Simulation of Modulation Response of 3s-DBR Lasers

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***Abstract*—Modulation responses of a 3s-DBR laser are studied by numerical simulations, which are based on calculation of transient impulse response of the device with the developed TWDM model. Simulated results indicate that this method provides an effective way to estimate modulation bandwidth of the 3s-DBR laser.**

***Keywords*— DBR laser; modulation bandwidth; impulse response;**

I. Introduction

The time- and wavelength-division multiplexed passive optical network (TWDM-PON) has been chosen as a primary solution to the next-generation PON stage 2 (NG-PON2) [1]. As shown in Fig.1, multi-wavelength will be used for both upstream and downstream at this TWDM-PON system. Compared with former PON technologies such as G-PON and XG-PON, the tunable transceivers employed at optical network unit (ONU) are the unique components. The transmitter should be wavelength tunable to meet the requirement of tunability of upstream wavelengths. Monolithic integrated three sections distributed Bragg reflector (3s-DBR) lasers are good compromise due to their relatively high output power, wide tuning range and low manufacturing costs when compared to other tunable lasers. To handle the dramatically increasing internet traffic in access network, downstream and upstream bitrates are growing and high speed directly modulated 3s-DBR lasers are expected.

Modulation bandwidth of the lasers is key characteristics for high speed directly modulated lasers. Normally modulation bandwidth of the laser can be calculated by small-signal analysis by deriving modulation transfer function from the rate equation [2]. Alternatively, modulation response of the lasers can be obtained by applying a small sinusoidal perturbation to a time domain simulation model [3].

A novel method by using the impulse response was first proposed by Lowery to study enhanced maximum modulation response of a complex-coupled DFB laser [4], where a current impulse was applied to the transmission-line laser model (TLLM) and then modulation responses of the DFB laser were obtained by fast Fourier transforming (FFT) of the impulse response. Since the impulse is a superposition of all frequency components in frequency domain, the impulse response could completely characterize the dynamic characteristics of the laser [5].

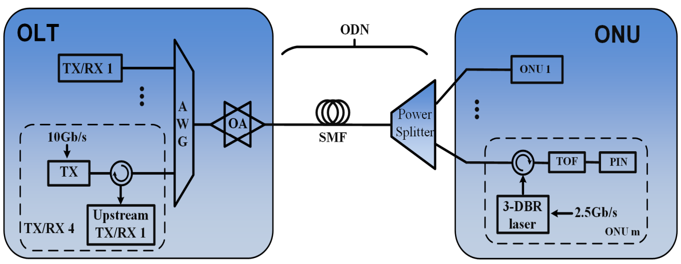

Fig. 1.Architecture of an asymmetric TWDM-PON system

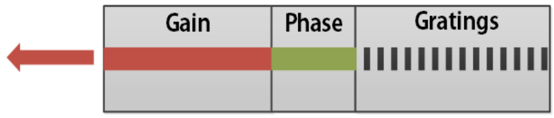

Fig. 2.Structure of the 3s-DBR laser

In this paper, we extended this method to study modulation response of a 3s-DBR laser. Based on the time domain travelling-wave (TDTW) method, a theoretical model of the 3s-DBR laser is first developed and then transient impulse responses of the device are calculated. Results are compared to eye-diagrams at different modulation rates, which indicate that the impulse response method combining with the TDTW model provides an effective way to estimate modulation bandwidth of the 3s-DBR laser.

II. Laser Structure and Simulation Model

As shown in Fig.2, the 3s-DBR laser consists of the gain section, the phase section and the grating section. The length of the three sections is $300\mu m$、$100\mu m$ and $300\mu m$, respectively. Other parameters of the device are similar with ones in [6].

Based on time domain travelling-wave model (TDTW), a theoretical model of the 3s-DBR laser is developed [6]. The coupled equations are solved first in the time domain by a first-order difference approximation to the partial differential, and then we can obtain the traveling wave formula as follows:

$$\begin{aligned} \frac{1}{v_g}\frac{\partial F}{\partial t}+\frac{\partial F}{\partial z} &= (\Gamma g-\alpha-j\delta)F+j\kappa R+S_F \\ \frac{1}{v_g}\frac{\partial R}{\partial t}-\frac{\partial R}{\partial z} &= (\Gamma g-\alpha-j\delta)R+j\kappa F+S_R \end{aligned} \tag{1}$$

where v_g is the group velocity, F and R represent the forward and reverse waves in the waveguide respectively. Γ is the optical field confinement, α is the internal loss, g is the optical field gain, and κ is the coupling efficient of the gratings. δ is the detuning factor which is given by

$$\delta=\frac{\omega_0}{c}n_{eff}-\frac{\pi}{\Lambda} \tag{2}$$

where ω_0 is the reference frequency, c is the speed of light in vacuum, n_{eff} is the effective refractive index, and Λ is the grating period. S_F and S_R are the spontaneous noise coupled into the forward and reverse fields.

To calculate the modulation response, an impulse is then input to the above model. After fast Fourier transforming, the frequency response can be obtained. When the amplitude of the impulse is small enough, frequency response is approximated as small-signal modulation response, since the impulse is a superposition of all frequency components in frequency domain.

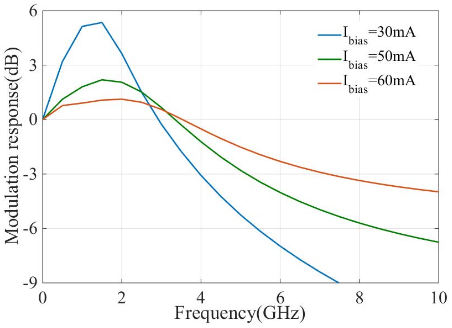

Fig. 3. Modulation response at different biases

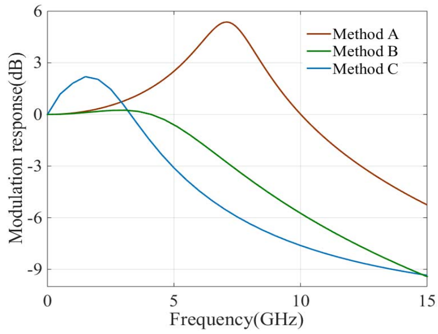

Fig. 4. Modulation response calculated by different methods.

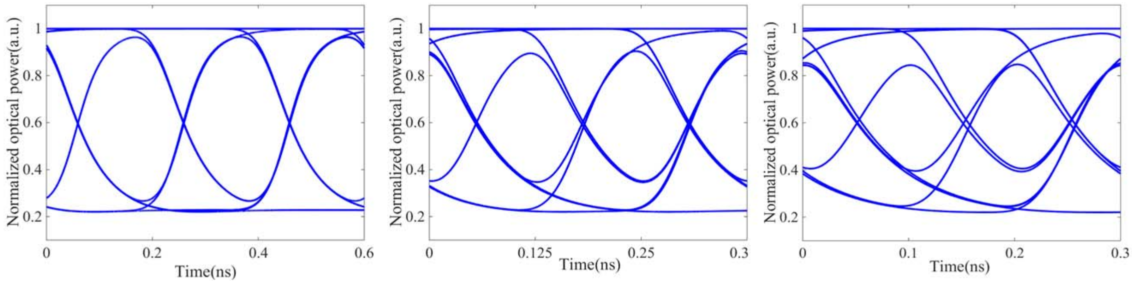

Fig. 5. Eye diagrams of the 3s-DBR laser modulated at 5Gbps, 8Gbps and 10Gbps, respectively.

III. RESULTS AND DISCUSSION

In our simulation, the impulse current is approximated by a current pulse with width of about 1 ps, it is superimposed on the bias current I_{bias}. The currents injected to the phase and the grating section are $5mA$ and $10mA$ respectively. The modulation response is obtained by fast Fourier transforming the transient impulse response of the laser in time domain.

Fig.3 shows simulated modulation response of the laser at different bias currents, where amplitude of the impulse current is about 5% of the bias current. Clearly from Fig.3, the resonance peak becomes flatten as the bias current increases, and the 3dB bandwidth increases from about 4GHz to 7GHz. This is because the output power and photon density increase with the current. This trend is consistent with the measured modulation response of the DBR lasers [7].

For comparison, the modulation response curves of the device are calculated by using three different methods (Method A: transfer function derived from rate equations, Method B: small-signal response by sinusoidal perturbation in TDTW model, Method C: FFT of impulse response in TDTW model), as shown in Fig.4. The 3s-DBR laser parameters are kept same and the bias current I_{bias} is set to be $50mA$ for all cases. For three methods, the 3dB modulation bandwidth obtained is quite different, about 12.5GHz, 7.5GHz and 5GHz, respectively. The 3dB modulation bandwidth obtained by method C is lowest, this is because the impulse current contains harmonics in frequency domain compared to small sinusoidal perturbation with single frequency.

Fig.5 shows simulated eye diagrams at modulation rate of 5Gbps, 8Gbps and 10Gbps with a bias current I_{bias} of $50mA$. Obviously, the eyes are only open well at 5Gbps, and degrade at higher modulation rates. These results demonstrate that the impulse response method provides an effective help with estimation of modulation bandwidth of the device.

IV. CONCLUSIONS

In conclusion, we investigated the modulation response of the 3s-DBR laser by calculating the transient impulse response of the device based on the developed TWDM model. Simulated results indicate that this simulation method provides an effective way to estimate modulation bandwidth of the laser, which will be helpful for designing high speed directly modulated 3s-DBR laser.

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