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Gain-Switched Distributed Feedback Laser Suitable for Ultrafast Optical Trigger

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Presently the speed limitation of electronic circuits comes from the time delay associated with the electrical interconnecting lines at multi Gbit/s levels. A possible solution would be to employ optical triggering, taking advantage of very high speed switching capability of semiconductor lasers. We report a realization of 1 Gbit/s repetition, 20 psec optical pulse train with single longitudinal mode using a gain-switching scheme for an InGaAsP/InP DFB laser. Effect of gain saturation mechanism in amplifying media and a possible improvement of switching performance by introducing multi-electrode structure are theoretically discussed. The multi-electrode strucutre has also a capability of enhancing "chirp" characteristics of a laser, which is favorable in external pulse compression scheme.

1. Introduction

It has recently been pointed out that very high speed electronics of the next generation would require the optical interconnection technology which is characterized by immunity to electromagnetic interference and by ultrafast response in switching. The authors have been engaged in the trial to exploit time domain optical clock scheme for signal multiplexing and sampling applications. For these purposes development of light sources as the clock generator is requested. Typical specification of them should be (a) generation of very short pulses (1 ~ 100 ps), and (b) high repetition frequency (1 ~ 10GHz). Only recently the efforts were started to develop such semicondcutor lasers as fulfilling these requirement under single longitudinal mode operation. The purpose of the present work is to investigate experimentally the capability of gain switching scheme of InGaAsP/InP distributed feedback lasers with parasitic capacitance suppression condition and to analyze the performance limitation aiming at improving the overall performance of the device as the optical trigger generator.

2. Gain-Switching Characteristics of an InGaAsP/InP DFB Laser.

The driving circuit configuration of an InGaAsP/InP distributed feedback laser is shown in Fig. 1. The device was prepared by Fujitsu Laboratories, which has a structure with suppressed parasitic capacitance.

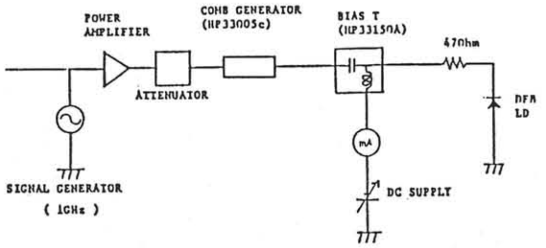

Fig. 1 Driving circuit of DFB laser diode.

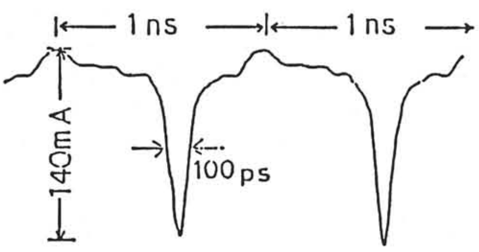

Fig. 2 Typical electrical current waveform fed to LD.

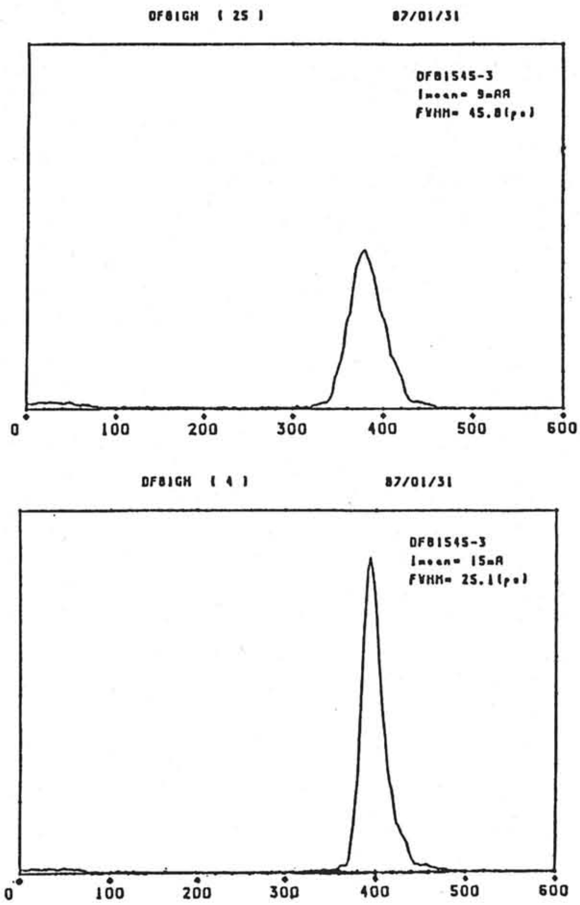

Fig. 3 Typical optical output waveforms measured by a streak camera.

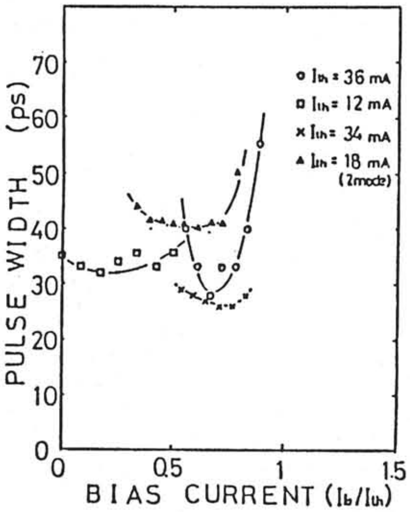

Fig. 4 Bias current dependence of optical pulse width (experiment).

Fig. 2 illustrates the typical current waveform which is fed to the laser diode (FWHM 100 ps). Due to the nonlinearity of laser medium light output waveform is compressed compared with input electrical waveform, as shown in Fig. 3, the streak camera output with time resolution less than 10 ps. The optical pulse width (FWHM value) was ranging in 20 to 30 ps, depending on dc bias levels. Experimental bias current dependence of pulse width has a minimum below the dc lasing threshold bias condition, as shown in Fig. 4.

3. A model analysis of gain saturation effect considering finite intraband relaxation time.

The observed dependence of the optical pulse width on dc bias current is different from the prediction based on the conventional rate equation model for a gain-switched semiconductor laser. With the modification of the induced emission rate to the saturable form

$$g = \frac{g_0}{1 + S/S_0} ,$$

The analysis gives the result as shown in Fig. 5, consistant with experiment. Here g_0 is unsaturated gain, S and S_0 are space-averaged photon density and saturation parameter, respectively.

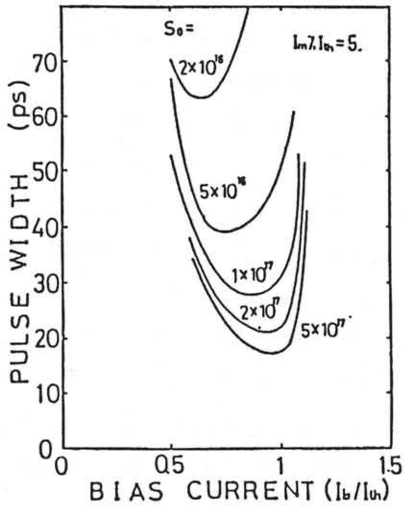

Fig. 5 Bias current dependence of optical pulse width (theory).

As discussed previously by Yamada and Suematsu, and by Bowers and by Olshansky more recently, the gain saturation may come from spectral hole burning effect in the conduction band due to finite intra-band relaxation time τ_{in}. Approximating the intra-band relaxation process (Fig. 6) by four discrete level, the saturation parameter S_0 is related to τ_{in} by the expression

$$S_0 \equiv \frac{1}{\Gamma v_g a'\{(1-u_c)\tau_c + (1-u_v)\tau_v\}}$$

The best fit to experiment was obtained for $S_0 = 1 - 2 \times 10^{17} cm^{-3}$, corresponding to the estimate of τ_{in} 0.1 - 0.2 ps. These values are close to the ones reported previously based on different approaches.

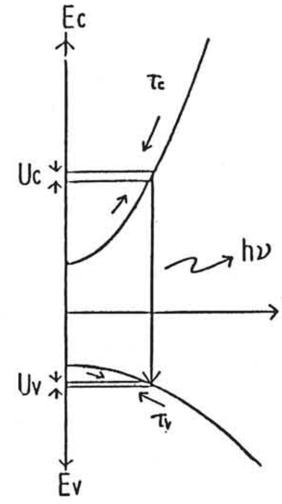

Fig. 6 A model of intra-band relaxation process leading to spectral hole burning.

4. Improvement of switching characteristics by non-uniform-pumping of a laser using tandem electrode configuration.

To overcome the limitation imposed by the gain saturation mechanism, we analyzed the Q-switching mode of operation of such a device structure as shown in Fig. 7.

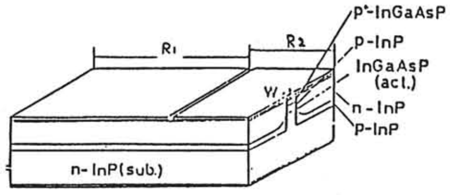

Fig. 7 A geometrical configuration of tandem electrode laser suitable for enhanced Q-switching and controlled "chirp" characteristics.

The tandem electrode structure allows to control the axial distribution of optical gain, with unpumped section the laser would operate in Q-switching mode. Fig. 8 shows the simulated temporal change of the waveforms of (a) injection current density J, (b) carrier density n_g in gain section, (c) carrier density n_a in absortion section, and (d) photon density s. It can be seen that the presence of saturable absorber would shorten the pulse width by around 30% in typical conditions. Moreover the presence of saturable absorber pushes up the initial basing threshold, resulting in the increase in the time derivative of carrier density during the emission of light pulse, which leads directly the enhancement of "chirping" characteristics. This modification is very favorable if the laser is combined with external pulse compressor like dispersive optical fiber or grating pair for generating still shorter pulse width.

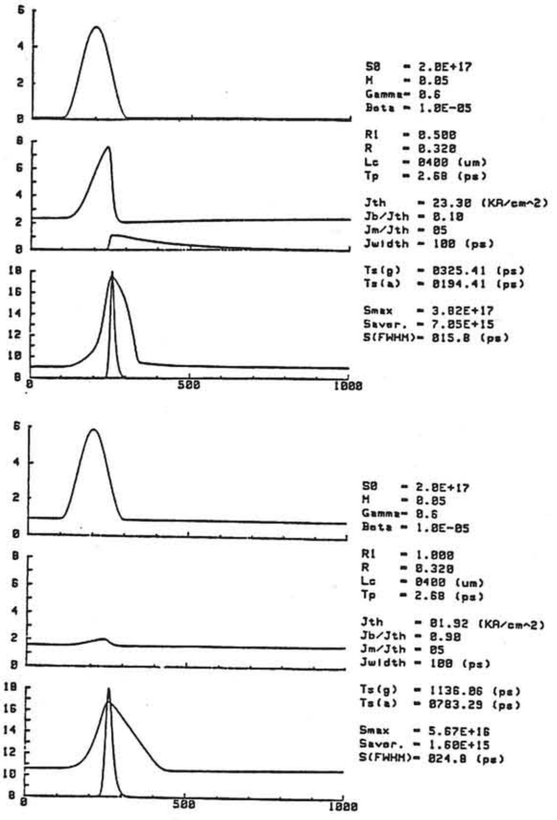

Fig. 8 (A) tandem laser, (B) convensional laser. (a) current, (b) n_g, (c) n_a, (d) log S, (e) S.

5. Conclusion

In summary an experimental effort to generate ultra-short pulse trains with high repetition rate from semiconductor laser is reported. With gain-switching scheme, applied to a distributed feedback laser of parasitic capacitance suppressing structure, we achieved 1 GHz repeated, 20 ps pulses with single DFB mode, peak power exceeding 100 mW. The bias level dependence of pulse width indicates the presence of gain saturation mechanism in amplifying medium. The experimental data are compared with a rate equation analysis considering finite intra-band relaxation time τ_{in}. The best fit was obtained for τ_{in} of 0.1 - 0.2 ps, consistent with the values reported on InGaAsP laser under sinusoidal modulation experiment by Bowers & Olshansky. To overcome the restriction associated with the gain saturation mechanism, we discussed the pulse modulation characteristics of multi-electrode semiconductor lasers. The rate equation analysis showed a shortening of pulse width due to Q-switching mechanism. The enhanced "chirp" characteristics in this structure are also favorable in shortening the pulse width by an external dispersive compressor.

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References

1. J.E. Bowers, "Relation between Bandwidth and Resonance Frequency and the Determination of Bandwidth Limitation", International Conference on Semiconductor Lasers, Kanazawa, 1986.
2. R. Olshansky, V. Lanziser, W. Powazinik and R.B. Lauer, "Frequency Response of 18 GHz Vapor Phase Regrown BH Lasers", International Conference on Semiconductor Lasers, Kanazawa, 1986.
3. K. Kamite, H. Sudo, M. Yano, H. Ishikawa and H. Imai, "DFB Laser with Bandwidth Larger than 9 GHz", International Conference on Semiconductor Lasers, Kanazawa, 1986.
4. Y.T. Lee, A. Shimizu, T. Kamiya,"Pulse modulation of Tandem-Type Semiconductor Laser", JSAP Spring Meeitng (March) 1987, 28p-ZE-2