The Effect of Facet Reflections in Index-Coupled Distributed Feedback Lasers with Coated Facets

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Abstract—**The effect of facet reflections and different grating parameters on side-mode suppression ratio in index-coupled distributed feedback lasers without a phase-shift section is analyzed. The single-mode device yield and the facet reflectivities needed for achieving a high yield are evaluated.**

Keywords-distributed feedback lasers; facet reflectivity; side-mode suppression ratio; single-mode yield

I. Introduction

Index-coupled distributed feedback (DFB) lasers with a phase-shift section and perfect anti-reflection (AR) coatings have a high single-mode yield, but the yield deteriorates rapidly for facet reflectivities of only a few percent due to the phase-shift randomness of the non-zero facet reflections [1].

Many studies of the DFB lasers' single-mode yield have been carried out [1-9]. However, in these studies it is assumed that one facet has a perfect AR coating or only few certain facet reflectivies are considered. Furthermore, often only few κL-values (where κ is the coupling coefficient and L is the length of the grating) are considered or κL is fixed, and studies are made for structures with a phase-shift section and a first order grating. Also the effects of the grating order, m, and the filling factor, γ, are often excluded from analyses.

The single-mode yield is usually determined by using criteria for the minimum threshold gain difference, and for the maximum acceptable ratio between the maximum and the minimum field intensity along the cavity. The first criterion evaluates the suppression of the strongest competing mode, whereas the latter condition takes the spatial hole burning (SHB) into account. However, the single-mode yield obtained this way doesn't give much information on the distribution of side-mode suppression ratios (SMSRs) among the devices of the batch. It only gives the probability that a device from the batch has a SMSR that is above a certain threshold value.

Since it has been found out that for κL-values larger than 1.6, the conventional theoretical yield calculations fail due to SHB [6], we have considered only κL-values smaller than 1.5. This upper limit takes also into account that our analysis addresses in particular high-speed DFB lasers with surface gratings. Bigger κL-values are very unlikely for such lasers because, on one hand, the surface gratings have a relatively low coupling coefficients, while on the other hand, the device length is limited by targeting a high modulation bandwidth.

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II. Simulation Method

The SMSR is defined as the ratio of the output power in the main laser mode to that in the next strongest mode. An approximate formula, used in our study, is given in [10].

The threshold gain condition for a DFB laser decomposed in the front facet plus the rest of the structure, whose reflectivity is calculated using the transfer matrix [11], is

$$R_1 |r(\lambda, \alpha_m)|^2 = 1 \qquad (1)$$

where $r(\lambda,\alpha_m)$ is the wavelength and absorption/gain dependent amplitude reflection coefficient for the whole DFB structure including the facet power reflectivity R_2 but excluding the facet power reflectivity R_1, as illustrated in Fig. 1. The phase condition requires that $r(\lambda,\alpha_m)$ is real and positive.

d_1 in Fig. 1 is the distance between the high-reflection coated facet and the first grating period, and d_2 is the distance between the AR-coated facet and the last grating period. The analyzed grating has a rectangular-shaped effective refractive index variation between $n_{eff} + ½\Delta n$ and $n_{eff} - ½\Delta n$, with the filling factor γ given by $\Lambda_1/(\Lambda_1+\Lambda_2)$. The SMSR is calculated at $3I_{th}$, where I_{th} is the threshold current. If not mentioned explicitly, the other parameters used in the simulations are: κ = 20 cm^{-1}, L = 500 μm, m = 1 and γ = 0.5.

III. Simulation Results

For perfect AR coating (R_2 = 0), the SMSR no longer depends on d_2 and R_1 should be as high as possible (although the best achievable SMSR increases only a few dB when R_1 increases from 0.7 to 1.0). However, in real DFB lasers R_2 = 0 can't be obtained, and the SMSR is dependent on d_2 as well, as shown in Fig. 2 for the DFB structure with R_1 = 0.95 and various R_2.

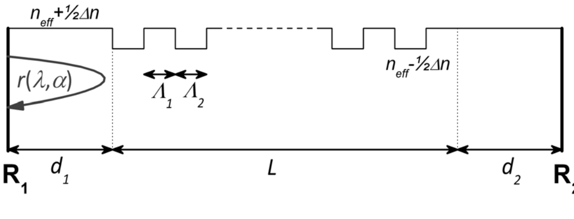

Figure 1. Structural parameters used in the study.

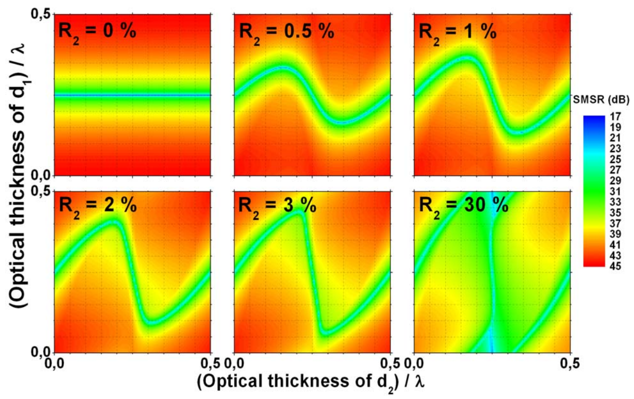

Figure 2. SMSR as a function of d_1 and d_2 when $R_1 = 0.95$.

The SMSR variation doesn't depend substantially on m, whereas γ affects only the optimal facet positions, as presented in Fig. 3 for $R_1 = 0.95$ and $R_2 = 0.02$. Furthermore, the SMSR variation is only slightly affected, if R_1 changes between 0.7 and 1.0. When κL is increased from 1.0 to 1.5 either by increasing κ to 30 cm^{-1} or by increasing L to 750 μm, the plot of the SMSR as a function of d_1 and d_2 for $R_2 = 0.02$, shown in Fig. 4, resembles the one obtained with κL = 1.0 and $R_2 = 0.01$ (upper-right panel of Fig. 2). That is, d_2 has less effect on the SMSR when κL increases. Furthermore, the SMSR variation depends on the κL product, and not on κ or L separately.

The parameters that substantially affect the influence of facet reflections on SMSR are d_1, d_2, R_2 and the κL-value. Fig. 5 shows the distributions of possible SMSRs when (not so important parameters) $R_1 = 0.95$, m, γ and L are fixed, whereas R_2 and κ are varied.

The values of R_2 resulting in the best yield of devices with SMSRs of at least 35.0, 37.5, 40.0 or 42.5 dB as a function of κL when $R_1 = 0.95$ are shown in Fig. 6.

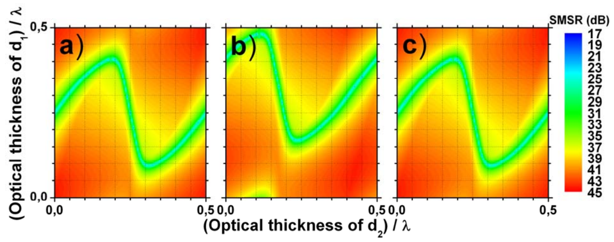

Figure 3. SMSR variation when (a) $m = 1$ and γ = 0.5, (b) $m = 1$ and γ = 0.8, and (c) $m = 3$ and γ = 0.5.

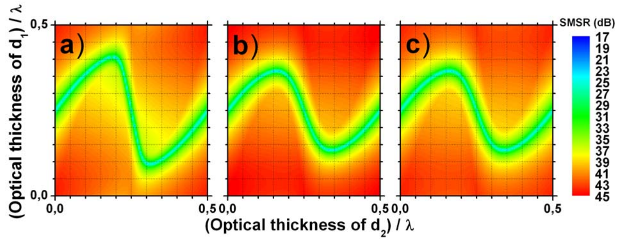

Figure 4. SMSR variation when (a) κ = 20 cm^{-1} and L = 500 μm, (b) κ = 30 cm^{-1} and L = 500 μm, and (c) κ = 20 cm^{-1} and L = 750 μm.

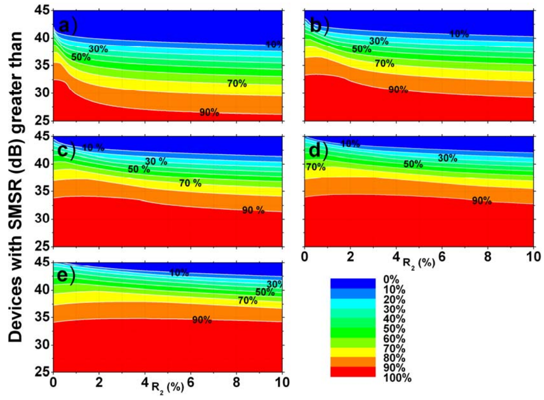

Figure 5. Distribution of SMSRs when $R_1 = 0.95$, $R_2 = 0 - 0.10$ and (a) κL = 0.50, (b) κL = 0.75, (c) κL = 1.00, (d) κL = 1.25, (e) κL = 1.50.

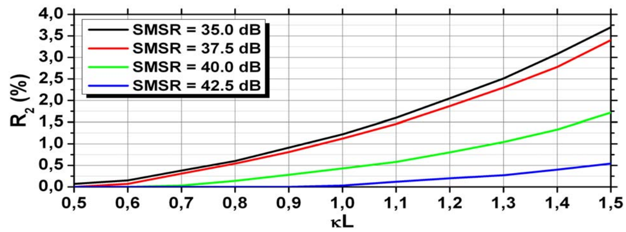

Figure 6. The value of R_2 resulting in the best yield of 35.0, 37.5, 40.0 or 42.5 dB devices as a function of κL when $R_1 = 0.95$.

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