Calculation of Reflection Loss in Fundamental TE Mode Versus Angle of Tilted End Facet of Superluminescent Light Emitting Diodes

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Abstract

In this paper we study the acquisition of fundamental TE mode reflection in rectangular cavities from a tilted face (end mirror) of superluminescent light emitting diodes (SLD). When its width is 3 micrometers and the inclination of the mirror is 3 , the result will be a reduction of nearly 20 dB of reflection. While if the width is 6 micrometers, the inclination of the mirror 2 will cause an excess reflection loss of 20 dB. The results obtained in our paper for small tilt angles are the Gaussian approximation of the guided state. While our results differ greatly from the Gaussian approximation for larger angles and larger reflection losses.

Keywords: reflection loss, superluminescent light emitting diode (SLD), Gaussian approximation, fundamental TE mode, tilted facet.

1. Introduction

A superluminescent light-emitting diode (SLDs) is an optoelectronic device with the characteristics of a laser diode (LD) and a light-emitting diode (LED) [1]. These diodes work in automatic amplified emission (ASE) and this automatic emission is amplified by stimulated emission [2]. Optical coherence tomography (OCT) systems [4], fiber optic gyroscopes (FOGs) [3], speckle-free illumination [7, 6] and wavelength-division-multiplexing (WDM) test systems [5] are among the applications. are the number of SLDs. An SLD has a structure similar to a laser diode, but optical feedback suppression at the faces (cavity ends) eliminates the lasing mode [8]. Different waveguide geometries are used to suppress the resonance and laser feedback of the device, for example, bent waveguide, tilted waveguide, inclined engraved face, anti-reflection coating on the faces, etc. [9.[

Maximizing laser mode losses on reflection from end mirrors in special applications such as distributed feedback (DFB) lasers, superluminescent light emitting diodes (SLDs) and traveling wave laser amplifiers [8,10], we are interested in this It is an article. Covering the end surfaces of the laser with dielectric films or with multilayer dielectric mirrors[11,12] are good ways to reduce reflection losses. In this paper, we seek to obtain a new method. Also, in order to absorb less light by the laser cavity, it seems that it is better to adjust the laser cavity so that it meets its end face at a sufficiently large angle [13-17]. Note that the problem of reflection loss from a tilted mirror is exactly the same as the problem of losses suffered by a guided wave in a tilted mirror in a cavity [18]. This latter problem can be solved with the assumption that the guided state can be approximated by a Gaussian field distribution [19]. This Gaussian approximation is a very good approximation for small tilt angles or low tilt (or reflection) losses. Also, for large tilt angles, the vanishing field outside the cavity core is more important and this field can be represented by weak Gaussian approximation. In this paper we calculate the reflection loss from a tilted mirror for the fundamental TE mode of a slab cavity from a conventional SLD. The slab cavity model can be used to describe the laser mode in a channel or bulge cavity in the approximation of the effective refractive index [20]. The obtained results are of course almost valid. Note that the use of TE mode of the slab to calculate the slope loss does not limit the generality of the result.

2. Formulation and Calculation

Fig. 1 shows a laser slab cavity (effective index approximation of a channel cavity) that is terminated by a mirror placed at angle θ relative to its axis. The mirror is assumed to be the interface between the laser crystal and air. For a perfect mirror, the problem of finding the reflection coefficient of the guided mode that turns back on itself is equivalent to the problem of computing the tilt loss for a slab cavity of tilt angle 2θ. For a mirror of finite reflectivity, the tilt loss must be multiplied by the Fresnel reflection loss corresponding to the tilted mirror. The Fresnel reflection loss is known exactly only for plane waves, and due to the low error and no large impact on the slope loss prediction, we use this plane wave result for the guided TE mode Fresnel reflection loss. We do the following to calculate the reflection loss from the tilted mirror. We represent the guided reflected wave with an equivalent output wave on the tilted cavity, shown by dotted lines in Fig. 1. The ground state in this tilted cavity is excited by the incident field. If the two fields were perfectly aligned, the transmission coefficient would be unity. The loss is caused by phase mismatch.

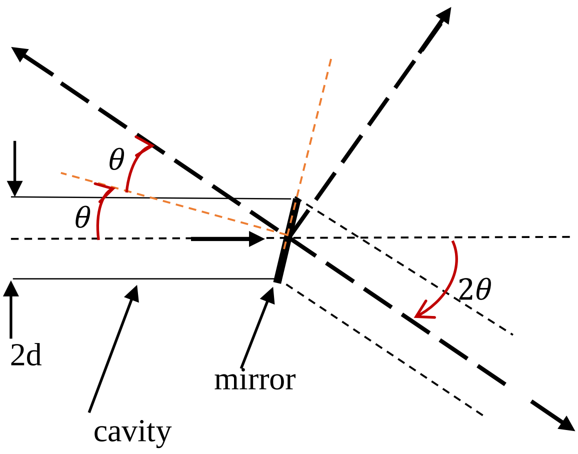

Fig. 1. A laser slab cavity

This effect is accounted for by multiplying the incident field by the phase factor

$$e^{i2\theta\beta x}. \tag{1}$$

The parameter β is the propagation constant of the guided TE mode and x is the transverse coordinate as indicated in Fig. 1. The amplitude transmission coefficient (equal to the reflection coefficient from a perfectly reflecting mirror) is now given by [13]:

$$c = \frac{\beta}{2\omega\mu_0 P_0}\int_{-\infty}^{\infty} \left|E_y\right|^2 e^{i2\theta\beta x}dx \tag{2}$$

where E_y is the y component of the fundamental TE mode of the cavity. The other parameters in this equation are the angular light frequency ω, the magnetic permeability of vacuum μ_0, and the power P_0 transported by the TE mode. The power reflection coefficient is obtained from c as

$$R_g = R_f(\theta)|c|^2 \tag{3}$$

where $R_f(\theta)$ is the Fresnel reflection coefficient of a plane wave that is reflected from the tilted dielectric interface between laser crystal and air [21]. Another important parameter needed for the following discussion is the V number of the slab cavity defined by

$$V = \frac{2\pi d}{\lambda}\sqrt{n_1^2 - n_2^2} \tag{4}$$

n_1 and n_2 are the effective refractive indices of the slab core and cladding. The fundamental TE mode can be characterized by a width parameter. In the core region of the slab and in the region near the core-cladding boundary outside the core the mode field is approximated very closely by a field of the form [14]:

$$E_y = Ae^{-\left(\frac{x}{w}\right)^2} \tag{5}$$

where the width parameter w characterizes the distribution of the field strength. The corresponding width parameter for the power is $w_p = w/\sqrt{2}$. If a given beam width w is assumed, the V value required to obtain this beam width can be computed from [19]:

$$V^2 = \frac{\sqrt{\pi/2}}{w/d} exp\left[2\left(\frac{d}{w}\right)^2\right] \tag{6}$$

The inverse of this formula can be approximated as [14]:

$$\frac{w}{d} = 9.2063 \times 10^{-3} + \frac{1.7265}{\sqrt{V}} + \frac{0.38399}{V^3} - \frac{9.1691 \times 10^{-3}}{V^5} \tag{7}$$

Differences in these equations compared to [19] are caused by our present use of 2d in agreement with [21] instead of d to describe the width of the slab. Note that this change also affects the definition of V. if we substitute the Gaussian approximation (5) of the TE mode field into (2) and (3) we obtain the simple formula [19]:

$$\bar{R}_g = R_f(\theta) exp\left[-\left(\frac{2\pi n_2 w\theta}{\lambda}\right)^2\right] \tag{8}$$

3. Examples and Discussion

The following examples are computed for a hypothetical laser cavity with core refractive index $n_1 = 3.5$ operating at a wavelength of $\lambda = 1.3$ µm. In addition, we characterize the slab cavity by the width of its core 2d and by the full power width of its mode $2w_p = \sqrt{2}w$.

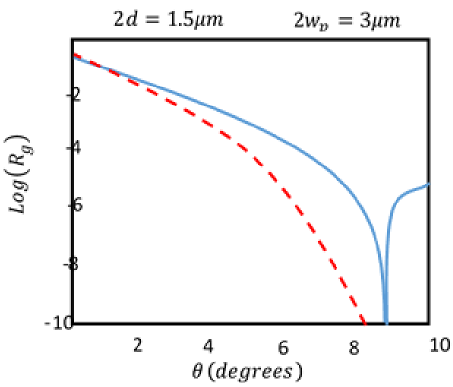

Fig. 2. Logarithm of reflection coefficient as a function of mirror tilt angle for mode power full width $3\mu m$ and slab full width $1.5\mu m$.

Once d and w are specified, V can be computed from (6) and the cladding index n_2 follows from (4). As a first example we have plotted in Fig. 2 the reflection loss of the fundamental TE mode of a laser cavity with a power full width $2w_p = 3\mu m$ and the core full width, $2d = 1.5\mu m$. The Fresnel reflection loss $R_f(\theta)$, needed, is computed for each tilt angle θ and the refractive index difference between cladding index n_2 and the refractive index unity of air [21]. The value of $R_g < 1$ at $\theta = 0$, apparent in the figures, is caused by the Fresnel reflection loss of the field from the index discontinuity (mirror) between cladding and air encountered at normal incidence. The solid line was computed from (3) the reflection loss accurate relation while the broken line represents the corresponding Gaussian approximation (8). The figures show clearly that the Gaussian approximation agrees very well with the more accurate formula for large values of R_g. For small values of R_g, which may be of particular interest for DFB lasers, traveling wave laser amplifiers, and for SLDs the Gaussian approximation deviates significantly from the accurate reflection loss for the fundamental TE mode. Fig. 3 differs from Fig. 2 in that now $2w_p = 6\mu m$.The core widths of the slab are assumed to be $2d = 2\mu m$. As expected, the reflection coefficient of the wider mode field is far more affected by mirror tilt than the narrower fields shown in Fig. 2. It is notable that the Gaussian approximation is independent of the assumed values of the core width but depends only on the width of the mode field. The dependence of the modal reflection coefficient on the core width can be explained in terms of the field decay parameter $\gamma = W/d$ in the cladding material. Whereas the Gaussian field approximation (5) is completely deter- mined by the assumed field width w , the actual field of the fundamental TE mode of the slab agrees well with the Gaussian approximation inside the slab core but departs from it in the cladding where its rate of decay is given by the value of γ which, in turn, depends on the V number and the core width.

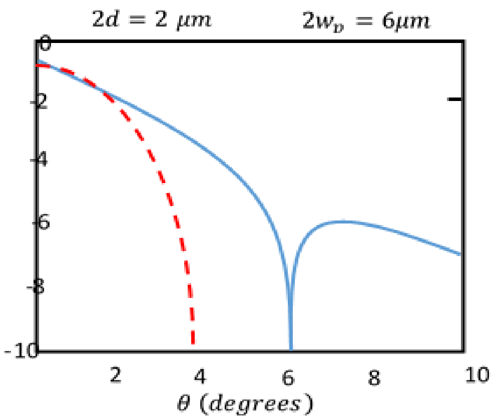

Fig. 3. Logarithm of reflection coefficient as a function of mirror tilt angle for mode power full width $6\mu m$ and slab full width $2\mu m$.

Conclusion

We derived a simple formula (8) for the reflection coefficient of the fundamental TE mode of a slab cavity reflecting from a tilted mirror in a superluminescent light emitting diode (SLD). An approximation assuming that Fresnel reflection of the field occurs. We have compared the modal reflection loss formula with the exact formula (3). Our results clearly show that the Gaussian approximation agrees well with the more accurate formulation for large reflectance values. For small reflectance values, the Gaussian approximation deviates significantly from the exact reflectance loss for the fundamental TE mode. The reflection coefficient of the wider mode field is much more affected by the mirror tilt than the narrower fields.

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