Processing of Non-Physical Solutions in Semiconductor Laser Modeling

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Abstract: Based on the rate equations of the semiconductor laser, we use the SDD (Symbolically defined device) component for simulation in ADS (Advanced designed systems). During the modeling process, the junction voltage is introduced by the classic Shockley relationship, and the rate equations are transformed. Because the magnitude of the numerical solution of the carrier density and photon density in the rate equations of the laser are generally very large, the simulation process of the equivalent circuit model of the semiconductor laser will cause numerical overflow. In this paper, the transformations of the rate equations are used to improve the convergence problem caused by the non-uniqueness of the numerical solution. The model simulates the DC, AC and transient characteristics of a semiconductor laser by writing the converted rate equations into an SDD device.

1. Introduction

In 1962, the first semiconductor lase was invented[1]. The semiconductor laser has an important impact on the noise performance and nonlinear distortion of the optical communication link [2]. Compared with the numerical model with a relatively large amount of computation, the semiconductor laser circuit model is more concise and effective, and is suitable for simulating the characteristics of semiconductor lasers in circuit simulation software[3]. This article implements model simulation by writing the rate equations of a semiconductor laser into an SDD device in ADS after certain transformations.

2. Model Principle and Implementation

In the rate equations of the laser, the numerical solution of the carrier density and photon density can reach more than the twentieth power of ten. In this way, overflow easily occurs during simulation. In order to improve convergence, the rate equations can be transformed.

2.1.Model Principle

The starting point for constructing a laser circuit model is rate equations describing the electron-optical characteristics of the laser. The rate equations are shown below:

$$\frac{dN}{dt}=\frac{I_A}{qV_{act}}-g_0(N-N_{om})[1-\varepsilon S]S-\frac{N}{\tau_n} \quad (1)$$

$$\frac{dS}{dt}=\Gamma g_0(N-N_{om})[1-\varepsilon S]S-\frac{S}{\tau_p}+\Gamma\beta\frac{N}{\tau_n} \quad (2)$$

Where N is the carrier density, N_{om} is the transparent carrier density, V_{act} is the active area volume, S is the photon density, τ_n is carrier lifetime, τ_p is the photon density, Γ is the filed limiting factor, β is the spontaneous emission factor, and ε is the gain compression factor.

$$N=N_e[\exp(qV/\eta kT)] \quad (3)$$

$$S=\Gamma S_n(m+\delta)^2 \quad (4)$$

Equation (3) is the relationship between the carrier density and the junction voltage, which is the classic Shockley relationship. N_e is the equilibrium minority carrier density, η is an empirical constant, and S_n is the normalization constant. To improve the convergence of the model, we substitute equations (3) and (4) into equations (1) and (2) for transformation[4-5]. So the following equations are obtained.

$$\frac{dV}{dt}=\frac{1}{N_e(q/\eta kT)\exp(qV/\eta kT)}\left\{\frac{I_A}{V_{act}}-\frac{N_e\exp(qV/\eta kT)}{\tau_n}-g_0[N_e\exp(qV/\eta kT)-N_{om}]\cdot\left[1-\varepsilon\Gamma S_n(m+\delta)^2\right]\right\} \quad (5)$$

$$\frac{dm}{dt}=\frac{1}{2S_n}g_0[N_e\exp(qV/\eta kT)-N_{om}]\left[1-\varepsilon\Gamma S_n(m+\delta)^2\right]\cdot\Gamma S_n(m+\delta)-\frac{1}{2\tau_p}(m+\delta)+\frac{\beta}{\tau_n}\cdot\frac{N_e\exp(qV/\eta kT)}{2S_n(m+\delta)} \quad (6)$$

2.2.Model Implementation

The voltage or current of a certain port can be defined as a function of other voltages or currents[6]. The semiconductor laser model in ADS as shown in Figure 1. In this paper, we use the 4-port SDD device, and write equations (5) and (6) into SDD4P.

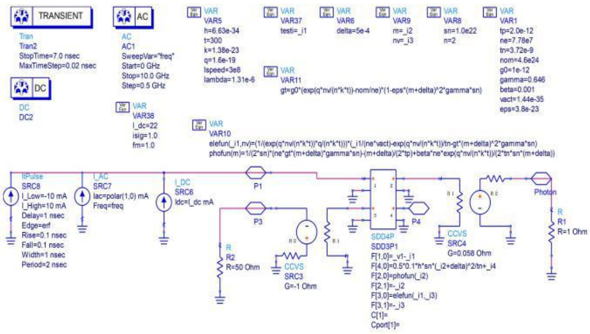


Figure 1: Model of semiconductor laser in ADS.

In the SDD device of Figure 1, there are four ports, where P1 is the input current P3 is the carrier density, P2 is the output light intensity, and P4 is the output voltage. The relationship between output optical power and photon density as follow.

$$P_{out} = \frac{0.5V_{act}\eta_0 hf}{\Gamma\tau_p} S = \frac{0.5V_{act}\eta_0 hf}{\tau_p} S_n(m+\delta)^2 \quad (7)$$

According to the above model, DC, AC, and transient simulations of semiconductor lasers can be performed.

3. Simulation Result Graph and Analysis

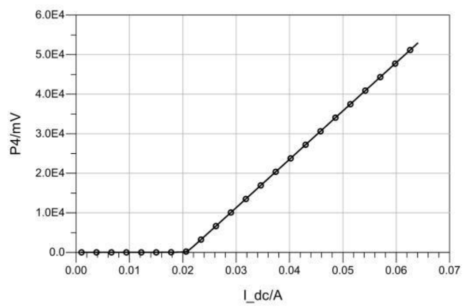


Figure 2: DC characteristics.

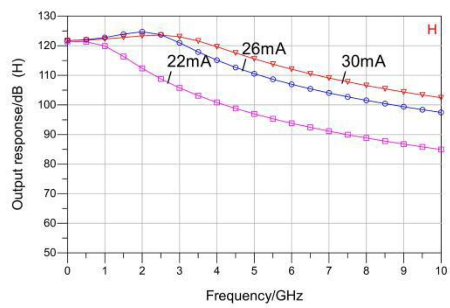
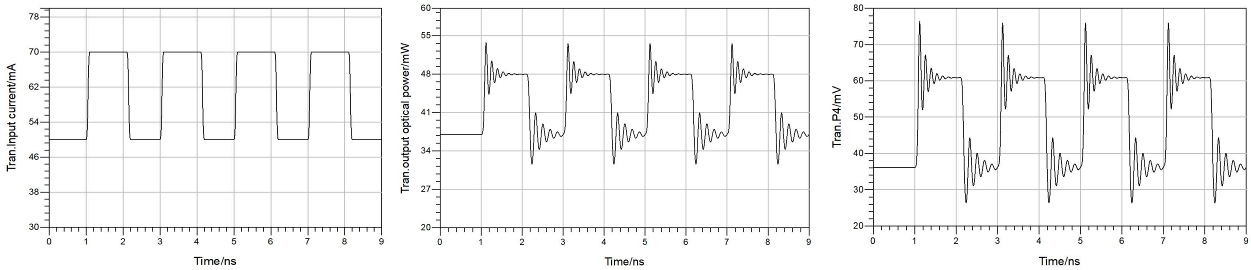


Figure 3: AC characteristics.

The circuit uses a DC source in the DC simulation. The results are shown in Figure 2, and the threshold current is 21mA. From Figure 3, it shows the AC simulation results when the bias current is 22mA, 26mA, 30mA.And the resonance frequency increases with the increase of the bias current.

Compared with Figure 4 (a), there are relaxation oscillations of the Figure 4 (b). This phenomenon is an inherent characteristic of the optical-electrical interaction in the laser. It can be seen that the output of the circuit model and the output light intensity waveform are generally consistent from Figure 4 (b) and (c).



(a) Input pulse sequence (b) Output optical power pulse (c) Output voltage pulse

Figure 4: Transient input and output characteristics.

4. Conclusions

This article uses the SDD device in ADS to simulate the semiconductor laser model. The model is used to simulate the DC, AC and transient characteristics of semiconductor lasers. The convergence of simulation values is solved by transforming the rate equations of the semiconductor lasers. This model can be applied to the design of RF optical transmission links and the parameters characterization of semiconductor lasers.

Acknowledgments

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