All-optical demultiplexing of 1.28 Tb/s to 10 Gb/s using a Chalcogenide photonic chip

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Abstract: We report the first demonstration of all-optical Tbaud switching on a compact photonic chip. A 1.28 Tbaud return-to-zero signal was demultiplexed via four-wave mixing in a highly nonlinear, dispersion-engineered 7-cm Chalcogenide planar waveguide.

OCIS codes: (070.4340) Nonlinear optical signal processing; (190.4360) Nonlinear optics, devices.

1. Introduction

The growing demand for higher bandwidth in optical systems is motivating research to enhance the transmission rate per-channel. Recently the focus has been on establishing the feasibility of Tbaud transmission for Tb/s Ethernet applications [1] using optical time division multiplexing (OTDM). In this context, Mulvad *et al.* [1] demonstrated 1.28 Tbaud OTDM switching, using tens of meters of highly nonlinear fiber (HNLF). Although impressive results were obtained, the performance was limited by signal degradation due to dispersion in the HNLF. Furthermore, this approach is not compatible with photonic integration. Integrated all-optical solutions are being developed based on materials with large optical nonlinearity. Semiconductor optical amplifiers [2] offer enormous nonlinearities, but suffer from free-carrier dynamics at high bit-rates, which translates into a significant system penalty. Periodically poled $LiNbO_3$ [3] has been exploited in numerous high-bit rates experiments but need temperature control and quasi-phase matching is required, which is not always compatible with ultrafast processing. Chalcogenide (ChG) planar waveguides, on the other hand, do not suffer free-carrier absorption, are stable at room temperature, do not require quasi-phase matching and can be dispersion engineered. They are an ideal platform for Tb/s bitrates due to the high nonlinear response $\gamma=2\pi n_2/A_{eff}$, (A_{eff} is the effective mode area), which results in a very compact device [4].

In this paper, we report the first demonstration of > 1 Tb/s OTDM switching using a photonic-chip based all-optical device. We demonstrate error-free, four-wave mixing (FWM) based de-multiplexing of 1.28 Tb/s to 10 Gb/s using a highly nonlinear ($\gamma \approx 9900$ /W/km), dispersion-engineered ChG planar waveguide. Excellent performance was achieved with very high FWM conversion efficiency, low power penalty and no indication of an error-floor.

2. Working principle and experimental setup

The working principle of the FWM based de-multiplexing is described in Fig. 1(a) [5]. In this approach, the high bit-rate signal was co-propagated with pump control pulses at a sub-harmonic repetition rate. The pump pulses was adjusted to coincide with the desired channel of the high bit-rate signal, converting it to a new idler wavelength [6].

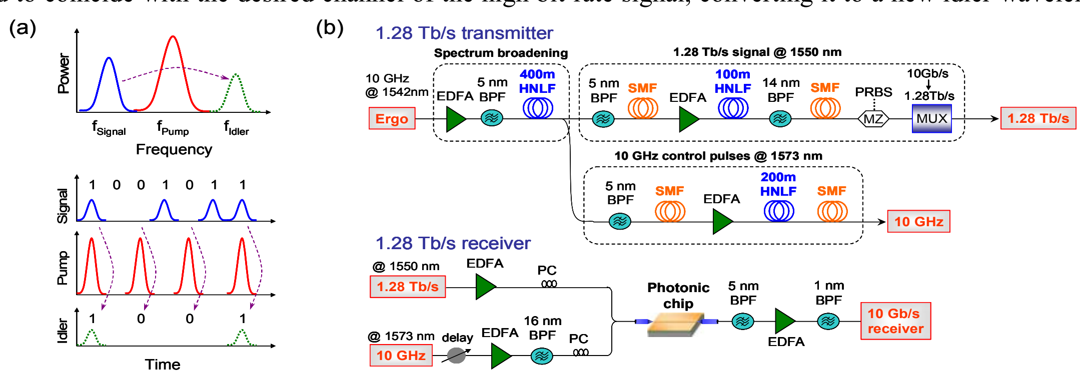

Fig. 1: (a) Working principle of FWM based demultiplexing of a high bit-rate signal [5]. (b) Experimental setup for 1.28 Tb/s all-optical demultiplexing by FWM in a 7-cm length ChG planar waveguide.

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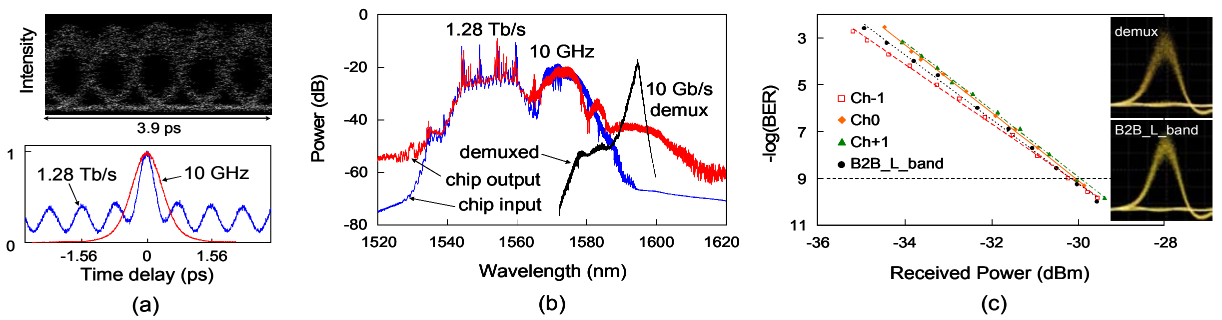

Fig. 2: (a) Eye diagram (top) and AC trace (bottom) of a 1.28 Tb/s signal and AC trace of 10 GHz pulses. (b) Optical spectra at input, output of the waveguide and before optical receiver. (c) BER measurements and corresponding eye diagrams of demultiplexed 10 Gb/s signal.

The de-multiplexed signal was then extracted from the output by spectrally filtering this idler. The key device in this de-multiplexing scheme is a 7 cm long As_2S_3 rib planar waveguide. The effective core area A_{eff} of the TM mode of this waveguide was reduced to ~ 1 μm^2 to enhance its nonlinearity and shift the zero dispersion wavelength closer to 1550 nm. This short, low dispersion waveguide offers low walk-off, thus enabling high FWM conversion efficiency.

The experimental setup is shown in Fig. 1(b). Both 1.28 Tb/s and 10 GHz pump pulses were generated from the 10 GHz erbium glass oscillating (ERGO) laser followed by two-stage nonlinear pulse compression. In the first stage, the output from an ERGO laser, was spectrally broadened with linear chirp by self-phase modulation (SPM) in a dispersion-flattened normal-dispersion HNLF. These pulses were filtered at 1550 nm (signal) and 1573 nm (pump), and then compressed in SMF fibers with anomalous dispersion. This compression process was repeated in the second stage. The compressed 10 GHz pulse train centered at 1550 nm was then encoded with data using a Mach-Zehnder (MZ) modulator. The seven-stage multiplexing (MUX) of 2^7 - 1 bit delay length interleaved the signal up to 1.28 Tb/s (eye diagram is shown in Fig. 2(a)(top)). This 1.28 Tb/s signal (P_{ave} ~ 100 mW) and 10 GHz control pulses (P_{ave} ~ 60 mW) were finally coupled to the TM mode of a waveguide via lensed fibers.

3. Experimental results and discussion

The AC waveforms of the 1.28 Tb/s and 10 GHz control pulses are shown in Fig. 2(a) (bottom), measured at the input to the waveguide. The full-width at half maximum of the 1.28 Tb/s and the 10 GHz control pulses were ~ 370 fs and ~ 450 fs, respectively. Although the width of the pump pulses was slightly broader than the signal width, they only overlap with one data channel at a time. Fig. 2(b) shows the optical spectra of a 1.28 Tb/s source signal and a 10 GHz pulse train at the input and output of the waveguide. The FWM idler (λ_i ~ 1596 nm) appeared at the output of the waveguide emphasizing the high FWM conversion efficiency of this chip.

The quality of the FWM idler extracted from the output spectrum using two BPFs is demonstrated by the eye diagrams and bit-error-rate (BER) measurements as shown in Fig. 2(c). In this experiment, the 10 Gb/s de-multiplexed signal was obtained in the L-band. Therefore our de-multiplexed signal is compared to the back-to-back (B2B) L-band 10 Gb/s data, whose wavelength was converted, and passed through the same BPFs. The 10 Gb/s de-multiplexed eye diagram shows a clear opening with just slightly more noise compared to the B2B_L_band 10 Gb/s signal. Fig. 2(c) also reveals negligible power penalty at a BER of 10^{-9} for three adjacent channels of the 1.28 Tb/s signal. These results highlight the excellent performance in de-multiplexing 1.28 Tb/s data signal with negligible signal quality degradation and without indication of error-floor in BER measurements.

4. Conclusions

We have demonstrated, for the first time, Tb/s signal processing on a compact photonic chip. A 1.28 Tb/s single wavelength, single polarization return-to-zero signal was successfully de-multiplexed via FWM in a highly nonlinear, dispersion-shifted ChG planar waveguide. Error-free performance was obtained.

5. References

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