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Optical 3R Wavelength Conversion by a combination of Self-pulsating DFB Laser and SOA-based Mach-Zehnder Interferometer

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1. Introduction

All-optical wavelength conversion is a key function to reduce both cost and power consumption in near future communication networks. A Mach-Zehnder interferometer with semiconductor optical amplifiers (SOA-MZI) is attractive to realize this function. However, only a few reports on practical realization of monolithically integrated SOA-MZI have been performed so far [1-3] owing to the complexity of device fabrication process. For the device operation of SOA-MZI, optical 3R (Re-amplification, Re-timing, Re-shaping) functions are desirable to avoid a degradation of optical signals. Short pulse laser sources which can recover optical clock pulses, such as self-pulsating DFB laser diodes (SP-DFB LDs) [4, 5] or mode-locked lasers (ML-LDs), are required for this purpose. In particular, tunability of repetition frequency is an advantage of SP-LDs. In this report, we present an SP-LD which operates with multi bit rates of both 10 and 40 GHz. Second, features of the fabricated SOA-MZI are explained. Finally, we present first all-optical wavelength conversion operation at 10 Gbps with optical 3R with hybrid combination of SOA-MZI and SP-LD.

2. Self-pulsating DFB LD

We fabricated a three-electrode SP-DFB LD with a buried heterostructure. Gratings in the front and the rear DFB sections with an InGaAsP bulk active layer were fabricated by electron beam lithography, while a transparent waveguide region for phase tuning was formed between the two DFB sections by butt-joint regrowth procedure. A schematic structure is shown in Fig. 1. Both DFB sections were 300 μm long and wavelength detuning of the gratings was designed to be 4 nm. SP operations at both 10 and 40 GHz were observed for different drive conditions. Figure 2(a) shows RF and optical spectra of 10 GHz SP signal under a condition of front DFB current If=50 mA and rear DFB current Ir=15 mA. Several lasing modes around 1547 nm were observed in the optical spectra and this was a feature of SP due to dispersive-Q switching mechanism [4]. On the other hand, Fig. 2(b) shows RF and optical spectra of 40 GHz signal under a condition of If=70 mA and Ir=80 mA. Dual lasing modes were observed in the optical spectra and this was a feature of SP due to mode beating mechanism [6]. Thus, multi bit rate SP operation at 10 and 40GHz which will improve system applicability was confirmed with a single device.

3. Monolithically integrated SOA-MZI

Figure 3 shows the device structure of monolithically integrated SOA-MZI. SOA of 1800 μm length and transparent passive waveguides consist of both arms. Unintentional lasing of SOA at low carrier density was avoided by a suppression of optical reflection from the interface of SOA and transparent waveguide with 45-degree-tilted butt joint structure [7]. Multimode interference couplers were used to form an interferometer. Gain peak wavelength of SOA-MZI was 1.58 μm. Input optical control pulses were injected into only one side arm, whereas another input light of a different wavelength was injected into both arms. Converted signal was generated by a phase change of the SOA and separated from the control pulses by a wavelength filter.

4. All-optical wavelength conversion with re-timing

Figure 4 shows a setup of the wavelength conversion experiment with optical 3R [8]. Control signal of 10 Gbps RZ-PRBS was generated by two lithium niobate light modulators. Wavelength of the control signal was 1555 nm. The control signal was injected into both SP-LD and SOA-MZI with a similar intensity of -2.5 dBm. Timing jitter of the control signal was degraded with ASE noise addition by an EDFA to investigate the effect of optical 3R operation. Optical clock signal was recovered as the injection-locked signal of SP-LD and injected into SOA-MZI with an intensity of +7 dBm. Figures 5(a), (b) and (c) show waveforms of wavelength-converted output, recovered optical clock and degraded input, respectively. Timing jitter was improved from 5.5 ps to 3.5 ps by using SP-LD.

Wavelength conversion characteristics were investigated as a function of control signal wavelength. Figure 6 shows waveforms of converted output obtained for input wavelengths from 1555 nm to 1575 nm. As shown in the figure, all-optical wavelength conversion operation with optical 3R was experimentally demonstrated over 20 nm range of control input wavelength. Wavelength-converted output showed fair waveforms for all input wavelengths, although slight degradation was observed for longer input wavelength. In the present case, lasing wavelength of SP-LD is ~30 nm apart from the gain peak of SOA. The observed degradation was ascribed to the large gain difference between the control input wavelength of 1575 nm and the optical clock input wavelength of 1547 nm. Wavelength conversion waveforms at 40 Gbps (not shown here) under similar experimental conditions was more degraded owing to the same cause. However, the timing jitter of the converted signal and the ranges of the operating input wavelength or bit rate will be improved by making the SP-LD lasing wavelength near the SOA gain peak.

5. Conclusions

Self-pulsating DFB lasers and monolithically integrated SOA-based Mach-Zehnder interferometer were fabricated. All-optical wavelength conversion of 10 Gb/s RZ-PRBS optical signal with timing jitter reduction was successfully demonstrated by their hybrid combination for a wide wavelength range of input signal.

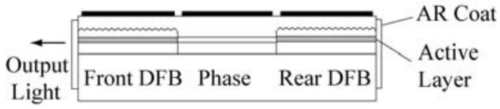
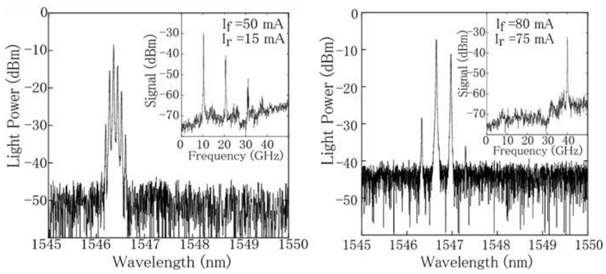


Fig. 1 Schematic device structure of self-pulsating DFB-LD.



(a) (b)

Fig. 2 RF and optical spectra of the device output.
(a) self-pulsation at 10 GHz and (b) self-pulsation at 40 GHz.

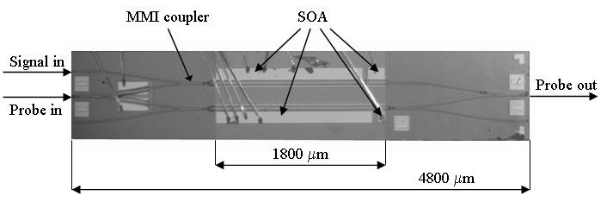


Fig. 3 Device structure of monolithically integrated SOA-MZI.

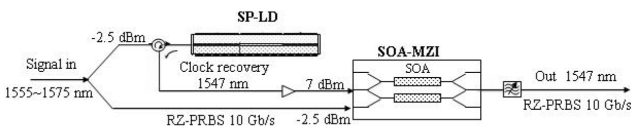


Fig. 4 Experimental setup of wavelength conversion.

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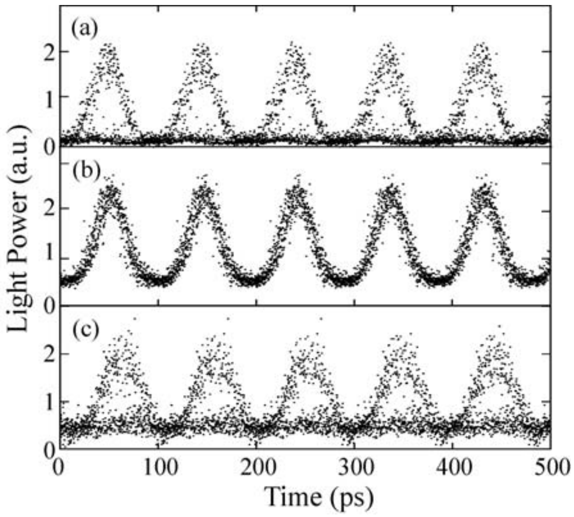

Fig. 5 Waveforms of input and output optical signals.
(a) wavelength converted signal, (b) recovered optical clock pulses from SP-LD, (c) PRBS signal input with noise addition.

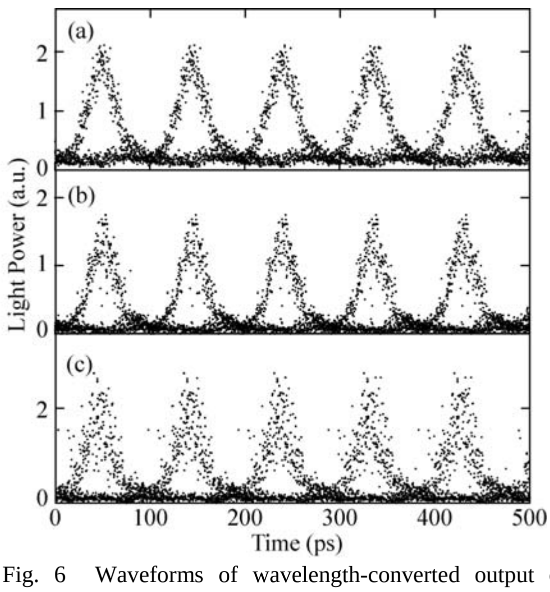

Fig. 6 Waveforms of wavelength-converted output optical signals for various input wavelengths. (a) from 1555 nm to 1547 nm, (b) from 1565 nm to 1547 nm, (c) from 1575 nm to 1547 nm.