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All-optical multi-wavelength conversion using absorption modulation of an injection-locked FP-LD

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Abstract: An all-optical multi-wavelength converter using absorption modulation of an injection-locked Fabry-Perot laser diode (FP-LD) is demonstrated at 2.5 Gb/s. The multi-wavelength converter can simultaneously provide 1 to 4 channel outputs and support both inverted and non-inverted conversion. By optimizing the wavelength of pump signal and polarization states of pump, probes, and the FP-LD, all converted outputs show high extinction ratio and negligible crosstalk power penalty. The results guarantee to increase the number of output channels. The proposed scheme can be applied to multicasting functions as well as 1xN wavelength conversion in an all-optical wavelength division multiplexed network.

Keywords: wavelength conversion, Fabry-Perot laser diode, injection-locking, multicasting
Classification: Photonics devices, circuits, and systems

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1 Introduction

All-optical wavelength converter becomes a key functional element in wavelength-division multiplexed (WDM) optical network due to its capabilities of transparent interoperability, contention resolution, wavelength routing and, in general, better utilization of the fixed set of wavelengths [1]. For a multi-wavelength converter (MWC), several schemes have been proposed so far. Those schemes are based on cross-absorption modulation in an electro-absorption modulator [2], or cross-gain modulation of amplified spontaneous emission spectrum of a semiconductor optical amplifier [3]. However, these schemes have been suffered from high crosstalk power penalty (CPP), which is proportional to the number of channels.

In this paper, an all-optical MWC at 2.5 Gb/s is demonstrated. It uses absorption modulation of an injection-locked Fabry-Perot laser diode (FP-LD) and supports both inverted and non-inverted outputs. We optimize the wavelength and polarization states of a pump beam, four probe beams, and the FP-LD. The experimental results show considerable improvement in probe power extinction ratio (PPER) and low power penalties in bit-error-rate (BER) test even when four outputs operate simultaneously. The results ensure that the proposed all-optical MWC can be applied to embodying multicasting functions in WDM network.

2 Operation principle

Fig. 1 (a) shows the operation principle of the MWC based on absorption modulation of TE mode probe beam by a FP-LD injection-locked by TE-mode pump beam. The FP-LD used in the experiment has a multiple quantum well structure and favors TE mode. When a FP-LD is injected with TE-polarized light, whose wavelength is close to one of TE longitudinal modes of the FP-LD, the corresponding mode is locked while other modes are suppressed. However, when TM-polarized light is injected, the FP-LD shows

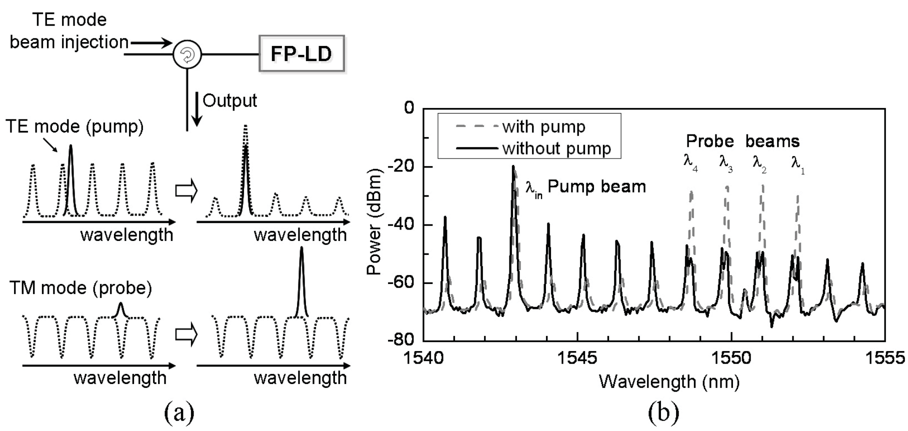

Fig. 1. (a) TM mode absorption by the FP-LD injection-locked by TE mode beam. (b) Output spectra of the MWC with (solid line) and without (dot line) pump signal.

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absorption nulls at its TM mode peaks [4]. When a TE-polarized pump beam locks the FP-LD, locking causes reduction of carrier density in the FP-LD and leads red shift of absorption nulls due to strong coupling between gain and refractive index in semiconductor materials. Therefore, a modulated pump beam can lead absorption modulation of TM-polarized probe beams.

Fig. 1 (b) shows the measured spectra for the injection-locked and unlocked FP-LD. The TE-polarized optical pump, λ_{in}, is aligned with the central TE longitudinal mode of the FP-LD. And the TM-polarized continuous probe beams, λ_i (i = 1, 2, 3, 4), are coupled into the FP-LD after being spectrally aligned with TM longitudinal modes of the FP-LD. When the pump signal is "0" level, all probe powers are absorbed by the nulls of the FP-LD. That is, the probe signals are filtered out by the absorption property of the FP-LD. When the pump signal is "1" level, the nulls are moved by the red-shift phenomenon so that probe powers are released toward the output port. Thus non-inverted all-optical multi-wavelength conversion is achieved from λ_{in} to λ_i. To obtain inverted output, all the probe wavelengths should be set at slightly longer wavelengths from their corresponding local absorption minimums. Then, a pump optical signal of "1" level will trigger the shift of those minimums toward the probe wavelengths and the probe beams are blocked. As a result, inverted multi-wavelength conversion is achieved.

3 Experimental results

Fig. 2 shows the experimental setup for the all-optical MWC. In Fig. 2, the FP-LD has a nominal lasing wavelength at 1542.92 nm and longitudinal mode spacing of 1.14 nm. The FP-LD was biased at 16 mA (I_{th} = 11 mA). The pump beam from TLD0 was first modulated by a Mach-Zehnder intensity

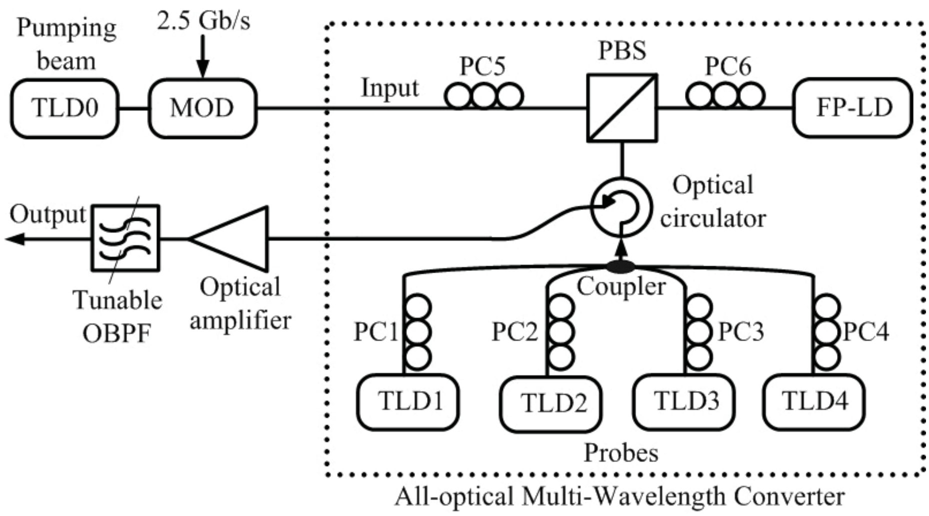

Fig. 2. Experimental setup for the 1x4 MWC. TLD: Tunable Laser Diode, MOD: Optical intensity Modulator, OBPF: Optical Band-Pass Filter, PBS: Polarization Beam Splitter, PC: Polarization Controller.

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modulator at 2.5 Gb/s using non-return-to-zero signal of 2^{31}-1 pseudo random bit sequence. Then, it was aligned with TE polarization by PC5 and coupled into the FP-LD via the PBS. The pump beam wavelength was set at 1542.98 nm (detuning = 0.06 nm) near to the central longitudinal mode of the FP-LD so that the FP-LD is easily locked to the pump beam when the beam is “1” level. The continuous probe beams from tunable lasers (TLD1 to TLD4) were coupled into the FP-LD via the circulator and the PBS after being spectrally aligned with the TM longitudinal modes of the FP-LD. To have polarity-preserving, or non-inverted, wavelength conversion, the probe wavelengths were adjusted to four absorption null positions 1548.68 nm, 1549.82 nm, 1550.96 nm, and 1552.10 nm, respectively, when the pump beam was ‘0’ level.

Fig. 1 (b) shows the spectra of output signals after the circulator when the pump signal is activated (solid line) or not (dot line). All the PPERs were very high (> 20 dB). Fig. 3 (a) shows waveforms for back-to-back, inverted, and non-inverted signals. The back-to-back eye diagram had extinction ratio of 17 dB. The non-inverted eye diagrams have a little bit lower extinction ratios, from 14 dB to 16 dB. For the inverted conversion, extinction ratios ranged from 8 dB to 12 dB, which are still acceptable degradations. Fig. 3 (c) presents BER performances. The channel 1 and channel 2 shown negligible

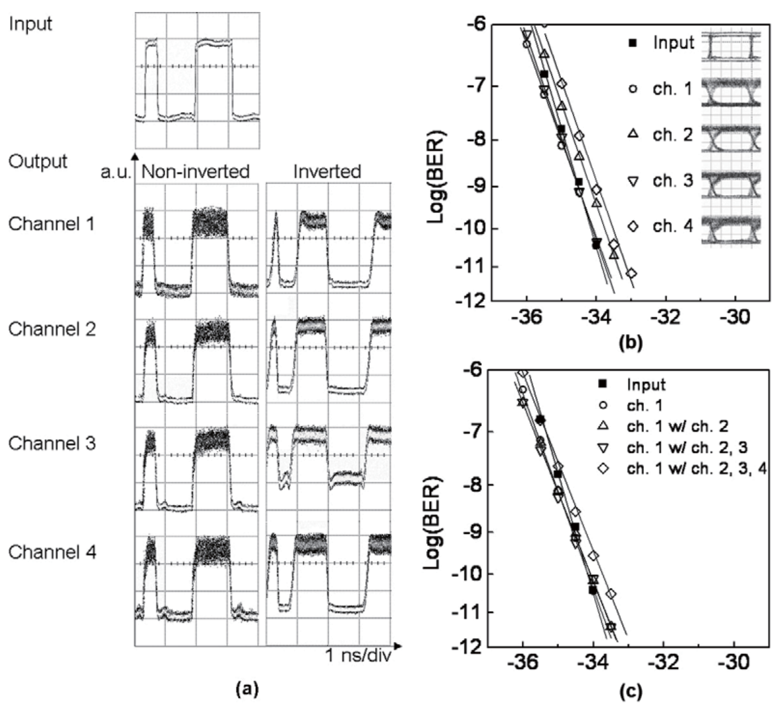

Fig. 3. Waveforms and BER measurements. (a) Pump waveform and inverted and non-inverted waveforms of four outputs. a.u: arbitrary unit. And, BER measurement curves of (b) output of four channels and (c) channel 1 when other channels are activated. Inset of (b): eye diagrams of pump and each channel output.

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penalties, however, the channel 3 and channel 4 shown 0.3 dB and 0.5 dB penalties, respectively. To verify the power penalties corresponding that one channel suffers from other activated channels, the BER performance of channel 1 was monitored while other channels were added increasingly. As presented in Fig. 3 (c), power penalties were so small that can be neglected excluding all channel operation case. From Fig. 3 (c), we can notify that there is room for increase of the number of the output channel because BER curves show acceptable penalties even when four output channels are turned on simultaneously. The expansion of the number of outputs could follow this work, in the near future. Also, the proposed all-optical MWC can simultaneously provide multiple outputs which have same information but different wavelengths. Thus, it can be applied to embodying multicasting functions in a WDM network.

In the experiment, we found that the pump beam wavelength must be near the central wavelength or, in other words, the highest gain area of the FP-LD to get the largest injection-lock detuning range, which results in better performance of the MWC. Also, the polarizations of all probe and pump beams and the FP-LD should be carefully adjusted as the following: making the pump and the FP-LD have TE polarization states and all probe beams have TM polarization states, respectively. Those factors strongly impact against PPERs, CPP, and available number of channels, in general.

4 Conclusion

The all-optical MWC using absorption modulation of an injection-locked FP-LD was demonstrated with both non-inverted and inverted waveforms. By locating the pump wavelength at the highest gain area of the FP-LD and by optimizing polarization states of pump and probe beams and the FP-LD, the MWC showed high PPER in spectrum analysis and low power penalties in BER test. The pump wavelength was successfully converted into multi-wavelengths even when all probe wavelengths are purposely located in successive absorption-null positions of the FP-LD. The proposed scheme can be used for multicasting of pump optical data in a core node of a WDM network due to simple and cost-effective configuration.

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