Quantum dot (QD) lasers display low feedback sensitivity in comparison to quantum well (QW) lasers. This advantageous dynamical behavior is ascribed to their smaller phase-amplitude coupling that is expressed in small linewidth enhancement factors $\Gamma$. Therefore QD lasers are excellent candidates for directly modulated lasers needed for future telecom applications. We investigate the complex dynamics of a semiconductor QD laser subject to optical feedback from a distant mirror. In dependence of the feedback strength we obtain complex bifurcation scenarios for the intensity of the emitted laser light.

### Microscopic QD model combined with Lang-Kobayashi like field equation

- Turn-on dynamics
  - Response of photon density $n_{ph}$ to current pulse with feedback ($K = 0.96$) and without feedback ($K = 0$).

- Equation of motion for electrical field amplitude
  - Total field $\mathcal{E}(t) = \mathcal{E}(t)e^{j\omega t}$ normalized: $\mathcal{N}_{ph}(t) = \mathcal{N}_{ph}(0)e^{j\omega t}$
  - $\mathcal{E}(t) = (1 - \frac{1}{2}) \left( \mathcal{E}^{\text{wall}}(t) + \mathcal{E}^{\text{ext}}(t) - j2\pi \frac{\mathcal{N}_{ph}(t)}{\mathcal{N}_{ph}(0)} \right)$

- External Cavity Modes (ECMs)
  - Rotating wave ansatz: $\mathcal{E}(t) = \mathcal{N}(t) e^{j\omega t}$
  - Equation for frequency deviations: $\Delta \omega_{ph} = \frac{\chi}{\mathcal{N}_{ph}(0)} \left[ 1 + \frac{1}{2} j \mathcal{N}_{ph}(t) - \frac{\mathcal{N}_{ph}(t)}{\mathcal{N}_{ph}(0)} \right] + \mathcal{N}_{ph}(t)\dot{\mathcal{N}}(t) + j \mathcal{N}_{ph}(t)\dot{\mathcal{N}}(t)$

- ECMs in dependence of $K$ are created pairwise in saddle-node bifurcations ($\Gamma_0$).

### Rate equations for QD laser [LUE09]

$$\frac{d}{dt} N_{QD} = -2\alpha N_{QD} + \Delta N_{QD} + \beta N_{QD}$$

- $K = 0.123$

### First laser instability at $K_c$

- Laser loses stability in a Hopf bifurcation at the critical feedback strength $K_c$. $K_c$ is plotted as a function of the $\alpha$- and the $\Gamma$-factor.

#### Dependence of $K_c$ on $\alpha$-factor

- Analytical expression for lowest bound of $K_c$ at which first ECM loses stability [LEV95]:
  - $K_c = \alpha$ (red line in (iii))

- $K_c$ decreases with increasing $\alpha$-factor.

- QW lasers are more sensitive to optical feedback than QD lasers.

#### Dependence of $K_c$ on $\Gamma$-factor

- Parabolic shape of $K_c$ as function of $\Gamma$ is due to two competing processes [LEV95]:
  - 1. $K_c$ decreases with increasing carrier lifetimes $\tau_\text{c}(\Gamma) = \frac{1}{\Gamma_0^2 + \Gamma_0^2}$
  - 2. $K_c$ increases with differential gain $\Delta N_{QD}$ and thus with $\Gamma$-factor.

### Conclusion

- Combining a Lang-Kobayashi like field equation with microscopically based carrier rate equations, we can explain the reduced feedback sensitivity found in QD devices by the relatively small number of ECMs in comparison to QW devices.

- The small number of ECMs originates from a weaker phase amplitude coupling in QD laser that is modeled by smaller $\alpha$-factors.

---

**References**


---

**Institut für Theoretische Physik, Technische Universität Berlin**

**Mail**: otto@itp.tu-berlin.de

**Web**: http://www.itp.tu-berlin.de/schoell/