EFFECT OF INJECTION CURRENT ON SOME STATIC CHARACHTRISTICS OF QUARTERLY WAVELENGTH-SHIFTED DISTRIBUTED FEEDBACK LASER DIODES

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Abstract:

Quarterly wavelength shifted (QWS) distributed feedback (DFB) laser structures are commonly referred to be associated with high mode selectivity, zero-frequency detuning and small threshold density. The present work shows the effect of the injection current on some static characteristics (photon density, carrier density , refractive index, gain margin and optical power) of QWS DFB laser diodes.

Keywords*: distributed feedback lasers, phase-shifted, laser diodes, single-mode gain.*

1.Introduction

Nowadays, distributed-feedback (DFB) lasers play a decisive role in high bit-rate optical communication systems, where they present single longitudinal mode (SLM) operation over the largest range of current injection[1]. According to the coupling wave theory [2], the electric field distribution along the cavity may be defined according to the amplitude of the two counter-running waves. They are coupled with each other by the corrugation, whose amplitude is defined by coupling coefficient. The laser emission features are seen to be strongly dependent on the conditions assumed at the cavity ends [3]. These are often coated with anti-reflective (AR) films. However, the symmetric structure of these mirrorless cavities is associated with double degenerate patterns, which prevent the single-lasing mode (SLM) operation [4].

To avoid the degradation of SLM operation with the current injection, various non-conventional DFB laser structures have been proposed [5], the most popular of them corresponding to the introduction of a phase-shift of $\pi/2$ placed in the middle of the corrugation cavity. It is known as the quarter wavelength-shifted (QWS) laser [6]. They presents the highest mode selectivity and the smallest current density, besides a zero-frequency detuning and small threshold current density for strong coupling coefficients. Fig. 1 shows a schematic representation of the laser structure under study.

Unfortunately this structure is usually associated with strong non-uniformities in the carrier and photon distributions along the cavity. This phenomenon is currently designated as the spatial hole-burning (SHB) effect and leads to a quick degradation of the laser performance in the high power regime [7].

The main goal of this work is to present the effect of the injection current on some static characteristics (photon density, carrier density , refractive index, gain margin and optical power) of QWS DFB LDs.

2.Theory

In the present analysis the calculations use the transfer matrix formulism[8]. To perform the transfer matrix method (TMM) based model laser threshold analysis, the laser cavity with length L is divided into M concatenated sections, which are identified by the constancy of its structural parameters. For the m-th section with length L_m, those structural parameters are: the corrugation period Λ_m, the amount of feedback per unit length K_m and the phase of the section grating with respect to the left side of the cavity Ω_m. Each section is described by two counter propagating electrical field waves described by their complex amplitudes $E_R(z)$ and $E_S(z)$, which allow the internal electrical field intensity E(t,z), to be determined according to[1](see Fig. 2)

$$E(t,z) \propto R\{[E_R(z)+E_S(z)]\exp(jwt)\} \quad (1)$$

where t is the time, z is the z-axis coordinate, $R\{[E_R(z)+E_S(z)].\exp(jwt)\}$ is the real part operator , $j=\sqrt{-1}$ and w is the field angular frequency. Equation (1) assumes that the longitudinal laser axis coincides with the z-axis. In the TMM the column matrices related to $E_R(z)$ and $E_S(z)$ components are considered for the same spatial position.

On the basis of the coupled wave equations, the transfer matrix for the m-th section of the one-dimensional DFB laser structure indicated in Fig. 2 is given by[1]:

$$T(z_{m+1}/z_m)=\begin{bmatrix} t_{11}^m & t_{12}^m \\ t_{21}^m & t_{22}^m \end{bmatrix}$$

(2)

and it links the column matrices related to the complex electric fields of the wave solutions at z_m and z_{m+1}

$$\begin{bmatrix} E_R(z_{m+1}) \\ E_S(z_{m+1}) \end{bmatrix}=T(z_{m+1}/z_m)\begin{bmatrix} E_R(z_m) \\ E_S(z_m) \end{bmatrix}$$

(3)

where t^m_{11} , t^m_{12} , t^m_{21} and t^m_{22} are given, respectively, by

$$t_{11}^m=\frac{\xi_m-\rho^2\xi^{-1}}{(1-\rho^2)\zeta_m};t_{12}^m=\frac{\rho(\xi_m-\xi_m^{-1})e^{-j\Omega_m}}{(1-\rho^2)\zeta_m}$$

$$t_{21}^m=\frac{\rho(\xi_m-\xi_m^{-1})e^{j\Omega_m}}{(1-\rho^2)\zeta_m^{-1}};t_{22}^m=-\frac{\rho^2\xi_m-\xi_m^{-1}}{(1-\rho^2)\zeta_m^{-1}}$$

(4)

with $\xi_m=e^{\gamma_m(z_{m+1}-z_m)}$ and $\zeta_m=e^{j\beta(z_{m+1}-z_m)}$

The propagation constant β_m , and the complex propagation constant γ_m

are given, respectively by

$$\beta_m=\frac{\pi}{\Lambda};\gamma_m=\sqrt{(\alpha-j\delta_m)^2-k_m^2}$$

(5)

where α and δ are the gain and detuning for the propagation modes respectively. The fields at ends of the cavity are connected by the elementary matrix product

$$\begin{bmatrix} E_R(L) \\ E_S(L) \end{bmatrix} = T^{Total} \begin{bmatrix} E_R(0) \\ E_S(0) \end{bmatrix}$$

(6)

where

$$T^{Total} = \prod_{m=M}^{1} T(z_{m+1}/z_m)$$

(7)

The formulation of the transfer matrices for other modified DFB laser structures are straightforward, as far as the changes are correctly translated to the metrical formalism. Namely, the inclusion of the phase-shift (PS) discontinuity φ , is given by the following matrix[9]

$$\begin{bmatrix} e^{j\varphi} & 0 \\ 0 & e^{-j\varphi} \end{bmatrix}$$

(8)

assuming that the field discontinuity is small along the plane of the PS. In this case the matrix (8) should be included in the matrix product T^{Total} indicated in equation (7) at the correspondent z position.

The oscillation condition corresponds to the vanishing of the incoming waves and it is determined by the following requirement

$$t_{22}^{Total}(\alpha, \delta) = 0$$

(9)

where t_{22}^{Total} is the fourth element of the matrix T^{Total} , given by equation(7). In QWS DFB, the spectrum is always symmetric with a solution at the Bragg wavelength. Whether this one is the main mode or not depends on the PS located[9]. For a grating with a first-order Bragg diffraction, the mode gain and the detuning can be expressed, respectively as:

$$\alpha(z) = \frac{\Gamma g(z) - \alpha_{loss}}{2}$$

(10)

$$\delta(z) = \frac{2\pi}{\lambda} n(z)(\frac{1}{\lambda} - \frac{1}{\lambda_B})$$
(11)

where Γ is the optical confinement factor, α_{loss} is the total loss, n(z) is the effective index, λ_B is the Bragg wavelength and λ is the lasing mode wavelength

When the injection current increases above the threshold current, the photon density S(z) and carrier density N(z) have nonuniform longitudinal distributions. Non-uniformities on photon and carrier distributions induce important changes in the refractive index according to:

$$\Delta n(z) = -\frac{Ba\lambda}{4\pi} \Delta N(z)$$
(12)

where B is the laser bandwidth and a is proportionality constant

The carrier density depends on the injection current I and the local optical field intensity $/E/^2$ according to[10]:

$$\frac{dN}{dt} = \frac{I}{qV} - \frac{N}{\tau(N)} - \frac{g(N)}{h\upsilon} / E /^2$$
(13)

where I is the current injection through the active region of volume V, $h\nu$ is the photon energy and q is the electron charge.

The normalized gain margin *ΔαL* corresponding to the difference between the normalized gain related to the lasing mode (LM) and the most probable side mode (SM) of DFB LD, i,e[6],

$$\Delta\alpha L = (\alpha L_{SM} - \alpha L_{LM})_{th}$$
(14)

The carrier lifetime τ(N) is given by:

$$\tau(N) = 1/(A + BN + CN^2)$$
(15)

where A the Spontaneous emission rate, B the raditive recombination coefficient and C the Auger recombination coefficient.

The total electric field is given by

$$/ E /^2 = / E_R(0) /^2 + / E_S(0) /^2$$
(16)

The local photon density inside the cavity can be expressed as

$$S = \frac{2\varepsilon_0 n(z) n_g \lambda}{hc} c_0^2 / E /^2$$
(17)

The total optical power at n_{th} facet can be determined as:

$$P_n = \frac{dwhc}{\Gamma\lambda} v_g S_n$$
(18)

where d and w are the thickness and width of the cavity layer, respectively.

3. RESULTS

The calculations have been performed for three values of injection current: $I=1.5I_{th}$, $I=2.5I_{th}$ and $I=3.5I_{th}$ for quarter wavelength-shifted (QWS) laser structure schematically shows in Fig.1. The photon density distribution in QWS laser cavity can be observed in Fig. 3 for different values of injection current ($I=1.5I_{th}$, $I=2.5I_{th}$ and $I=3.5I_{th}$). Fig. 4 shows the axial variations of carrier density as a function of normalized distance for different values of injection current ($I=1.5I_{th}$, $I=2.5I_{th}$ and $I=3.5I_{th}$). Fig. 5 shows the refractive index as a function of normalized distance for different values of injection current ($I=1.5I_{th}$, $I=2.5I_{th}$ and $I=3.5I_{th}$). Variation of the output power as a function of injection current is shown in Fig. 6. Finally Fig. 7 shows the variation of gain margin as a function of normalized current density.

4. DISCUSSION

- The axial-variation of photon density varies with the level of injection current; we can say that for each value of z the photon density is dependent to ($I-I_{th}$).
- The longitudinal distributions of photon density, carrier density and refractive index are symmetric around the mid point z=L/2.

- Normalized single mode gain difference (gain margin) decreases as the injection current increases.
- Output optical power along the laser cavity increases as the injection current density increases.

5. CONCLUSIONS

Effect of injection current for QWS DFB laser diodes are investigated using transfer matrix method. The variation of refractive index and carrier density is less sensitive to the level of injection current and this is explained by the fact that the carrier density is clamped when the diode is driven above threshold, while the photon density variation along the cavity length is high sensitive to the level of injection current, where we can see that for each point along the laser cavity the photon density is proportional to ΔI (i.e, $\Delta I = I - I_{th}$). Normalized single mode gain difference (gain margin) decreases as the injection current increases duo to the spatial-hole burning (SHB). Optical power is proportional to injection current density.

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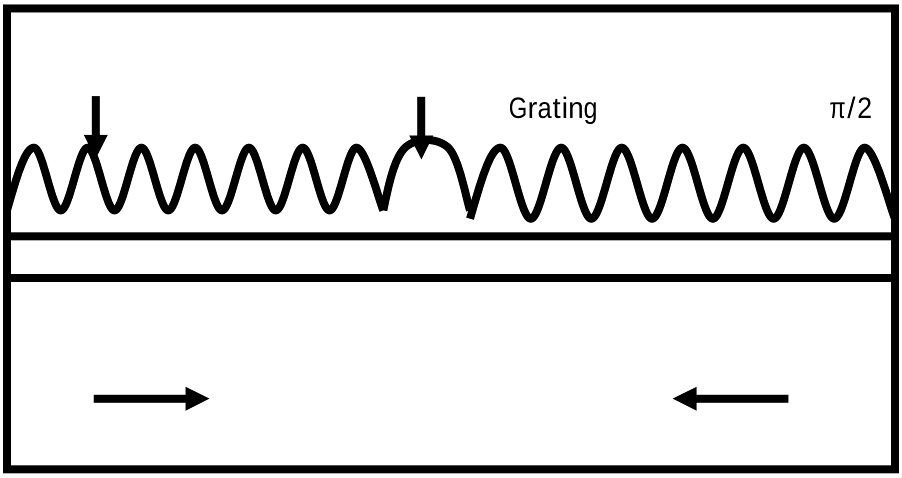

Fig.1 Schematic diagram of QWS DFB structure

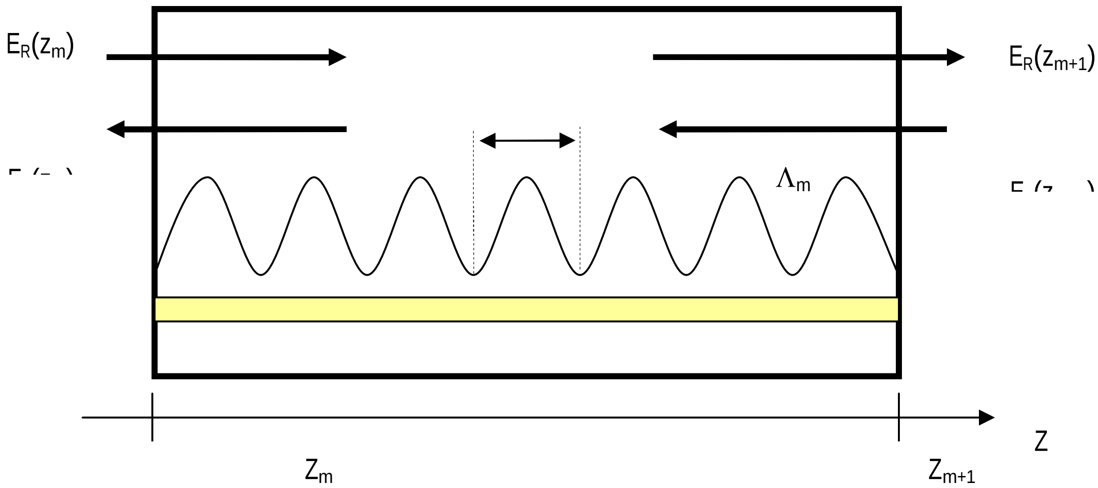

Fig. 2 A simplified Schematic diagram for a one-dimensional DFB laser structure section, placed between $z=z_m$ and $z=z_{m+1}$

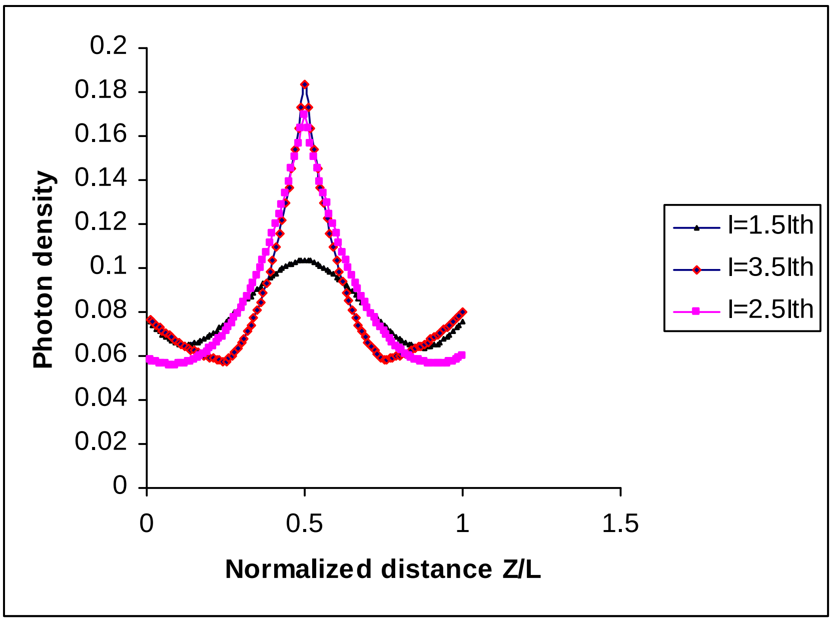

Fig.3 Photon density versus normalized distance for QWS DFB LD for different values of injection current

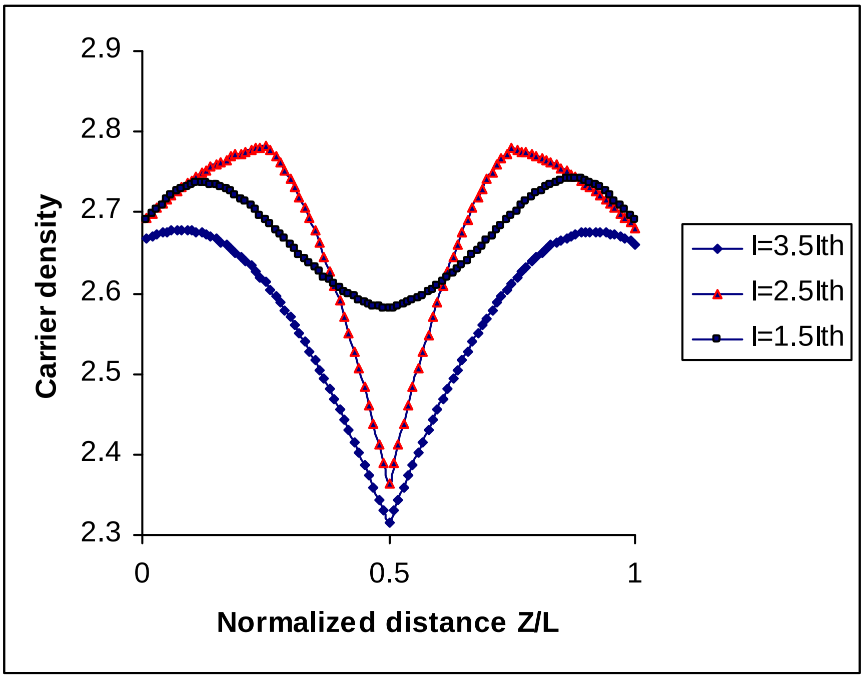

Fig.4 Carrier density versus normalized distance for QWS DFB LD for different values of injection current

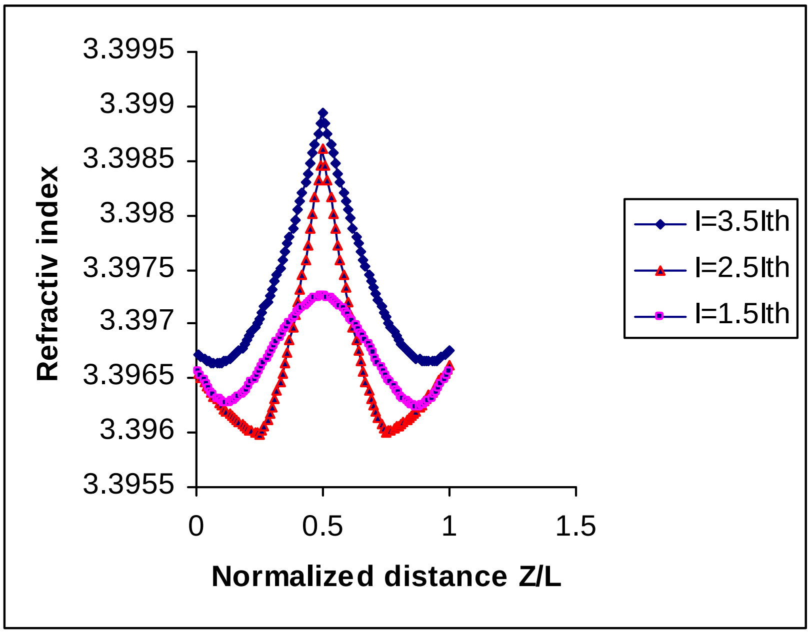

Fig.5 Refractive index versus normalized distance for QWS DFB LD for different values of injection current

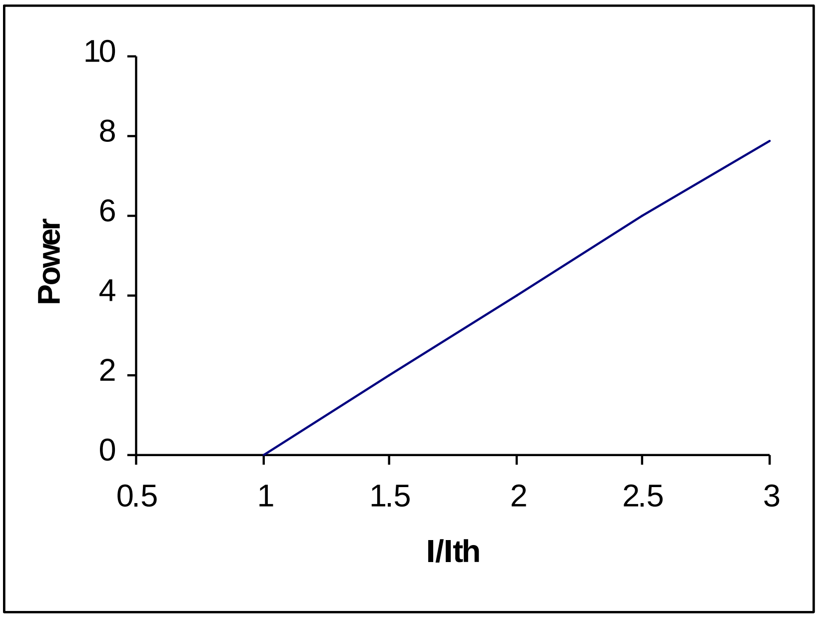

Fig. 6 Variation of the output optical power as a function of injection current

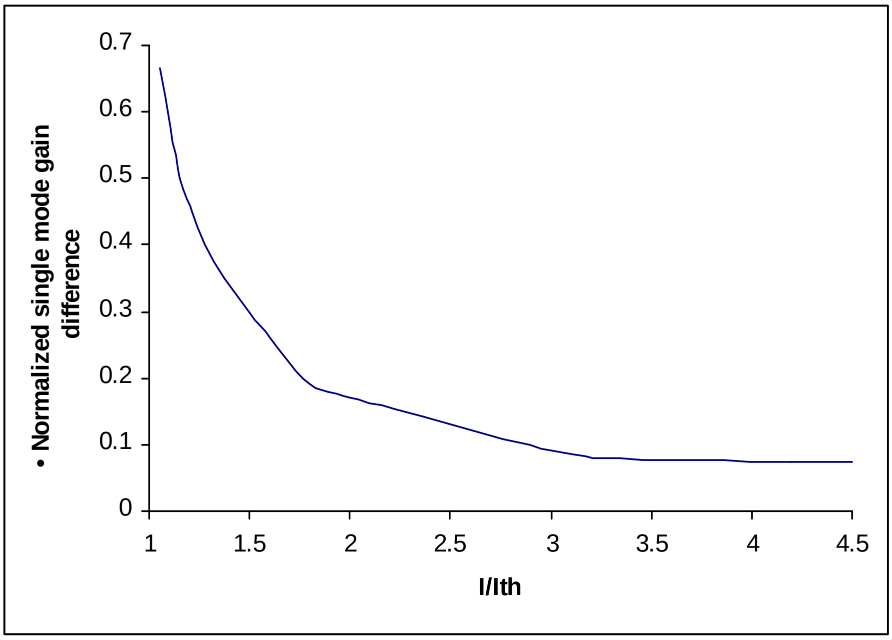

Fig. 7 variation of Normalized single mode deference (gain margin) as a function of normalized current density.