OPTIMAL DESIGN OF MONOMODE TRANSMITTER MODULE

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ABSTRACT

A simple model of an external cavity is used to investigate optimum configurations for achieving a high degree of spectral purity in one mode. A new figure of merit for monomode behaviour is defined.

INTRODUCTION

An attractive technique to achieve 1.55μm single-mode laser transmitters for high bit-rate long-haul optical communications systems is based on the use of a short external cavity. It has been shown(1) that a concave spherical mirror positioned about 200μm from one facet of the laser can produce sufficient feedback to give stable single longitudinal mode operation even under conditions of high-speed modulation. Control circuitry can be contained in a single integrated circuit which is designed to adjust the position of the external reflector so as to maximise the power emitted from the laser(2).

In the present contribution we present an analysis of the mode selectivity offered by such a transmitter module and discuss the optimum configuration. The analysis is based on numerical solution of multimode rate equations under steady-state conditions.

ANALYSIS

The cavity configuration to be considered is illustrated in Fig. 1. A hemispherical mirror of reflectivity R_M is situated at distance L_e from one facet; the coupling of the laser to the external cavity is described by a field coupling coefficient ε. The parameters R_M and ε are conveniently combined into a single modified reflectivity R_E defined by $R_E = \varepsilon^2 R_M$. The phase change in the cavity is given by $\psi_e = 2\pi L_e/\lambda$ where λ is the wavelength. Standard theory then gives the effective reflectivity R of the laser facet plus external cavity as(3)

$$R = \frac{R_2 - 2\sqrt{R_2 R_E}\cos 2\psi_e + R_E}{1 - 2\sqrt{R_2 R_E}\cos 2\psi_e + R_2 R_E} \qquad (1)$$

The modulation depth of this effective reflectivity is thus given by

$$R_{max} - R_{min} = \frac{4\sqrt{R_2 R_E}\,(1-R_2)(1-R_E)}{(1-R_2 R_E)^2} \qquad (2)$$

A plot of this quantity versus the external reflectivity R_E is given in Fig. 2 for various values of facet reflectivity R_2. For the usual case achieved in practice[1,2] there is very weak external coupling (R_E<<1) and then the maximum value of (R_{max}-R_{min}) is obtained when $R_2 = 1/3$. Thus neither reflective nor antireflective coatings would increase the modulation depth of effective reflectivity, as also can be seen in Fig. 2. As long as the external coupling is small, uncoated lasers, when interacting with a cavity with no additional dispersive elements, are expected to be more selective than lasers with coated mirrors.

In order to analyse the behaviour of the laser in the external cavity, we have used the value for R from eqn. (1) in steady-state solutions of the multimode rate equations. The results are then expressed in terms of the photon densities N_m in each longitudinal mode m, taking m=0 as the dominant mode. The procedure applied in the computer solution corresponds to the technique that would normally be adopted in practice, namely (i) tuning the gain spectrum above threshold so that the peak coincides with a free-running laser mode, and (ii) tuning the external cavity to make a maximum of R coincide with a laser mode. Since the rate equations contain no noise terms, the ratios N_0/N_m predicted by this method are usually much larger than those measured for real transmitters. In order therefore to produce results which could be meaningfully compared with experiment, we introduce a 'figure of merit', M_m for each mode m, defined as

$$M_m = \frac{(N_m/N_o)_{R_E}}{(N_{\pm 1}/N_o)_{R_E=0}} \times 100\% \qquad (3)$$

where the subscript R_E refers to the case with an external cavity and R_E=0 refers to the free-running laser.

RESULTS

Table 1a shows computed values of M_m for m= ±1, ±4 and a range of values of R_E. The other parameters were L=200μm, L_e≃200μm, R_2=0.3, and other material parameters appropriate for 1.55μm GaInAsP lasers[4] at twice threshold. For this case of L≃L_e, since the group index of the laser material is approximately 4, the modulation of effective reflectivity given by the external cavity has a period equal to 4 mode spacings of the free-running laser. Using calculated gain spectra[4] appropriate to the drive current it is therefore possible for either the ±4 modes or the ±1 modes to compete for the 0 mode power, depending on the value of the reflectivity R_E. Thus Table 1a shows that for R_E=1% and 5% the ±4 modes are the strongest competitors whilst for smaller values of R_E (when tuned to the 0 mode) the ±1 modes are favoured.

When L_e≃400μm the maxima of effective reflectivity coincide with 0, ±2 mode wavelengths. This results in a higher power share for ±2 modes and a poorer mode selectivity (see Table 1b).

Table 1a also shows for R_E=0.1% the effects of de-tuning the external cavity to coincide with modes on either side of the gain spectral maximum. This leads to asymmetry in the power spectrum, with the +4(-4) mode as a secondary mode when the external cavity is tuned to the longer-(shorter-) wavelength mode -1(+1) of the free-running laser.

For very low values of external reflectivity, the gain spectral variation will be as strong as that given by the external cavity reflectivity modulation. To investigate the values of reflectivity for which this may occur we use eqn. (1) in conjunction with the usual laser threshold condition, to give

$$\sqrt{R_M} \simeq \frac{\Gamma L \quad \Delta g \sqrt{R_2}}{(1-R_2)(1+\cos 2\psi_e)} \qquad (4)$$

where Δg is the gain difference between primary and secondary laser modes, and Γ is the optical confinement factor. For the parameters given above, eqn. (4) shows that $R_E \simeq 10^{-5}$ is the lowest value of external reflectivity for which the cavity mode selectivity dominates over that given by the internal gain spectrum.

CONCLUSION

A simple model of an external cavity has been used with multimode rate equations in order to investigate the effects of varying reflectivity and tuning/detuning the cavity. The results are expressed in terms of a figure of merit which shows the degree of spectral purity as compared to that for the free-running laser. The optimum configuration for a 1.55μm laser is $L_e \simeq L$ and uncoated laser facets. On the basis of the figure of merit the external hemispherical reflector should have a reflectivity of at least 0.1%

TABLE 1 Figure of merit M_m (note that smaller values of M_m correspond to a better selectivity).

1a. $L_e \simeq 200\mu m$

R_E (%)	Tuned to laser mode	M_m (%)			
		m			
		-4	-1	+1	+4
0	0	5.9	100	100	6.7
0.001	0	5.9	45	45	6.5
0.01	0	6.0	21	21	6.3
0.05	0	6.2	11	11	6.0
0.1	-1	3.7	6.4	9.5	13
0.1	0	6.4	8.0	7.9	5.8
0.1	+1	20	10	6.9	3.9
1	0	7.0	3.0	3.0	5.1
5	0	5.4	1.7	1.8	5.4

1b. $L_e \simeq 400\mu m$

		-2	-1	+1	+2
5	0	24	0.41	0.44	20

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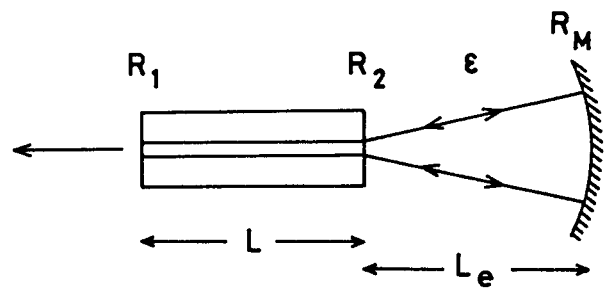

Fig. 1 External cavity configuration

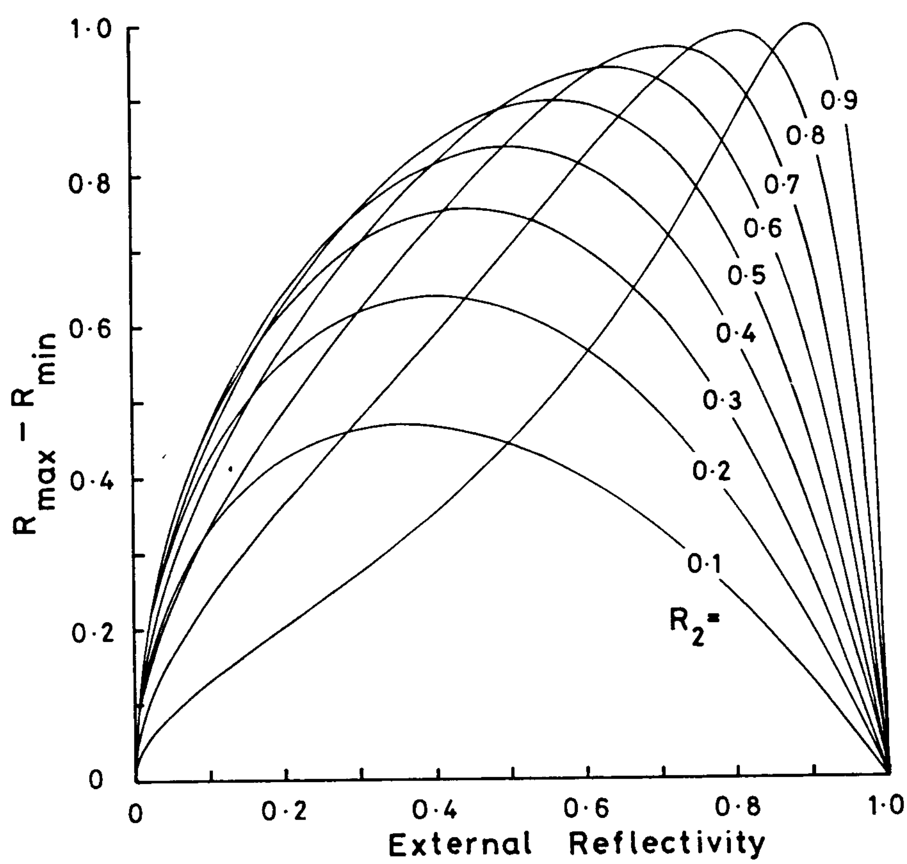

Fig. 2 $R_{max}-R_{min}$ vs R_E for R_2 varying from 0.1 to 0.9