

## Amplifier Modulation for Low-Chirp From a Monolithic Strained-Layer MQW InGaAsP/InP Distributed-Feedback-Laser/Tapered Amplifier

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**Abstract** By modulating the amplifier current, we obtain low chirp, high power (11.4 mW average power) and high speed ( $>1.2$  GHz) operation at 1.29  $\mu$ m wavelength from a strained-layer MQW InGaAsP/InP DFB laser integrated with a tapered-stripe amplifier.

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Although electroabsorption modulators integrated with distributed feedback (DFB) lasers can produce low-chirp high-speed modulated output<sup>[1]</sup>, they have the disadvantages of requiring complicated selective growth and producing only modest output power. Integrated optical amplifiers need less complicated growth and can produce higher power output and low chirp when modulated<sup>[2,3]</sup>. Though the modulation speed and contrast ratio of an amplifier can be limited by carrier lifetime and output power saturation, strained multi-quantum well (MQW) material and operation at high optical power can help improve the modulation bandwidth<sup>[4]</sup>. Modulation of an optical amplifier at several GHz with 20dB contrast ratio is feasible<sup>[5]</sup> and can prove to be a useful source for present day optical fiber communication systems. In addition, modulating tapered -striped amplifier used for free space communications, which require high power and low chirp signal, has been reported<sup>[2]</sup>. In this paper, we adopted a strained-layer multi-quantum well InGaAsP/InP dis-

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tributed feedback (DFB) laser integrated with a tapered-stripe amplifier, achieved low-chirp modulation at speeds in excess of 1.2GHz and an average output power of 11.4mW by modulating the amplifier current.

The active region of the integrated device consists of four 11nm wide InGaAsP( $\lambda_g \sim 1.48\mu\text{m}$ , 1.38% compressive strain) quantum wells, separated by 12nm wide InGaAsP( $\lambda_g \sim 1.1\mu\text{m}$ , lattice matched to InP) barriers. An index-grating was fabricated by regrowth to give a DFB laser with a CW lasing wavelength of  $1.29\mu\text{m}$ . The stripe width of the laser was  $2\mu\text{m}$ , and the length of the DFB section was 0.6mm. An amplifier, with a stripe width that was linearly tapered from  $2\mu\text{m}$  to  $28\mu\text{m}$  over a length of 0.4mm was integrated with the DFB laser. The amplifier and DFB sections were electrically isolated and the amplifier facet was antireflection coated.

Fig. 1 shows the measurement set-up, RF signal and DC bias are injected into amplifier or DFB-LD by Bias Tee, which used for high speed AC modulation.

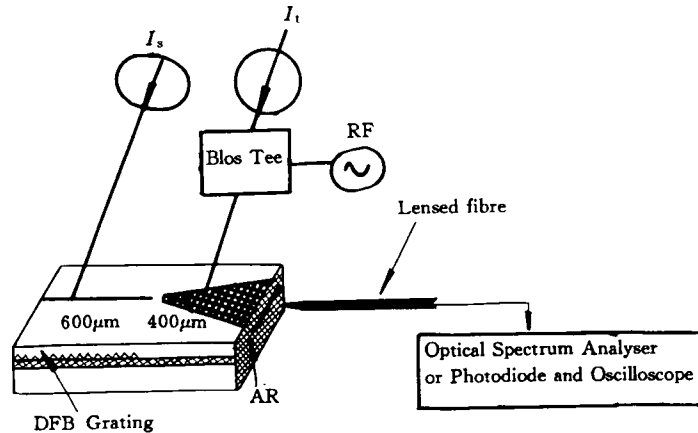


Fig. 1 Experimental setup to characterize the DFB laser integrated with tapered amplifier

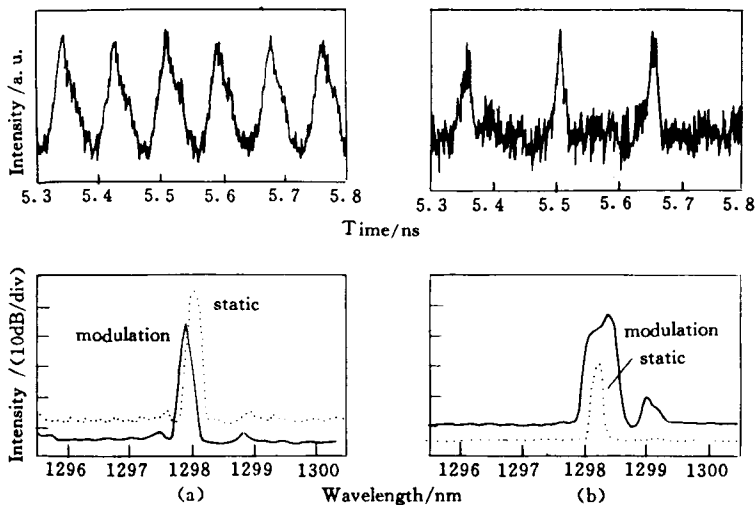


Fig. 2 (1) The optical signal observed under a large signal modulation of the amplifier and (2) measured spectra. The dotted trace is the static spectrum and the solid trace is the modulation spectrum.

The optical signal are coupled to optical spectrum analyzer or photodiode by fiber lens. Fig. 2 compares the output spectra obtained under (a) 10dBm 1.2GHz RF modulation amplifier with 115mA DC bias, while DFB-LD is DC biased at 162mA, and (b) 10dBm 665MHz RF modulation DFB-LD with 102mA DC biased, while the amplifier is DC biased at 97mA. In case (a) (i. e. amplifier

modulation) no linewidth broadening was measurable using the HP70951B optical spectrum analyzer (resolution  $\sim 0.1\text{nm}$ ) while a broadening by a factor of about 2 was observed in case (b) (i. e. DFB modulated directly). Because of the mount parasitic, the higher than 1.2GHz modulation speed was unable both for amplifier and DFB LD. Direct measurement of the modulation bandwidth by sweeping the frequency and observing the photodiode signal in an RF spectrum analyzer was attempted but the result was limited to 1.6GHz for both cases of direct modulation of the DFB and modulation of the amplifier. To predict the potential of the speed and contrast ratio of modulating amplifier, we measured the relaxation oscillation period and the contrast ratio of lower speed modulation: (1) when the amplifier is driven by a large amplitude fast electrical pulse and the DFB is giving high output power, a relaxation oscillation period of 200ps was observed, indicating that the amplifier's intrinsic modulation bandwidth could be 4~5GHz; (2) Figure 3 shows optical output when amplifier is modulated by a 2.4 ns width electrical pulse at 1/10 duty cycle and 200mA amplitude under a DC bias of  $I_A=120\text{mA}$ ,  $I_L=102\text{mA}$ . The average fiber output power under CW and pulsed operation are  $15.5\mu\text{W}$  and  $33.56\mu\text{W}$  respectively. The peak power from the amplifier is about 587 mW (there is a  $-25\text{dB}$  coupling loss to the fiber lens), and the contrast ratio is large as 20.7 dB. This shows the potential of modulating tapered amplifier even under higher modulation speed can have an acceptable contrast ratio if properly biased.

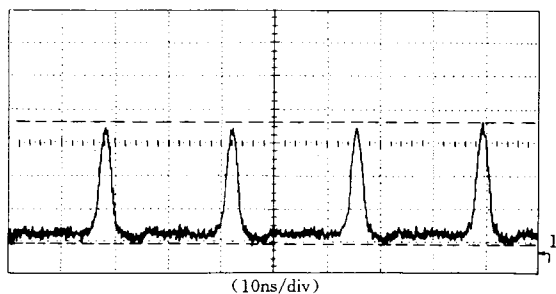


Fig. 3 Optical output when amplifier is modulated by a 2.4ns width electrical pulse at 1% duty cycle and 200mA amplitude and with a DC bias of  $I_A=120\text{mA}$ ,  $I_L=102\text{mA}$ .

cycle and 200mA amplitude under a DC bias of  $I_A=120\text{mA}$ ,  $I_L=102\text{mA}$ . The average fiber output power under CW and pulsed operation are  $15.5\mu\text{W}$  and  $33.56\mu\text{W}$  respectively. The peak power from the amplifier is about 587 mW (there is a  $-25\text{dB}$  coupling loss to the fiber lens), and the contrast ratio is large as 20.7 dB. This shows the potential of modulating tapered amplifier even under higher modulation speed can have an acceptable contrast ratio if properly biased.

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