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Analysis of Harmonic Distortions in MQW Laser Diodes Using an Equivalent Circuit Model

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Abstracts - We analyze harmonic distortions in multiple quantum well laser diodes using an equivalent circuit model of laser diodes. The nonlinear relationship between injected carriers and photons, leakage currents and gain compression are included in this model. This approach can easily visualize the effects of various parameters on harmonic distortions.

I. Introduction

Recently, there have been much interest in subcarrier multiplexed optical transmission systems for CATV and other applications. Multiple Quantum Well (MQW) laser diodes (LDs) for this purpose must have good linearity in order to achieve reliable signal transmission. Harmonic distortion(HD) that gives rise to intermixing of signals is one of the inevitable intrinsic characteristics of LD.

Generally, the origin of HD is related to the nonlinear relationship between photons and injected carriers. Another cause for HD is nonuniform longitudinal distribution of optical fields and carriers, namely spatial hole burning, and leakage currents of LD.

Many circuit models for analyzing DC and AC characteristics of LD have been proposed [1,2]. And there was an investigation of HD using circuit models of Fabry-Perot LD[3]. We investigate the HD using an equivalent circuit model that includes the leakage current effect, nonlinearity between photons and carriers. Spatial hole burning effect is included in our model through the gain compression factor. This approach allows us to easily visualize the effects of various parameters on HD.

II. Equivalent Circuit Model

The dynamics of LD can be easily described by the rate equations proposed by Nagarajan[4]. Modified three rate equations[5] are:

$$\frac{V_a}{V_{SCH}} \cdot I = I_s + \frac{\tau_s}{\tau_n} I_s + \tau_s \frac{dIs}{dt}$$

$$G(N,P) \cdot (1-\varepsilon_n S_n) \cdot Sn + \beta I_n = \Gamma R_p + \frac{C_p}{\Gamma}$$

$$I_s = I_n + \tau_n \cdot \frac{dI_n}{dt} + G(N,P) \cdot (1-\varepsilon_n S_n) \cdot Sn$$

Here, I is the injected current, I_s is the current in SCH, I_n is the current in QW, S_n is the normalized photon output, V_a and V_{SCH} are the volumes of active and SCH regions. τ_s, τ_n and τ_p are the carrier transport time, bimolecular recombination time, and photon life time, respectively, and ε is the gain compression factor, C_p is qV_aS_o/Γ and R_p is τ_p/C_p. The circuit model of LD can be derived from combining these three equations as shown in

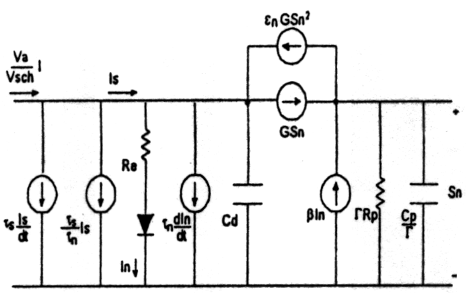

Fig. 1. Equivalent circuit model of MQW LD

Fig.1 [5], In this model, the photon density of LD is represented as output voltage, S_n.

III. Harmonic Distortions Analysis

We use 300㎛-long InGaAs/GaAs MQW LD parameters. With the circuit model, large signal analysis is easily performed by HSPICE simulator. Second and third HDs can be easily examined. First, input current(I) is applied as

$$I = I_{dc} + I_s \sin \omega t$$

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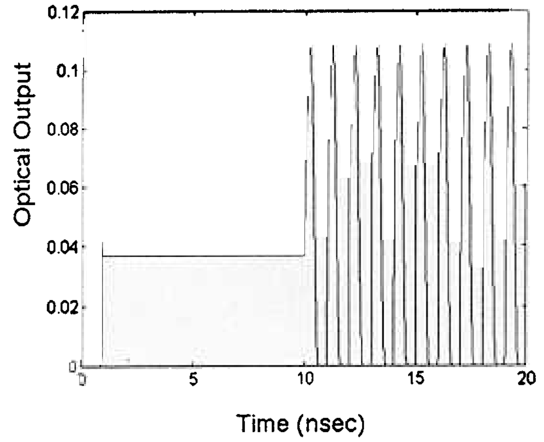

Fig. 2. Large signal response of LD

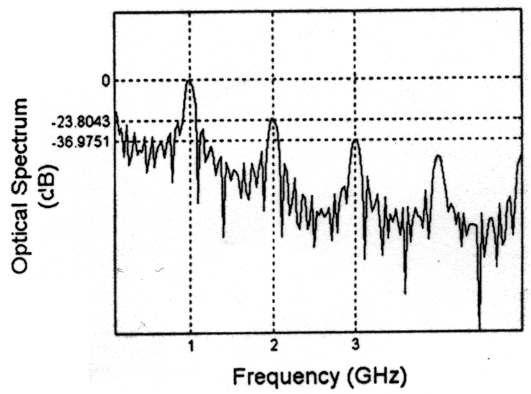

Fig. 3. Optical Spectrum with 1 GHz modulation frequency

where I_{dc} is the bias current, I_s is the bias current reaches steady state. Large signal response of LD with 1GHz frequency is shown in Fig. 2. In the circuit model, the sinusoidal signal is carefully applied after the response of sinusoidal signal is applied at 0 and 10 nano seconds, respectively. Turn-on delay and relaxation oscillation are observed. The optical output spectrum can be easily obtained by performing FFT(Fast Fourier Transform) on large signal response. Second and third harmonic terms can be seen from the output spectrum shown in Fig. 3. Second and third HDs are approximately -23 and -36dB with the bias current of 1.2 times threshold current and 20% modulation depth. Similarly, intermodulation distortion can be easily calculated with the multiple tone input. With the above approach, the dependence of HDs on various LD and modulation parameters can be easily investigated. Such an investigation is simpler than solving the rate equations numerically anddoes not require linearization as was done in

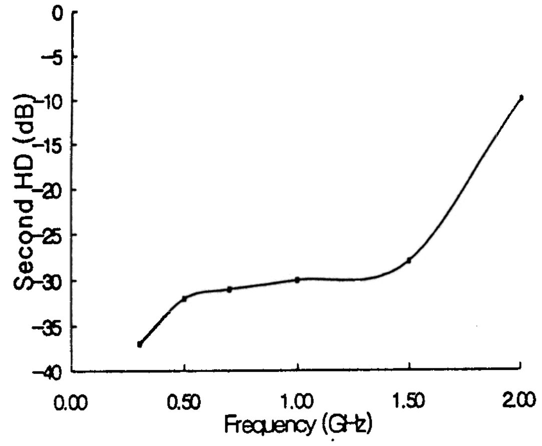

Fig. 4 Second-order HD as a function of modulation frequency

[6]. For example, Fig. 4 shows the dependence of second HD on the modulation frequency. As can be seen, HD increases as the modulation frequency increases toward the resonance frequency which, in the case shown in Figure 4, is 6GHz. HD dependence on bias currents, modulation depth, channel separation, as well as LD diode structures can be as easily investigated and their results will be presented at the conference.

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