10 GHz, 6.2 ps Transform-limited Coherent Optical Pulse Generation from a 1.55 μm, Self-injection Gain-switched DFB-LD

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Abstract: We demonstrate coherent optical pulse generation from a 1.55 μm, self-injection gain-switched DFB-LD. By using external spectral shaping, we generated a transform-limited 10-GHz, 6-ps Gaussian-pulse, which had neatly repetitive longitudinal modes with a 7 kHz-linewidth.

1. Introduction

Coherent multi-level transmission using an optical time division multiplexing (OTDM) scheme is attractive since it makes it possible to realize an ultrahigh-speed transmission at a channel rate exceeding 10 Tbit/s with a high spectral efficiency [1]. An optical pulse source that can generate a coherent return-to-zero (RZ) pulse train plays an important role in such a transmission. As a coherent pulse source, an optical comb generator consisting of a continuous wave, a narrow linewidth laser and an optical intensity modulator [2] or a mode-locked fiber laser [3] has been utilized. On the other hand, a gain-switched laser diode (GS LD) is very useful because it can easily generate a pico-second short pulse with a simple configuration. However, output pulses from a GS LD inevitably exhibit timing jitter and low coherence due to its operation principle [4]. Therefore, it was not easy to apply a GS LD to coherent optical transmission immediately.

Intensive efforts have been made to improve the output characteristics of a GS LD. For example, a transform-limited (TL) pulse train has been generated by utilizing a simple bandpass filter for spectral shaping and chirp compensation [5]. Moreover, the timing jitter suppression and linewidth reduction of each longitudinal mode have been demonstrated by externally injecting a CW light into a 1.5 μm GS DFB LD [6,7]. Furthermore, a 2.5 GHz, 24 ps optical pulse train with a timing jitter of 1.4 ps has been generated from a GS DFB LD with a self-optical feedback circuit [8]. However, the linewidth reduction of a GS LD with a self-injection scheme has not been clarified yet. In addition, there has been no report on a TL 10 GHz pulse train with narrow longitudinal modes from a GS LD.

In this paper, we describe the generation of a TL coherent pulse train from a 1.55 μm, self-injection GS DFB LD accompanied by spectral shaping. With this configuration, we successfully generated a 10 GHz, 6.2 ps Gaussian shape coherent pulse with an optical spectrum consisting of multiple longitudinal modes with a linewidth as narrow as 7 kHz. This narrow linewidth is almost the same as that of fiber lasers. This indicates that the present method provides a high quality coherent pulse in a simple manner.

2. Configuration of 1.55 μm gain-switched DFB LD with self-optical feedback circuit

Figure 1 shows the configuration of a 1.55 μm GS DFB LD with a self-optical feedback circuit. It consists of a 1.55 μm InGaAsP multi-quantum well (MQW) GS DFB LD, a polarization-maintained (PM)-circulator, a 20:80 PM-coupler, a PM-variable optical attenuator, a PM-variable optical delay line, and a PM-isolator. Gain-switching is achieved by directly modulating the injection current of the DFB LD with a 10 GHz sinusoidal signal (+29 dBm) in

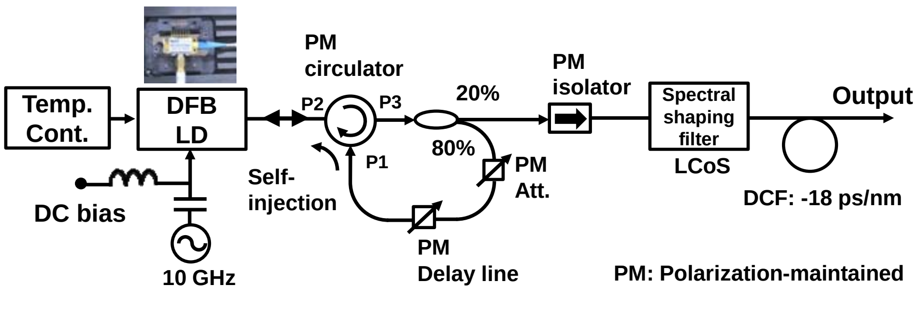

Fig. 1. Configuration of 1.55 μm GS DFB LD with a self-optical injection circuit.

conjunction with a DC bias current. Thus, we obtain an RZ optical pulse train with a 10 GHz repetition rate. With this configuration, we obtained an output power of 3.8 mW after the isolator with a driving current of 90 mA. Part of the laser output is fed back to the GS DFB LD after controlling its optical feedback power and feedback delay time with a variable optical attenuator and a delay line, respectively. The optical feedback power is defined as the input power to port-1(P1) of the circulator. A liquid crystal on silicon (LCoS)-based programmable optical filter is used for spectral shaping. The linear frequency chirp is compensated for with a dispersion compensating fiber (DCF) with a dispersion of -18 ps/nm.

3. Output characteristics of 1.55 μm gain-switched DFB LD with self-optical feedback circuit

First, we show the output characteristics of our GS DFB LD without optical feedback and spectral shaping. We measured the optical spectrum and corresponding time-domain waveform of the GS DFB LD driven with a DC bias current of 90 mA, where a 0.01 nm-resolution optical spectrum analyzer and a 500 fs-resolution optical sampling oscilloscope were used. Figures 2(a) and (b) show the optical spectrum and time-domain waveform, respectively. Since the coherence of the laser output was low and the timing jitter was large, the longitudinal mode structure could not be observed in the optical spectrum, and the time-domain waveform also had large intensity and timing fluctuations.

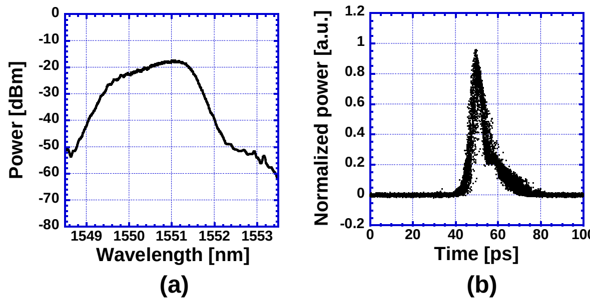

Fig. 2. Optical spectrum (a) and time-domain waveform (b) of GS DFB LD without self-optical feedback.

Figures 3(a)~(c) show the experimental results when the optical feedback was carried out with a feedback power of 3 dBm for a different delay time. The output characteristics of the GS DFB LD were greatly improved by appropriately adjusting the delay time, and we obtained a stable optical pulse with a 5.4 ps pulse width that had a longitudinal mode structure in the optical spectrum as shown in Fig. 3(a). In Fig. 3(a-2), small humps are observed at the trailing edge of the pulse. These are due to longer-wavelength components caused by the chirp (red shift) associated with the LD gain-switching operation. Although the linear chirp was compensated for with the DCF, nonlinear components remained. These components can be removed by appropriate optical filtering [5,8]. We evaluated the delay time dependence of the output characteristics by changing the relative delay time against the results in Fig. 3(a). When the feedback timing did not coincide with the rise time of the optical pulse in the GS DFB

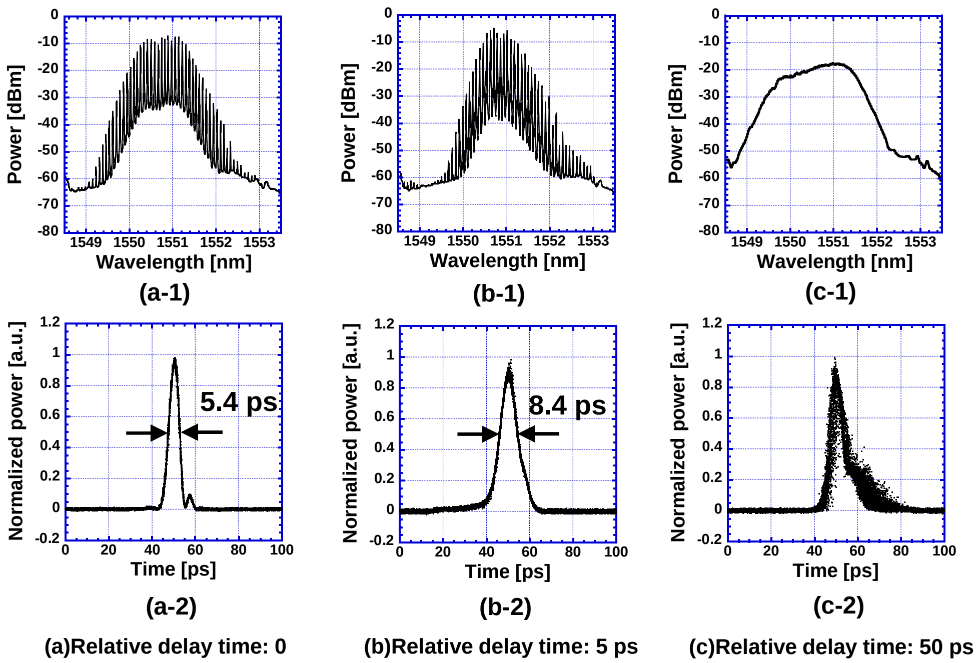

Fig. 3. Optical spectrum (a) and time-domain waveform (b) of GS DFB LD with self-optical feedback for different relative delay times.

LD, the optical feedback was not effective and the output characteristics of the GS DFB LD were worse as shown in Figs. 3(b) and (c). It is important to note that the round-trip time of the feedback must be equal to an integral multiple of 100 ps, that is a 10 GHz repetition rate. This process resembles laser mode-locking.

We formed the optical spectrum shown in Fig. 3(a) into a Gaussian shape with the LCoS filter. Figures 4(a) and (b) show the optical spectrum and the corresponding time-domain waveform after shaping. By removing the longer-wavelength components with the optical filter, we obtained an ideal Gaussian time-domain waveform without humps as shown in Fig. 4(b). The spectral width and pulse width were 73 GHz and 6.2 ps, respectively. The time-bandwidth product was 0.45, which indicated that the pulse was a TL Gaussian pulse.

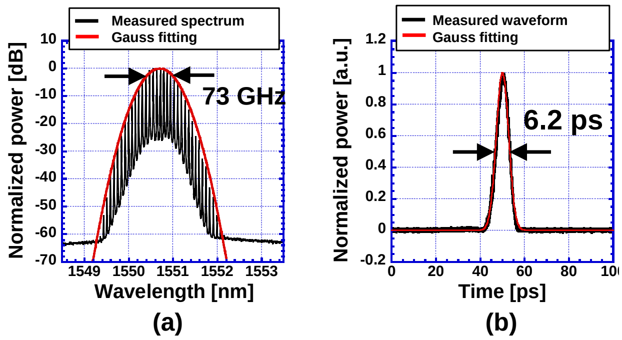

Fig. 4. Optical spectrum (a) and time-domain waveform (b) of GS DFB LD with self-optical feedback and spectral shaping.

We extracted one of the optical spectra in Fig. 4(a) with a narrow optical filter and evaluated its linewidth using a delayed self-heterodyne detection method with a 25-km delay fiber. Figures 5(a)~(c) show the delayed self-heterodyne spectrum of an extracted longitudinal mode at different wavelengths of 1550.41, 1550.66, and 1550.89 nm, respectively. These linewidths were all approximately 7 kHz. The linewidth characteristics in the oscillation modes were not wavelength dependent. Without self-optical feedback, we could not measure the linewidth caused by the degradation of laser coherence.

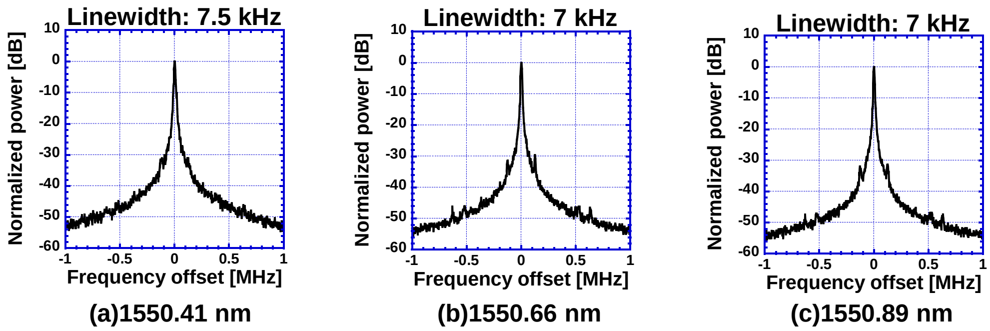

Fig. 5. Delayed self-heterodyne spectra of extracted longitudinal mode of self-injected GS DFB LD for different wavelengths.

4. Conclusions

We presented a coherent optical pulse source using a 1.55 μm self-injected GS DFB LD with spectral shaping. Optical feedback enabled us to greatly improve the output characteristics of the GS DFB LD, and we obtained a TL coherent optical pulse train with a pulse width of 6 ps at a 10 GHz repetition rate. The linewidths of the output longitudinal modes were as narrow as 7 kHz, and there was no wavelength dependence. The present laser is expected to be an attractive light source for ultra-high speed coherent optical pulse transmission with high-order multiplicity. Furthermore, this laser may be very useful when combined with spectral broadening as a coherent multi-carrier source, since it has multiple longitudinal modes with narrow linewidth characteristics.

5. Acknowledgements

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6. References

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