Influence of Nonlinear Gain on Direct Modulation Characteristics of 2s-DBR Lasers: Numerical Study

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Abstract — ***A theoretical study of effect of nonlinear gain on the direct modulation characteristics of two section DBR (2s-DBR) lasers is presented. Based on multimode rate equations with nonlinear gain terms, simulations are performed. The nonlinear gain is found to have influences on the direct modulation characteristics of the 2s-DBR lasers, including the carrier photon resonance (CPR) and the photon photon resonance (PPR).******Keywords—Direct modulation, nonlinear gain, SMSR, multimode rate equations***

I. Introduction

High speed directly modulated semiconductor lasers are of great interests in optical access networks. According to IEEE 802.3ca task force, the direct modulation speed is supposed to reach 25Gbps. Since the modulation speed of conventional laser is restricted by the CPR, many researchers take advantages of the PPR to improve the modulation characteristics of lasers, such as distributed-feedback (DFB) lasers with passive feedback [1], DBR lasers with an additional PPR mode [2] and multiple mode interference (MMI) laser [3]. The PPR effect requires two spectrally neighbored longitudinal modes, the frequency interval of which is about tens of gigahertz. In this case, impact of nonlinear gain is becoming significant and should be taken in to account [4]. Different from the modes competition or other spectrally symmetrical effects, nonlinear gain is a kind of asymmetrical effect. When two spectrally neighbored longitudinal mode become close to each other, gain of the longer wavelength mode will be increased while that of the shorter one is suppressed. So under certain conditions, the longer wavelength mode will be enhanced even if it suffers from larger loss than the shorter one, leading different behaviors from conventional laser.

In this paper, multimode rate equations with nonlinear gain terms are developed to study modulation characteristics of a 2s-DBR laser shown in Fig.1. Side mode suppression ratio (SMSR) with different wavelength interval and loss ratio of the two modes is first calculated, and small signal response under different SMSR are than simulated to study the influence of nonlinear gain on behavior of the laser.

Fig. 1. Structure of the two section DBR laser

II. Simulation Model

According to [4], the beating of two modes leads to perturbations of carrier density and media polarization, thus introducing the nonlinear gain effects. Based on two-mode rate equations, taking into account the nonlinear gain terms [5], we can rewrite the rate equations as follows:

$$\frac{dN}{dt}=\frac{I}{qV}-\frac{N}{\tau_n}-c_g\frac{g_N(N-N_{tr})}{1+\sum_{i,j}\varepsilon_i S_j}\left|\vec{E}_1+\vec{E}_2\right|^2-c_g\sum_i g_{NLi}S_i \tag{1}$$

$$\frac{dS_i}{dt}=\Gamma\left(c_g\frac{g_N(N-N_{tr})}{1+\sum_{i,j}\varepsilon_i S_j}+c_g g_{NLi}\right)S_i-\frac{S_i}{\tau_{pi}}+\Gamma\beta S_i \quad (i=1,2) \tag{2}$$

with $\vec{E}_{1,2}(t,\vec{r})=\varphi(x,y,t)\vec{u}(t,z)e^{-j\omega_{1,2}t}$ and $S_{1,2}\propto\left|\vec{E}_{1,2}\right|^2$,

where I is the injection current, V is the volume of active layer, q is the unit charge, c_g is the group velocity, N and S are carrier and photon density, respectively, τ_n and τ_p are carrier and photon lifetime, Γ is the optical field confinement factor, β is the spontaneous emission factor, and g_{NL} ,the nonlinear gain, can be written as:

$$g_{NLi}\approx\frac{\omega_i g_N(N-N_{tr})n_{eff}\sqrt{S_1S_2}}{1+\sum_{i,j}\varepsilon_i S_j}\frac{dn}{dN}\frac{1}{\Delta\Omega_{ij}} \tag{3}$$

where g_N is the differential gain, N_{tr} is the transparency carrier density, dn/dN accounts for the refractive index variation with carrier density, $\Delta\Omega_{ij}=\omega_i-\omega_j$ is the angular frequency spacing of the two modes, and ε the gain suppression factor, including cross-gain suppression factor and self-gain suppression factor.

The equation (3) indicates that the nonlinear gain is not only dependent on $\Delta\Omega_{12}$, but also on photon density of the two modes. And g_{NL} will become negative for the shorter wavelength mode.

The classical 4th Runge-Kutta method is used to solve the equation(1)-(2) for obtaining static and dynamic response of the laser.

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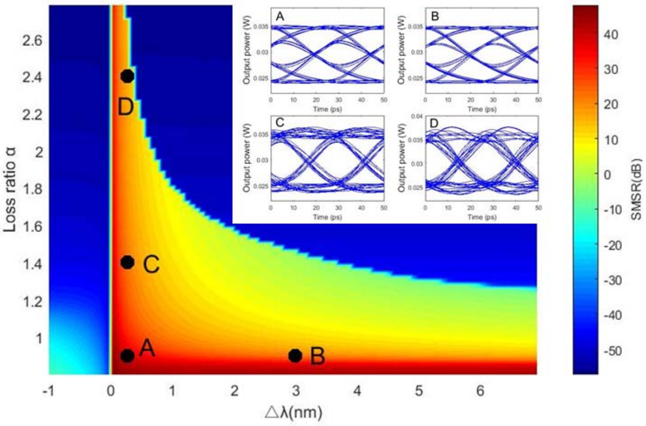

Fig. 2 SMSR for different wavelength interval and loss ratio. Insert : eye diagrams for four cases: 1) case A, Δλ=0.28nm, α=0.9, SMSR=38.34dB; 2) case B, Δλ=3nm, α=0.9, SMSR=22.19dB; case C, Δλ=0.28nm, α=1.4, SMSR=21.77dB; 4) case D, Δλ=0.28nm, α=2.4, SMSR=15.83dB

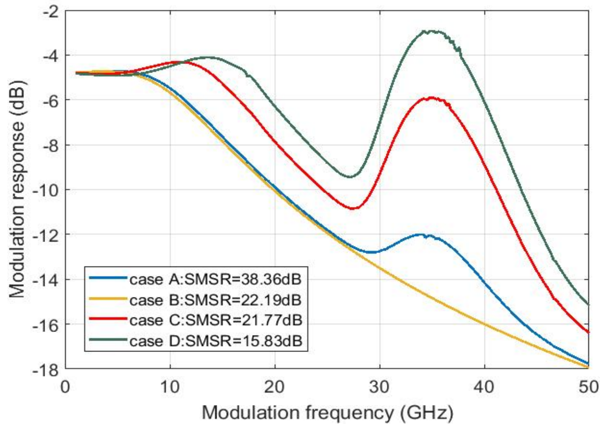

Fig. 3. Small signal response for different cases

III. RESULTS AND DISCUSSION

In this simulation there are only two main mode in consideration. The bias current I_{bias} is set to be 80mA. The modulation amplitude is 30mA when calculate eye diagram.

SMSR for different wavelength interval $\Delta\lambda=\lambda_1-\lambda_2$ and loss ratio ($\alpha=\alpha_{loss1}/\alpha_{loss2}$) is calculated and shown in Fig.2, where the wavelength of mode 1 is fixed at 1550nm. By changing the bias current and parameters of the grating section, loss ratio and wavelength interval of the two modes will also change, thus leading to different SMSR ($SMSR = 10\log 10\left(P_1 / P_2\right)$, P_1 and P_2 are output power of mode 1 and mode 2 respectively). Because of nonlinear gain ,there is a region in which the SMSR keeps positive even if the loss of mode 1 is much larger than mode 2, but the SMSR goes down quickly to negative values as Δλ increases, corresponding to the fact that nonlinear gain is a asymmetric effect, and has a significant impact only when the Δλ is small enough.

Eye diagrams at 40 Gbit/s for different cases are given in the insert of Fig.2. Clearly, the Q-factor is improved from case A to case D as SMSR decreases. The eye diagrams in case C and D are almost open compared to that in case A and B. Similar trends have been reported with experiment results in [6]. Noticed that without PPR effect, the eye diagram in case B is much more worse than case C while its SMSR is close to the latter.

In order to explore influence of nonlinear gain on small signal response, a sinusoidal perturbation is added into the active section. Simulation results are presented in Fig.3. The second resonance peaks in case A, C and D are due to the PPR effect ($f_{ppr}=\Delta\Omega_{12}/2\pi$) and the peak increases rapidly as SMSR decreases. Meanwhile, the frequency and intensity of CPR (at lower frequency , < 25GHz) is also enhanced, especially for case C and case D. Obviously, we can change parameters of the laser to get an optimal SMSR to improve the CPR and PPR, as well as dynamic characteristic of the laser. Since f_{ppr} in case B is far from CPR frequency, we cannot observe the second resonance peak in this case when modulation frequency is less than 50GHz.

IV. CONCLUSIONS

In this paper, the laser model based on multimode rate equations with nonlinear gain terms has been developed to investigate modulation characteristics of the two section DBR laser. Results indicate that nonlinear gain has great impact on SMSR, and thus changing intensity of both CPR and PPR. By choosing proper SMSR, it is possible to improve modulation characteristics for high speed applications.

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