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Optical Wavelength Conversion Over 18 nm at 2.5 Gb/s by DBR-Laser

T. Durhuus, R. J. S. Pedersen, B. Mikkelsen, K. E. Stubkjaer, M. Öberg, and S. Nilsson

Abstract—Wavelength conversion over 18 nm is demonstrated at 2.5 Gb/s without change in BER performance. The converting element is a three-section DBR laser operating by gain saturation. Both IM-to-IM and IM-to-FM conversion schemes are investigated. For the latter scheme, a conversion gain of 10 dB is measured.

INTRODUCTION

WAVELENGTH converters, that transform information on one wavelength to another, will be important in future optical switches and wavelength multiplexed networks [1], [2]. Especially in order to perform space switching [1], the wavelength converter can be used in conjunction with fixed filters to route the signals, but also to increase the capacity and the flexibility in wavelength division multiplexed networks [2].

The wavelength conversion function can be obtained by several mechanisms, e.g.: i) four wave mixing in semiconductor optical amplifiers [3], ii) absorptive bistability in DBR- and Y-lasers [4], [5], as well as iii) gain saturation in semiconductor optical amplifiers [6]. In all these cases the bandwidth is limited by the carrier lifetime and therefore the bitrate is restricted to a few Gb/s. Especially the components relying on absorptive bistability are slow due to the long carrier lifetime in absorbers.

In this letter we demonstrate wavelength conversion by optical depletion of the carrier density in the gain region of a DBR laser operating above threshold. Therefore the signal bandwidth is ideally limited by the relaxation frequency of the laser which varies from 3–9 GHz depending on the bias conditions. By this method we have obtained penalty-free wavelength conversion over 18 nm at a bitrate of 2.5 Gb/s.

DEVICE DESCRIPTION AND PRINCIPLE OF OPERATION

The laser we use in the wavelength conversion experiment is a three section butt joint flat surface buried heterostructure DBR laser. The lengths of the gain-, the phase-, and the Bragg-section are 270, 200, and 600 μm , respectively.

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The operation principle is conceptually simple: The DBR laser is biased above threshold and emits at a wavelength λ_o , chosen by the current to the Bragg section. An intensity modulated signal at a wavelength λ_i is injected into the laser and causes a modulation of the carrier density in the gain section resulting in an intensity modulation (IM) and a frequency modulation (FM) of the output signal at λ_o . Thereby the information on the incoming signal at λ_i is transferred to the lasing wavelength (λ_o). Consequently, two operation schemes are possible as shown in Fig. 1: Intensity-to-intensity (IM/IM) conversion or intensity-to-frequency (IM/FM) conversion. The efficiency of the two conversion schemes depends on the biasing condition of the DBR laser and will be discussed below.

An important parameter for a device used in WDM systems is the optical wavelength span in which it can operate. The lasing wavelength λ_o can be tuned by adjusting the bias current to the Bragg (and phase) sections. For a similar device, as used in our experiments, a tuning range of 4 nm towards shorter wavelengths and 18 nm towards longer wavelengths has been reported [7]. The possible wavelength span for the input wavelength λ_i is given by the gain-bandwidth of the gain section. Therefore, it is possible to convert both from short to long wavelengths as well as from long to short wavelengths by the proposed conversion scheme.

EXPERIMENTS

In order to investigate the two operation schemes the experimental setup shown in Fig. 2 is used. The signal laser is emitting at 1531 nm and is directly modulated by a PRBS generator. This signal is coupled via a 3 dB coupler and a tapered fiber to the wavelength converter and is used as the input signal that carries the information to be converted. The output signal from the converter is filtered by a 20 GHz fiber Fabry-Perot filter before it is coupled to the Mach-Zehnder interferometer (IM/FM-mode) or coupled directly to the front-end (IM/IM-mode). To achieve IM to IM conversion with high extinction ratio the input signal and the bias to the converter (DBR-laser) should be adjusted so that the lasing mode of the wavelength converter is "turned off" when the input signal is "high." As an example, a coupled input power of -4 dBm increases the threshold current of the converter from 20 to 40 mA, giving an optimum bias of approximately 40 mA for the given input power when the converter is operating

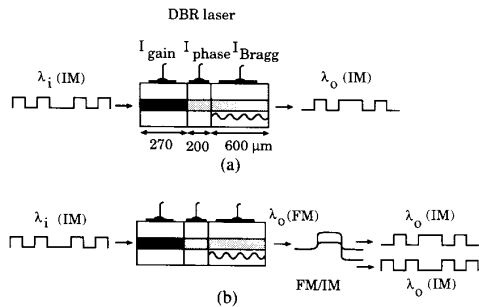


Fig. 1. Principle of operation. (a) IM-to-IM conversion. (b) IM-to-FM conversion (and FM to IM by fiber-MZI).

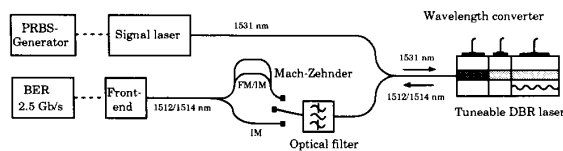


Fig. 2. Experimental setup.

in the IM-to-IM mode. A bias current more than 40 mA will decrease the extinction ratio of the converted signal whereas a lower bias current will give large relaxation oscillations on the converted signal and increase the turn-on delay. This is shown in Fig. 3 where measurements of the pulse forms for the input signal and the converted signal are given for different bias conditions of the converter. For a bias of 40 mA rise and fall times of 75 and 150 ps have been measured indicating the possibility of multigigabit operation.

For the IM-to-FM conversion the bias to the converter should be high since the FM response for the actual device increases with bias current. Fig. 4 shows the attainable frequency deviation for the converted signal (1514 nm) as a function of the input power (1531 nm). The FM-efficiency is measured for a modulation frequency of 1225 MHz and for a bias current to the gain section of 94 mA. For optical modulation of the laser the low frequency dip due to thermal effects is avoided and consequently the FM-response is flat below the relaxation frequency. However, the measurements clearly show that the FM-response increases with optical input power. At 100 μW a frequency deviation of 1.1 GHz is obtained whereas it is 4 GHz at 300 μW . Consequently, when IM to FM conversion is used the input power has to be controlled in order to assure that the frequency deviation matches the free spectral range of the Mach-Zehnder Interferometer. As an example an input power of -4 dBm requires a MZI with a free-spectral range (FSR) around 12 GHz.

To assess the performance of the wavelength converter a system experiment at 2.5 Gb/s is carried out. The input signal (1531 nm) to the converter has an average input power of -4 dBm and an extinction ratio of 8 dB. First, the BER for IM-to-IM conversion is measured where the

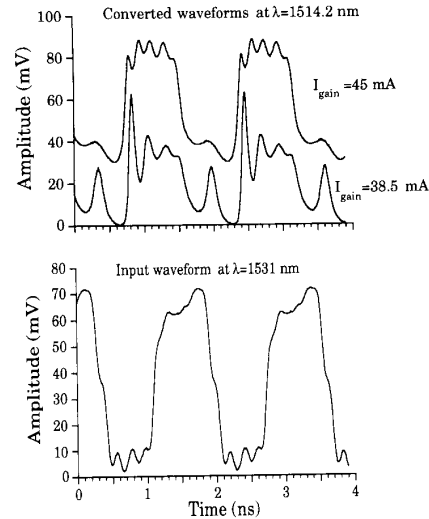


Fig. 3. A 1.2 Gb/s 101010 input waveform from the signal laser at 1531 nm and the wavelength converted amplitude modulated output waveforms from the converter.

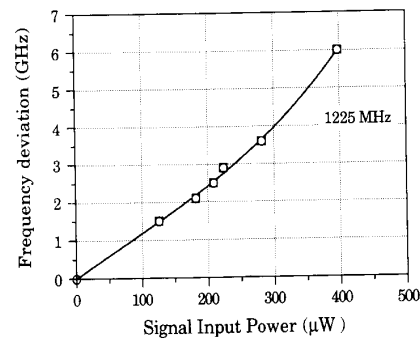


Fig. 4. Frequency deviation versus input power to the converter. Modulation frequency: 1225 MHz.

bias point to the gain section of the converter is set to 45 mA. Furthermore, to address the tuning ability, measurements at two output wavelengths are carried out namely at 1514.2 and 1512.9 nm. Fig. 5 shows the BER measurements versus received power at the two output wavelengths together with BER measurements of the input signal (1531 nm). The small penalty of 1 dB in the sensitivity for the converted signals compared to the input signal is attributed to lower extinction ratios which are 5.3 and 4.5 dB at 1514.2 and 1512.9 nm, respectively.

For the IM-to-FM scheme, the converted signals are directed to a fiber-MZI with a FSR of 12 GHz. In these measurements the bias current to the gain section is set to 94 mA and the average input power is -4 dBm. Also in this case we perform BER measurements for two output wavelengths, 1514.1 and 1512.5 nm. The results are shown in Fig. 5 and clearly wavelength conversion without degradation in BER performance is obtained at both wave-

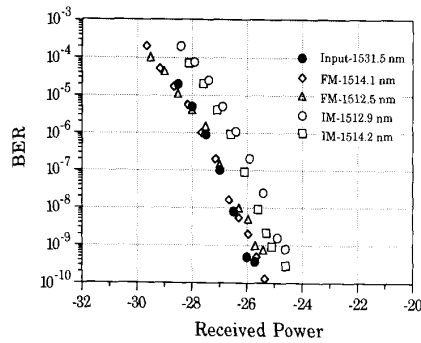


Fig. 5. Measured BER curves at 2.5 Gb/s for wavelength converted FM and IM output signals as well as for the input signal.

lengths by the IM-to-FM scheme. The improved performance, compared to the IM-to-IM scheme is due to high extinction ratios in excess of 10 dB of the converted signals after the MZI. The high extinction ratio is illustrated in Fig. 6 where a 2.5 Gb/s demodulated FM data-pattern at 1512.5 nm is shown. Also a measured eye diagram at a BER of 10^{-9} is shown. In addition, the IM-to-FM scheme offers a high gain defined as the ratio between the power of the converted signal, after the MZI, and the power of the input signal. At the bias current of 94 mA the output power after the MZI is 6 dBm giving a gain of 10 dB for an input power of -4 dBm.

CONCLUSION

Wavelength conversion at 2.5 Gb/s is demonstrated over 18 nm with a tuneable DBR laser. The conversion mechanism is based on gain saturation and is ideally limited by the relaxation frequency (~ 9 GHz) of the DBR laser; therefore, high-speed operation is possible. Two operating schemes have been investigated: i) The IM-to-IM conversion scheme that gives extinction ratios of 4–5 dB for the converted signals resulting in sensitivity penalties of 1 dB; and ii) the IM-to-FM conversion scheme that gives extinction ratios of 10 dB and shows penalty-free conversion. In addition, a conversion gain of 10 dB is measured.

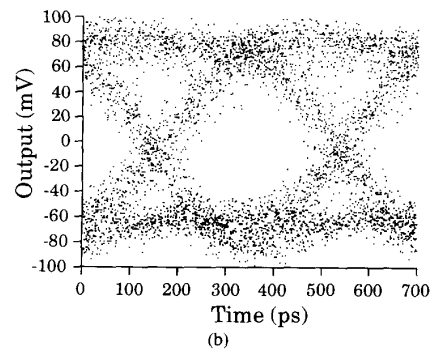
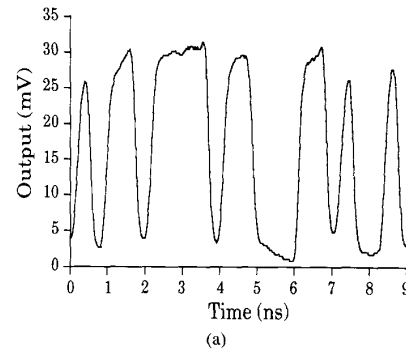


Fig. 6. (a) Wavelength converted FM data sequence at 2.5 Gb/s (demodulated by MZI). (b) Eye diagram at 10^{-9} BER.

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