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Gain Switch of an AlGaInP Red Light Semiconductor Laser Diode

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Abstract: We solve the single mode coupled rate equations by computer, simulate the behavior of a gain switch of an AlGaInP red light semiconductor laser diode, and find the characteristic of FWHM of pulses changing with the amplitude of modulation signal, the bias current, and the modulated frequency. On this basis, we conduct experiments. The experiment results accord with the simulations well.

Key words: red light; semiconductor laser diode; gain switch; pulse
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1 Introduction

An AlGaInP red light laser diode (wavelength from 650 to 670nm) is an important type of semiconductor laser and has been widely used in communication, information storage, medical treatment, and measurement fields. The development of ultra fast optical data communications in LAN and E-O sampling applications[1,2] has made the red light ultra short pulse laser diode important.

Ultra short pulses can be generated from a laser diode though a gain switch and mode lock. The gain switch modulates the laser diode directly. It has many advantages, including that the pulses can easily be synchronized with the modulation signal and that the frequency can be easily changed. In a gain switch, the laser diode can be biased below the threshold[3], modulated by a large sin signal[4] or current pulse signal[5]. Optical pulses tens of picosecond (ps) or shorter[6] can be generated. In the near infrared band, technology for gain switches has been intensively studied, but there is little research on red light laser diodes and hardly any such papers have been published in domestic journals.

In this article, we demonstrate the gain switch of an AlGaInP red light semiconductor laser diode. First, the simulation is made near the frequency of 1 GHz by computer, then experiments are conducted, and 70 ~ 100ps optical pulses are generated under large sin signals at a frequency of 0.8~1GHz.

2 Simulation

The dynamic behavior of laser diodes can be simulated by solving the single mode coupled rate equations through numerical simulation:

$$\frac{\mathrm{d}n}{\mathrm{d}t} = \frac{\eta_i j}{q_e d_a} - \frac{n}{\tau_{sp}} - vg(n)s$$

$$\frac{\mathrm{d}s}{\mathrm{d}t} = \left(\Gamma vg(n) - \frac{1}{\tau_{ph}}\right)s + \Gamma\gamma\frac{n}{\tau_{sp}}$$

In the equations, n is the electron density (cm^{-3}), s is the photon density (cm^{-3}), η_i is the injection current efficiency (commonly j is the current injected into the active region, so $\eta_i = 1$), $j = j_0 + j_c \times \cos(\omega t)$ is the current density ($\mathrm{A/cm}^2$) (j_0 and j_c are the bias current and amplitude of the injection current, and ω is frequency), d_a and q_e are the thickness of the active region (cm) and the electron charge (C), τ_{sp} is the electron spontaneous recombination lifetime (s^{-1}), τ_{ph} is the photon lifetime (s^{-1}), v is light velocity in the active region (cm/s), $g(n)$ is the peak gain (c/m), Γ is the optical confinement factor, and γ is the spontaneous radiation factor. $g(n)$ can be expressed in log form in the quantum well active region:

$$g(n) = g_w \ln\frac{n}{n_e}$$

where g_w is the gain constant (cm^{-1}) and n_e is the transparent carrier density (cm^{-3}).

When the laser diode modulates, it usually works in several modes. The simulation of the rate equations cannot accord absolutely with real experiments, but we can find some qualitative conclusions to instruct our experiments. We mainly simulate the optical pulse width's variation with the amplitude and frequency of the modulation signals and bias current. In a quantum well AlGaInP red light laser diode, for example, the typical parameter values are[7]:

$d_a = 4 \times 10^{-6}$ cm, $v = 8.328 \times 10^{-9}$ cm/s, $\tau_{sp} = 3 \times 10^{-9}\mathrm{s}^{-1}$, $\tau_{ph} = 3.26 \times 10^{-12}\mathrm{s}^{-1}$, $g_w = 1500\ \mathrm{cm}^{-1}$, $\Gamma =$

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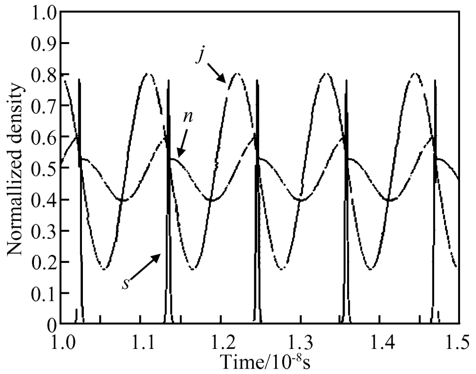

Fig. 1 Gain switch of s, n, and j versus time

0.06, $\gamma = 1\times10^{-4}$, $n_c = 1.1\times10^{18}$ cm^{-3}.

Figure 1 shows the result of simulation for a gain switch of s, n, and j as a function of time (t). The pulses occur in the process of n falling quickly.

The laser diode used in the experiment is an AlGaInP ridge waveguide quantum well laser made by our lab. Its 3dB bandwidth is relatively small. When biased slightly higher than the threshold value, its bandwidth is 1.2GHz. So we mainly simulated the gain switch of the laser diode under a large sin modulate signal near 1GHz. Figures 2～4 show the curves of the full width half maximum (FWHM) of optical pulses as a function of amplitude of modulation signal (Fig. 2), bias current (Fig. 3), and modulation frequency (Fig. 4) when the laser diode is biased under the threshold value (jth in the figures is the threshold current of the laser diode).

From the results of Figs. 2～4, we can conclude that:

(1) When the DC bias is slightly lower than the threshold, the FWHM of the optical pulse decreases as the amplitude j_c increases.

(2) The FWHM of the optical pulse decreases as the DC bias increases, when the DC bias is under the threshold value.

(3) The FWHM of the optical pulse increases slowly as the frequency increases slowly near 1GHz, when the DC bias is under the threshold value.

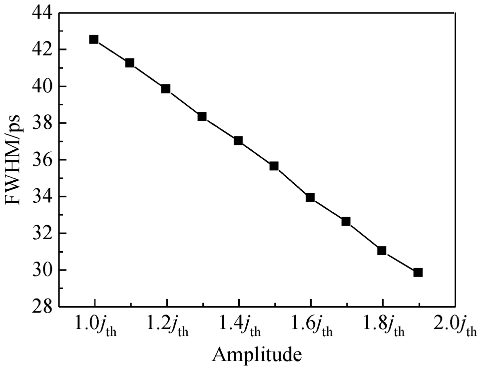

Fig. 2 FWHM versus amplitude of modulation signal (Frequency: 900MHz, bias DC: 0.8jth)

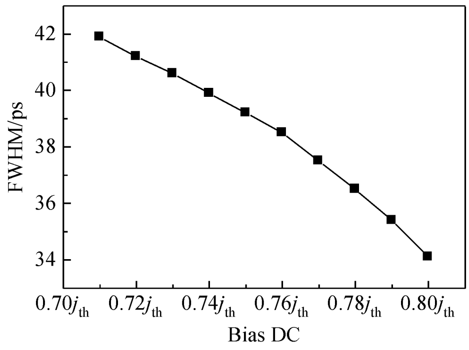

Fig. 3 FWHM versus bias current (Frequency: 900MHz, amplitude: 1.6jth)

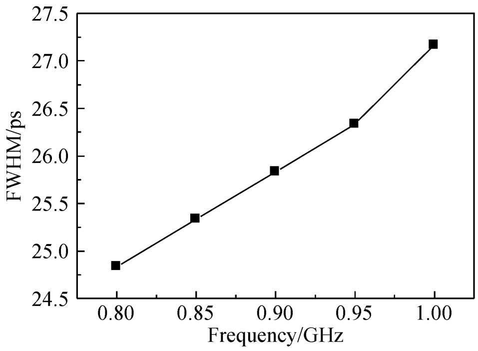

Fig. 4 FWHM versus frequency of modulation signal (Amplitude: 1.5jth, bias DC: 0.9jth)

3 Experiment and analysis

The laser diodes used in experiments had a wavelength of 660nm, a cavity length of 900μm, a threshold value of 40mA, and an output power of 20mW at 50mA. After packaging, the laser diode was directly modulated by a large sin signal. At the same time, a DC bias was injected into the laser through a Bias T (T bias connector), which can separate DC and DC signals. An optical lens converged the output light to high speed photo-detectors (Hamamatsu G4176). A high speed oscilloscope was used to detect the current pulse signal. Figure 5 shows the experimental equipment and Figure 6 shows the ultra short waveform detected by the oscilloscope.

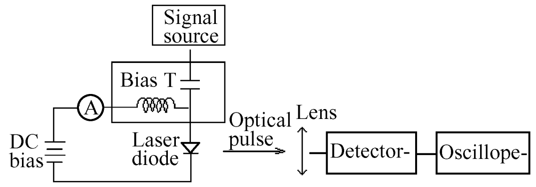

Fig. 5 Equipment diagram of the experiment

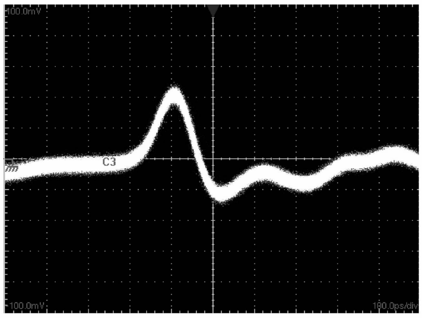

Fig.6 Waveform of ultra short pulse 1 square in the diagram represent 100ps

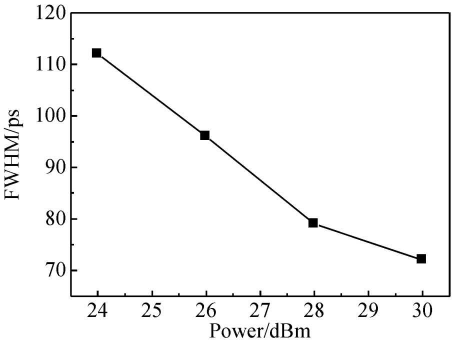

Fig.7 FWHM versus power of modulation signal（Frequency：900MHz，DC biased：0.8jth）

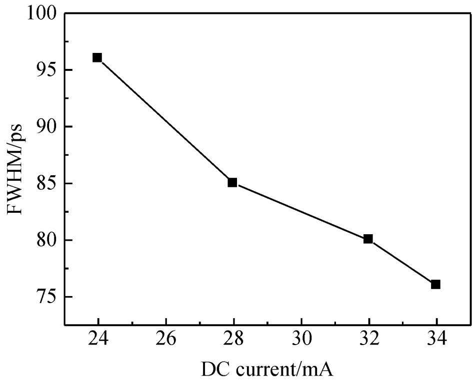

Fig.8 FWHM versus bias DC（Frequency：900MHz，power：28dBm）

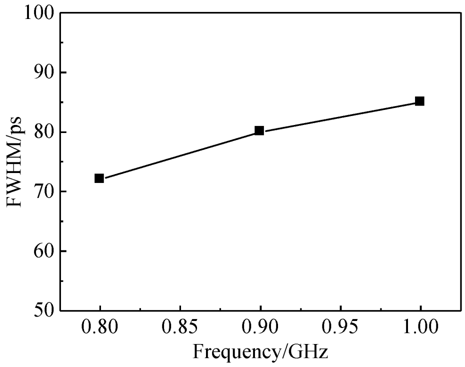

Fig. 9 FWHM versus frequency Frequency under 1GHz（power：26dBm，DC biased：0.9jth）

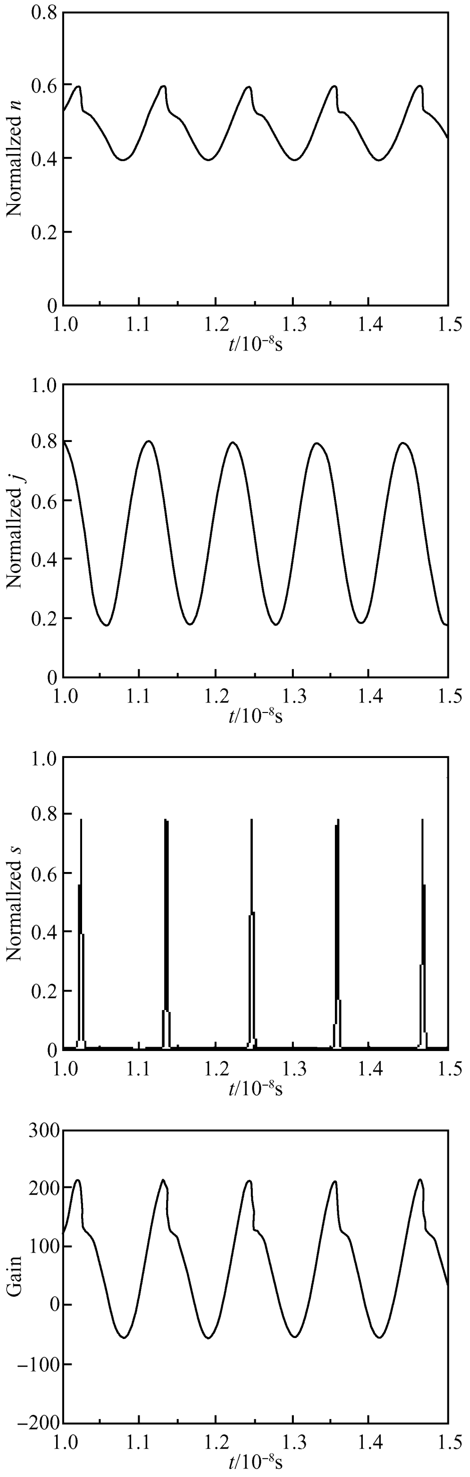

Fig.10 Gain switch of n，s，j，and gain versus time

Figures 7～9 show the results of the experiments，the FWHM of optical pulses changing with signal power，which is a direct ratio with the square of the amplitude of signal，bias DC，and modulation frequency. Compared with the simulation results，we find that the variation trend is the same. The FWHM of optical pulses from the experiments is relatively large（70～100ps），and the parameters of the diodes should be optimized to reduce the optical pulse width.

For clarification，we separately plot n，s，j，and *gain* (g) as a function of time in Fig. 10. The figure indicates that there is a time delay between n and j, s, and g. Gain g is synchronized with n. At the initial time of injection current j, n is very small, g is below zero, and s is almost zero. As j increases, n rapidly reaches a maximum $n_{\max}$, which is larger than the threshold carrier density n_{th}. n_{th} is the density that the gain produced by laser light traveling a round trip is equal to the loss in the cavity. When n is larger than n_{th}, stimulated emission and nonradiative recombination will consume the inject carriers instantly. When n reaches $n_{\max}$, g reaches $g_{\max}$, and simulated emission will increase rapidly under $n_{\max}$ and $g_{\max}$. As the emission rate increases, s starts to increase rapidly like an avalanche. When s starts to increase rapidly, n and g decrease rapidly. When n decreases to below n_{e}, g is lower than zero again, s decreases to a very small value, and the optical pulse emission process is over. Thus, the pulses occur as n falls quickly.

So, if n accumulates to a larger value before s starts to increase rapidly, the emission rate will be larger, the pulse generation process will shorten, and the power of the pulse will be larger. Increasing the amplitude of the modulation signal and DC bias aids n accumulation, so the pulse width will decrease. When increasing modulation frequency, the current injection rate will be fast and n has little time to accumulate, so the pulse width will increase. On the contrary, a laser diode working at a higher speed will shorten the whole lase period, including the pulse generation process. Increasing the modulation frequency is double-faced to pulse width. Because the bandwidth of the laser diode used in the experiment is relatively small, we can only study its characteristic near 1GHz. In a wide frequency range, Yeung[3] demonstrated that the pulse width may change as the frequency increases, but it will not change significantly.

4 Conclusion

We can conclude from the simulation of gain switch of ridge waveguide AlGaInP red light laser diode that: when the bias DC is lower than the threshold of the laser diode, the FWHM of optical pulse decreases with increasing bias DC and amplitude of modulation signals, when the modulation frequency is near 1GHz, the FWHM of optical pulse increases with increasing frequency. The experiments prove that the results accord with the simulations well.

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AlGaInP 红光半导体激光器的增益光开关

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摘要： 通过计算机求解单模耦合速率方程，理论模拟了红光半导体激光器的增益开关特性，得出了光脉冲宽度随调制信号振幅、偏置电流以及调制频率的变化规律．在此基础上进行了实验验证，实验结果与理论符合得很好．

关键词： 红光；半导体激光器；增益开关；脉冲

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