



Wavelength conversion from C- to L-band at 10 Gbit/s including transmission over 80 km of SSMF

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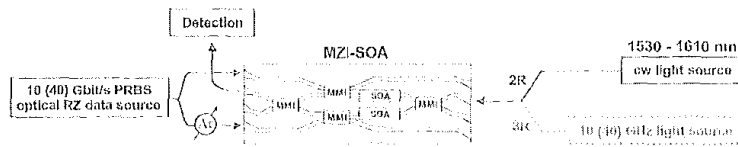
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CW11 Fig. 1. Operational scheme of MZI-SOA wavelength converter (2R or 3R) for C- and L-band.

blocking when routing the signals.¹ Interferometric devices have regenerative capabilities² and are therefore of special interest to guarantee cascability. Ultrahigh bit rate lightwave systems have been introduced exploiting not just the standard C-band (1530 to 1565 nm) but also the L-band (1565 to 1610 nm) of optical fibers.^{3,4} They will consequently require robust and efficient broadband wavelength converters with preferably regenerative capabilities. We present a monolithically integrated Mach-Zehnder interferometer with semiconductor optical amplifiers (MZI-SOA) that demonstrates efficient all-optical 2R regenerative 10 Gbit/s wavelength conversion over the full C- and L-band with a negative penalty of about -1 dB. The converted output signals have an optical signal-to-noise ratio (OSNR) better than 45 dB. All-optical 2R⁵ and 3R⁷ regenerative wavelength conversion at 40

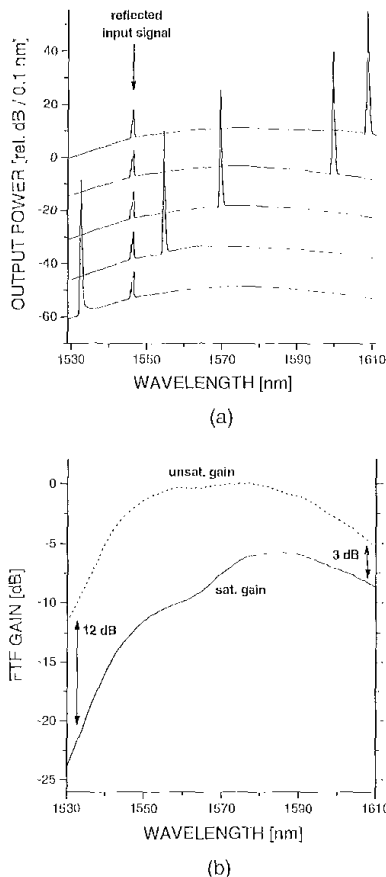
Gbit/s within the entire C-band has been already reported using the same kind of device. We show that the device has the capability for regenerative wavelength conversion at 10 Gbit/s even in and beyond the L-band.

The MZI-SOA is an active-passive InGaAsP/InP structure with a monolithically integrated 500 μm long SOA in each interferometer arm. The device has been fully packaged into a module⁷ and is viable for real network applications. For regenerative wavelength conversion operation the device is driven by the so-called differential control scheme injection and acts here as an ultrafast modulator that overcomes carrier dynamic limits of the SOA.⁸ Here, the data signal is split into two control signals and is cross-phase modulating the counter-propagating new wavelength signal, as shown in Fig. 1. In the experiment, a gain-switched DFB laser at 1546 nm generated 5 ps optical pulses that were externally modulated by a 10 Gbit/s pseudo-random bit sequence (PRBS $2^{31} - 1$). A tunable external cavity laser provided cw light in the wavelength span of 1530 to 1610 nm. The converted output signals were directly launched into the receiver for bit error rate (BER) measurements.⁹

As shown in Fig. 2 the output signals exhibited a very high OSNR of 45 dB and more. BER measurements of the converted output signals show a negative penalty and a steeper BER curve than the back-to-back measurement, which can be explained by noise redistribution of the interferometer transfer function.³ The device has an unsaturated small-signal gain bandwidth of 57 nm (1543 to 1600 nm) which is centered at 1570 nm. Under 10 Gbit/s wavelength conversion operation however, the gain compression is significantly higher in the C-band than in the L-band, the conversion efficiency is therefore lower than in the L-band. Thus, 40 Gbit/s wavelength conversion in the L-band is expected to work better than those in the C-band already demonstrated.⁶ The device is insensitive to the polarization of the input signal.

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CW11 Fig. 2. Spectra of 10 Gbit/s wavelength converted output signals (left) and small-signal fiber-to-fiber (FTF) gain within the C- and L-band in the unsaturated case and under operation (right).

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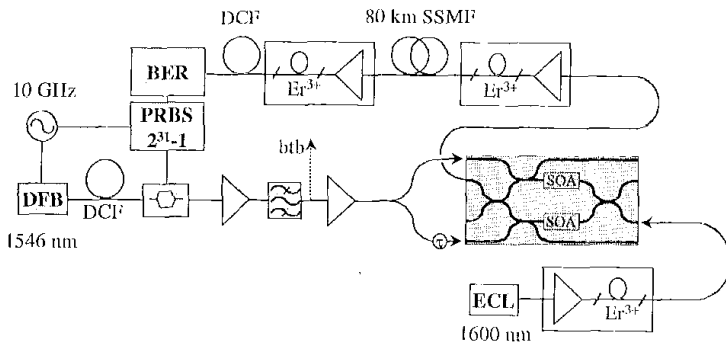
Wavelength conversion from C- to L-band at 10 Gbit/s including transmission over 80 km of SSMF

H.N. Poulsen, A. Buxens, A.T. Clausen, P. Jeppesen, M. Dülk,^{*} St. Fischer,^{*} E. Gämper,^{*} W. Vogt,^{*} W. Hunziker,^{*} F. Gini,^{*} H. Melchior,^{*} Res. Ctr. COM, Tech. Univ. of Denmark, Building 349, 2800 Lyngby, Denmark; E-mail: hnp@com.dtu.dk

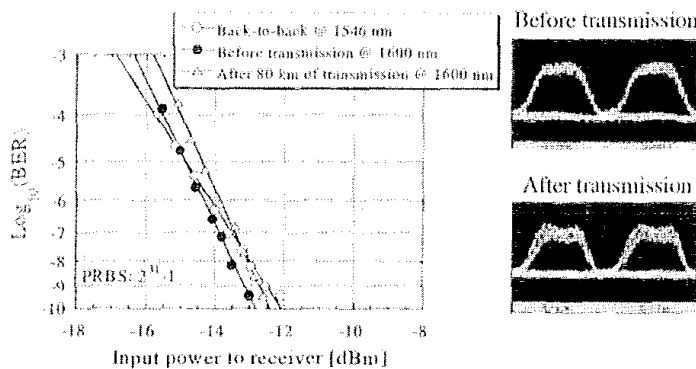
As the need for capacity increases, means to accommodate the growth is getting increasingly important. Hence, higher bit rates and ever increasing number of WDM channels is being employed.^{1,2} This has led to the introduction of the L-band (ranging from 1570 to 1610 nm) as the new transmission window, opening up for— in conjunction with the C-band— an astonishing 80 nm of available bandwidth.³ However, as the number of wavelength channels increases, the need for wavelength conversion is becoming ever more pronounced.⁴ To perform the wavelength conversion, interferometric structures such as the monolithically integrated Mach-Zehnder interferometers (SOA-MZI) using semiconductor optical amplifiers as phase-shifting elements have proven excellent candidates.⁵ Here we present the conversion and transmission properties of a fully packaged device capable of wavelength conversion from C- to L-band having more than 80 nm of wavelength conversion range.⁶

The experimental setup is shown in Fig. 1. A gain-switched DFB laser in conjunction with dispersion compensation fiber (DCF) is used to generate pulses with a FWHM of 5 ps at 1546 nm, which are externally modulated by a 10 Gbit/s PRBS ($2^{31} - 1$). The 10 Gbit/s bit stream is amplified and launched into the SOA-MZI as control pulses using a differential scheme to overcome the limitations imposed by the SOA carrier recovery time. The CW light in the L-band regime was provided by a tunable external cavity laser (ECL) and launched into the SOA-MZI, counter-propagating the control pulses. The converted signal at 1600 nm is launched into 80 km of standard single mode fiber (SSMF), passively dispersion compensated by wideband DCF⁷ and detected at the receiver. Here it should be noted, that the receiver is not pre-amplified and, consequently, the input power is measured just before the photodiode. To amplify the signals in the L-band before the SOA-MZI and in the transmission span, 3 L-band amplifiers were constructed based on conventional C-band amplifiers followed by a length of Erbium doped fiber giving 25 dB of gain and up to 10 dBm of output power.

The BER characteristics of the wavelength converted signal before and after transmission are seen in Fig. 2. First, comparing the BER characteristics of the 1546 nm back-to-back and the wavelength converted at 1600 nm a



CW12 Fig. 1. Experimental setup for wavelength conversion and transmission in the L-band.



CW12 Fig. 2. BER characteristics (left) and eye diagrams (right) before and after transmission @ 1600 nm.

negative penalty of ~0.7 dB is observed. This improvement is due to the redistribution in the SOA-MZI of the ASE noise induced by the EDFAs on the signal. Likewise, this redistribution also explains the increased steepness comparing the BER curve after wavelength conversion to 1600 nm to that before at 1546 nm.

Comparing the signal at 1600 nm before and after transmission a penalty below 0.5 dB is seen, demonstrating not only the noise redistribution and the quality of the pulse shape, but also the excellent chirp characteristics of the SOA-MZI. These advantages are also emphasised by the eye diagrams shown in Fig. 2, which show no significant pulse distortion. The penalty observed is mainly ascribed to the dispersion compensation, which is optimised at 1550 nm.

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CW13 10:45 am

All-optical wavelength conversion scheme based on 20 Gb/s RZ data

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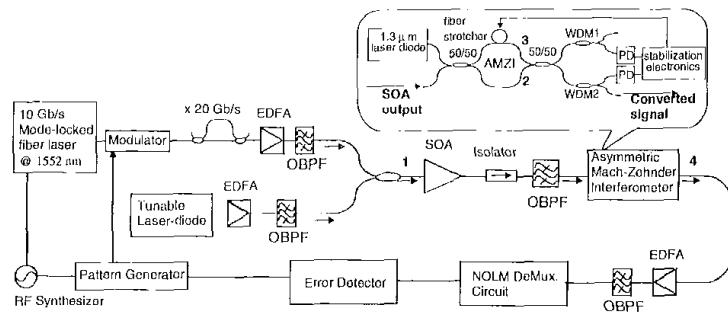
High-speed all-optical wavelength converters are essential components of future wavelength division multiplexed optical networks. Semiconductor-optical-amplifier (SOA) based wavelength converters operating up to 40 Gb/s are becoming attractive because of their small size and integrability. Wavelength conversion in the SOA can be achieved either by cross-gain modulation (XGM) in a single amplifier or by cross phase modulation (XPM) in two amplifiers placed in an Mach-Zehnder interferometer (MZI).

In this paper, we demonstrate a hybrid scheme of a single-SOA and asymmetric MZI (AMZI) for wavelength conversion of 20 Gb/s RZ format data.

Figure 1(a) shows the experimental set-up used. A 10 Gb/s RZ data sequence of 1552 nm wavelength was generated by modulating the output pulses of a 5 ps long mode-locked erbium-doped fiber laser with a LiNbO₃ electro-optic modulator driven by a pattern generator. These RZ data pulses were amplified by an Er-doped fiber amplifier up to a mean optical power of 10 dBm after two times multiplexed to 20 Gb/s data stream, and then launched into the SOA via a 3-dB coupler. A wavelength tunable laser diode was used as a cw probe beam, and launched into the SOA with an optical mean power of 0 dBm. The SOA has a gain peak at 1540 nm and a small signal gain of 30 dB. The wavelength converted output signal from the SOA is injected in an AMZI through an optical bandpass filter selecting the converted signal at the probe wavelength. The AMZI was stabilized against environmental perturbations with an electronically feedbacked fiber stretcher controlling length of its one arm. The stabilization scheme consists of a 1313 nm DFB LD, two identical 1550/1313 nm dichroic couplers of WDM1 and WDM2 couplers, two photo-diodes (PDs), and an electronic stabilizing circuit. The 1313 nm DFB LD was selected to provide an independent stabilization light beam compared to the 1550 nm signal wavelength.

When an RZ input signal at wavelength of λ_s is injected into the SOA, which is driven into the saturation regime, the SOA gain is accordingly modulated with the reverse polarity. By injecting a cw light at another wavelength of λ_c , this modulation is encoded on this new wavelength λ_c . The rise time of the converted signal is determined by the input pulsewidth, while the fall time is determined by the relatively long carrier lifetime. The waveform distortion of the SOA output due to this slow gain recovery is then removed by using the AMZI. Two components coming out from both output arms of the AMZI corresponding to the slow gain recovery tail of the SOA are used to cancel out each other. As a consequence, the input RZ signal of λ_s is copied into a new wavelength of λ_c with the same polarity.

Figs. 2(a), (b), and (c) show the typical eye diagrams and measured BER performance of 10 Gb/s and 20 Gb/s RZ signal wavelength



CW13 Fig. 1. Experimental set-up for all-optical RZ wavelength conversion.

Wednesday, May 10