Technical Note – No. 3

Antireflection Coated Diode Lasers

Antireflection coating of the diode laser is required as soon as the diode is placed within an external cavity. The deposition of the coating and the characteristics of the coating are a highly sophisticated feature and shall be discussed in this section.

The mirror facets of diode lasers typically have a reflectivity of 30% to 40% due to difference in the value of the refractive index of the laser material and air. Antireflection coating of the facets is achieved mostly by multiple dielectric layers. The coating is realized by state of the art deposition techniques which provide highest quality and reliability. Most of our antireflection coatings are specified to have a residual reflectivity of below 5E-4. These specifications are oriented by the requirements of the application of diode lasers in external cavities. Typical values are almost one order of magnitude better.

As a consequence of the coating, the losses of the solitary diode laser increase and the threshold current dramatically increases. This is of course desired for external cavity applications since with external cavity the additional losses are compensated by the distant reflector. If the feedback due to the external cavity is too low, external and the internal cavity start to compete and chaotic behavior arises which is well known in literature as the coherence collapse.

The shift of the threshold current with decreasing facet reflectivity can be estimated by the well known rate equations description of carrier density N and photon density S.

$$\frac{dN}{dt} = J - \frac{N}{t_n} - \frac{dg}{dN}\left(N - N_{th}\right)S \qquad (1)$$

$$\frac{dS}{dt} = \Gamma_{conf}\frac{dg}{dN}\left(N - N_{th}\right)S - \frac{S}{t_S} + b\,\Gamma_{conf}\frac{N}{t_n} \qquad (2)$$

J is the pump current density which is determined by the injection current and the active volume of the laser, τ_n is the carrier lifetime, *dg/dN* is the differential gain, and N_{th} is the carrier density at threshold. Γ_{conf} is the confinement factor which accounts for the fact that only part of the optical mode is in the active volume. τ_s is the photon lifetime and *b* is the fraction of the spontaneous emission which is coupled into the lasing mode. Fore more details of the rate equation description of diode lasers, c/f Sacher et al., Phys. Rev. A 45, 1893 (1992).

The photon decay rate $1/\tau_s$ is separated into two terms, one accounting for the usual losses, one accounting for the additional losses due to the coating. In particular, we set:

$$\frac{1}{t_S} = \mathrm{v}_g\left(a_{\mathrm{int}} - \ln\left(R_1R_2\left(1 - r_2\right)\right)/2L\right) \qquad (3)$$

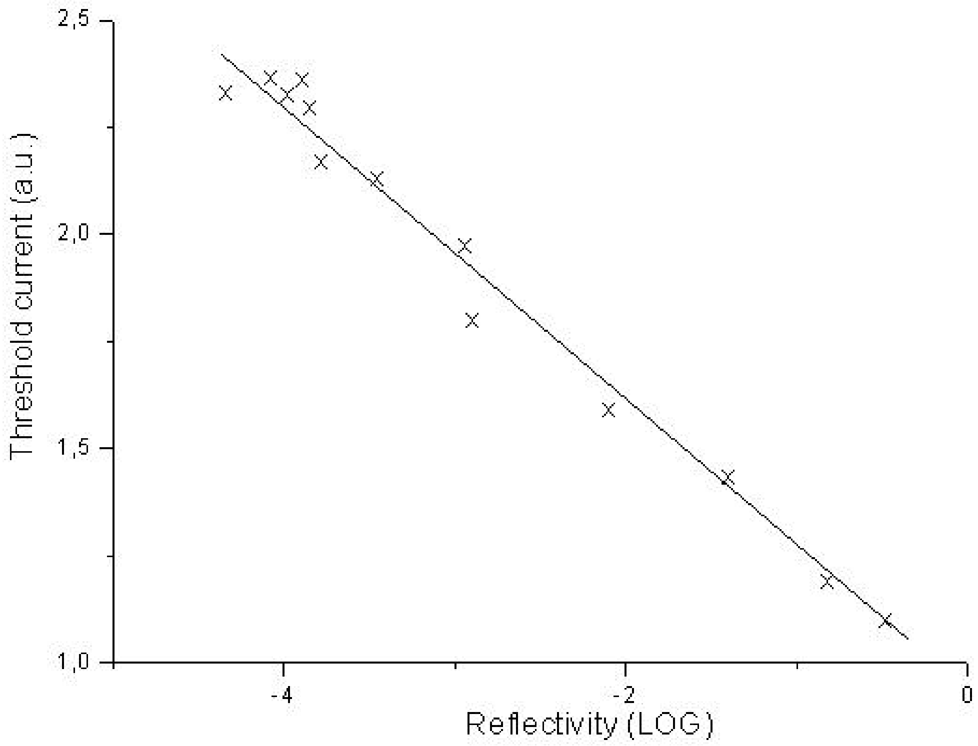

Figure 1: Normalized threshold current density as a function of reflectivity in a semi-logarithmic depiction.

with the group velocity v_g, the internal losses α_{int}, the original reflectivity R_1 and R_2 of the two facets and the diode length L. The term $(1-r_2)$ accounts for the decrease of the facet reflectivity with time during the deposition process. This equation can be expressed as:

$$\frac{1}{t_S} = \Gamma + k \qquad (4)$$

where Γ is the modified photon decay rate without coating and $\kappa = v_g(-\ln(1 - r_2(t))/2L)$ is the variation of the photon decay rate due to the coating. With this Ansatz, we obtain a simple expression for the threshold current density J_{th} as a function of the additional losses:

$$J_{th} = \frac{N_{th}}{t_n} + \frac{k}{t_n G_N} \qquad (5)$$

N_{th} is the carrier lifetime and G_N is the differential gain. The threshold linearly increases with κ. Inserting the expression for κ one obtains the threshold current density J_{th} as a function of the reflectivity. As shown in Figure 1, the threshold current density (normalized to its original value) exhibits an exponential dependence on the reflectivity.

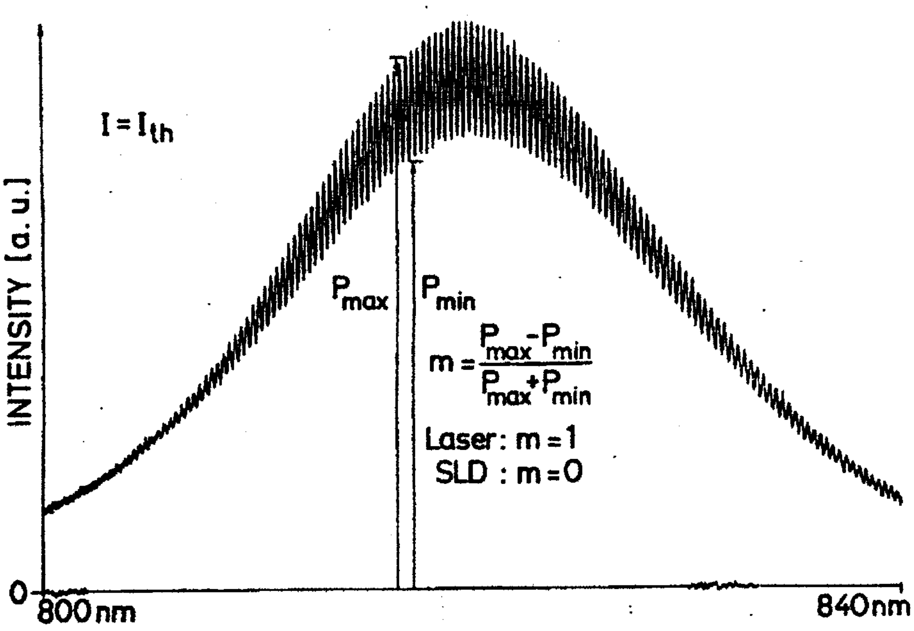

Figure 2: Spontaneous emission spectrum of semiconductor laser amplifier measured at the original threshold current. The modulation index *m* is used to determine the residual reflectivity.

Estimation of the Residual Reflectivity

The performance of the external cavity laser diode critically depends on the quality of the antireflection coating. Therefore, it is essential to characterize the quality of the coating or, with other words, to determine directly the reflectivity of the coated facet. Our method follows a scheme proposed by Kaminov et al., IEEE J. Qunantum. Electron, QE-19, 493 (1983). It is based on the fact that even though the reflectivity of the facets might be strongly reduced weak Fabry-Perot modes of the cavity are still present. These Fabry-Perot modes appear as a ripple on the spontaneous emission spectrum as seen in Figure 2. The modulation index m is given by: m = (P_{max} – P_{min})/ (P_{max} + P_{min}) where P_{max} and P_{min} are the optical power at the maximum and at the adjacent minimum of the ripple, respectively. In order to determine the residual reflectivity, the gain factor g has to be calculated from:

$$m = \frac{2g}{1+g^2} \qquad (6)$$

The gain factor at the original threshold current provides R_2:

$$R_2 R_1 = (gR_1)^2 \qquad (7)$$

(Here we consider that only one facet is coated so that R_2 is reduced and that R_1 remains unchanged). Accordingly, to determine the residual reflectivity R_2 the diode laser has to be operated at its original threshold current and its spontaneous emission spectrum is evaluated to provide the modulation index *m*. Then, the residual reflectivity is calculated following the scheme described above.