Tutorial:
Laser Diodes with External Feedback

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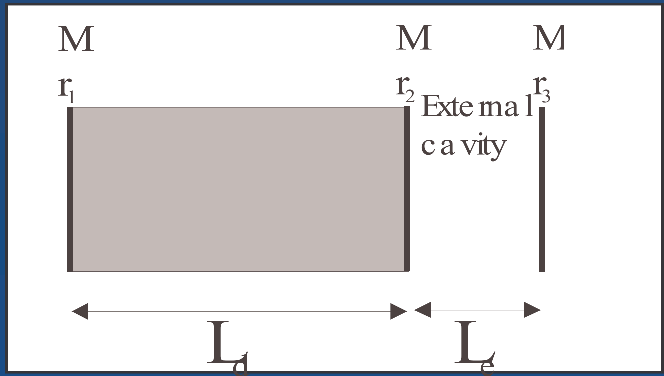
Content of the tutorial:

1. Introduction to laser diodes with external feedback (RISOE)
2. Laser diodes with phase conjugate feedback (RISOE)
3. Extended laser diode cavities with fixed and
dynamic filters (LCFIO)

4. Feedback cavities based on wavelength multiplexing(RISOE)

Optical feedback in diode lasers

Diode lasers are very sensitive to optical feed-back due to the low Q-factor and high gain of the lasercavity.



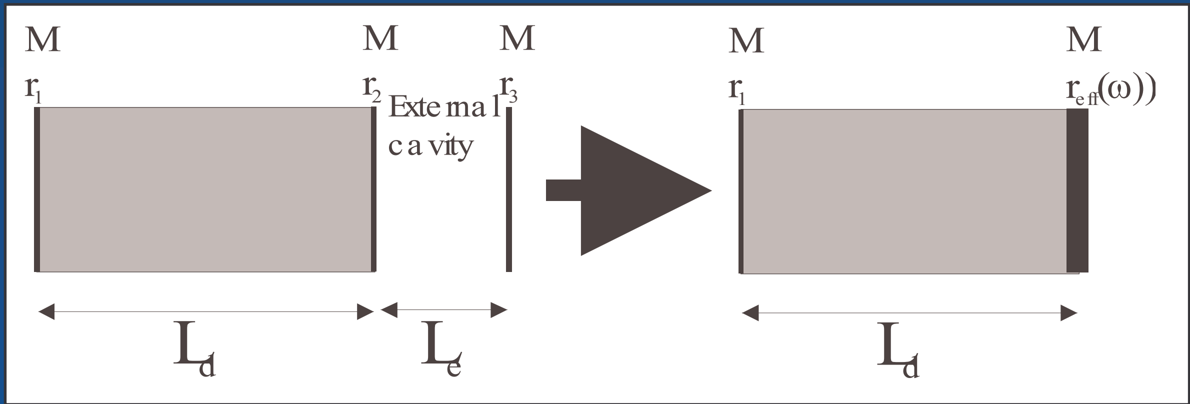
The optical feedback techniques lead to many new attractive properties of diode lasers such as:

- Linewidth reduction
- Tunability
- Improved spatial and temporal coherence
- Modelocking

However, the optical feedback may also lead to detrimental effects such as coherence collapse with chaotic behaviour

Threshold gain and oscillation frequency

A coupled cavity model may be used for the analysis of diode lasers with optical feedback.



At threshold the oscillation condition is:

$$r_1 r_{eff}(\omega) e^{(g_{th}-\alpha_m)L_d} e^{i\omega\tau_d} = 1 \text{ where } \quad \mathrm{r_{eff}}(\omega) = \frac{r_2 + r_3 e^{i\omega\tau_e}}{1 + r_2 r_3 e^{i\omega\tau_e}}$$

where $\tau_d=2n_dL_d/c$ and $\tau_e=2L_e/c$ are the round-trip times.

Threshold gain and oscillation frequency

The gain and the oscillations frequency can be obtained from the ”oscillations condition by solving this equation for the amplitude and phase:

$$g_{th} = \alpha_m - \frac{1}{L_d} \ln[r_1 |r_{eff}(\omega)|]$$

$$\omega - \omega_q = -\frac{1}{\tau_d}[\alpha \ln[\frac{|r_{eff}(\omega)|}{r_2}] - Arg[r_{eff}(\omega)]]$$

Where $\omega_q = 2\pi q/\tau_d$ is the frequency of the laser diode without feedback and where an additional phase shift has been included due to the carrier induced variation of the refractive index by the α parameter given by:

$$\alpha = -2k \frac{dn/dN}{dg/dN}$$

where n is the refractive index, g is the gain and N is the carrier density.

Linewidth reduction with external feedback cavities

The linewidth reduction is given by

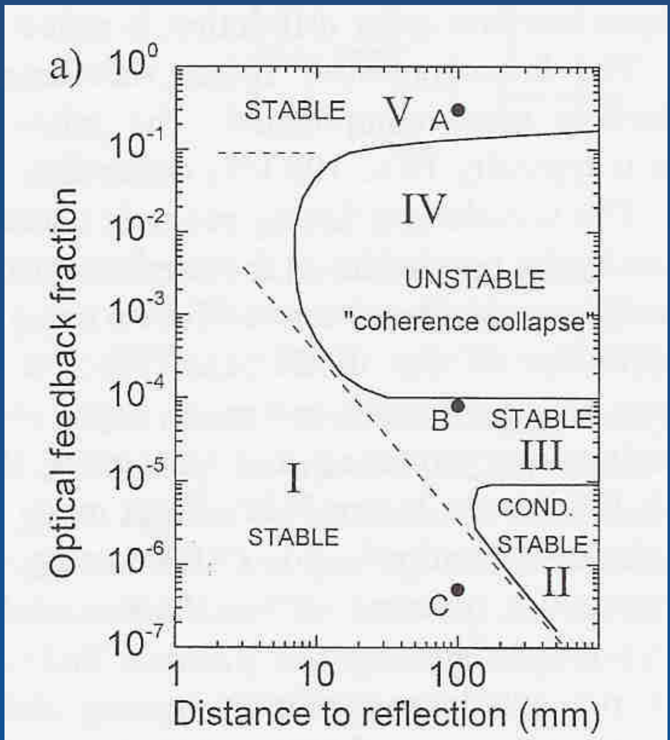
$$\Delta\nu = \Delta\nu_0 (\frac{d\omega_q}{d\omega})^{-2}$$

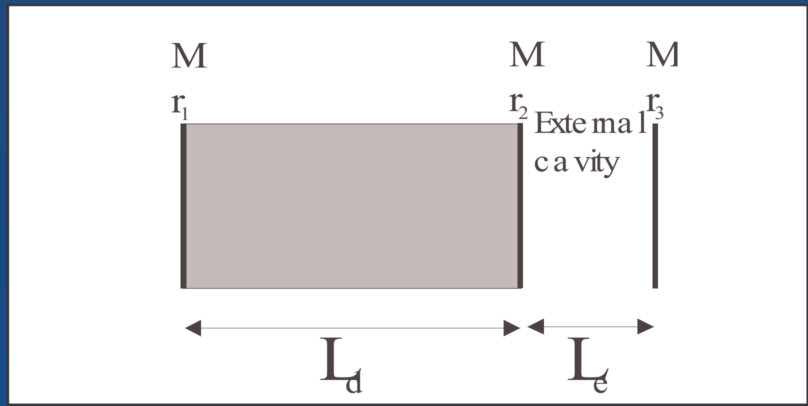
where

$$\frac{d\omega_q}{d\omega} = 1 + \frac{1}{\tau_d}\{\alpha \operatorname{Re}[\frac{d \ln r_{eff}(\omega)}{d\omega}] - \operatorname{Im}[\frac{d \ln r_{eff}(\omega)}{d\omega}]\}$$

where $\Delta\nu_0$ is the linewidth without feedback and $d\omega_q / d\omega$ is the frequency-chirp reduction factor.

Stability regimes for lasers with optical feedback





Regime I: Stable regime where the linewidth is narrowed or broadened broadened depending on the phase of the feedback

Regime II: Conditionally stable

Regime III: Stable single mode operation is obtained with linewidth reduction

Regime IV: Unstable operation with coherence collapse

Regime V: Stable operation with significant linewidth reduction

Ref.:
Y. Kitaoka et al., IEEE J. Quantum Electron, vol. 32, pp. 822-827,1996
H. Talvitie, Thesis, Helsinki University of technology, Finland ,1998 (ISBN 951-22-4221-4)

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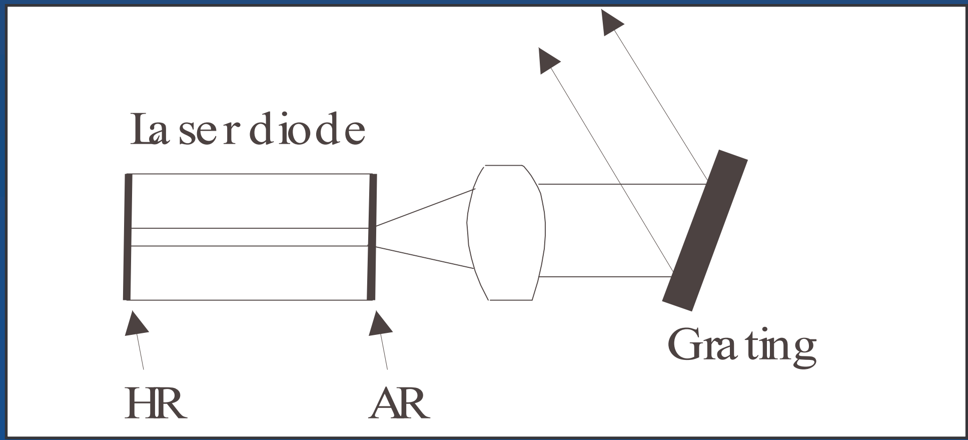
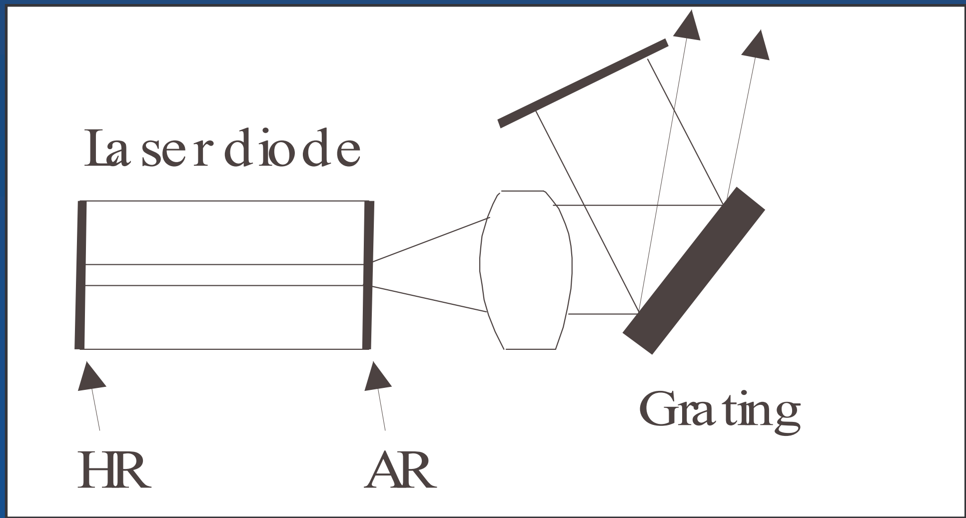
Optical feedback in the Littrow configuration



In the Littrow configuration the first order diffraction is feed back to the laser and the zero order diffraction is used as an output beam. The wavelenght tuning range is typically 10-50 nm which is limited by the bandwidth of the semiconductor gain medium. Usually high quality antireflection coating on the output facet is required to prevent self oscillation in the laser diode.

The wavelenght is changed due to $\lambda = 2a\sin(\theta)$

Optical feedback in the Littman configuration



In the Littman configuration the first order diffraction is reflected back from an additional mirror and the laser beam is coupled out from the zero order diffraction.

Usually high quality antireflection coating on the output facet is required. Coating with up to 5% reflectivity has been used but with limited tuning range. Optical feedback of the order of 20 % to 30 % is needed.