Modeling of Coupled Nano-Cavity Lasers

Modeling of nanocavity light emitting semiconductor devices is done using the semiconductor laser rate equations with spontaneous and stimulated emission terms modified for Purcell enhanced recombination. The modified terms include details about the optical and electronic density-of-states and it is argued that Purcell enhancement should also be included in stimulated recombination term, contrary to the common practice in the literature. It is shown that for quantum well devices, the Purcell enhancement is effectively independent of the cavity quality factor due to the broad electronic density-of-states relative to the optical density-of-states. The low effective Purcell effect for quantum well devices limits the highest possible modulation bandwidth to a few tens of gigahertz, which is comparable to the performance of conventional diode lasers.

Compared to quantum well devices, quantum dot devices have narrower electronic density-of-states and are not affected by the reduction of the Purcell enhancement to the same degree. The highest modulation bandwidth is found for below threshold operation, where the bandwidth is not cavity-limited.

Using finite-difference time-domain methods, systems of passive, coupled photonic crystal nanocavity structures are simulated. The resonance frequencies of in-phase and out-of-phase coupled quadrupole modes in rectangular photonic crystal H1 cavities are extracted and are found to vary non-trivially with the intercavity separation. A qualitative explanation is given in terms of the in-plane mode profiles. Farfield emission patterns for the structures are calculated based on the finite-difference time-domain simulations. It is found that only systems with an even number of holes separating the cavities show clear signs of being coupled. This non-trivial coupling behavior is useful for design of coupled systems.

A tight-binding description for coupled nanocavity lasers is developed and employed to investigate the phase-locking behavior for the system of two coupled cavities. Phase-locking is found to be critically dependent on exact parameter values and to be difficult to achieve for systems with large linewidth enhancement factors and low Purcell enhancement such as quantum well based lasers.

Realistic numbers for the coupling strength are extracted from finite-difference time-domain simulations.

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