DFB Laser Diode Parameter Extraction Based on Rate-Equation Model

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Abstract

DFB-LD parameters based on the rate equations are extracted. The extraction method needs measurement of optical output power and input current relationship, laser modulation responses at different biases and the transfer function of dispersive optical fiber with a directly modulated LD. Total of thirteen parameters are accurately extracted.

I. Introduction

Accurate computer simulation at the design stage is very important in order to realize high-performance lightwave communication systems. For this, reliable models for optical components as well as accurate parameter values are required. For DFB lasers, the rate-equation models are usually used that include several parameters whose numerical values need to be experimentally determined.

We analyze the static and dynamic characteristics of a directly modulated DFB LD and extracted the numerical values for the rate-equation parameters.

II. Theory and measurement

The rate equations that we use for our parameter extraction is given below [1,2].

$$\frac{dS(t)}{dt} = \Gamma g_0 \frac{N(t) - N_0}{1 + eS(t)} S(t) - \frac{S(t)}{t_p} + \frac{\Gamma b N(t)}{t_n}$$

$$\frac{dN(t)}{dt} = \frac{I(t)}{eV_a} - g_0 \frac{N(t) - N_0}{1 + eS(t)} S(t) - \frac{N(t)}{t_n}$$

$$\frac{df(t)}{dt} = \frac{1}{2} a \Gamma g_0 \left(N(t) - N_{th}\right)$$

In the above equations, $S(t)$ represents the photon density, optical confinement factor, g_0 differential gain, e gain saturation parameter, t_p photon life time, t_n carrier life time, V_a active volume, a linewidth enhancement factor, $N(t)$ carrier density, N_0 transperancy carrier density, N_{th} threshold carrier density, b spontaneous emission factor, and $f(t)$ phase of the electric field inside the LD. Our goal is determining numerical values for these parameters for a given DFB LD. The DFB LD used in our investigation is commercially available 1.55μm DFB LD in a butterfly package with fiber pigtail.

Our measurement and fitting procedures are performed in three steps. First, from the steady-state solution of the rate equations, we can obtain the well-known relation between optical power output and input current,

$$P(t) = \frac{hch}{2el}\left(I(t) - I_{th}\right) \qquad (1)$$

where h is Plank's constant, h is the total quantum efficiency and I_{th} is threshold current. From a power vs current measurement, we can easily determine h and I_{th}.

Second, we determine the resonance frequency, damping factor and several dynamic parameters of the directly modulated LD. In order to do this, we eliminate the problems of the accurate microwave calibration, LD mount effects and parasitic components of the laser by the frequency response subtraction method[3]. One frequency response is measured slightly above the threshold and another is measured far above the threshold. By subtracting one from the other, all the parasitic effects can be completely cancelled out. The resulting frequency response is given as

$$R(w) = 10\log_{10}\left(\frac{w_0^2}{w_0^2 - w^2 + 2jgw} \cdot \frac{w_0'^2 - w^2 + 2jg'w}{w_0'^2}\right) \qquad (2)$$

where w'_0, w_0, g' and g are the resonance frequencies and dampng factors at higher bias current levels and near the threhold bias level.

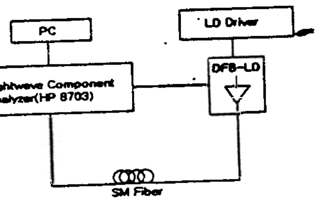

Fig 1. Experimental setup

We use the measurement setup shown in fig. 1. The resulting subtracted frequency responses are shown in Fig. 2. When we fit the equation (2) to the measured results, we obtain numerical values for the resonance frequencies and damping factors at several bias levels. The fitting was done using the Levenberg-Marquardt algorithm[4]. Fig. 3 shows the extracted (resonance frequency)^2 vs. injection current. The slope of the fitting line gives the value for $\Gamma g_0/eV_a$. Fig. 4 shows the relation between the resoance frequency and the damping factor. The slope for the fitting line gives the value for the K factor, also known as Petermann's constant.

Third, in order to determine fiber dispersion parameter, linewidth enhancement factor, and chirping frequency, similar measurement was done but with 30km-long fiber inserted between the LD and the PD. The normalized transfer power between LD amd PD also has no parasitic components[5]. Fig.5 illustrates measured as well as fitted fiber transfer functions. As shown, at high frequencies above 10GHz, the fitting is not accurate. This is due to the lack of accuracy in the rate-equation model as pointed by Peral and Yariv[6]. Nevertheless, values for D, alpha and fc can be determined from this fitting process.

In Table 1,2 the numerical values for the extracted LD parameters are summarized.

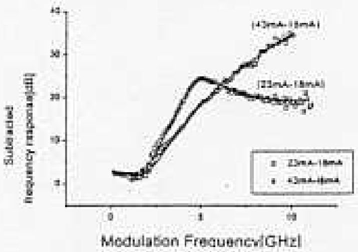

Fig. 2 Response Subtraction vs. Mudlation Frequency

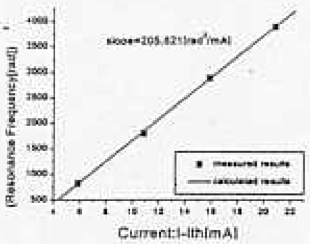

Fig. 3 Resonance Frequency^2 vs. Current

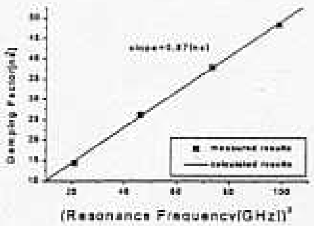

Fig. 4 Damping Factor vs. Resonance Frequency^2

III Conclusion

We have presented a simple parameter extraction procedure that is not limited by the packaging or parasitic effects of LD. Using this, we extracted numerical values for thirteen important DFB parameters. We acknowledge Dr. Hyun-Jae Yoon at Neoptek for kindly allowing us the use of lightwave component analyzer.

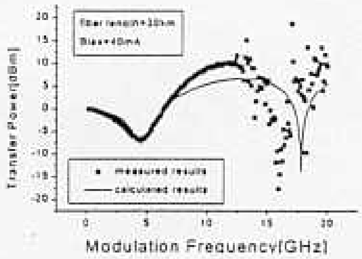

Fig. 5 Normalized Power vs. Modulation Frequency

<Table1>

Parameters	Description	Dimension	Value
I_{th}	Threshold Current	mA	17.16
b	Spontaneous Emission Factor	-	0.000087
h	Quantum Efficiency	-	0.14
t_n	Carrier Life Time	ns	0.086
t_p	Photon Life Time	ps	2.1
e/g_0		ps	1.03
K	K factor	ns	0.87
$\Gamma g_0/eV_a$		GHz^2/mA	5.21
D	Dispersion Parameter	ps/nm-km	14.99
a	Linewidth Enhancement Factor	-	4.57
f_c	Chirping Frequency	MHz	773.6

<Table2>

Bias current[mA]	Resonance frequency[GHz]	Damping factor[ns^{-1}]
23	4.5	14.4
28	6.7	26.2
33	8.5	37.9
38	9.9	48.3

IV. Reference

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