Ultrafast all-optical-gate-type mode-locked pulse laser without using any optical-fiber amps

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***Abstract*— In optical pulse generator using Delayed-Interference-Signal-wavelength-Converter (DISC) type all-optical gate, we use Semiconductor Optical Amplifiers (SOAs) instead of Erbium-Doped Fiber Amplifier (EDFA) in optical amp parts. We succeeded in generating pulse by adjusting the polarization state to optical axis of SOAs in optical amp part. The pulse width is 5.3 ps, repetition frequency is 10.5 GHz, and extinction ratio is 12 dB.**

Keywords-mode-locking; all-optical; semiconductor optical amplifier (SOA); optical pulse generator

I. INTRODUCTION

The demand for broadband network has been increasing in the world. In present fiber network system, optical signal is converted to electrical signal for signal process. This electrical signal process causes the limit of data speed (< 40 GHz). To overcome the limit, all-optical-signal processing devices are expected [1-2]. In these devices, high-repetition-rate, stable and integrated optical clock-pulse generator is demanded for control light.

One of the optical clock-pulse generators is Mode-Locked Laser Diodes (MLLD). There are two types of MLLD. One is using saturable absorber, which is able to generate ultrafast clock-pulses (> 1 THz) [3]. The other is using phase modulator, which is limited repetition-rate by the modulator's operation speed (< 40 GHz) [4].

Another is all-optical-gate-type mode-locked pulse laser, which is using Semiconductor Optical Amplifiers (SOAs) and Mach-Zehnder Interferometer (MZI) [5-11]. The mode-locked pulse laser DISC-loop [6-11], which includes delayed-interference-signal-wavelength-convert-er (DISC) [12-13] is expected for the light source, because it has two advantages. First, it is settable pulse width, repetition-rate, and center wavelength freely. Second, it can generate high-repetition-rate (> 40 GHz) pulse in principle, because it is not used phase modulator.

DISC-loop has been proposed and investigated since 2001. In 2001, repetition-rate 10 GHz optical clock-pulse was generated [6]. In 2005, threshold gain condition for pulse generation was proposed and demonstrated [7]. In 2006, repetition-rare 40 GHz optical clock-pulse was generated [8]. Single-mode pulse oscillation was achieved by using high finesse etalon in 2007 [9]. In 2008, threshold condition of feedback polarization for pulse generation was proposed and demonstrated [10]. Recently, pulse generation method using external modulated light was proposed and investigated for preventing damage of SOAs caused by high-energy pulse of Q-switch [11].

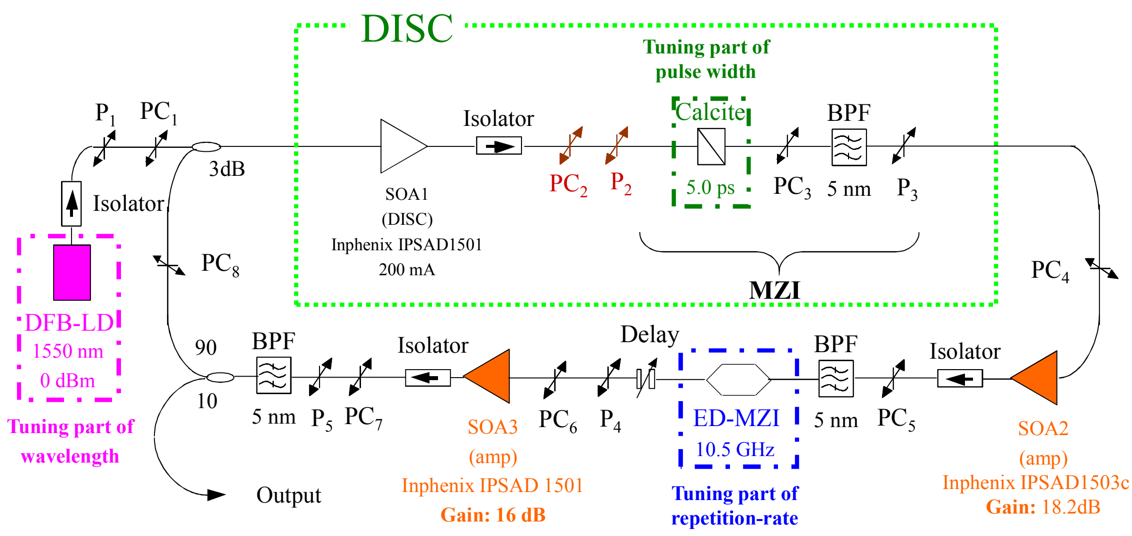
Integration of DISC-loop is required for integrated all-optical signal processing devices as control light source. We have used Erbium-Doped Fiber Amplifier (EDFA) for the gain medium. However EDFA makes difficult to integrate DISC-loop, because of its long length. On the other hands, SOA is easier to integrate, because of its small size.

In this work, we investigate DISC-loop which uses SOA in amp parts and succeeded in generating pulse. The pulse width is 5.3 ps, repetition frequency is 10.5 GHz, center wavelength is 1550 nm, and extinction ratio is 12 dB.

II. EXPERIMENTAL SETUP

The mode-locked pulse laser DISC-loop in this work is schematically shown in Fig. 1. It is composed of Distributed Feedback Laser Diode (DFB-LD) which is input continuous wave (cw) light source, isolator, Polarizer (P), Polarization Controller (PC), 3 dB coupler (3 dB), DISC, SOA, Band-Pass Filter (BPF), Energy-Dividing Mach-Zehnder Interferometer (ED-MZI), Delay and 10:90 coupler. The DISC is composed of SOA, Mach-Zehnder Interferometer (MZI) and BPF, and works as reshaping. The SOA in DISC (SOA1) is used for generationg cross gain modulation and cross phase modulation. In this work, MZI is composed of Calcite, PC3 and P. SOA2, SOA3 are used for optical amplier instead of EDFA. The gain of SOA2 is 18.2 dB, the gain of SOA3 is 16 dB.

Pulse width is settable freely by delay time of Calcite in MZI. Repetition-rate is settable freely by Free Spectrum Range (FSR) of ED-MZI. Center wavelength is settable freely by cw light wavelength from DFB-LD. In this work, we set pulse width 5.0 ps, repetition-rate 10.5 GHz and center wavelength 1550 nm.



DFB-LD: Distributed Feedback Laser Diode, P: Polarizer, PC: Polarization Controller, DISC: Delayed-Interference-Signal-wavelength-Converter, SOA: Semiconductor Optical Amplifier, BPF: Band Pass Filter, ED-MZI: Energy-Dividing Mach-Zehnder Interferometer

Fig 1. Experimental setup

III. PRINCIPLE OF PULSE OSCILLATION

The principle of pulse generation in DISC-loop is below.

1. In DISC, input cw light is shaped with one pulse from noise. The center wavelength is same as the wavelength of cw light. The pulse width is same as the delay time of Calcite in MZI respectively.
2. The pulse is amplified by SOAs in amp parts.
3. Pulses are generated by ED-MZI. The repetition-rate of the pulses are same as the FSR of ED-MZI.
4. The polarization of feedback pulses are adjusted to optical axis of SOA in DISC by PC8 so that feedback light is cut by P2 in DISC for pulse generation.
5. Input cw light is shaped with pulses from feedback pulses in DISC. The shaped cw light (pulses) is circuited in ring cavity.
6. Optical clock-pulse is generated by repeating process 2 to 5.

IV. CONDITION OF PULSE OSCILLATION

To generate clock-pulse in DISC-loop, it is necessary to fulfill three conditions.

1. Threshold Gain in optical amps

The round gain in ring cavity is more than 0 dB for pulse oscillation (shown in (1)).

$$G_{amp} - T_{DISC} + L_{passive} > 0 \qquad (1)$$

Where G_{amp} is the gain in optical amps (SOAs), T_{DISC} is the transmittance of DISC for pulse, $L_{passive}$ is passive loss without DISC. In this paper, G_{amp} is 34.2 dB, T_{DISC} is 13 dB, $L_{passive}$ is -15.7 dB.

2. Synthesizing frequency of ED-MZI and ring cavity

FSR of ED-MZI is multiple times of basic frequency in ring cavity (shown in (2)).

$$f_{FSR} = m\, f_{ring} \quad (m=1, 2, \cdots) \qquad (2)$$

Where f_{FSR} is FSR of ED-MZI, f_{ring} is basic frequency in ring cavity. To fulfill the condition (2), we use delay to adjust the optical length for tuning basic frequency in ring cavity.

3. Adjusting polarization of input and feedback light

Polarization of input cw light from DFB-LD is optical axis of SOA in DISC, and polarization of feedback light from ring cavity is orthogonal mode of cw light. The feedback light polarization condition is shown in (3).

$$G_{amp} + G_{SOA\text{-}DISC} + L_{DISC} + L_{pol} + L_{passive} < 0 \quad (3)$$

Where, $G_{SOA\text{-}DISC}$ is the SOA gain in DISC, L_{DISC} is passive loss in DISC, L_{pol} is the polarization loss of P1 in DISC and shown in (4).

$$L_{pol} = 10\log(\sin^2(2\theta)) \qquad (4)$$

Where, θ is the difference angle between polarization of feedback light and optical axis of P1 in DISC. To control the polarization of the lights, we adjust PC in each part.

V. EXPERIMENT RESULT AND DISCUSSION

The output light from DISC-loop with adjusting polarization is shown in Fig.2. The pulse width is 5.3 ps, repetition frequency is 10.5 GHz, and center wavelength is 1550 nm. These results agree with the set values. The time-bandwidth product is 0.50 fitted with Gaussian shape. Compared with the transform limit 0.44, the output pulse is chirped a little. The mode-locked time is from seconds to minetes. Compared with DISC-loop which is EDFA in optical amp parts, the output pulse is unstable.

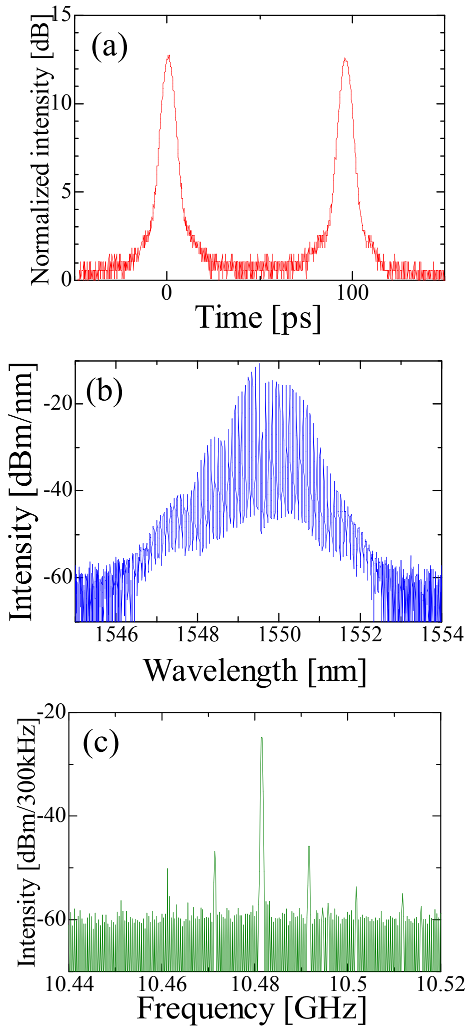


Fig 2. DISC-Loop Output light with adjusting polarization
(a) Time waveform (b) Optical spctrum (c) Electrical spectrum
From (a) and (b), output pulse is pulse width 5.3 ps and band-width 95 GHz (0.74 nm) respectively. The time-bandwidth is 5.3 ps×95 GHz = 0.50

On the other hand, Fig.3 is the output light from DISC-loop without adjusting polarization (In the case of Fig.3, the delay time of calcite is 2.3 ps, FSR of ED-MZI is 10.5 GHz and cw light from DFB-LD is 1550 nm). From Fig.3, mode-locked pulse is not obtained in any case that feedback polarization and optical length in ring cavity are adjusted.

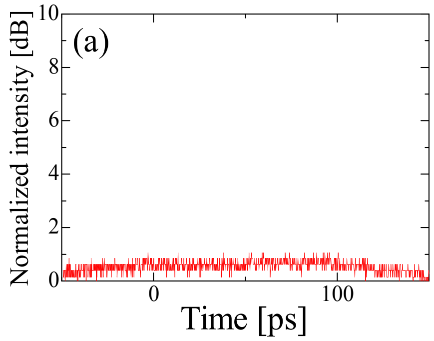


Fig 3. Output pulse without adjusting polarization
(a) Time waveform

From these results, we found that input light polarization to SOAs for amp is optical axis to generate pulse in addition to three conditions in session Ⅲ. The reason is that NPR through SOAs in optical amp part is suppressed for maximum transmittion at polarizer after SOAs in optical amp part..

VI. CONCLUSION

In this work, We investigate DISC-loop which uses SOA in amp parts and succeeded in generating pulse. The pulse width is 5.3 ps, repetition frequency is 10.5 GHz, center wavelength is 1550 nm, and extinction ratio is 12 dB. The mode-locked time is from seconds to minetes. Compared with DISC-loop which is EDFA in optical amp parts, the output pulse is unstable. We found that input light polarization to SOAs in optical amp part is adjusted to the optical axis for generating pulse in addition to three conditions in session Ⅲ. The reason is that NPR through SOAs in optical amp part is suppressed for maximum transmittion at polarizer after SOAs in optical amp part..

Next research is resolution of the pulse oscillation process in sinusoidally modulated light injection type DISC-loop. This research helps to demonstrate the effectiveness of preventing damage of SOAs caused by high-energy pulse of Q-switch.

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