Using multimode Fabry-Perot laser without external-injection for wavelength conversion

C.H. Yeh, C.W. Chow, C.H. Wang, F.Y. Shih, Y.F. Wu and S. Chi

Proposed and experimentally investigated is an all-optical wavelength converter using a multi-quantum-well multi-longitudinal-mode Fabry-Perot laser diode without any external probe beam or external built-in cavity. The input wavelength can be converted at 2.5 Gbit/s by the converter and the power penalty of 3.5 dB is observed at a bit error rate of 10^{-9}. The proposed converter apparatus is simple and cost-effective for wavelength division multiplexing network applications.

Introduction: Wavelength division multiplexing (WDM) is an important technology for broadband fibre-optic transmissions, because the capacity is easy to increase by adding a new wavelength that determines the signal destination in the WDM transmission network. The wavelength-blocking problem in large networks can be overcome by using wavelength converters. The wavelength converter is also required for flexible wavelength management in fixed wavelength systems [1, 2]. Therefore, wavelength converters are the important components allowing transparent interoperability, contention resolution and wavelength routing for WDM applications [3]. Several techniques for the wavelength conversions have recently been reported and studied, such as using the nonlinear optical gating inside fibre loop, cross-gain modulation, cross-phase modulation and four-wave mixing techniques based on the semiconductor optical amplifier (SOA) [3, 4]. Furthermore, an all-optical wavelength converter using a low-cost Fabry-Perot laser diode (FP-LD) has also been proposed based on injection locking techniques [5, 6] for 2.5 Gbit/s signal conversion. In accordance with [3–5], most of the all-optical wavelength converters require an additional probe wavelength. It would increase the cost and complexity of the converter. In addition, using an external built-in cavity inside the FP-LD also complicates the laser scheme [6].

In this Letter, we propose and demonstrate a simple scheme for a wavelength converter using a multi-longitudinal-mode (MLM) FP-LD. Based on the proposed wavelength converter, the input wavelength can be converted at 2.5 Gbit/s with 3.5 dB power penalty at a BER of 10^{-9}.

Experiment and discussion: Fig. 1 shows the experimental setup for the wavelength converter. The proposed wavelength converter consists of a multi-quantum-well MLM FP-LD, a polarisation controller (PC), an optical circulator (OC) and a bandpass filter (BF). In this measurement, the optical spectrum and output power are measured by an optical spectrum analyser (OSA) with a 0.05 nm resolution and a power meter (PM).

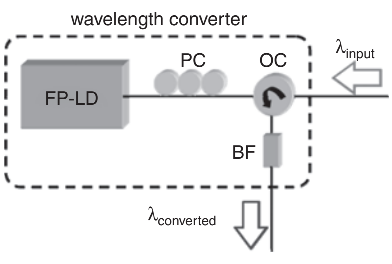

Fig. 1 *Experimental setup for wavelength converter scheme*

In this proposed converter architecture, the threshold current of the MLM FP-LD used is 9 mA and the mode spacing ($\Delta\lambda$) is 1.1 nm. The BF is used to filter the corresponding mode of FP-LD that we want for wavelength converting and to suppress the other sidemodes. The 3 dB bandwidth and average insertion loss of the BF used are around 0.4 nm and 5 dB, respectively, and the central wavelength is set at 1537.30 nm. The PC is placed between the FP-LD and OC to adjust the polarisation state of the input signal to maximise the conversion efficiency. Fig. 2 shows the output spectra of the free-running MLM FP-LD, which is illustrated by the short dash line; and input wavelength (λ_{input}) of 1537.32 nm, which is illustrated by the solid line. The input signal is modulated by non-return-to-zero (NRZ) data at 2.5 Gbit/s, 1.25 Gbit/s and 625 Mbit/s. Its average power is 0.6 dBm. In this experiment, the λ_{input} will pass through the proposed converter for wavelength conversion. The bias current of the FP-LD used is 24 mA at a temperature of 25°C and the central wavelength and gain-bandwidth of the FP-LD are 1542.87 nm (power = −7.2 dBm) and around 20 nm, respectively.

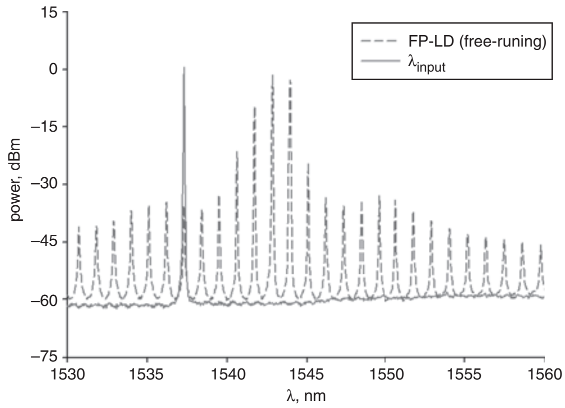

Fig. 2 *Output spectra of free-running MLM FP-LD operating at 24 mA at temperature of 25°C and input wavelength of 1537.32 nm with 0 dBm output power*

In this experiment, we select the central output wavelength of the FD-LD (with maximum power level) to act as the converted wavelength ($\lambda_{converted}$). When λ_{input} injects into the FP-LD, the output spectrum of the FP-LD without passing through the BF is shown in Fig. 3 by the dashed line. Fig. 3 also shows the two highest peak wavelengths at 1537.32 and 1542.87 nm, after the launching of λ_{input}. Compared with the third higher peak wavelength in Fig. 3, the sidemode suppression ratio (SMSR) of the selected $\lambda_{converted}$ and λ_{input} are 23 and 18 dB.

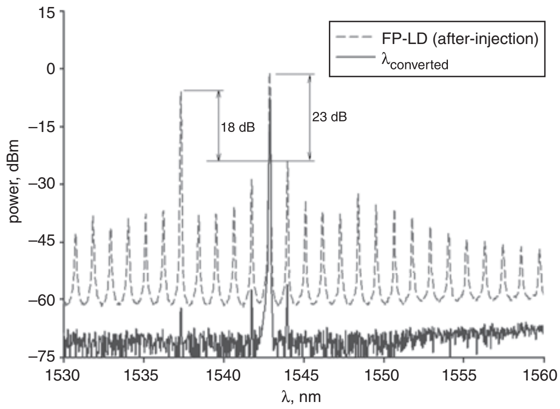

Fig. 3 *Output spectra of FP-LD after external injection of 1537.32 nm (λ_{input}) without (short dashed line) and with (solid line) using BF to filter central wavelength ($\lambda_{converted}$) of 1542.87 nm*

By comparing the optical spectra of the FP-LD before (Fig. 2) and after the launching of λ_{input} (Fig. 3), we can see that this conversion mechanism is different form the wavelength conversion based on pump-probe wavelength injection locking or self-injection locking. We can see that the input signal does not suppress other sidemodes of the FP-LD, but its power has been depleted to the made mode (central wavelength) of the FP-LD; that is, the power of the $\lambda_{converted}$ is increased owing to this mechanism. The output spectrum of the FP-LD after passing through the BF, $\lambda_{converted}$, is also illustrated in Fig. 3 by the solid line.

In this measurement, the input signal λ_{input} is modulated by an external Mach-Zehnder (MZ) modulator at 625 Mbit/s, 1.25 Gbit/s and 2.5 Gbit/s, using an NRZ pseudorandom binary sequence (PRBS) with a pattern length of $2^{31} - 1$. Fig. 4 shows the eye diagrams at 2.5 Gbit/s, 1.25 Gbit/s and 625 Mbit/s data rate of the input signal λ_{input} and the converted signal $\lambda_{converted}$. They are all clear and widely opened under various modulated rates. To realise the wavelength conversion performance, bit-error-rate measurements are performed. Fig. 5 shows that the converted operation leads to a ~3.5 dB power penalty at a BER of 10^{-9} under 2.5 Gbit/s NRZ modulation. It is also worth mentioning that the wavelength conversion is not based on pump-probe wavelength injection locking or self-injection locking. Hence, it is not sensitive to the polarisation of the input signal. We observe that polarisation dependence of the input signal is less than 2 dB at a BER of 10^{-9}.

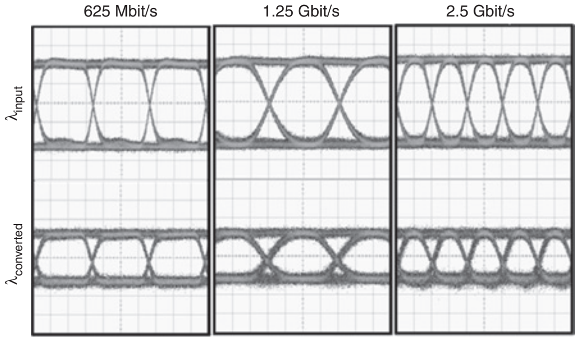

Fig. 4 *Output eye diagrams at 625 Mbit/s, 1.25 Gbit/s and 2.5 Gbit/s data rate, with input signal λ_{input} before and after passing through proposed wavelength converter*

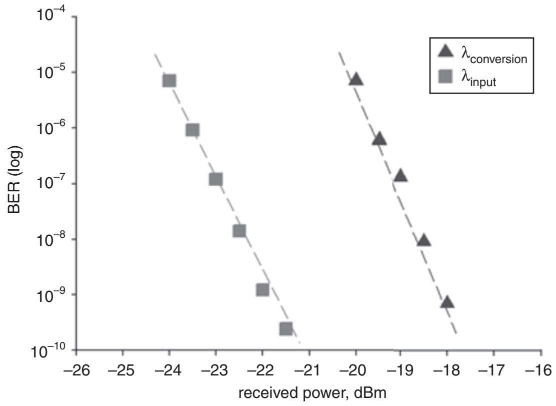

Fig. 5 *Bit error rate curve for 2.5 Gbit/s NRZ modulation with pattern length of $2^{31} - 1$*

Conclusions: We propose and experimentally investigate an all-optical wavelength converter using a MLM FP-LD without any external probe wavelength or external built-in cavity operating. The input wavelength λ_{input} can be converted at 2.5 Gbit/s even if the input wavelength is far away from the central wavelength of the FP-LD. A power penalty of 3.5 dB is observed at a bit error rate (BER) of 10^{-9} in the wavelength converted signal. Therefore, the proposed wavelength converter has the benefits of being simple and cost-effective.

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C.H. Yeh (*Information and Communications Research Laboratories, Industrial Technology Research Institute, Chutung, Hsinchu 31040, Taiwan, Republic of China*)

E-mail: depew@itri.org.tw

C.W. Chow, C.H. Wang, F.Y. Shih and S. Chi (*Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan, Republic of China*)

Y.F. Wu and S. Chi (*Department of Electro-Optical Engineering, Yuan Ze University, Chungli, Taoyuan 32003, Taiwan, Republic of China*)

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