On effective index approximations of photonic crystal slabs

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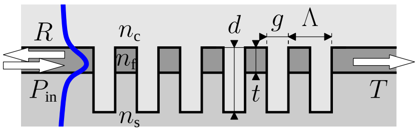
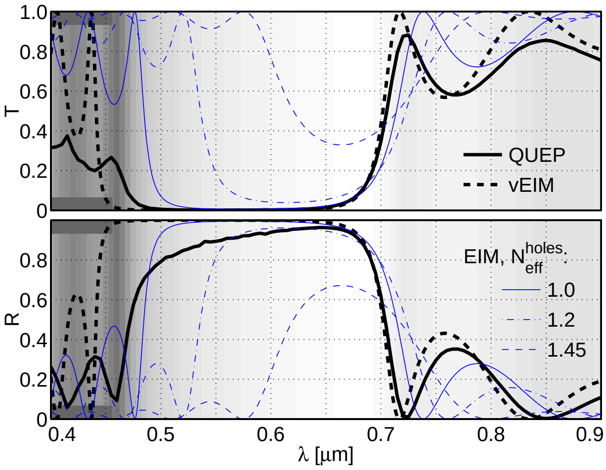
To assess the quality of effective index approximations for photonic crystal slabs, we consider a reduction of 2-D problems for waveguide Bragg gratings to 1-D, and compare with rigorous 2-D solutions. A variational procedure permits to establish reasonable effective indices even if locally no guided modes exist.

Summary

The propagation of light through slab-like photonic crystals (PCs) is frequently described in terms of effective indices (effective index method EIM, cf. e.g. Ref. [1]). One replaces the actual 3-D structure by an effective 2-D permittivity, given by the propagation constants of the slab modes of the local vertical refractive index profiles. Though the approach is usually described for the approximate calculation of waveguide modes, it is just as well applicable to propagation problems. Our aim is to check the approximation by analogous steps that reduce finite 2-D waveguide Bragg-gratings, which in turn can be seen as sections through 3-D PC membranes, to 1-D problems, which are tractable by standard transfer matrix methods. A 2-D Helmholtz solver (QUEP [2], reference) allows to solve the 2-D problem rigorously, i.e. to assess the quality of the EIM approximation. The EIM-viewpoint becomes particularly questionable if locally the vertical refractive index profile cannot accommodate any guided mode, as e.g. in the holes of a PC membrane. We check numerically a recipe [1, 3], based on a variational view on the EIM, to uniquely define an effective permittivity even then.

Our simulations (cf. also [4]) show clearly that a treatment of a propagation problem involving a high contrast PC membrane in terms of effective indices can hardly be expected to be more than a mere qualitative, or rather crude quantitative, approximation. Nevertheless, situations may arise where, for various reasons, there are no options but to restrict simulations of 3-D devices to 2-D. One should then at least invest the small effort to determine the variational correction term, and perform the 2-D calculation for the thus established effective permittivity profile (which may well turn out to be smaller than 1.0 locally, or even negative). At least for the given examples we could observe that the resulting variational effective index approximation (vEIM) comes closer to reality than any "conventional" EIM with educated guesses of effective indices for regions without local modes.





Deeply etched waveguide Bragg grating, rel. guided transmission T and reflection R versus vacuum wavelength λ; $N_{\mathit{eff}}^{\mathit{slab}} \in [1.87, 1.67]$, $N_{\mathit{eff}}^{\mathit{holes}} \in [0.82, 0.71]$ (vEIM); shading $\sim$ losses (QUEP); patches: multimode slab; $n_c : n_f : n_s = 1.0 : 2.0 : 1.45$, $\Lambda = 0.21\,\mu m$, $g = 0.11\,\mu m$, $d = 0.6\,\mu m$, $t = 0.2\,\mu m$.

References

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[3] E. W. C. van Groesen, J. Molenaar. *Continuum Modeling in the Physical Sciences*. SIAM, USA, 2007.
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