POLARITONS AND NANOCAVITIES IN PHOTONIC CRYSTAL SLABS

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Waveguide-embedded photonic crystals (PCs), also known as PC slabs, are characterized by the presence of truly guided modes lying below the light line of the cladding material in the k-ω plane, and of quasi-guided modes above the light line: the former are lossless in an ideal system without disorder, while the latter are subject to intrinsic radiative losses due to out-of-plane diffraction. PC slabs are very promising for the control of photonic modes in 3D.

In this theoretical work we present a theory of the interaction of excitons with photonic modes, as well as of photonic crystal cavities, in PC slabs with strong refractive index contrast and a 2D triangular lattice of air holes. The method for the calculation of both guided and quasi-guided photonic eigenmodes relies on expanding the magnetic field on the basis of guided modes of an effective homogeneous waveguide with an average dielectric constant in each layer. Diffraction losses of quasi-guided modes and Q-factors in nanocavities are calculated by perturbation theory (the photonic analog of Fermi's Golden rule). Effects of disorder, especially for propagation losses of truly guided modes, can be included by introducing a model of variable hole size with a Gaussian distribution.

When the PC slab supports an excitonic resonance (e.g, a GaAs membrane containing one or a few quantum wells), the interaction of excitons with the radiation field may be in a strong-coupling regime and gives rise to polariton states. These *photonic crystal polaritons* are formed either when the exciton interacts with a truly guided photonic modes, or when the diffraction-limited linewidth of the photonic mode is smaller than the exciton-photon coupling. A quantum-mechanical theory for the formation of PC polaritons is formulated and it leads to a second-quantized Hamiltonian which is diagonalized by a generalized Hopfield transformation. The polariton eigenenergies obtained from this procedure are in very good agreement with those obtained from semiclassical scattering-matrix theory, where the complex excitation energies are derived from the positions and linewidths of resonant structures in reflectance spectra.

Photonic crystal cavities are characterized by full photonic confinement in three dimensions, small modal volumes V, and large quality factors Q, making them very attractive for the control of radiation-matter interaction. Cavities consisting of one or a few missing holes in the triangular lattice are treated by repeating the point defect with a supercell periodicity, leading to the complex energies of confined photonic modes. The Q-factor is found to increase rapidly with the number of missing holes, so that the ratio Q/V (which is relevant, e.g., for the Purcell effect) becomes larger than in semiconductor microcavities. The Q-factor can be further increased by fine tuning the positions and radii of the nearby holes, according to the principle of "gentle confinement". The predicted values of the Q-factors are in good agreement with those measured from resonant optical spectra of nanocavities in Silicon-based PC membranes [2].

[1] L.C.Andreani and M.Agio, IEEE-JQE **38**, 891 (2002); Appl. Phys. Lett. **82**, 2011 (2003).
[2] Y. Akahane, T. Asano, B.-S. Song, and S. Noda, Nature **425**, 944 (2003).