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All-optical wavelength conversion with multicasting at 4 × 10 Gbits/s up and down using a Fabry-Perot laser diode

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Abstract: We demonstrate an all-optical wavelength converter with multicasting at 4×10 Gbits/s up and down conversion using gain modulation in an FP-LD. We also explain the gain modulation technique using the bistability behavior of the injection locked FP-LD. The wavelength converter shows the average power penalty of 1.5 dB at a bit error rate of 10^{-9} and the extinction ratio of outputs over 12 dB, both for up and down conversions.

Keywords: FP-LD, bistability, gain modulation, multi-wavelength
Classification: Fiber optics, Microwave photonics, Optical interconnection, Photonic signal processing, Photonic integration and systems

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1 Introduction

An all-optical wavelength converter is a key component of the wavelength-division-multiplexing (WDM) optical networks for transparent interoperability, contention resolution, wavelength routing and in general, better utilization of the network resources under dynamic traffic patterns [1]. To increase the traffic carried by the WDM system, a wavelength conversion is needed [2]. Most of the wavelength converters that have been investigated are based on single channel conversion [1]. In case of multi-wavelength conversion, a couple of schemes have been investigated and they are based on cross-absorption modulation (XAM) in an electro-absorption modulator [3], or cross-gain modulation (XGM) of amplified spontaneous emission of a semiconductor optical amplifier [4]. However, the schemes based on XAM or XGM have drawbacks due to a high crosstalk power penalty which is proportional to the number of channels. To mitigate this problem, it was proposed a multi-wavelength converter based on absorption modulation of an injection locked Fabry-Perot laser diode (FP-LD) [5]. This scheme shows a low power penalty and a high extinction ratio (ER). However, in the absorption modulation scheme, the speed is limited up to 2.5 Gbits/s and an additional continuous wave (CW) holding beam is required for increasing the bit rate over 2.5 Gbits/s [6]. The absorption modulation scheme also requires an expensive and highly polarization-sensitive polarization beam splitter (PBS) for separation of transverse magnetic (TM) modes. Moreover, an extra polarization controller (PC) is required in FP-LD side. The additional CW holding beam, PC and PBS make the system complex and costly. Utilizing the PBS inside the module seems the system impractical because the PBS is highly polarization sensitive.

In our previous work [7], we demonstrated single to multi-wavelength conversion at 10 Gbits/s rate. However, the scheme cannot provide multi-wavelength up and multi-wavelength down conversion separately. In this paper, we successfully demonstrate an eight probes wavelength conversion module in which it is implemented a multi-wavelength 4×10 Gbits/s up and down conversion in the same module by using gain modulation in an FP-LD. This module provides multi-wavelength conversion with multicasting function both for up and down conversion, separately. The principle of gain modulation is quite different from the absorption modulation technique. The gain modulation technique doesn't require any PBS. It supports high speed operation without the additional holding beam. The proposed architecture using gain modulation is simple and cost-effective. It supports high-speed operation with multi-wavelength up and multi-wavelength down conversion with multicasting function.

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2 Gain modulation

In this section, we explain the gain modulation phenomena by the bistability characteristic of the injection locked FP-LD. Fig. 1 (a) shows the measured bistability characteristic of an injection locked FP-LD. It shows that, for higher detuning, the FP-LD becomes locked more strongly with higher power injection. For 0.10 nm detuning, the injected power for locking is around −7 dBm and bistability range is around 1.5 dB. For 0.14 nm detuning, the injected power for locking is more than −1 dBm and bi-stability range is over 3 dB. From the bistability characteristic, it can be noted that for a probe beam of lower detuning, it requires lower power to lock the FP-LD, and the locking strength is weaker than the pump beam of higher detuning, because the higher detuning pump locks the FP-LD with higher power and suppress the side modes of FP-LD more than that of probe. Here 'detuning' means the 'wavelength detuning' and it is the wavelength difference between target mode of FP-LD and the external injected beam.

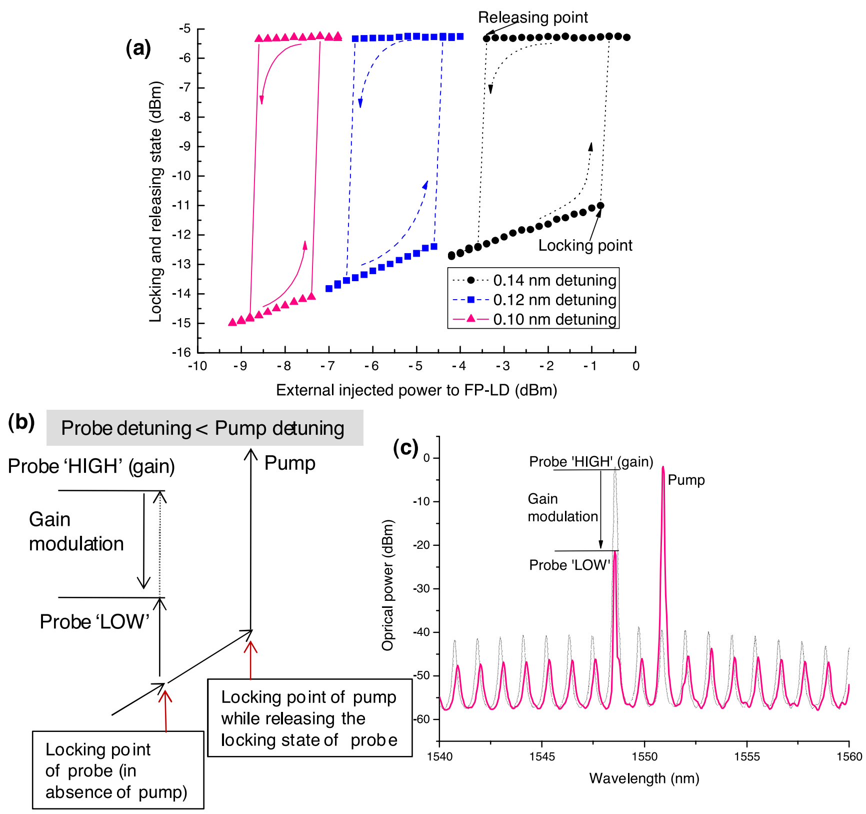

Fig. 1. (a) Bi-stability characteristics of an FP-LD (b) Gain modulation phenomena and (c) Experimental observation of gain modulation traced by an optical spectrum analyzer.

In gain modulation phenomenon, the probe injection has the lower power and lower detuning than that of the pump injection. As shown in Fig. 1 (b), the locking of probe happens with lower power and lower detuning in absence of pump beam. When the pump beam with higher power and higher detuning

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is injected, the probe releases its locking state while the locking of pump beams happens. According to bistability characteristics, the locking state of probe with lower power and lower detuning is weaker than that of the pump with higher power and higher detuning. Hence, the pump can release the locking state of probe easily. This releasing phenomenon of the locking state of probe by the pump is the gain modulation. To experience the real phenomenon, the experimental observation of gain modulation traced by the optical spectrum analyzer is shown in Fig. 1 (c).

3 Experimental results and discussion

Fig. 2 shows the experimental setup for the all-optical multi-wavelength conversion at 4×10 Gbits/s both for up and down conversion. In this experiment, the FP-LD has a nominal lasing wavelength of 1550.18 nm and longitudinal mode spacing of 1.14 nm. The FP-LD has the threshold current (I_{th}) of 4.0 mA; and it was biased at 12.0 mA. The experimental setup has two functions; one is multi-wavelength 4 × 10 Gbits/s up conversion and another one is multi-wavelength 4 × 10 Gbits/s down conversion. In the experimental setup, for multi-wavelength 4 × 10 Gbits/s down conversion, first, the optical circulator (OC) connecting coupler was connected to down conversion side, L, and the transverse electric (TE) mode beams of the four probes (LD1 to LD4) by controlling the polarization controllers (PCs) were injected to the FP-LD with detuning of 0.06 nm and the power of −8 dBm each. Then the modulated pump beam of LD0 by a Mach-Zehnder intensity modulator at 10 Gbits/s using non-return-to-zero signal of $2^{31} - 1$ pseudo random bit sequence was aligned by the PC to get TE polarization and was coupled into the FP-LD via the circulator. The pump beam power before conversion was 0.5 dBm and the wavelength was set at 1550.32 nm (detuning = 0.14 nm) near to the central longitudinal mode of the FP-LD. The probes were set far from each other to investigate that this scheme guaranties wide band multi-wavelength conversion.

The spectra of the output signals from the output terminal of the OC of multi-wavelength 4 × 10 Gbits/s down conversion are shown in Fig. 3 (a); the power levels of all 4 probes are HIGH (dots) without pump injection and LOW (solid line) with pump injection.

Similarly when the OC connecting coupler was connected to up conversion side, R, [Fig. 2] the module was operated as multi-wavelength 4 × 10 Gbits/s up converter and the spectra of output signals of up conversion are shown in Fig. 3 (c); the power levels of all 4 probes are HIGH (dots) without pump injection and LOW (solid line) with pump injection. It is mentioned that the wavelength of the input pump signal was 1550.32 nm while the wavelengths of up conversion probes were 1552.84 nm, 1555.92 nm, 1558.16 nm and 1562.80 nm and the wavelengths of down conversion probes were 1536.72 nm, 1540.08 nm, 1543.44 nm, 1546.80 nm. By using filters in the output terminal, we can get either four down converted wavelengths or four up converted wavelengths output, simultaneously or separately, according to application.

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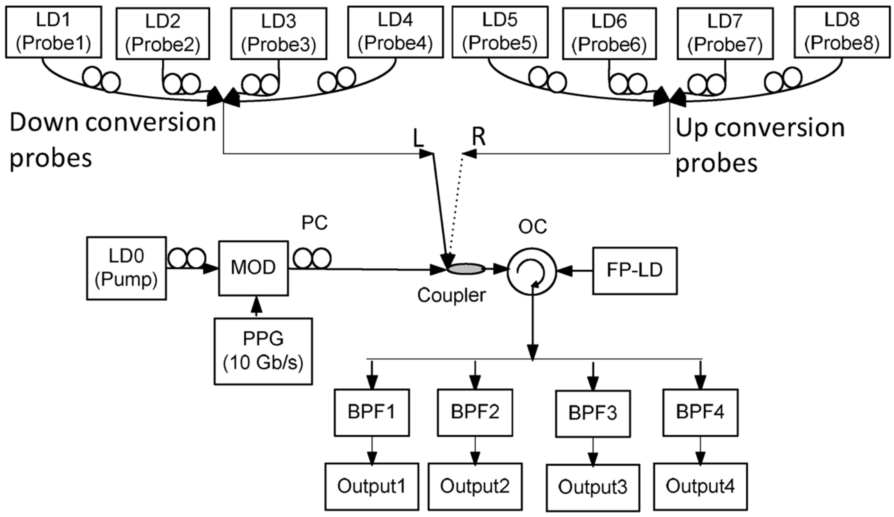

Fig. 2. Experimental setup for the multi-wavelength 4×10 Gbits/s up and down conversion module. LD: Tunable Laser Diode, MOD: Optical intensity Modulator, BPF: Optical Band-Pass Filter, PC: Polarization Controller, OC: Optical circulator, FP-LD: Fabry-Perot laser diode.

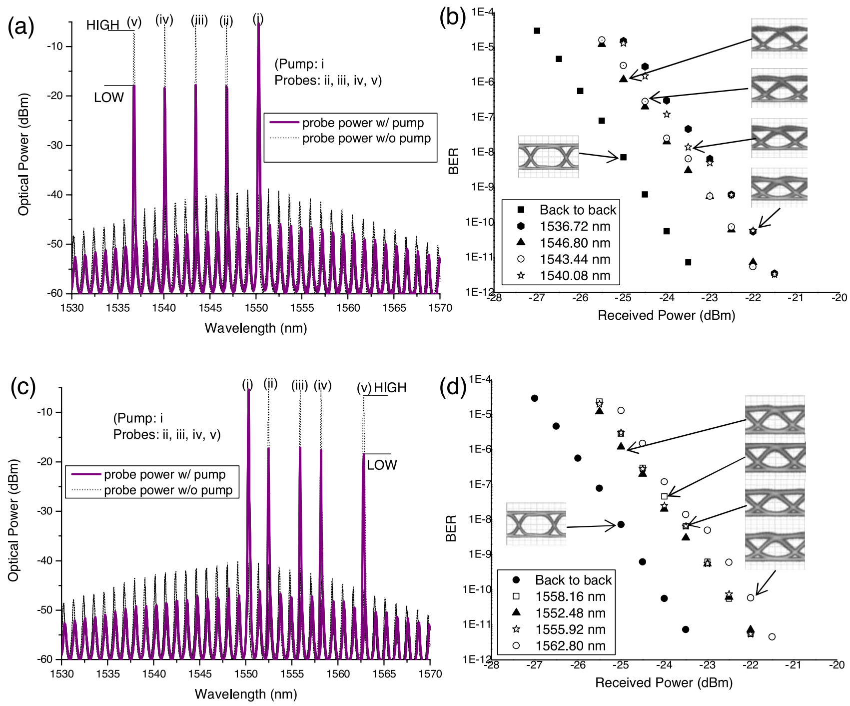

Fig. 3. Results: (a) Optical power spectra of multi-wavelength 4×10 Gbits/s down converted probes with (solid)/without (dot) pump, (b) BER curves and eye diagrams of 4×10 Gbits/s down converted signals, (c) Optical power spectra of 4×10 Gbits/s up converted probes with (solid)/without (dot) pump, (d) BER curves and eye diagrams of 4×10 Gbits/s up converted signals.

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We performed the BER measurements in our experiment. Fig. 3 (b) shows the measured BER curves along with eye diagrams of multi-wavelength 4×10 Gbits/s down converted wavelength signals and Fig. 3 (d) shows the measured BER curves along with eye diagrams of multi-wavelength 4×10 Gbits/s up converted wavelength signals together with back to back measurements. It can be seen that the wavelength conversion leads to an average power penalty of 1.5 dB in each of the up and down conversion at a BER of 10^{-9}.

We measured eye diagrams of each converted signal and observed over 12 dB ER for both up and down conversions. The low power penalty and high ER prove that this wavelength conversion scheme performs well. Moreover, as can be noted that, no BER floor was observed up to BER values of 10^{-12}, which proves the excellent performance of the multi-wavelength up and multi-wavelength down conversion at 4×10 Gbits/s rate.

The investigated results of all-optical multi-wavelength converter module of 4×10 Gbits/s up and down conversion guaranty to increase the number of channels. The demonstrated all–optical multi-wavelength up and multi-wavelength down conversion supports multiple outputs simultaneously which carry the same information but different wavelengths. Thus, this scheme can be used to implement multicasting functions in WDM optical networks. The advantage of this scheme is that it supports multi-wavelength up and multi-wavelength down conversion separately in the same module.

4 Conclusion

We demonstrate an all-optical wavelength conversion module with multicasting function at 4×10 Gbits/s up and down conversion using gain modulation in a Fabry-Perot laser diode. To investigate the module performance, we measure the BERs and ERs of each output signals. The average power penalty of 1.5 dB at a bit error rate of 10^{-9} and the extinction ratio of outputs over 12 dB were measured both for 4×10 Gbits/s up and down conversions. Moreover, no bit error floor was observed up to BER values of 10^{-12}. Hence, the module can be used in future WDM optical networks as multi-wavelength up and multi-wavelength down conversion with multicasting function.

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