Analysis of optical defect cavities in 1D grating structures with quasi-normal mode theory

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Subject of our investigation are resonance phenomena in optical cavities that are realized as defects in 1D grating with piecewise constant refractive index distribution. Upon viewing the cavity as a passive system with intrinsically leaky behaviour due to open boundaries where waves are permitted to leave the structure, the cavity can be characterized in terms of complex frequencies associated with unbounded field profiles (leaky modes, or quasi-normal-modes QNMs [1], [2]).

The imaginary part of the frequency represents the energy decay, closely related to the Q-factor of the cavity. Our aim is to predict the response of the structure to external excitation and/or parameter perturbations, based on the profiles and eigenfrequencies of the QNMs supported by the cavity. Fig. 1 introduces a typical structure and shows a QNM field profile with the eigenfrequency next to the bandgap resonance (i.e. near the single peak of high transmission inside the forbidden frequency band of the periodic grating)..

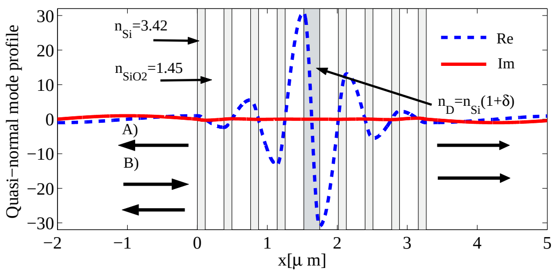

Fig. 1 *1-D defect grating; we consider alternatively A) an eigenvalue problem with outgoing waves at both ends (QN mode analysis) and B) the transmission problem with an incident wave at one end of the structure. Field profile associated with the major defect resonance. All layers are of the quarter-wavelength optical thickness and defect layer of the half-wavelength normalized to the wavelength λ=1.55 μm.*

Next we apply a time-independent perturbation theory for QNMs [1] to obtain a first order correction to the complex frequency of the major cavity mode. As shown in Fig. 2, a modification of the refractive index of the central defect layer effects mainly a shift of the real part of the QNM eigenfrequency. Finally, the QNM eigenfrequency perturbation permits to estimate immediately the transmission properties of structures with modified defect index. According to Fig. 3, the optical transmission as predicted by the approximate QNM expansion agrees excellently with a direct calculation by a standard transfer-matrix method (TMM). The agreement, even for a quite substantial relative refractive index difference of about δ=±5%, confirms that the description based on a single QNM constitutes indeed an adequate cavity model in the present frequency range. All calculations are based only on the single QNM and that is a special attractiveness of the result.

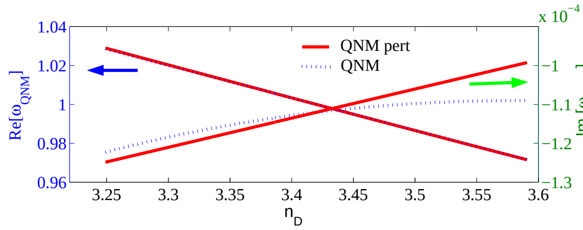

Fig. 2 *Complex QNM eigenfrequency versus the defect refractive index, direct QNM analysis and perturbation evaluation.*

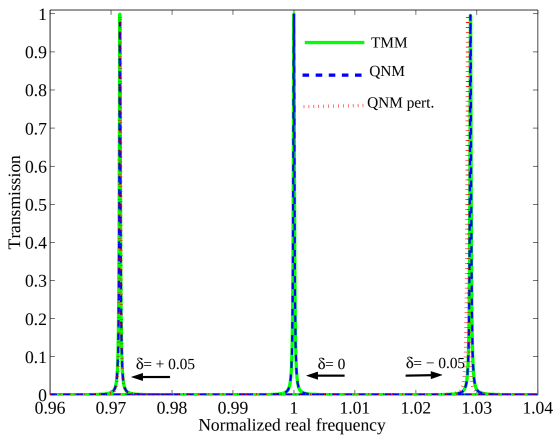

Fig. 3 *Spectral transmission, QNM models (direct, and using a perturbation description) and TMM reference.*

References

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[2] A. Settimi et al., *Quasi-normal mode description of waves in one-dimensional photonic crystals.* Phys. Rev. E., 68:026614, 2003.