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Effect of Injection Current on the Normalized Gain Amplitude, Normalized Detuning Coefficient and the Output Power of Axial Distributed Coupling Coefficient Distributed Feedback Laser Diode (ADCC–DFB–LD)

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Abstract

An axial distributed coupling coefficient (ADCC) distributed feedback (DFB) laser diode (LD) in which the coupling coefficient (K) has been distributed axially on both sides of the phase shift region. The effects of injection current on the normalized gain amplitude, normalized detuning coefficient and the output power are investigated using transfer matrix method. The results show that the ADCC DFB laser exhibits high single mode stability at different injection currents above threshold and the main mode operates close to Bragg wavelength at high injected current. For different injection currents the optical output power has been increased with decreased the coupling coefficient.

Keywords: Laser diode; Distributed feedback; Optical communication

تاثير تيار الحقن على مقدار التحصيل ومعامل الانحراف والطاقة البصرية الكلية لتركيب ليزر الشبه الموصل ذو التغذية الاسترجاعية الموزعة وتوزيع محوري لمعامل الترابط (ADCC DFB LD)

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الخلاصة

ليزرات التغذية الاسترجاعية الموزعة (DFB) واحد تراكيبها هو ليزر التغذية الاستراجاعية الموزعة ذو التوزيع المحوري لمعامل الترابط (ADCC DFB) حيث يتوزع محوريا على جانبي منطقة قلب الطور (PS) . في هذا العمل تم مناقشة تاثيرات تيار الحقن على مقدار التحصيل ومعامل الانحراف وكذلك الطاقة البصرية الكلية وعلاقتها بمعامل الترابط باستخدام طريقة المصفوفة المنتقلة (TMM) . حيث اظهرت

النتائج ان تركيب ADCC DFB يظهر ثبات عالي في تحصيل النمط المنفرد (SM) ولمدى واسع من تيار الحقن وتكون قريبة من طول موجة براغ في تيار الحقن العالي .وكذلك تاثير تيار الحقن على الطاقة الكلية لقيم مختلف من معامل الترابط K.

1. Introduction

Distributed feedback (DFB) semiconductor lasers have attracted considerable attention recently because of their potential application in optical communication systems [1].The previous works agree with the influence of corrugation properties and coupling coefficient on the selectivity of single mode operation which is effected by the spatial hole-burning (SHB). For this purpose and in order to decrease the effect of SHB several DFB laser structures are proposed: quarterly wavelength (QW-DFB LD) with uniform coupling coefficient around the phase shift [2], quarterly wavelength distributed coupling coefficient (QW-DCC-DFB LD) [3] and the three phase-shift (3PS-DFB LD) [4] etc..

Between the uniform coupling coefficient distribution and multi-section with different coupling coefficient an axial distribution of coupling coefficient distributed feedback laser diode (ADCC-DFB LD) was proposed depending on the differential distribution of coupling coefficient along the laser axis [5]. In this laser the coupling coefficient distributed axially along the laser cavity around the phase shift region that is introduced at the laser center figure (1).

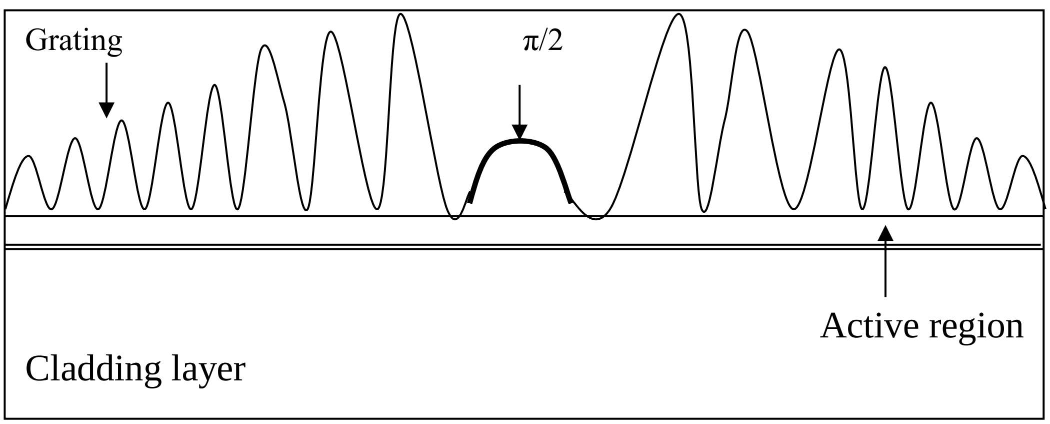

Fig.1 Block diagram of ADD-DFB LD

2. The Model

The model has been used in the present work describes the laser cavity (with length L) by a finite number of subsections, each one is defined by complex matrix relating the two counter-running waves due to the coupled mode equations [6]. In each subsection all the laser parameters are kept constant also the reflectivity at the end facets suppose to be zero. The analysis followed in this work called transfer matrix method (TMM) where the whole matrix that describes the field propagation inside the laser cavity is (M) and it is a 2x2 complex matrix which is the product of successive matrices related to each subsection, as follows[7]:

$$\begin{bmatrix} u_n \\ \upsilon_n \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \begin{bmatrix} u_0 \\ \upsilon_0 \end{bmatrix} = [M] \begin{bmatrix} u_0 \\ \upsilon_0 \end{bmatrix} \qquad (1)$$

where u(z) and ν(z) correspond to the right and left-going waves receptivity.

$$M = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} = \prod_{i=s}^{1} M^{i} \tag{2}$$

where

$$M^{i} = \begin{bmatrix} m^{i}{}_{11} & m^{i}{}_{12} \\ m^{i}{}_{21} & m^{i}{}_{22} \end{bmatrix} \tag{3}$$

where M^i is the transfer matrix of the i^{th} subsection having length: $L_i=z_{i+1}-z_i$. the matrix elements M^i_{kl}(k=1,2 and l=1,2) are[8]:

$$M^{i}_{11} = \left[(e^{\gamma_i L_i} - \Gamma_i^2 e^{-\gamma_i L_i})/(1-\Gamma_i^2)\right] \tag{4a}$$

$$M^{i}_{12} = \left[-\Gamma_i \, (e^{\gamma_i L_i} - e^{-\gamma_i L_i})/(1-\Gamma_i^2)\right] \tag{4b}$$

$$M^{i}_{21} = -M^{i}_{12} \tag{4c}$$

$$M^{i}_{22} = \left[(e^{-\gamma_i L_i} - \Gamma_i^2 e^{\gamma_i L_i})/(1-\Gamma_i^2\right] \tag{4d}$$

where

$$\gamma_i = (\alpha_i^2 - j\delta_i^2) + K_i^2 \tag{٥}$$

$$\Gamma_i = \left[jK_i / (\alpha_i^2 - j\delta_i^2) + K_i^2\right] \tag{6}$$

where α_i is the gain amplitude, δ_i is the mode detuning from Bragg condition, Γ_i is the reflectivity at the grating, γ_i is the wave propagation constant, K_i is the coupling coefficient, z is a point on the cavity axis and s is the total number of subsections[8].

Generally in phase-shifted PS-DFB lasers the matrix [M] contains the partial matrix related to the phase-shift interface [M_Φ]. This one is described by the angle Φ (for QWS-DFB $\Phi=\pi/2$). Then the transfer matrix associated to a phase-shift located at the z plane of the corrugation is given by [9]:

$$\begin{bmatrix} u(z^+) \\ \upsilon(z^+) \end{bmatrix} = \left[M_\phi\right] \begin{bmatrix} u(z^-) \\ \upsilon(z_-) \end{bmatrix} = \begin{bmatrix} e^{j\phi} & 0 \\ 0 & e^{-j\phi} \end{bmatrix} \begin{bmatrix} u(z^-) \\ \upsilon(z^-) \end{bmatrix} \tag{7}$$

The normalized gain amplitude (gain margin) αL corresponding to the difference between the normalized gain related to the lasing mode (LM) and the most probable side mode (SM) of DFB LD [10], i.e

$$\Delta\alpha L = (\alpha L_{SM} - \alpha L_{LM}) \tag{8}$$

Also the field non- uniformity is related to a parameter called flatness given by[11]:

$$F = \frac{1}{L}\int_0^L \left[\frac{I(z)}{I_{av}} - 1\right]^2 dz \tag{9}$$

The optical output power can be expressed as [12]:

$$P = \frac{dw}{\Omega} v_g \frac{hc}{\lambda} S \qquad (10)$$

Where d and w are the thickness and width of the active layer respectively, Ω is the optical confinement factor, v_g is the group velocity, h is the Planck's constant and c is the free space velocity and S is the photon density inside the cavity.

3. Results

For ADCC-DFB structure, the effect of injection current on the normalized gain amplitude is shown in figure (2). Figure (2) shows the results of the lasing mode and the non lasing side modes, it's clear that (αL) value of each mode varies in different way. When the biasing current increases from the threshold value the amplitude gain for both lasing mode and side mode (+1) is slowly varying between $I/I_{th}=1$ and $I/I_{th}=1.5$ and continues constant to $I/I_{th}=4$ the effect of injection current on the normalized detuning coefficient is plotted in figure (3) where the normalized detuning coefficient (δL) versus the normalized injection current I/I_{th} is shown. It is obvious that no change in the wavelength with increasing biasing current and the lasing mode is found closer to the gain peak.
The output power versus normalized current is shown in figure (4) for different K= (10-30) cm^{-1}.

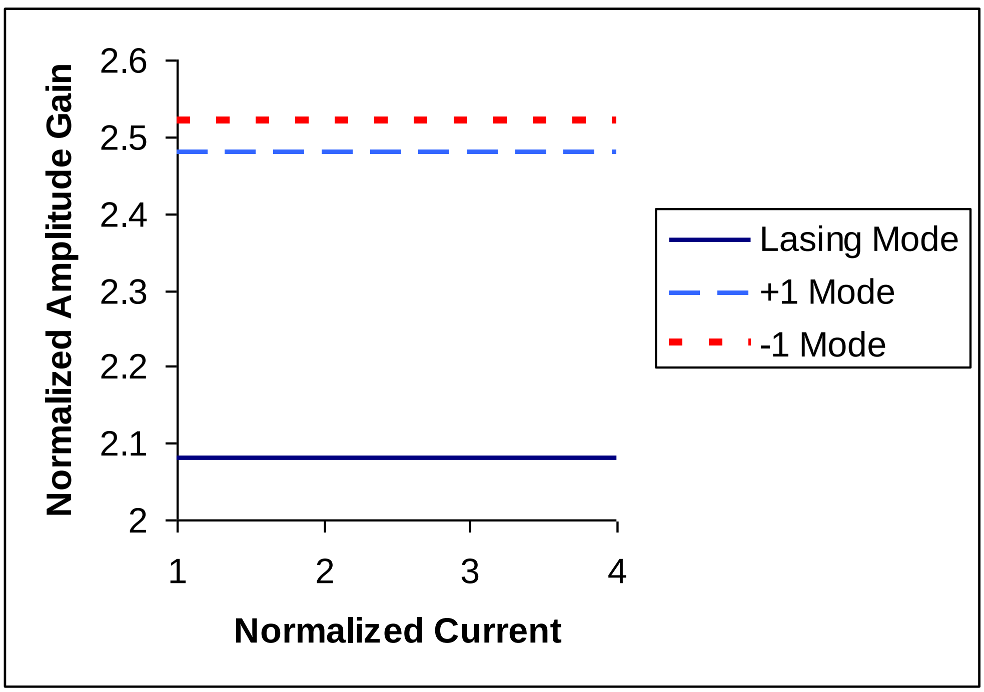

Fig.2 Normalized amplitude gain αL For ADD-DFB laser structure versus the normalized injection current (lasing mode and nonlasing side mode ±1)

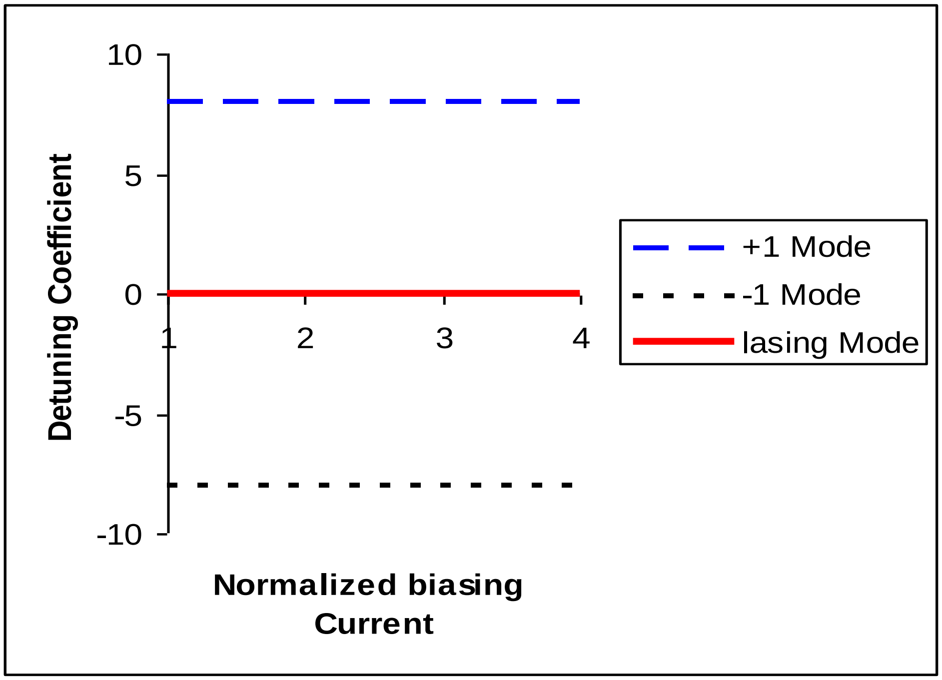

Fig.3 Normalized detuning coefficient δL For ADD-DFB laser structure versus the normalized injection current (lasing mode and nonlasing side mode ±1)

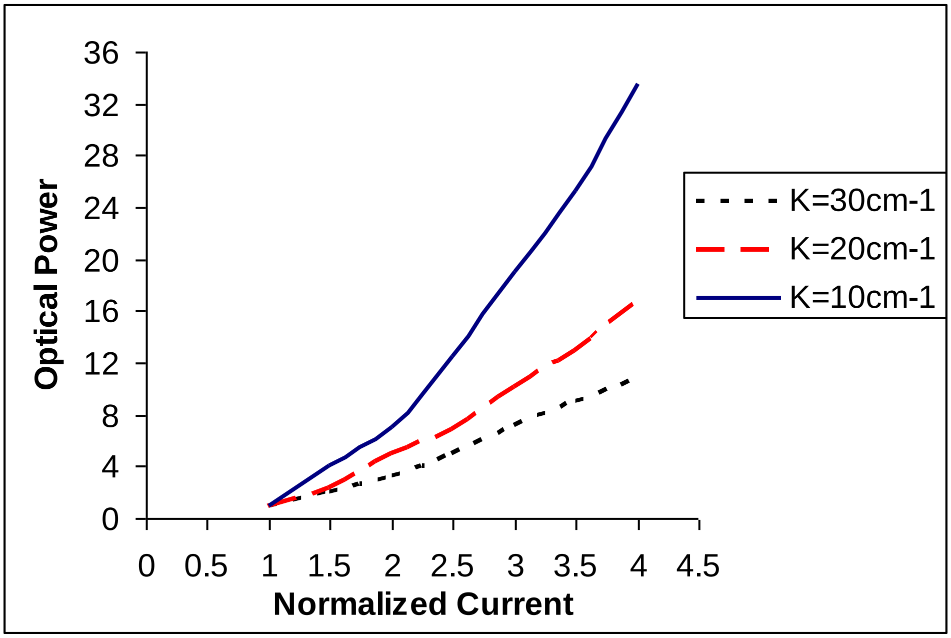

Fig.4 Optical output power for ADD-DFB laser structure with different K

4. Conclusions

A numerical model based on matrix techniques has been implemented to study the effect of injection current on the normalized gain amplitude, the normalized detuning coefficient and the output power. The results show that the high single mode stability occurred at different injected currents above threshold with slowly varying for the normalized gain amplitude of the main mode, the high injected current above threshold keeps the main mode operates close to the Bragg wavelength and finally the optical output power for different injected currents increases with decreasing the coupling coefficient due to the SHB effect above threshold.

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