Semiconductor Wavelength Converter with Wide Dynamic Range

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***Abstract*—Semiconductor optical amplifier based wavelength converter in Mach-Zehnder interferometer configuration realizes bit rate transparent and wide dynamic range wavelength conversion up to 43 Gbps employing simple feedback control with monitor PD and gain control SOA.**

Keywords- Mach-Zehnder; Wavelength converter; SOA; PD; Dynamic range

I. Introduction

Rapid global growth of mobile phone including huge amount of smart phone spreads in addition to the conventional internet so that increasing rapid internet traffic require continuous optical communication network expansion over the world. Sustainable growth of the optical backbone network must be realized simultaneously. Therefore all optical network is one of the plausible candidate to meet the above request and optical wavelength conversion is an key technology for the next generation optical communication network with energy efficiency and flexibility.

Among various wavelength converter technologies, a semiconductor optical amplifier (SOA) is most plausible one due to advantages of its compactness, high conversion efficiency, and possibility of higher order degree integration. Thus, several wavelength converter technologies with SOA have been investigated, such as SOA Mach-Zehnder interferometer (MZI) based on cross-gain modulation (XGM) and cross-phase modulation (XPM) [1-3] or four-wave mixing (FWM).

Monolithic integration is mandatory for the next generation devices, such as 40G MZ TLD [4], 100GbE PD [5], and so on. Since SOA-MZI wavelength converter integrates several optical parts, such as SOAs, PDs, and waveguides, in the same manner.

However, wavelength converter based on SOA has disadvantage of limited dynamic range for an input signal power. To overcome this, we have proposed an SOA-MZI wavelength converter with gain control SOA (G-SOA) and expanded dynamic range by adjusting G-SOA gain manually [6].

This paper presents a wide dynamic range wavelength converter using a simple feedback control with a monitor photo diode (PD) and a G-SOA. We demonstrate wide dynamic range wavelength conversion for 43 Gbps NRZ signal.

II. SOA-MZI based wavelength converter

A wavelength converter not only covers C-band wavelength range but also accommodates with wide speed range of bit rate and different format of RZ and NRZ in order to support all optical network. Figure 1 shows schematic diagram of SOA-MZI wavelength converter. The basic SOA-MZI consists of two SOAs and phase shifters located on both MZ arms. Port P1, P2 and P3 are a probe light input port, a signal light input port and an output port of wavelength converted signal, respectively. Continuous wave (CW) probe light injected into the P1 passes through SOA1 and SOA2 in the MZI configuration. Signal light launched into the P2 passes through the G-SOA which is located to control signal input power, propagating through SOA2 along with the probe light. As probe light is modulated by signal light through XGM and XPM in SOA2, it is transformed to wavelength converted signal through interference between those probe lights from the SOA1 and the SOA2 and then emitted from the P3.

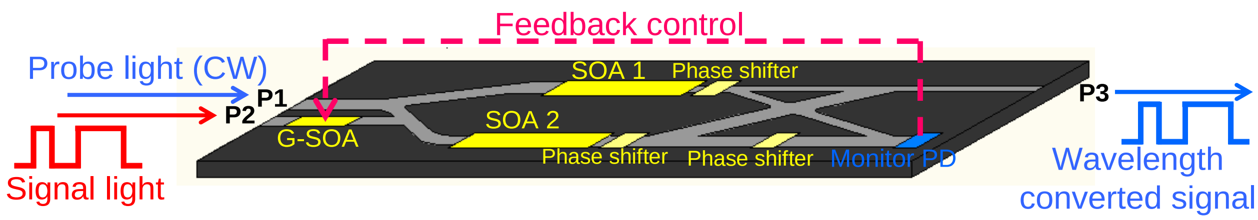

Figure 1. Schematic diagram of SOA-MZI wavelength converter monolithically integrated with a monitor PD and a gain control SOA

It is important to achieve enough fast response to support wide speed range of 2.5 Gbps to 40 Gbps and both RZ and NRZ. To achieve the above, SOA designs in MZI require high gain in small active area [1]. Wavelength converter with such optimized design has accomplished bit rate transparent between 2.5 Gbps and 40 Gbps with both RZ and NRZ format.

III. A SIMPLE FEEDBACK CONTROL METHOD AND WAVELENGTH CONVERTER CONFIGURATION TO ENHANCE DYNAMIC RANGE

This type of wavelength converter needs to be well organized to achieve such a high performance. An important point is the signal input power into the SOA2, which set to be some specific value under various conditions. In the real network, input signal power could vary so that the device needs a function to keep the input power constant. Since the phase modulation of the probe light depends strongly on signal input power into the SOA2, this restricts the superior wavelength conversion for wide signal input power range. One solution is to keep the signal power into the SOA2 constant at optimal signal power level in order to enhance dynamic range of input power for wavelength conversion by adjusting G-SOA.

We introduced a simple feedback control to maintain a constant signal power into SOA2. In particular, it is to keep the monitor PD current at its maximum by controlling the G-SOA bias current. The monitor PD after MZI on the opposite side of the P3 detects the wavelength converted signal level for feedback control. The feedback control is based on relationship between signal power into the SOA2 and wavelength converted power. Figure 2 (a) shows calculated average power of wavelength converted signal as a function of bias current of the G-SOA for 43 Gbps NRZ signal under constant signal input power at the P2. Figure 2 (b), (c) and (d) are calculated eye diagrams at points A, B, and C in Fig.2 (a), respectively. The signal power into the SOA2 depends on bias current of the G-SOA. Clear eye opening is obtained at the maximum average power of wavelength converted signal of the point B. As wavelength converted signal with high extinction ratio and high amplitude is obtained under the condition that phase difference of the probe lights in MZ arms is π radian, the average power of wavelength converted signal becomes the highest. In case of lower bias current at the point A, eye pattern is deteriorated in Fig.2 (b). Phase difference of probe lights is smaller than π radian for lower input signal due to reduction in

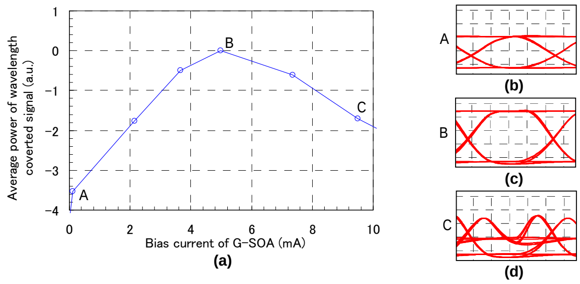

Figure 2. Characteristics of average power of wavelength converted signal and eye diagrams for 43Gbps NRZ signal. (a) Calculated average power of wavelength converted signal as a function of bias current of G-SOA. (b) The eye diagram at the point of A. (c) The eye diagram at the point of B. (d) The eye diagram at th e point of C

gain of the G-SOA and thereby average power of wavelength converted signal becomes small and extinction ratio is also low. Meanwhile, if the bias current of the G-SOA becomes high at the point C, eye pattern is distorted in Fig.2 (d). As the phase difference is larger than π radian for higher input signal due to increase of the G-SOA, overshoot occurs because of overmodulation for interferometer of probe lights and then its average power also decreases and extinction ratio becomes low.

For this reason, waveform with high extinction ratio and amplitude is obtained at the maximum power of wavelength converted signal. Since the monitor PD can detect its average power, signal power into SOA2 is maintained at optimal level and clear eye opening is easily obtained for wide dynamic range of signal input power by keeping the monitor PD current at its maximum by adjusting the G-SOA bias current using feedback control.

IV. EXPERIMENTAL SETUP AND RESULTS

Figure 3 shows schematic diagram of experimental setup. The wavelength and power of the probe light are 1537 nm and +6 dBm, respectively. The signal light of 1535 nm wavelength is modulated at 43 Gbps NRZ 2^{31}-1 pseudo random bit sequence (PRBS). The monitor PD and the G-SOA are connected with a feedback control system which detects the monitor PD current and adjusts the G-SOA bias current to keep the monitor PD current at its maximum. Wavelength converted signal is detected by oscilloscope and optical power meter.

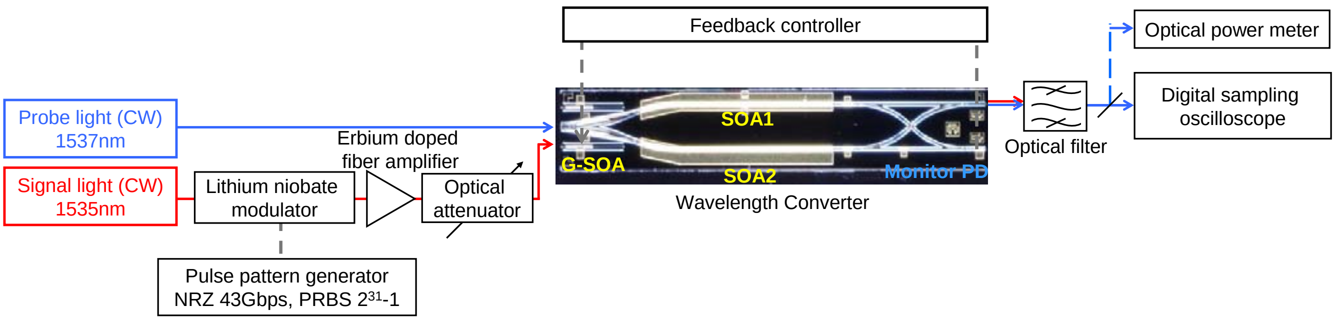

Figure 3. Schematic diagram of experimental setup.

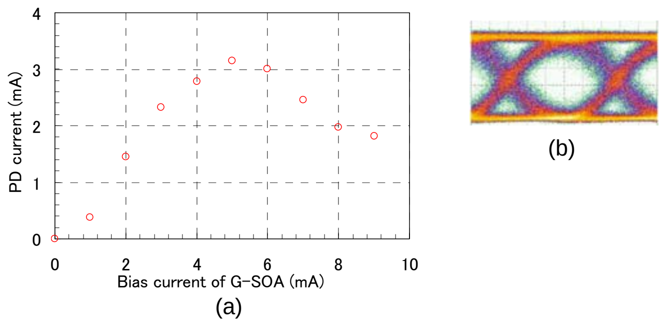

Figure 4. (a) Monitor PD current versus bias current of G-SOA. (b) The eye diagram of converted signal at the maximum monitor PD current.

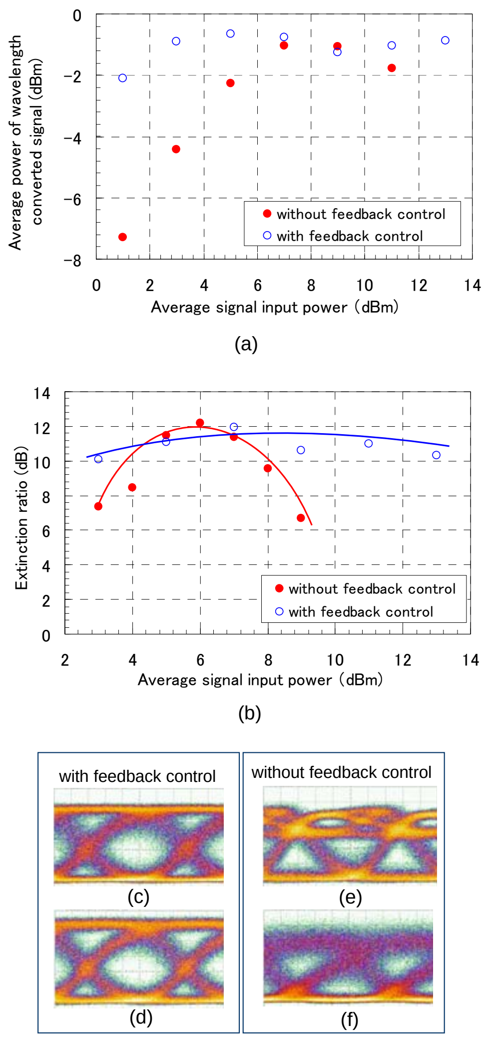

Figure 5. Characteristics of average power of wavelength converted signal and extinction ratio as well as eye diagrams of converted light. (a) Average power of wavelength converted signal as a function of average signal input power. (b) Extinction ratio versus average signal input power. (c) (d) Eye diagrams with feedback control in the power of +13 dBm and +3dBm, respectively.(e) and (f) Eye diagrams without feedback control in the power of +9dBm and +3dBm, respectively.

Figure 4 (a) shows the measured monitor PD current versus bias current of the G-SOA. Figure 4 (b) is an eye diagram at 5mA bias current of the G-SOA which indicates the maximum value of monitor the PD current. Clear eye opening is obtained at the maximum monitor PD current. These results coincide with the simulation results in Fig.2.

Figure 5 (a) shows measured average output power of wavelength converted signal as a function of average input signal power. The open circle is with feedback control and the closed circle is without feedback control and bias current of the G- SOA was fixed at 9.3 mA. Whereas the variation of average power of wavelength converted signal without feedback control is more than 7 dB, one with feedback control is less than 1.65 dB. The variation of its average power was suppressed by feedback control.

Dynamic range is evaluated with the extinction ratio of wavelength converted signal. Figure 5(b) shows measured extinction ratio versus average signal input power. Wavelength converted signal quality depends on signal power into the SOA2 tightly, but variation of extinction ratio is compensated by controlling the G-SOA with feedback control. Here, we set the criteria of extinction ratio to be more than 10 dB. The extinction ratio without feedback control is nearly 2dB range of signal power from +5 dBm to +7 dBm. In contrast, as dynamic range with feedback control is from +3 dBm to +13 dBm, feedback control prolongs dynamic range from 2 dB to 10 dB. Figure 5 (c) and (d) shows obtained eye diagrams with feedback control at the power of +13 dBm and +3 dBm, respectively. Figure 5 (e) and (f) are ones without it at the power of +9 dBm and +3 dBm. In case of no feedback control, eye diagram is distorted (closed) for high (low) signal input. Feedback control adjusted the bias current of the G-SOA to optimal current for each signal power, such as the bias current of 2.5 mA in Fig.5 (c) and 13.5 mA in (d). As a consequence, clear eye opening are obtained during wide dynamic range for input signal power.

V. Conclusion

Wide dynamic range wavelength converter with the monitor PD and the G-SOA using a simple feedback control are presented. The simple feedback control method was experimentally verified and wide dynamic range of 10 dB for 43 Gbps NRZ signal have been successfully demonstrated under the condition of extinction ratio above 10 dB.

References

[1] T. Hatta, et al., "Polarization-Insensitive Monolithic 40Gbps SOA-MZI Wavelength Converter With Narrow Active Waveguides", IEEE J. Quantum Electron., vol.13, no.1, pp. 32-39, 2007.

[2] Y. Miyazaki, *et al*., "Polarization – Insensitive SOA-MZI Monolithic All-Optical Wavelength Converter for Full C-band 40Gbps-NRZ Operation", ECOC 2006, Th3.4.2 (2006).

[3] D. Apostolopoulos, *et al*., "A New Scheme for Regenerative 40Gb/s NRZ Wavelength Conversion using a Hybrid Integrated SOA-MZI", OFC 2010, OThS6 (2010).

[4] N. Ohata, *et al*., "43Gbps Wavelength converter with wide dynamic range of 14dB", CLEO/Pacific Rim2009, ThG1-3 (2009).

[5] T. Takiguchi, et al., "40G RZ-DQPSK Transmitter Monolithically Integrated with Tunable DFB Laser Array and Mach-Zehnder Modulators", OFC2011, OMU3 (2011).

[6] Takemura, et al., "25Gbps x 4ch photodiode array with high responsivity for 100Gbps Ethernet", ECOC2010, P2.11