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New Bi-directional Mid Span Spectral Inversion using Bi-directional Four Wave Mixing in Semiconductor Optical Amplifiers

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Abstract: We report bi-directional four wave mixing in a SOA. A 10 Gb/s RZ 60 Km bi-directional mid-span spectral inversion (MSSI) experiment with less than 2 dB penalty is reported. Further we propose a new scheme, the "Swapping MSSI", which allows improved wavelength allocation and bandwidth utilisation.

Introduction

We present for the first time to our knowledge bi-directional four wave mixing (FWM) in a semiconductor optical amplifier (SOA). FWM in SOAs is modulation format and speed transparent up to several 100 Gb/s, and is therefore a promising technique for ultra high-speed dispersion compensation [1] or optical signal processing [2, 3].

We characterise the quality of the bi-directional four wave mixing by performing a 10 Gb/s bi-directional MSSI experiment over 60 km with 10 ps RZ pulses. The MSSI technique has previously proven its capabilities for high speed WDM transmission systems [4]. Bi-directional MSSI applied to WDM signals would be very attractive since it allows for efficient use of the transmission bandwidth [5] and for bi-directional optical networks [6,7] with high speed channels.

We also present a new MSSI method, the "Swapping MSSI". The idea is to avoid the waste of bandwidth experienced with the classical MSSI scheme, which requires a spare set of wavelength channels as shown in Fig 1a. Especially for dense WDM such a waste of bandwidth is intolerable.

The swapping technique doubles the wavelength capacity in the available wavelength window by placing the pump for the phase conjugation at the center of the wavelength comb rather than at the edge, as illustrated in Fig. 1b. So, the phase conjugated FWM of λ_1 will appear at λ_2 while that of λ_2 appears at λ_1 . Thereby the double number of channels can be accommodated. We verify the feasibility of the swapping MSSI in a bi-directional FWM experiment.

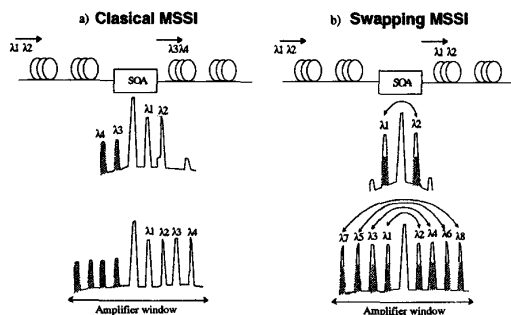


Figure 1. Schematic comparison between the a) classical and b) swapping MSSI.

Bi-directional four wave mixing in a SOA

First we demonstrate the possibility of obtaining two independent four-wave mixing products in a SOA when injecting a pump and signal simultaneously from both ends of the SOA. The quality of these four wave mixing products will be investigated in a MSSI experiment. The experimental set-up is depicted in Fig. 2. 10 Gb/s RZ signals are generated by gain-switching two DFB-lasers ($\lambda_1=1556$ and $\lambda_2=1560$ nm) at 10 GHz, followed by pulse compression with DCF (10 ps pulses). External modulation is applied to the pulse train using a PRBS sequence. After transmission over 30 km of NDSF the signals are demultiplexed, filtered and amplified. The signals are launched from each side of the SOA together with a local CW pump at $\lambda_3=1553$ nm inserted at both ends. Polarisation controllers, amplifiers and attenuators are used to obtain optimum polarisation state and signal levels to ensure the best FWM products. To separate incoming and out-going signals to the SOA we use circulators at both ends. The SOA is 1200 μm long, based on the M-DCPBH structure and optimised for a high optical confinement factor ($\Gamma=0.6$) [8], which improves the FWM efficiency. The filtered conjugate four wave mixing signals are combined and transmitted through another 30 km of NDSF. At the receiver the quality of each signal is supervised simultaneously by demultiplexing and observing the eye diagram of one signal while measuring BER curves for the other.

The simultaneous bi-directional FWM products can be observed in the spectra in Fig. 3. The average signal and

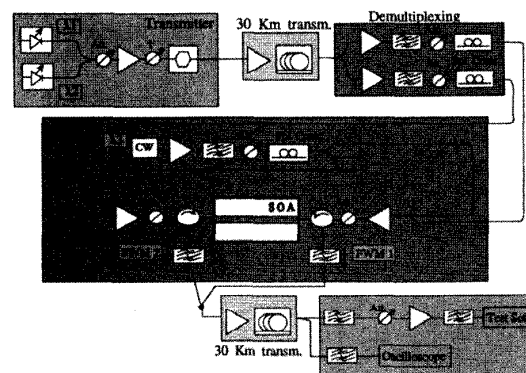


Figure 2. Experimental set-up used in the MSSI experiment.

pump power levels coupled into the amplifier are -4 dBm and 9 dBm, respectively (measured in the fiber). A conversion efficiency in the order of -18 dB is obtained for both signals. The optical SNR is 19 dB (0.5 nm resolution bandwidth) for the 1560 nm signal, and 17 dB for the 1556 nm signal. The peaks due to the residual power after demultiplexing can be observed.

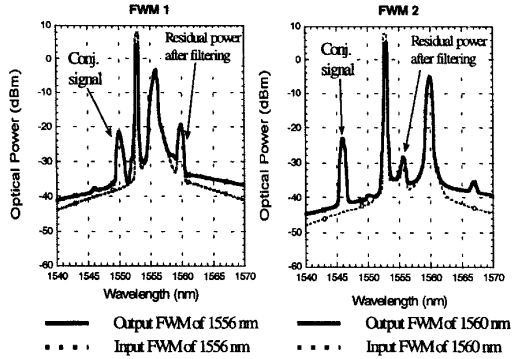


Figure 3. Simultaneous bi-directional FWM spectra.

BER measurements are presented in Fig. 4. When only one signal is transmitted the penalty induced by the MSSSI is 1 dB for the 1556 nm signal and no penalty for the 1560 nm. This difference is believed to be due to the lower SNR obtained for the 1556 signal. Less than 2 dB penalty is observed for simultaneous bi-directional MSSSI in the SOA compared to the unidirectional MSSSI case.

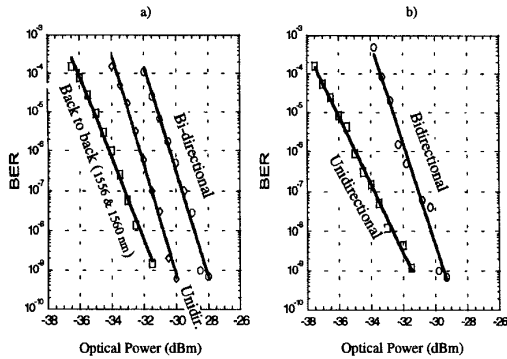


Figure 4. BER measurements for the phase conjugated signals at a) 1550 and b) 1546 nm in the 60 km MSSSI experiment.

Swapping MSSSI

The experimental set-up used for the swapping technique is basically the same as in the bi-directional FWM. The pump wavelength is changed to $\lambda_3 = 1558$ nm centered between λ_1 and λ_2 . We increase the transmission speed at λ_1 to 20 Gb/s by passive multiplexing while keeping λ_2 at 10 Gb/s to measure BER.

The spectra from the swapping MSSSI experiment are presented in Fig. 5. The expected asymmetric performance, due to the lower conversion efficiency towards longer wavelengths of FWM in SOAs, is avoided by independent tuning of the pump levels. A 2 dB difference can be observed in Fig. 5 for our experiment. Clear and open eyes can be observed for the 20 Gb/s channel at 1560 nm (Fig. 6b) after 60 km transmission while simultaneous error free operation is achieved for the 10 Gb/s channel at 1556 nm (Fig. 6c).

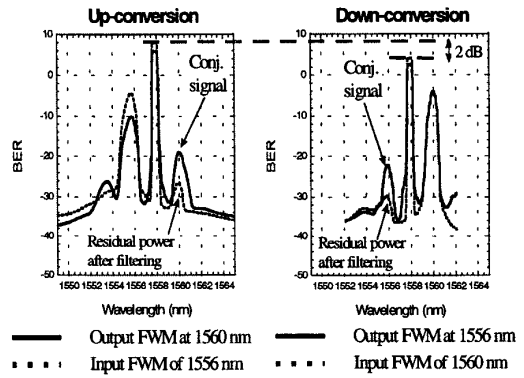


Figure 5. Simultaneous bi-directional FWM spectra from the swapping MSSSI.

The residual power after filtering gives rise to coherent crosstalk in the desired phase conjugated signal. This can be eliminated by improved filtering in the demultiplexing.

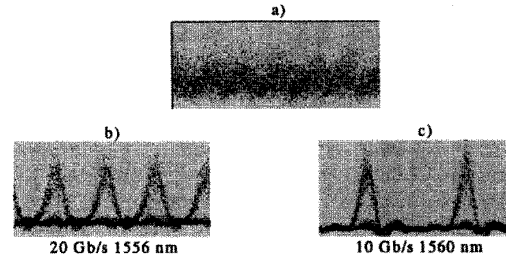


Figure 6. Eye diagrams after 60 km. a) no MSSSI. b) and c) swapping MSSSI.

The proposed FWM bi-directional scheme and the swapping MSSSI technique can be used at higher transmission speeds and for a larger number of channels.

Conclusion

We have demonstrated the possibility to perform simultaneous bi-directional FWM in a SOA for a 10 Gb/s MSSSI experiment over 60 km of fiber. The penalty when compared to single channel unidirectional FWM is less than 2 dB for both signals. The scheme can be upgraded to higher bit rates and number of channels, only limited by the SNR obtained in the FWM.

Further we have proposed a novel MSSSI method, the swapping MSSSI, which can improve the wavelength allocation and bandwidth utilisation.

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