Emission Linewidth in Semiconductor Microcavity Lasers

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The lower limit of the emission linewidth in lasers is determined by the spontaneous emission into the laser mode. This spontaneous emission coupling can be modified through the design of the laser structure. In semiconductor microcavity lasers, coupling efficiencies up to 30% have been achieved.[1]

Generally, the spontaneous emission rate depends on the photon emission probability of the active material and of the density of states (DOS) of the corresponding photon modes (in semiconductors it depends on the product of the electron-hole occupation probabilities and the carrier density of states). Whereas the carrier DOS in semiconductors is strongly influenced by many-body effects in the electron-hole plasma, the photon DOS is determined by the laser structure.

Within this context, semiconductor microlasers make an excellent system to study the quantum mechanical properties of laser light and the underlying interaction between the quantized laser field and the electrons and holes in the gain medium. To examine these systems, we developed a theory that considers the spectral interplay of stimulated and spontaneous emission and the cavity loss according to a kinetic equation for the spectral laser intensity. The nonequilibrium dynamics of the carrier system are discussed in terms of a Boltzmann equation that includes carrier-photon, carrier-carrier, and carrier-photon scattering.[2]

Solutions of the nonequilibrium carrier kinetics show that frequency-selective carrier recombination and generation lead to a nonequilibrium carrier distribution, which is a Fermi-Dirac distribution if the laser intensity is not too high. However, the effective electron-hole-plasma temperature deviates significantly from the lattice temperature.[3]

Our studies of the laser characteristics for different spontaneous emission coupling confirm a dramatic reduction of the laser threshold for increased coupling. However, we were surprised to find that the laser linewidth is dominated by spontaneous emission and nonequilibrium carrier fluctuations at large coupling and does not display the usual inverse power dependence, *i.e.*, Schalow-Townes linewidth narrowing. A comparison of theoretical and experimental results for different spontaneous emission couplings are shown in the figure below. Because of the large linewidths found in these studies, semiconductor microlasers may be inappropriate for applications in which bandwidth is an important criteria.

References

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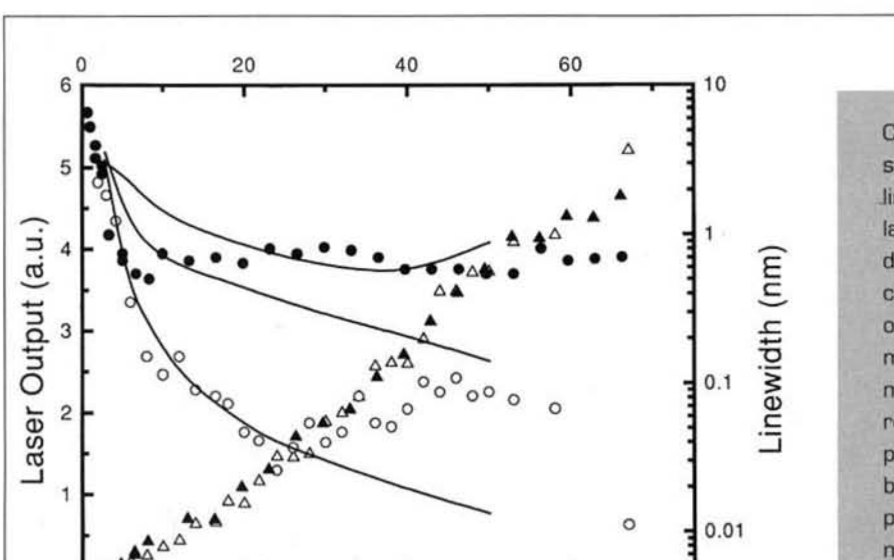
2. F. Jahnke *et al.*, "Transient nonequilibrium and many-body effects in semiconductor microcavity lasers," J. Opt. Soc. Am. B (to be published).
3. F. Jahnke and S. W. Koch, "Theory of carrier heating through injection pumping and lasing in semiconductor microcavity lasers," Opt. Lett. **18**, 1993, 1438-1440.



Comparison of experimental (open and solid symbols) and theoretical (lines) results for the linewidth and output intensity of microdisk lasers. The solid data points are for a 2.2 μm diameter microdisk (spontaneous emission coupling measured to be 0.1-0.3) and the open points are for a 5 μm diameter microdisk (spontaneous emission coupling measured to be 0.02-0.05). The theoretical results are for spontaneous emission couplings of 0.4, 0.1, and 0.01 (from top to bottom). The theory linewidths and pump powers have been normalized to the experimental values.