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Semiconductor based demultiplexer and wavelength conversion at 320 Gbits/sec

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Abstract: We demonstrate error-free 320 Gb/s SOA based optical time-domain demultiplexing and wavelength conversion. It is pointed out that ultrafast optical gating (1.8 ps) can be realized by using a single SOA and a detuned optical band-pass filter

OCIS codes: (190.5970) Semiconductor nonlinear optics, (250.5980) Semiconductor optical amplifier

1. Introduction

All-optical time-domain demultiplexers and wavelength converters are considered as important building blocks in the future high-capacity optical networks. Demultiplexers and wavelength converters that utilize nonlinearities in semiconductor optical amplifiers (SOAs) have attracted considerable research interest due to their integration ability and power efficiency [1]. A number of SOA-based approaches have been demonstrated [2-5], but, the slow SOA recovery time (typically several tens to hundred ps) can cause unwanted pattern effects in the converted signal, which limits the maximum operation speed.

In this paper, we present error-free and pattern-independent time-domain demultiplexing and wavelength conversion at 320 Gb/s using a single SOA. To our knowledge, this is the highest operation speed for error-free SOA-based signal processing ever reported. Both the demultiplexer and the wavelength converter consist out of a commercially available fiber pig-tailed SOA cascaded by an optical band-pass filter. The SOA used in the experiment has a full gain recovery time of 56 ps. By using a well-designed optical band-pass filter, the recovery-time of the total system (SOA and filter) can be shortened to 1.8 ps. Such a short recovery time is sufficient for demultiplexing a 40 Gb/s channel out of a 320 Gb/s data-stream and for wavelength conversion of a 320 Gb/s return to zero (RZ) signal. This approach has a simple configuration and allows photonic integration. The work was sponsored by STW EET6491 and IST-LASAGNE (FP6-507509) and the NRC Photonics grant.

2. Experiment and results

A schematic of the experimental setup is shown in Figure 1. The setup was constructed by using commercial available fiber-pigtailed components. A 10 Gb/s optical clock signal with 1.7 ps-wide optical pulses, generated by an actively mode-locked fiber ring laser, is amplified and sent into a 250-m high nonlinear fiber (HNF), where the pulse width is compressed down to 1.0 ps. Afterwards, this 1.0-ps, 10 Gb/s optical clock is quadrupled (×4) to 40 Gb/s and is subsequently modulated by an external modulator at 40 Gb/s to form a 2^7-1 return-to-zero (RZ) pseudo random binary sequence (PRBS). This 40 Gb/s data stream is multiplexed to 320 Gb/s by using passive fiber-based pulse interleavers (×4, ×2). The 320 Gb/s RZ-PRBS data signal is combined with a continuous wave (CW) probe light and fed into an AOWC via a 3 dB coupler. As shown in the dashed box in the Figure 1a, the optical wavelength converter is made out of an SOA, a fiber Bragg grating (FBG), a 2.7 nm optical band-pass filter (BPF) and a delayed-interferometer. The delayed-interferometer consists of two polarization controllers (PCs), a polarization maintaining fiber (PMF) with 1.6 ps differential delay, and a polarization beam splitter (PBS). In principle, the delayed-interferometer in Figure 1 can be replaced by an integrated version shown in [3]. The SOA in the wavelength converter is a commercial product from Kamelian and is designed for high-speed nonlinear optical signal processing. The SOA pumping current is 400 mA. The center wavelengths of the 320 Gb/s data signal and the CW probe beam are 1540.32 nm and 1553.82 nm, respectively. The optical power is measured at the input pigtail of the SOA. The average optical power of the 320 Gb/s data stream is 3.5 mW and 1.8 mW for CW probe light.

The operation principle for this concept has been explained in [5-7]. The injected 320 Gb/s data signal modulates the SOA gain. As a result, the CW probe light is modulated via cross-gain modulation, causing inverted wavelength conversion. Moreover, the injected data signal also modulates the refractive index of the SOA, resulting in a chirped converted signal. The leading edges of the (inverted) converted probe light are red-shifted, whereas the

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trailing edges are blue-shifted [5, 6]. The detuned optical filter converts phase modulation into amplitude modulation and acts as a high-pass filter. If the detuning and the optical powers are matched, the slow recovery of the SOA can be completely suppressed. The SOA output is sent into a FBG and a 2.7 nm BPF through an optical isolator (ISO). The grating has a length of 2.2 mm and a chirp rate of 0.8 nm/mm in the grating period. The grating is centralized at 1556.56 nm and has a maximum transmission rejection of 28 dB. The 3 dB bandwidth for this grating is 5.6 nm. The center wavelength of the 2.7 nm BPF is 1551.27 nm. The FBG and BPF are utilized to reject the pump light and select the blue-shifted sideband of the probe light. The inverted 320 Gb/s converted signal is subsequently injected into the delayed-interferometer, where the polarity of the converted signal is changed, i.e., the inverted signal is converted into a non-inverted signal. The non-inverted signal is analysed using an optical sampling-oscilloscope, or demultiplexed for bit-error-rate (BER) analysis.

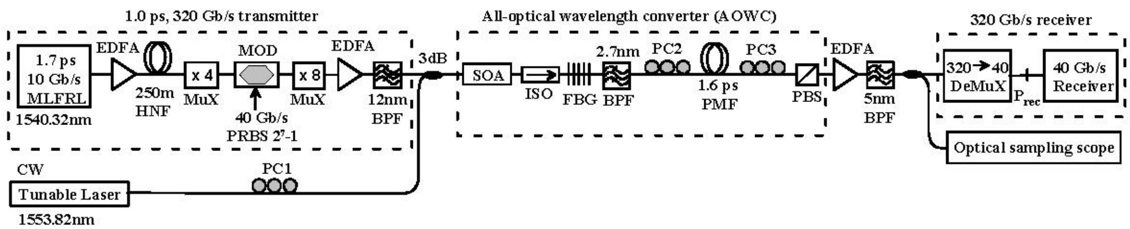

Figure 1: 320 Gb/s all-optical wavelength conversion setup.

After wavelength conversion, the non-inverted signal is demultiplexed from 320 Gb/s to 40 Gb/s by using optical filtering ultra-fast chirp dynamics in an SOA [8]. The demultiplexed 40 Gb/s data signal is fed into a 40 Gb/s receiver and a BER tester. The schematic of demultiplexer is shown in Figure 2.

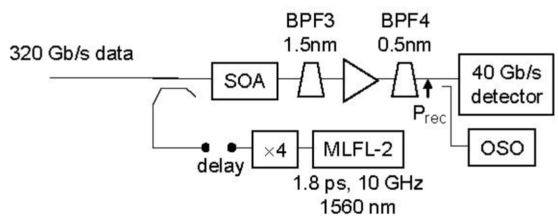

Figure 2: 320/40 Gb/s optical time-domain demultiplexer

A second 10 GHz mode-locked fiber laser is used to create a local clock signal. The clock signal and the data-signal are synchronised and simultaneously fed into the SOA. The demultiplexer employs a similar operation principle as the wavelength converter. The local clock modulates the SOA gain and refractive index, resulting in ultra-short (1.8 ps) switching window. This switching window is sufficient to gate a 40 Gb/s channel out of the 320 Gb/s data channel. Typical average optical powers injected into the SOA for optimum demultiplexing operation are 6.3 mW (320-Gb/s data), and 0.09 mW (40-GHz control). The left panel of Figure 3 shows the BER traces for all the demultiplexed 40 Gb/s channels. Error-free operation is obtained. Also eye-diagrams of the 320 Gb/s input channels and a demultiplexed channel is given. Clear open eyes are visible.

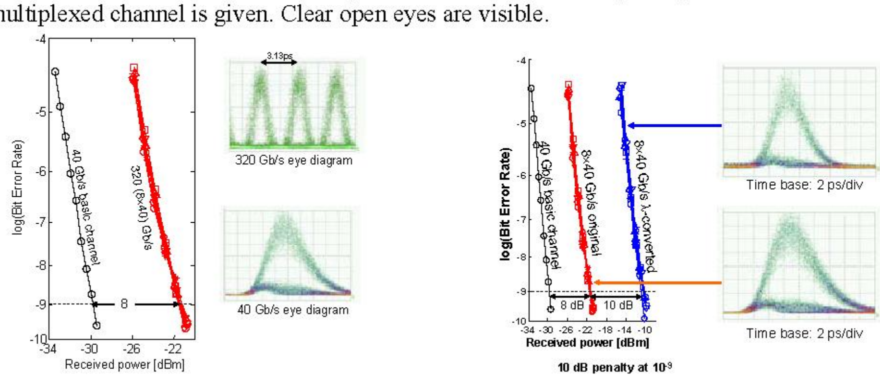

Figure 3: Left panel BER curves and eye diagrams for the demultiplexer. Right panel similar, but now for the wavelength converter

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The right panel of Figure 3 shows BER measurements of the 320 Gb/s input signal and the wavelength converted signal. All the eight 40 Gb/s tributaries are presented. In addition, the 40 Gb/s basic channel that is multiplexed to 320 Gb/s is also presented. It can be observed that the average sensitivity penalty of wavelength conversion at a BER=10^{-9} is about 10 dB with respect to that of the original 320 Gb/s. Moreover, no error-floor is observed, which indicates excellent performance of the wavelength converter. It should be noted that the spectrum of input 320 Gb/s pump light is very broad, and wavelength separation between the probe light and pump light is not sufficient. As a result, some residual pump light is contained in the AOWC output. This leads to a degradation of BER measurement. A better result is expected if the wavelengths of the pump signal and the probe signal are further separated.

3. Conclusions

We have demonstrated error-free and pattern-independent 320 Gb/s wavelength conversion by employing an SOA with an initial gain recovery time of 56 ps. The essential point in our approach is to employ optical filtering to select the blue-shifted sideband of the spectrum of the probe light, which leads to an effectively recovery time of less than 1.8 ps in the SOA. The optical filtering extracts the ultra-fast chirp dynamics in the SOA to overcome the slow gain recovery. Our wavelength converter has been demonstrated by using commercially available fiber pigtailed components. This wavelength converter has a simple configuration, operates at low power and allows photonic integration.

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