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All-optical Demultiplexing and Wavelength Conversion in an Electroabsorption Modulator

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Abstract: Cross-absorption modulation in an electroabsorption modulator is utilised to perform 80/10 Gb/s all-optical demultiplexing. An improvement in receiver sensitivity at 10 Gb/s is demonstrated when wavelength converting.

Introduction

The electroabsorption modulator (EAM) seems set to become a key component in ultra fast OTDM systems with its many possible functionalities and its inherent simplicity. Hence, the EAM has recently been demonstrated as the central component in a 160 Gb/s transmitter and a 160 Gb/s receiver [1]. All-optical functionalities demonstrated include wavelength conversion and regeneration at 40 Gb/s using cross-absorption modulation (XAM) [2], clock recovery and simultaneous demultiplexing at 20 Gb/s using XAM [3], wavelength conversion at 40 Gb/s using XPM [4], and 60 Gb/s transmultiplexing using XAM [5].

In this paper we demonstrate all-optical demultiplexing of an up to 80 Gb/s data signal down to a 10 Gb/s channel, and further demonstrate a negative receiver penalty when wavelength converting a 10 Gb/s signal in a multi quantum well EAM.

Basic Principle – Saturable Absorption

The principle for the demultiplexing and the wavelength conversion is cross-absorption modulation between two signals, and the experimental set-up is shown in figure 1.

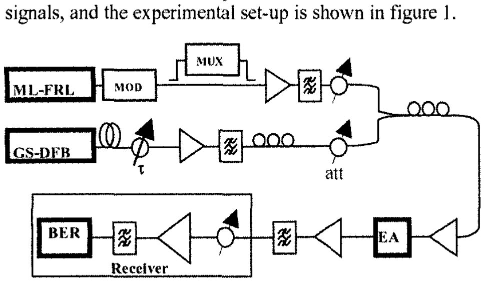


Figure 1: Schematic Set-up.

The EAM used here is a multi quantum well (MQW) InGaAsP device with 10 wells each 10 nm wide. By applying an external voltage to the EAM the absorption edge is shifted towards higher wavelengths through the quantum confined Stark effect (QCSE). Hence, wavelengths previously free to propagate through the EAM are absorbed [6]. Injecting a high power optical pump into the EAM can then bleach this electrically induced absorption. This absorption saturation is due to a combination of bandfilling in the quantum wells, and a reduction of the external field in the active region caused by the photogenerated carriers. In this experiment a gain-switched DFB (GS-DFB) laser with compressive fibre and a modelocked fibre ring laser (ML-FRL) are used to generate short pulses with widths of 6 ps and 2 ps respectively. The pulses are co-propagating into the EAM with a variable relative time delay, and with separate adjustable attenuators, allowing either of the two to act as the high power pump or the low power probe. The ML-FRL pulses are modulated with a 10 Gb/s 2^{31}-1 PRBS sequence in a $LiNbO_3$ MZ modulator and either used at 10 Gb/s or multiplexed up to a 40 or 80 Gb/s data stream. In the case of wavelength conversion, the GS-DFB laser acts as probe and is absorbed in the EAM unless a high power data pulse from the ML-FRL passes through. After the EAM the converted data is filtered through a passive λ-filter, and detected in the preamplified BER receiver. In the case of demultiplexing the data pulses from the ML-FRL act as probe pulses and are absorbed in the EAM unless a GS-DFB pump pulse at 10 GHz repetition rate saturates the absorption. After the EAM the demultiplexed ML-FRL pulses are filtered and detected in the BER receiver.

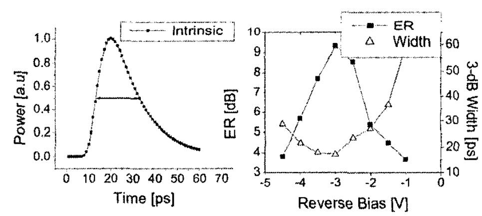


Figure 2: Left: Probed switching window (20 ps width). Right: window width and extinction ratio.

In figure 2 (left) the absorption saturation due to a 13 pJ pump pulse (from the ML-FRL) is probed with a weaker (0.1 pJ) GS-DFB probe pulse by changing the relative delay between the pulses [7]. The switching window shown is after deconvolution with the 6 ps probe pulse, and reveals the intrinsic switching window with a 3-dB width of only 20 ps. Due to the carrier sweep-out time, the window becomes asymmetric though. Hence, pulses in succeeding timeslots will not be completely suppressed and therefore give rise to intersymbol interference (ISI) when demultiplexing. However, in the 40 Gb/s case, i.e. with 25 ps separation between neighbouring channels, the transmitted power for the following channel is suppressed with 7.2 dB, and error-free demultiplexing should therefore be possible. In figure 2 (right), the 3-dB width of the switching windows and the extinction ratios (ER) for different bias values are shown. The narrowest window with highest ER is found around –3V, and is 16 ps wide and 9.3 dB high. However, the overall shape of the window is influenced by the bias, so the optimum bias point, where neighbouring channels are suppressed the most, depend slightly on the bit-rate.

Wavelength Conversion

Wavelength conversion is performed with both a CW probe and a pulsed probe. The ML-FRL acts as a data-modulated pump at 10 Gb/s with about 13 pJ pulse energy (18 dBm average power) at 1548 nm. The probe from the DFB laser is fixed at 1553 nm. In the CW case, the probe power is about 11 dBm, and in the pulsed case about 0.3 dBm average power (~12 dBm peak power).

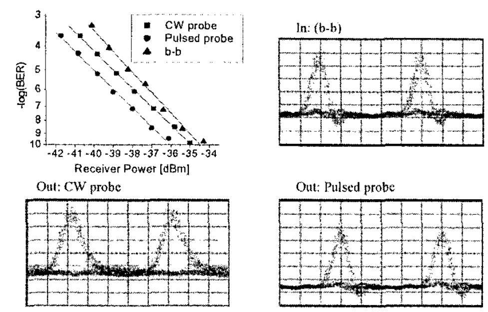


Figure 3: BER and eye diagrams for 10 Gb/s wavelength conversion.

Figure 3 shows the BER curves and eye diagrams for the two cases, for a bias of –2.2V. In both cases a negative penalty compared to the back-to-back (b-b) (directly from the transmitter to the receiver) is obtained. This is due to the nonlinearity of the transfer function, and clearly demonstrates the reshaping properties of wavelength conversion in an EAM [6]. In the CW case, the output eye clearly reveals a suppression of the "0"-level which is the fingerprint of the nonlinear transfer function. In the CW case the receiver sensitivity improvement is 0.5 dB, whereas in the pulsed probe case, the improvement is 1.6 dB. This better performance of the pulsed probe is primarily ascribed to the receiver's higher sensitivity to shorter pulses [8] (less average power is required to obtain the same SNR).

All-optical Demultiplexing

For demultiplexing, the GS-DFB acts as a 10 GHz pump (at 1553 nm) with only 8 pJ pulse energy available, and the ML-FRL serves as pulse source for the 10, 40 and 80 Gb/s probe bit streams (at 1558 nm) that are sent into the EAM. The probe has about 8 dBm average power in all cases. Figure 4 shows the successful 40/10 Gb/s demultiplexing results, in terms of BER curves and eye diagrams. The 10/10 Gb/s demultiplexing has no power penalty compared to the back-to-back case, but a slight change in slope. Since the 10/10 situation corresponds to the wavelength conversion situation, a 1.6 dB improvement is expected, but due to the less pump pulse energy available here the saturation of the absorption is not as effective. This is revealed by the slope change and the fact that there is no improvement in sensitivity. For the 40/10 Gb/s demultiplexing there is a 2 dB penalty, where the major part is ascribed to the lack of pump power, but also to ISI stemming from the asymmetric switching window.

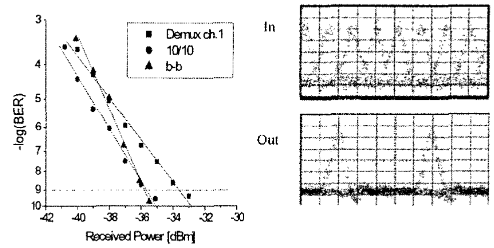
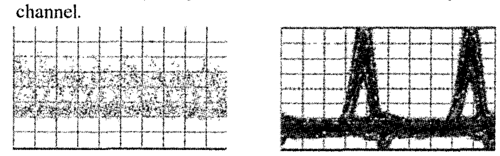


Figure 4: BER and eye diagrams for 40/10 demultiplexing.

Figure 5 shows the first promising results for 80/10 Gb/s demultiplexing. The EAM is set to –3V to obtain the narrowest switching window (intrinsic window ~16 ps), and clear and open eyes are obtained for the demultiplexed channel.



In (80 Gb/s) Out (10 Gb/s)

Figure 5: Eye diagrams for 80/10 Gb/s demultiplexing.

The performance is limited though by the available pump power and the exponential tail of the switching window. A better performance is however expected at higher pump powers, and this preliminary result shows the great potential for the EAM as an all-optical demultiplexer.

Conclusion

Successful wavelength conversion at 10 Gb/s is demonstrated with a negative penalty of 1.6 dB. Successful all-optical demultiplexing of a 40 Gb/s data signal down to 10 Gb/s is demonstrated error-free, and with a 2 dB penalty mostly ascribed to the limited pump power. An 80 Gb/s data signal is all-optically demultiplexed down to 10 Gb/s yielding clear and open eyes.

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