Modeling and simulations of light emission and propagation in open nanophotonic systems
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Light emission and propagation in photonic crystal membranes are studied theoretically, with an emphasis on waveguides, slow light effects, and coupled cavity-waveguide systems. A Bloch mode expansion formalism for optical modeling of photonic crystal membranes is presented, and perfectly matched layer boundary conditions are introduced to emulate the inherent openness of the photonic crystal membrane. The impact of the computational domain size and perfectly matched layer parameters on dipole emission in a photonic crystal membrane waveguide is investigated, and we find the associated computational uncertainty to be of larger magnitude than typical estimates found in literature. A photonic crystal waveguide with one or two side-coupled cavities is considered, and the local density of states is described using a semi-analytical quasi-normal mode theory. We propose original techniques for computing and normalizing quasi-normal modes in extended systems, and comparing to numerically exact calculations, the theory correctly predicts a slight asymmetry (one cavity) and a peak and a dip (two cavities) in the local density of states spectra. Next, the photonic crystal waveguide is interfaced with a side-coupled cavity and a scattering site in the waveguide, and we demonstrate that the shape of the transmission spectrum can be controlled by the cavity-scattering site distance, for example to exhibit a symmetric Fano shapes. Subsequently, we investigate an active photonic crystal waveguide in the slow light region and present an original coupled Bloch mode model, with material gain treated as a perturbation, that includes back-coupling between the counter propagating passive Bloch modes. We show that this gives rise to distributed feedback, which puts fundamental limitations on the maximum achievable gain of the slow light amplifier. Finally, dipole emission in photonic crystal membrane waveguides is analyzed, where we design slow and fast light waveguides for enhanced single-photon emission into a guided mode. We investigate spectra and spatial maps of dipole emission and find that the relative coupling into the guided mode, $\beta$, remains in excess of 50%, even in non-optimum situations, and quickly approaches unity towards the band edge. Preliminary experimental results that build on the theoretical designs demonstrate emission from position-controlled quantum dots into the waveguide mode. In a disjoint chapter, we study the localized surface plasmon modes of plasmonic nanodimers, and both theoretically and experimentally, we find an almost-inverse scaling of the relative shift of the plasmon wavelength with particle distance in the sub-radius range.

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