Our method approximates both the field profiles and the transmission for single and multiple cavity structures in both symmetric and nonsymmetric layer arrangements, for both weak and strong coupling between the defects.

We specialize to structures with piecewise constant refractive index distribution of high n_H and low refractive index n_L layers, with quarter-wavelength optical thicknesses L_H, L_L at a target frequency ω_0. High index layers are denoted by H, low-index layers by L and defect layers by D. We consider a symmetric arrangement of layers coded as $(HL)^4D(LH)^2LD(LH)^4$, where two defects are introduced as changes of thicknesses of layers $L_D = 2L_H$ and $n_D = n_H=3.42$, $n_L=1.45$, while outside the finite structure the refractive index is $n_0=1$ (air). This example represents strongly coupled FP cavities where the interaction is sufficient to introduce a significant separation of the resonance frequencies, and where a tight-binding approximation is not applicable.

Our approximation method enables both an accurate field representation and predicts the proper resonant transmission. Our analysis can be applied to photonic heterostructures that are very difficult to handle by supercell methods, and quantifies limitations of the tight-binding approximation for problems with very strong inter-cavity interaction.

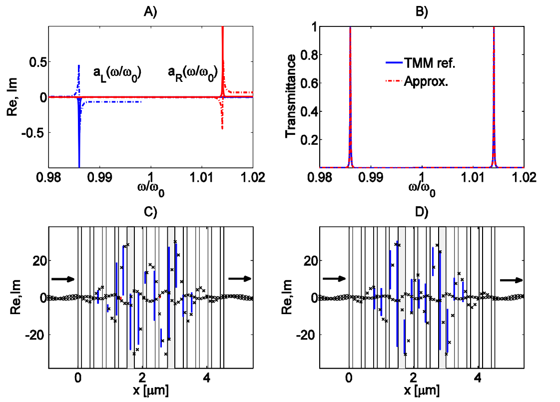

Fig. 2. *A) Decomposition coefficients (frequency dependent weighting factors in the field template). B) Transmittance obtained from the field representation using QNMs (dashed) and TMM reference (continuous). C) and D): approximated field obtained from the field representation using QNMs (marker) and TMM reference for the frequency of transmission resonance (solid line) for $\omega = Re(\omega_L)$ and) $\omega = Re(\omega_R)$.*

References

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[2] M. Maksimovic, M. Hammer, E. van Groesen, *Field representations for optical defect microcavities in multilayer structures using quasi-normal modes*, Optics Comm. (2007)- (*submitted*).