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640 Gbit/s Optical Wavelength Conversion using FWM in a Polarisation Maintaining HNLF

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Abstract

We report on the first demonstration of 640 Gbit/s wavelength conversion by FWM. This is demonstrated using a novel elliptic core PM-HNLF giving sufficient FWM conversion bandwidth.

Introduction

In high capacity optical communication systems with high per-channel serial bit rates, all-optical signal processing has significant potential benefits such as high operating speed, potential for increased transparency to modulation formats and a required power to run the system which does not necessarily scale with the bit rate of the signal to be processed. Several signal processing tasks must be addressed in high speed communication systems and networks, including wavelength conversion of data signals for e.g. data management in a system or contention resolution in a system node. Several approaches based on non-linear effects in optical fibres as well as semiconductor structures have been investigated. In semiconductors wavelength conversion has been demonstrated up to 320 Gbaud [1] and wavelength conversion in non-linear fibre was recently achieved at 640 Gbaud using cross-phase modulation (XPM) [2].

In this paper, wavelength conversion by four-wave mixing (FWM) in a novel elliptic core polarisation maintaining highly non-linear fibre (PM-HNLF) [3] is demonstrated for a 640 Gbit/s (640 Gbaud OOK) optical time division multiplexed (OTDM) data signal. This constitutes the highest reported operating speed of a FWM wavelength converter and only the second demonstration of 640 Gbit/s wavelength conversion to date. Error free conversion is achieved with an average penalty in receiver sensitivity of only ~3 dB compared to the original 640 Gbit/s data signal.

Experimental procedure

The experimental set-up is shown in Figure 1. The optical signal is generated by an erbium glass oscillator pulse generating laser (ERGO-PGL) with a pulse repetition rate of 10 GHz and a wavelength of 1557 nm. The pulses are data modulated with a 2^7-1 PRBS in a Mach-Zehnder modulator (MZM) and subsequently multiplexed to 40 Gbit/s in a passive fibre delay multiplexer (MUX). The 40 Gbit/s data pulses are then chirped and spectrally broadened by self phase modulation (SPM) in 400 m of dispersion flattened highly non-linear fibre (DF-HNLF, γ ~10 $W^{-1}km^{-1}$, dispersion D = -1.2 ps/nm/km at 1550 nm and a dispersion slope of 0.003 ps/nm^{2}km – from OFS Denmark). The positive dispersion in the remainder of the transmitter linearly compresses the data pulses to ~630 fs FWHM in the resulting 640 Gbit/s data signal. The data signal is launched into the wavelength converter where it is combined with the CW FWM pump. The polarisations of both signal and pump are aligned to the slow axis of the PM-HNLF (zero dispersion at 1545 nm, dispersion slope of 0.025 ps/nm^{2}km – from OFS Denmark) using a polarisation beam splitter (PBS). The PM-HNLF ensures stable polarisations of the interacting waves in the fibre and thus eliminates the polarisation changes due to PMD which can otherwise severely limit the spectral bandwidth of effective FWM conversion in optical fibre [4]. The CW pump at 1545 nm is phase modulated by XPM from the data signal in the PM-HNLF. This increases the threshold for Stimulated Brillouin Scattering (SBS) for the CW pump from 20.3 dBm for a linewidth of < 3 MHz, to more than 23.2 dBm which is the pump power in these experiments. At the output of the PM-HNLF a Fibre Bragg Grating (FBG) based notch filter is used to suppress the CW pump by ~40 dB. A 13 nm bandpass filter is used to suppress the original data

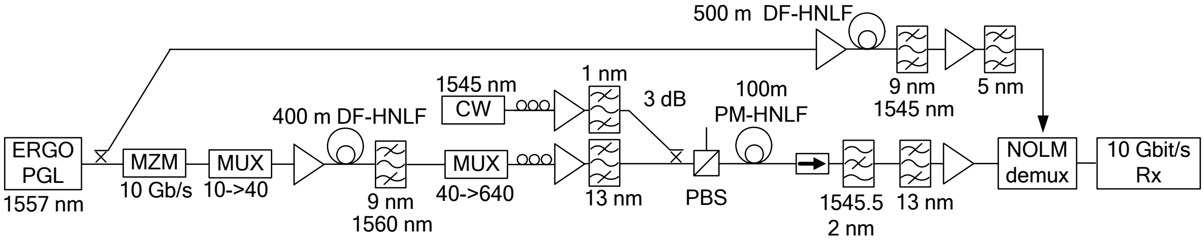

Figure 1: Experimental set up of the 640 Gbit/s FWM wavelength converter

signal at 1560 nm. The wavelength converted signal is demultiplexed to the 10 Gbit/s base rate for BER testing in a non-linear optical loop mirror (NOLM) using ~900 fs control pulses generated in a second chirp-dispersion pulse compressor based on 500 m of DF-HNLF with the same properties as the one described above.

Experimental results

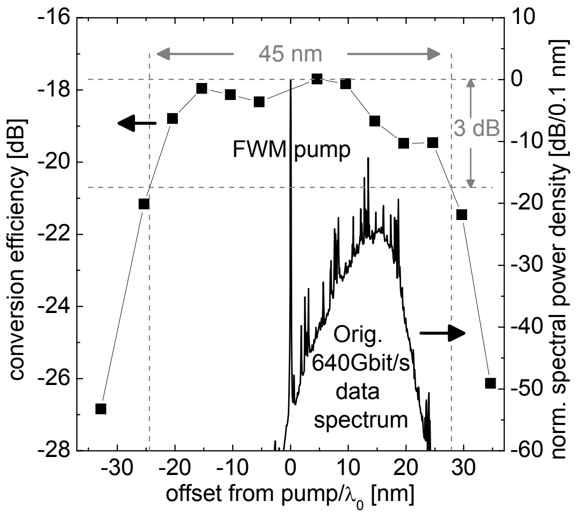

Figure 2: Left axis - Conversion efficiency for a CW probe with FWM pump at 1545 nm. Right axis – Optical spectrum of original 640 Gbit/s data and FWM pump.

A key consideration for a wavelength converter intended to operate at 640 Gbit/s or beyond is the spectral bandwidth of the converter, which must be sufficiently large to process the broad optical spectrum associated with temporally narrow pulses without distorting the spectrum of the converted signal. In Figure 2 the conversion efficiency of FWM in the PM-HNLF is plotted together with the spectrum of the original data signal and the CW pump. The conversion efficiency is seen to vary by only ~2 dB over the entire data spectrum, and the spectral 3 dB bandwidth of the converter is ~45 nm. The spectral bandwidth of the converter is thus sufficiently large as to allow for simultaneous conversion of the entire data spectrum with limited spectral distortion.

Figure 3 shows the optical spectrum at the output of the wavelength converter when converting a 640 Gbit/s data signal from 1560 nm to 1530 nm. The inset shows autocorrelations of the original and converted data signals. Pulse broadening of ~130 fs due to the wavelength conversion is observed. This is expected to be mainly due to spectral shaping caused by optical filtering and by the non-constant conversion of the spectrum seen in Figure 2. The converted pulses have a FWHM of 760 fs which is sufficient for 640 Gbit/s operation.

Figure 4 shows BER results for the wavelength converter. Error free operation is achieved with no indication of an error floor down to at least a BER of 10^{-10}. The inset in Figure 4 shows the receiver sensitivity at a BER of 10^{-9} for nine consecutive channels in the converted 640 Gbit/s data signal. All channels achieve error free operation with a variation in receiver sensitivity of less than 4 dB. The average receiver sensitivity after conversion is -31.5 dBm giving only ~3 dB penalty compared to the original signal.

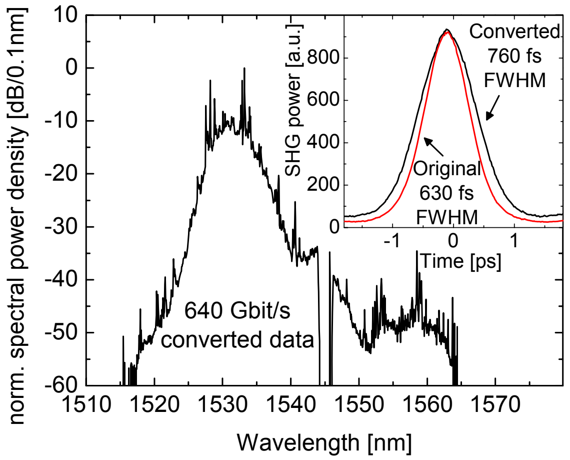

Figure 3: Optical spectrum of converted 640 Gbit/s data. Inset – Autocorrelations of original and converted data pulses.

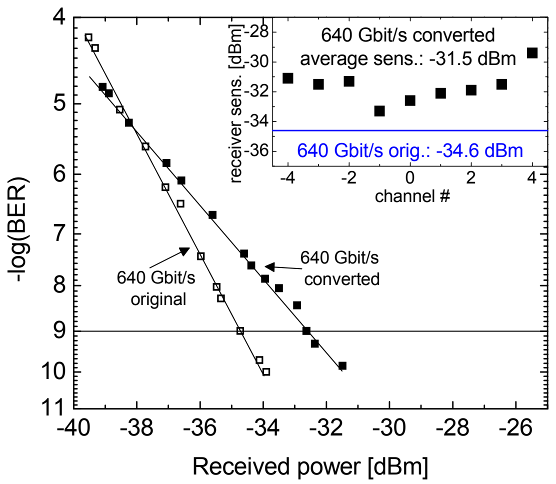

Figure 4: BER performance of wavelength converter. Inset – Receiver sensitivities for four channels on either side of the channel in the main plot.

Conclusions

We have demonstrated wavelength conversion at 640 Gbit/s by FWM for the first time, using a novel PM-HNLF. The wavelength converter operates error free and with low penalty.

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