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Theoretical Analysis of DFB Laser Integrated with EA Modulator

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Abstract

Characteristics including single-mode selectivity, chirping and output efficiency of conventional index-coupled (IC), quarter-wave-shifted (QWS) and gain-coupled (GC) DFB lasers integrated with EA modulators are calculated and compared. The chirping of GC-PIC is nearly the same as that of IC-PIC and QWS-PIC, but the single-mode selectivity of GC-PIC is much better. In the case of HR-AR coating which is favorite for high power operation, GC-PIC shows much higher probability of single-mode operation than IC-PIC, while QWS-PIC can not work at all.

Introduction

Long-haul, high-speed optical communication system requires the light source to have the advantages such as stable single-mode, low chirping and wide modulation bandwidth. DFB laser integrated with electroabsorption (EA) modulator is most promising because of its ultra-low chirping as well as high stability and reliality. In the laser section of the integrated light source, quarter-wave-shifted (QWS) structure is commonly used to solve the problem of mode degeneration in conventional index-coupled (IC) DFB structure [1]. However, QWS structure is easily affeted by external reflection, hence anti-reflection (AR) coating at both facets is required, which results in equal allocation of the output power to each facet. By introduction of gain-coupled (GC) DFB structure, the single-mode selectivity is not only enhanced but also not affected very much by external reflection [2]. Thus it is possible to increase the effective output power by applying asymmetric facet coating. We report here, for the first time, the theoretical analysis and comparison of single-mode selectivity, chirping and output efficiency of integrated sources with GC-, QWS, and IC-DFB laser sections.

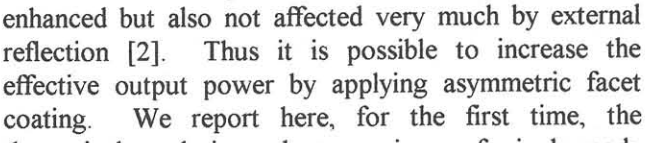

Fig.1 Schematic of DFB laser integrated with EA modulator

Calculation Model

The schematic drawing of our calculation model is illustrated in figure 1. Parameters and values used in the model are listed in table 1. The effect of modulator is equivalent to the effective reflectivity at the laser-modulator joint. The reflectivity "seen" at laser-modulator joint is expressed as

$$\rho_R = R_M \exp[-2jk_0 n_{eM} D - (\ln 10/10) M_d (1 + j\alpha_{HM}\Gamma_M)],$$

where both variations in absorption coefficient and refractive index of the modulator waveguide are considered due to linewidth enhancement factor α_{HM}. For DFB structure with given κ, threshold gain α_{th} and normaliaed lasing frequency δ can be calculated by solving coupled-wave equation [3]. Single-mode selectivity is evaluated by the threshold gain difference $\Delta\alpha_{th}L$ between the two modes with lowest threshold gain. The lasing wavelength is determined by $\lambda=1/2\pi k_s$, and the wave number of the emission light k_s is expressed as $k_s = [\delta + \pi/\Lambda - \alpha_{HL}\Gamma_L(\alpha_{th} - \alpha_{th0})]/n_{eL}$, where the linewidth enhancement factor of the laser α_{HL} is taken into account. The lasing wavenumber k_s derived from the characteristic equations of DFB laser must be self-consistent with k_0 in the expression of ρ_R, so iteration method is applied in calculation. The output efficiency, defined as the ratio of output power from modulator facet and the total output, is calculated from the solution of coupled-wave equation. 20×20 possible combinations of facet phases [4] are considered in the analysis and statistical results are given.

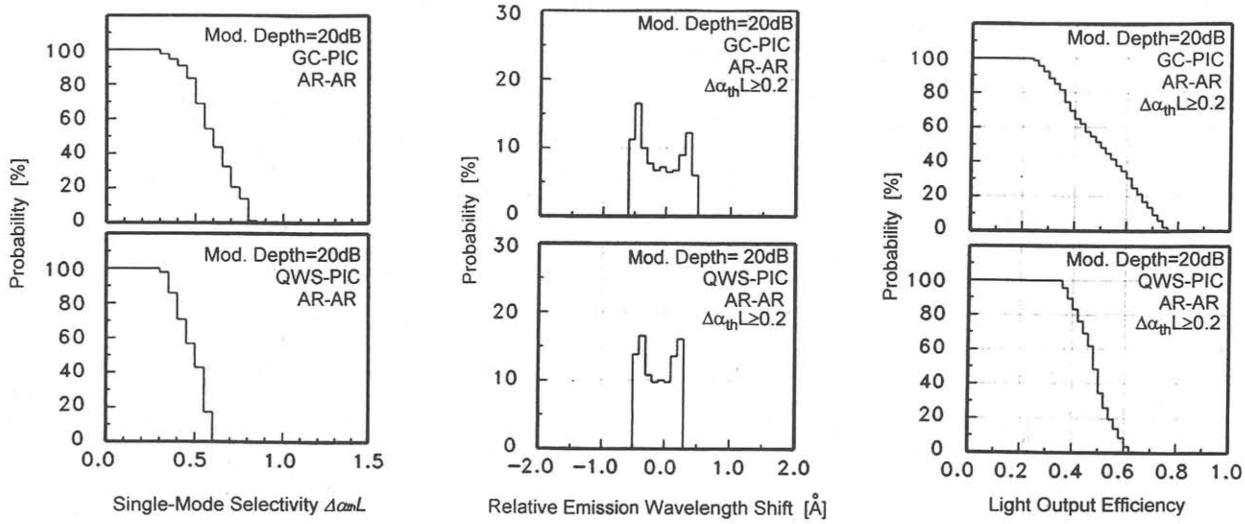

Fig.2 Results in the case of AR-AR coating: Probability of (a) single-mode selectivity, (b) wavelength shift, (c) light output efficiency

Results

1. The case of AR-AR coating. Figure 2(a) gives the probability where single mode selectivity exceeds a given value for QWS- and GC-PICs. IC-PIC is not discussed since the single-mode selectivity is extremely low. For GC-PIC, the probability where single-mode selectivity greater than 0.5 is about 82%, but for QWS-PIC, the probability is about 58%. These results indicate that single-mode yield of GC-PIC is much greater than that of QWS-PIC. Figure 2(b) gives the probability where the modulation-induced lasing wavelength shift $\Delta\lambda$ is in a given range for both GC-PIC and QWS-PIC. $\Delta\lambda$ for both kind of PICs are within ±0.5~0.6 A. The output efficiency of GC- and QWS-PIC at "on" state both averaged 0.5 from the results in figure 2(c).

2. The case of HR-AR coating. Figure 3(a) gives statistical results of single-mode selectivity for IC- and GC-PIC. QWS-PIC is not discussed since it has virtually no mode selectivity. About 52% of IC-PIC has single-mode selectivity greater than 0.2, but none is greater than 0.4. The GC-PICs with single-mode selectivity greater than 0.2 constitute 59%, and approximately 43% have mode selectivity of 0.4, which shows GC-PIC have distinguishing advantages over IC-PIC. The probability of devices with wavelength shift $\Delta\lambda$ in a given range for GC- and IC-PIC are shown in figure 3(b). Both are within ±0.4~0.5 A for devices with single mode selectivity greater than 0.2. From figure 3(c), we see that the probability of GC-PIC with output efficiency greater than 80% is about 35%, but that of IC-PIC is only around 10%. These results also reflect the advantages of GC-PIC.

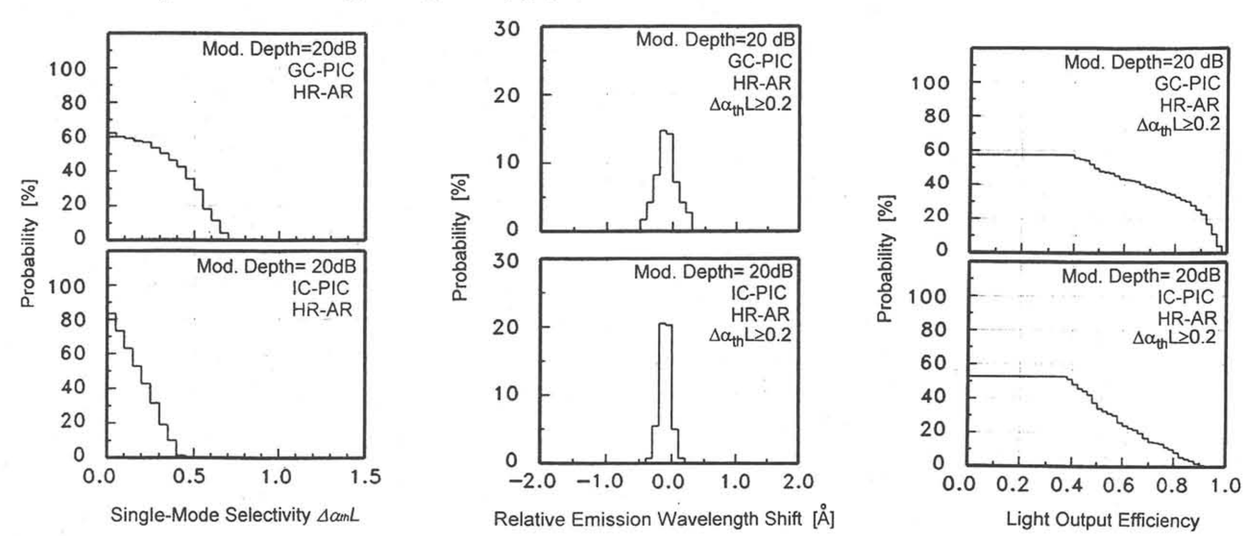

Fig.3 Results in the case of HR-AR coating: Probability of (a) single-mode selectivity, (b) wavelength shift, (c) light output efficiency

Table 1. Parameters and values used in the model

Name	*Symbol*	*Value*
laser section length	L	300 μm
modulator section Length	D	200 μm
reflectivity at laser- and modulator facet	R_L and R_M	1% (AR), 95% (HR)
reflectivity at left- and right-end of laser section	ρ_L and ρ_R	
coupling coefficient of GC-, QWS- and IC-PIC	κL	2+0.5j, 2, 2
linewidth enhancement factors of laser section	α_{HL}	1.5 (GC), 3 (IC and QWS)
linewidth enhancement factor of modulation section	α_{HM}	1
effective refractive index of laser and modulator section	N_{eL} and N_{em}	3.4
optical confinement factor of laser and modulator section	Γ_L and Γ_M	0.09
modulation depth in dB	M_d	

Conclusions

By statistical analysis of single-mode selectivity and chirping for IC-, QWS- and GC-PIC, we learn that the single-mode selectivity of GC-PIC is much greater than those of IC-PIC and QWS-PIC for both cases of AR-AR and HR-AR coating, although their modulation-induced wavelength shifts are similar. Furthermore, in the case of HR-AR coating, which is favorite for high power operation, GC-PIC shows much higher probability of single-mode operation than IC-PIC, while QWS-PIC can not work in this case. Considering the simplification of fabrication process of GC-DFB lasers, the GC-DFB laser integrated with electroabsorption modulator is very promising for optical communications.

References

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