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All-optical-gate-type mode-locked few-picosecond pulsed laser with externally injected, weakly modulated optical seed

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1. Introduction

Optical clock pulse sources that generate pulses shorter than 3 picoseconds with repetition frequency at around 10 GHz are valuable sources in several kinds of advanced optical systems presently and in the near future, such as optical time-division multiplexing (OTDM) communication systems, optical time-domain reflectometers, dilute gaseous molecule detectors, etc.[1, 2].

Advantages of this all-optical-gate-type mode-locked laser scheme [3-5] are, (1) it does not require a three-dimensionally-confined saturable absorber for shortening and stabilizing its output pulse's width, (2) in contrast to mode-locked fiber lasers, we'll be able to integrate these SOA-based clock pulse source lasers on several-millimeter-level chips, and (3) minimum major components embedded in the laser cavity are, simply, nonlinear SOA, delayed MZI, sometimes etalon, BPF, and output splitter, only.

This laser scheme had been studied, either without external modulation (i.e., passive mode-locking scheme [3-5]) or with relatively strong external modulation. First, when operating this laser without external modulation, Q-switched giant-energy pulses could suddenly occur and severely damage SOA's input facets in one shot (even though with very small probabilities), in the long-time processes of manual, precise, laser-cavity adjustments.

Secondly, when operating this laser with relatively strong external modulation in our more recent works, on the other hand, additional sub-pulses were generated from the laser cavity, in addition to primary mode-locked pulses. In this work, we characterize this laser's outputs before and after intentionally weakening the modulation degree of the externally injected optical seed light.

2. Our experimental setup

The experimental setup is schematically shown in Fig.1. Distributed Feedback Laser Diode (DFB-LD) emits continuous wave (CW) light. CW light is modulated by electro absorption modulator (EAM, OKI), and injected to the ring cavity. Modulation frequency is adjusted to the FSR of Energy Dividing Mach Zehnder Interferometer (ED-MZI), 10.5 GHz. Delay time which decides output pulse width is 2.3 ps. In this experiment, one of commercially available SOA modules (model 1117

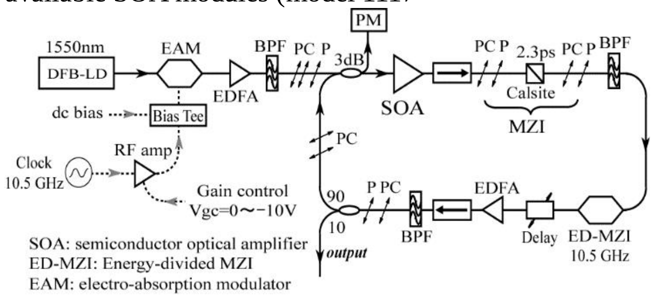

Fig.1 Our experimental setup for 2.3 ps, 10.5GHz, 1550 nm mode-locked pulse generation.

from Covega, drive current = 400mA) was used.

For our intentionally adjusting the modulation degree of externally injected seed light in a step-wise manner in this work, we decided to do it by either increasing or decreasing the dc-bias voltage to the gain-control input pin of our microwave amp module which amplified the microwave clock signal for driving the EAM.

3. Method to weaken modulation degree of the optical seed light

We weaken optical modulation degree by applying negative bias to the RF amp (electric signal's amp). And, negative dc bias to the bias tee can also weak it. Fig.2 (a) shows the result of controlling optical modulation degree. Fig.2 (b) shows the optical time waveform after EAM about 2 pattern modulation degree, 31 % and 6.8 % (and, CW light).

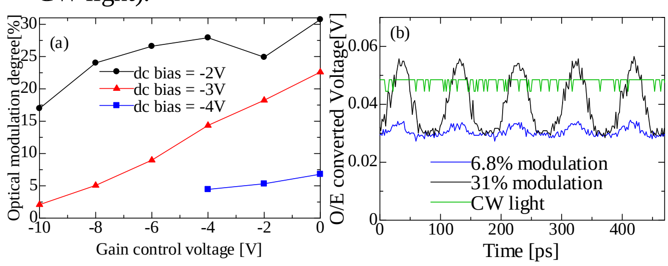

Fig.2 Measured modulation degree of our optical seed light.
(a) Modulation degrees when decreasing RF amp gain.
(b) Measured wave forms.

4. Laser outputs, after weakening modulation degree of the seed light in this work.

Fig. 3 shows typical auto-correlation traces of our laser outputs in this work. (The reason why one of the two peaks was lower than the other was because because our auto-correlatorôs sensitivity as a function of delay time was not uniform enough.)

Fig.3 (a) shows the output pulses when modulation degree is 31 %. Extinction ratio was 7.8 dB, and pulse width was 2.8 ps. And weak sub-pulses appeared. Fig.3 (b) shows about modulation degree 6.8 %. Extinction ratio grew 8.4 dB, and the sub pulses disappeared in the waveform. Pulse width was broadened to 7.6 ps.

Fig.4 shows the spectrum of mode-locked output pulses. (a): modulation degree 31 %, (b): modulation degree 6.8 %.

At 31 % modulation degree, time-bandwidth product was 0.52, but 1.89 at 6.8 %.

5. Conclusion

In the previous works with this mode-locked laser scheme since 1998, this laser scheme was studied either without external modulation (i.e., passive mode-locking scheme) or with relatively strong external modulation (i.e., synchronous mode-locking scheme). In this work, we succeeded in mode-locking the laser output pulses with weakening the modulation degree of the external optical seed from 31% to 6.8%. With this weakly modulated mode-locking, the sub-pulse-like noisy components (which we had observed with previously stronger modulation degrees) disappeared, successfully.

With this weakly modulated mode-locking, however, widths of their auto-correlation traces were broadened, typically by a factor of 2.5. Under weakly modulated mode-locking conditions in this work, we will study furthermore, improve this temporal broadening, and publish it elsewhere.

Reference

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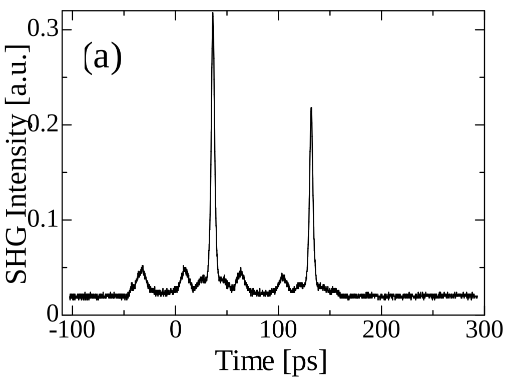


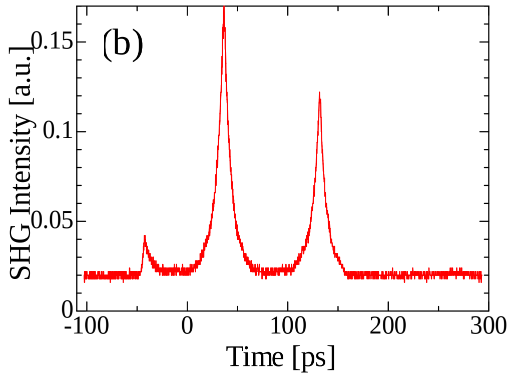
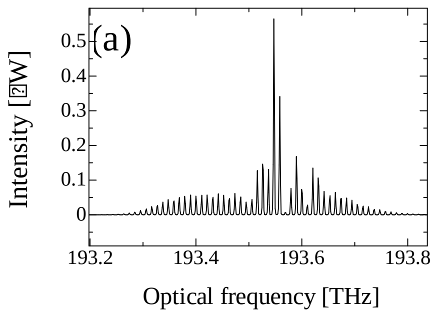


Fig.3 Measured auto-correlation traces from output port of our pulsed laser.

(a) Pulse width was 2.8 ps (assuming $\Delta\tau/\Delta\tau_c$ ratio of 0.707 from Gaussian pulse shape model), with 31%-modulated optical seed.

(b) Pulse width was 7.6 ps with 6.8%-modulated optical seed.



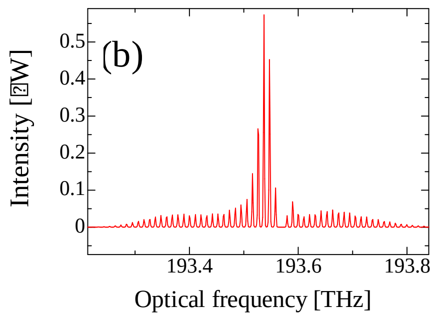


Fig.4 Measured optical spectra.
The optical frequency of our DFB laser (before EA modulation) was 193.60 THz, λ = 1549.6 nm.
Spacing between the equally spaced spectral lines was 10.5 GHz, which matched the pulseôs repetition frequency (indicated in Fig. 3(a) and (b)).
(a) Full-width at half-maximum was about 185 MHz, and $\Delta t \cdot \Delta f$ product was 0.52 with 31%-modulated optical seed.
(b) Full-width at half-maximum was about 248 MHz, and $\Delta t \cdot \Delta f$ product was 1.89 with 6.8%-modulated optical seed.