Dynamic Response of Buried Heterostructure and Stripe Geometry $\lambda/4$ DFB Semiconductor Lasers

Y.L. Ling, S.F. Yu and E.H. Li

Department of Electrical and Electronic Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong

Abstract A comparison between different lateral confinement structures in DFB laser is analyzed with identical material parameters and structure in transverse and longitudinal directions. Results show that stripe geometry DFB lasers offer better dynamic response than buried heterostructure DFB lasers.

It was indicated that carrier diffusion has significant influence on the damping rate, especially for stripe geometry lasers [1] which suffer high damping of relaxation oscillations. However, this may has a positive effect on the dynamic response of the devices. According to rate equation analysis of Fabry Perot laser, the relaxation oscillation frequency, ω_r, and damping rate, γ, may be related as $\gamma=K\omega_r^2 + 1/\tau_c$, where τ_c is the carrier lifetime and K is the damping factor [2]. This implies that the relaxation oscillation frequency of stripe geometry devices may be larger, due to a higher damping, than the other laser structures. Furthermore, it is expected that the dynamic response of DFB lasers are different to Fabry Perot lasers because of the longitudinal spatial hole burning effect. In this paper, we compare the small signal dynamic response of buried heterostructure and stripe geometry in $\lambda/4$ DFB laser structure including the effects of carrier spatial hole burning and time dependent lateral field profile.

Figure 1 shows the end view of buried heterostructure and stripe geometry 1.55μm InGaAsP DFB lasers with second-order grating. We considered the devices with $\lambda/4$ phase shifted and both facets anti-reflection coated. The cavity length is 400μm long and the width of the active region is 5μm wide. The differential gain in active and absorption regions and the corresponding transparent carrier densities are given as $3.0\times10^{-16}cm^2$ and $1.2\times10^{-15}cm^2$, $1.5\times10^{18}cm^{-3}$ and $1.7\times10^{18}cm^{-3}$, respectively. The carrier lifetime is equal to 3ns and the effective diffusion constant is set to $8.5s^{-1}cm^2$. The gain compression factor is $2\times10^{-17}cm^3$. For second order grating, the radiation loss coefficient is equal to $7cm^{-1}$. The total absorption and scattering losses in the waveguide is $20cm^{-1}$ and the linewidth enhancement factor is 4.86.

Figure 2 shows the small signal modulation response of both buried heterostructure and stripe geometry in $\lambda/4$ DFB lasers with κ=20 and $50cm^{-1}$, respectively. The lasers are initially biased to give a steady state output level (approximately 3.4mW), the AM and FM response are estimated from the impulse response of the lasers [3,4]. It is shown in figure 2(a) that the stripe geometry lasers have larger relaxation oscillation frequency and wider AM bandwidth than buried

heterostructure devices especially for large κ. The AM bandwidth is enhanced by more than 3GHz for devices with κ=50cm^{-1}. The increment of AM bandwidth has a value close to that using anti-phase complex coupled structure [5]. The FM response are shown in figure 2(b). It is noted that the FM response is not degraded by using stripe geometry structure.

The enhancement of relaxation oscillation frequency of stripe geometry semiconductor lasers can be understood from the modified expression of relaxation oscillation frequency [6], ω_f^2,

$$\omega_f^2 = \frac{\langle P_o \rangle}{\tau_p}\left(\Gamma_o \frac{\partial G_{eff}}{\partial N} + G_o \frac{\partial \Gamma_{eff}}{\partial N}\right) \tag{1}$$

where $\langle P_o \rangle$, G_o and Γ_o are the average photon density, material gain and confinement factor at steady state, respectively. $\partial G_{eff} / \partial N$ and $\partial \Gamma_{eff} / \partial N$ are the effective differential gain and differential confinement factor. τ_p is the effective photon lifetime.

In strong index guided devices, the carrier induced refractive index change in the active region has almost negligible effect on the optical field profile and $\partial \Gamma_{eff} / \partial N$ is approximately equal to zero. However, in gain guided structure, the confinement factor is increased with the carrier concentration and therefore $\partial \Gamma_{eff} / \partial N$ is positive. Hence, the time dependent lateral optical field has no effect on buried heterostructure lasers and a positive effect (increase ω_f) on stripe geometry lasers.

The relaxation oscillation frequency of DFB lasers is also affected by the cavity loss ($=1/\tau_p$) and the total photon energy, $\langle P_o \rangle$, stored inside the active region [3]. These parameters are influenced by spatial hole burning. It is noted that $\lambda/4$ devices with high κL (>2.0) have relatively large relaxation oscillation frequency [3] because the total energy stored in large κL device is relatively high and can compensate the variation of cavity loss ($1/\tau_p$ decreases as κL increases for $\lambda/4$ devices). In gain guided devices, this situation will be more apparent because the existence of $\partial \Gamma_{eff} / \partial N$ in equation(1) enhances the spatial hole burning effect.

The magnitude of $\partial \Gamma_{eff} / \partial N$ is a function of stripe width and the optimized AM bandwidth can be obtained with a suitable stripe width. The relation between $\partial \Gamma_{eff} / \partial N$ and the stripe width is shown in figure 3. It is shown that the value of $\partial \Gamma_{eff} / \partial N$ is increased with the reduction of stripe width. However, device with narrow stripe width is not desired because of high threshold current and self-sustained pulsation.

In conclusion, the results show that the small signal AM bandwidth of $\lambda/4$ DFB lasers can be enhanced by using stripe geometry structure. This is because the time dependent lateral optical field profile (i.e. $\partial \Gamma_{eff} / \partial N$) enhances the relaxation oscillation frequency of stripe geometry lasers.

In addition, the modulation bandwidth can be further increased by using devices with large κ (>50cm^{-1}). The total AM bandwidth can be increased by more than 3GHz.

References

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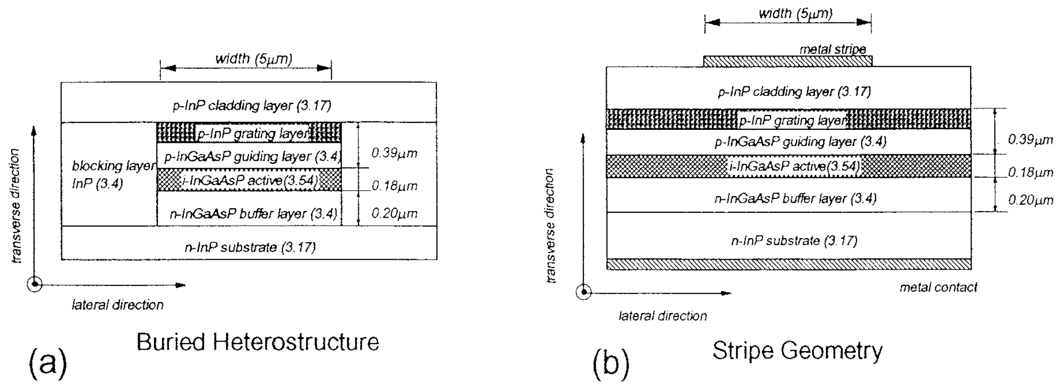

Figure 1 The cross section of the DFB lasers with (a) buried heterostructure and (b) stripe geometry.

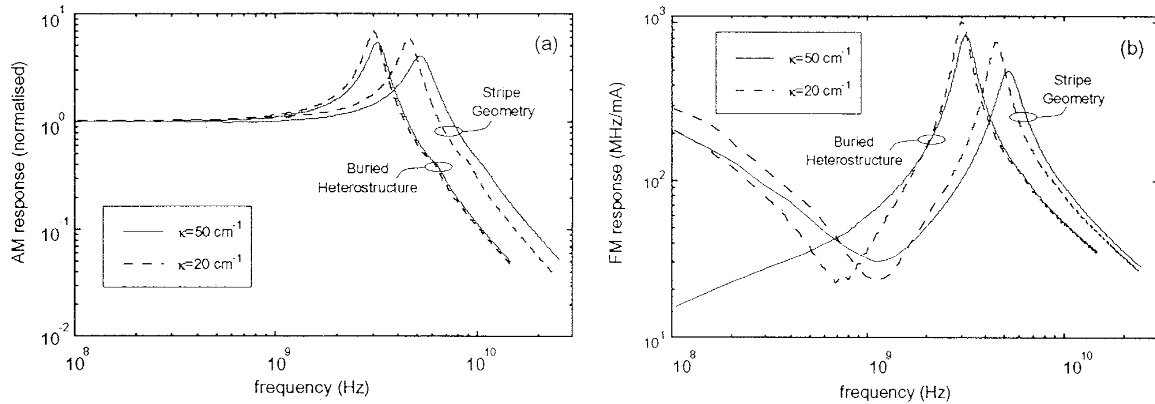

Figure 2 Small signal dynamic responses of buried heterostructure and stripe geometry λ/4 DFB lasers. (a) Normalised AM response and (b) FM response.

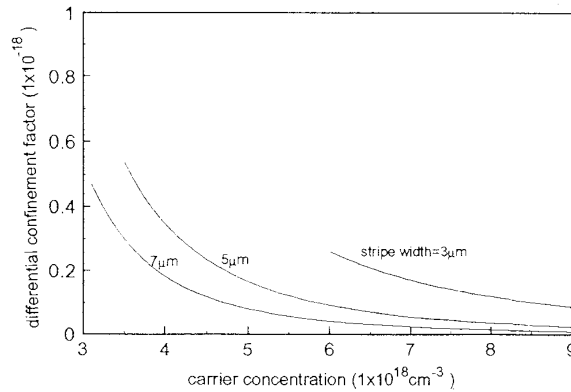

Figure 3 Calculated differential optical confinement factor as a function of carrier concentration and stripe width.