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40 Gbit/s wavelength multicast via SOA-MZI and applications

N. Yan, T. Silveira, A. Teixeira, A. Ferreira, E. Tangdiongga, P. Monteiro and A.M.J. Koonen

40 Gbit/s wavelength multicast is demonstrated by all-optical multi-wavelength conversion based on a single interferometer. Simultaneous 200 GHz spaced one-to-four conversion is achieved, error free until BER of 10^{-10} and with negligible sensitivity difference among all the multicast channels. Several new all-optical applications are also enabled by this technology.

Introduction: All-optical multi-wavelength conversion (MWC) allows simultaneous wavelength multicast without the necessity of optic–electronic–optic transponders, reduces the switching hardware and operational cost, lowers the blocking probability, and increases the optical network transparency and efficiency [1–4]. Recently, various MWC approaches have been reported but only a limited number can support data rates of 40 Gbit/s or higher: four-wave mixing (FWM) [1], supercontinuum [2], cross-absorption modulation [3], nonlinear polarisation switching [4] and cross-phase modulation (XPM) [5]. Among these, XPM in semiconductor optical amplifier Mach-Zehnder interferometer (SOA-MZI) excels over the others by offering the greatest combination of desirable features [5–7], including: integration potential, satisfactory and flat conversion efficiency, low power budget, and wide conversion bandwidth covering SOA gain spectrum. Moreover, SOA-MZI also allows differential schemes to operate beyond the speed limitations of SOAs.

However, so far MWC via an SOA-MZI has not been reported either with any bit error rate (BER) evaluation at 40 Gbit/s, or with standard channel spacing for commercial applications [5]. In this Letter, we characterise through BER measurements one-to-four MWC at 40 Gbit/s with International Telecommunication Union (ITU) 200 GHz channel spacing using a commercially integrated SOA-MZI in differential mode. Error free operation until BER of 10^{-10} was achieved with less than 1 dB optical signal-to-noise ratio (OSNR) sensitivity difference among all the MWC channels. Based on the performance, we further propose some new all-optical applications that can benefit from this technology.
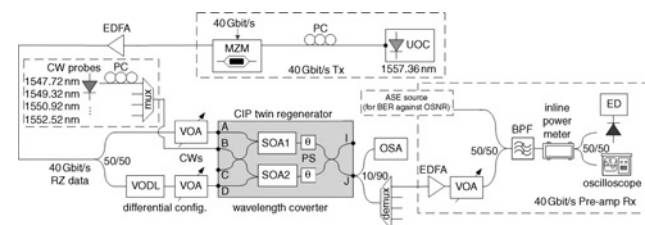
**Fig. 1** *Experimental setup for 4×40 Gbit/s all-optical wavelength multicast*

Tx/Rx: transmitter/receiver; PC: polarisation controller; EDFA: erbium-doped fibre amplifier; BPF: bandpass filter; VOA: variable optical attenuator; OSA: optical spectrum analyser

Experiment and results: The experimental setup is shown in Fig. 1. MWC was achieved by a hybrid integrated SOA-MZI regenerator purchased from the Centre for Integrated Photonics (CIP). An ultrafast optical clock (UOC) source generated 2 ps-wide 40 GHz optical pulses at 1558.17 nm. The clock was gated by a Mach-Zehnder modulator (MZM) with a $2^{31} - 1$ pseudorandom binary sequence to form the 40 Gbit/s return-to-zero (RZ) input signal. This signal was then tapped onto both SOA-MZI arms A and D, with the lower data path delayed for 7.6 ps by a variable optical delay line (VODL). The optical power for arms A and D was 11.6 and 1.3 dBm, respectively. Four continuous wave (CW) probes from 1547.72 to 1552.52 nm within the power range 3.4–5 dBm were combined using an ITU 200 GHz spaced multiplexer and fed into the SOA-MZI arm B. After MWC, the converted multicast data signals were demultiplexed and individually fed to a pre-amplified receiver and an error detector (ED). The −3 dB bandwidth of all the optical filters including the (de)multiplexers was 130 GHz. The photodetector (PD) had an electrical bandwidth of 37 GHz. Both SOAs were pumped with 400 mA current

to facilitate fast SOA recovery time. The phase shifter (PS) after SOA1 was set to 8 V to obtain non-inverted output at MZI port J.

Wavelength conversion is obtained through phase shift on the CWs, induced via XPM [5–7]. The MZI translates phase modulation into amplitude modulation. Since the phase change is only weakly dependent on the wavelength, input data can be transferred onto multiple CW channels. The differential configuration requires a delayed and attenuated signal travelling in the lower arm to cancel the broadened converted pulse tails owing to the slow SOA recovery time.

Fig. 2 shows the output spectrum with all the MWC eye diagrams as insets. Clear eye opening was obtained. FWM satellites due to the SOA nonlinear effect were observed, but the out-of-band FWM byproducts were more than 20 dB weaker than the MWC channels. The oscilloscope measured an average extinction ratio (ER) of 10.16 dB for the multicast channels, with the worst being 9.68 dB.
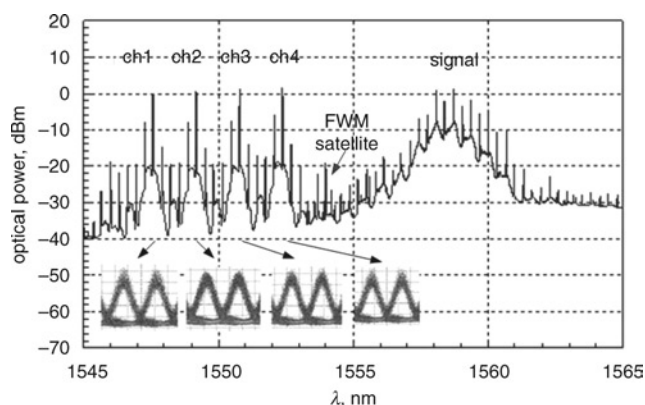
Fig. 2 *Output optical spectrum with all multicast channel eye diagrams as insets*

Fig. 3 shows BER measurements of all the MWC channels, a single wavelength conversion (SWC) and the input signal as reference. For each BER measurement, signal OSNR was degraded at the PD input by increasing the amplified spontaneous emission (ASE) noise level while keeping the signal power constant at −1 dBm to ensure linear operation of the electrical circuitry. The OSNR was taken using an inline power meter before the PD by disabling sequentially the signal or the ASE noise. The average OSNR penalties of the MWC channels at BER = 10^{-9} were ~3.5 dB relative to the SWC case and ~7 dB to the back-to-back reference. Less than 1 dB OSNR sensitivity difference among all the MWC channels was obtained. Regarding SWC, the penalty was mostly due to the pulse broadening caused by the slow SOA gain recovery time, as it could not be completely suppressed via the differential configuration. However, no error-floor was observed, which indicates excellent performance of the MWC.
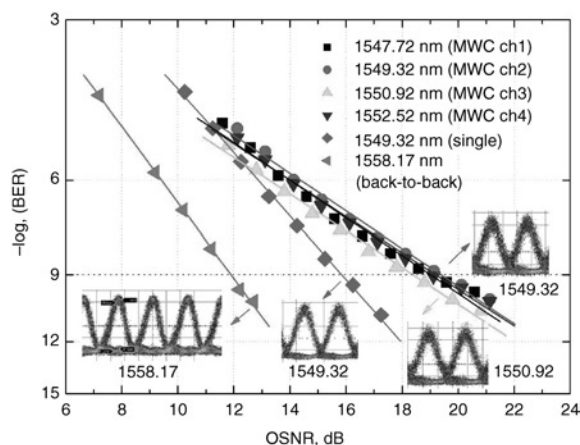
Fig. 3 *BER performance of 40 Gbit/s one-to-four multi-wavelength conversion, single wavelength conversion and back-to-back reference*

Applications: A number of desirable all-optical functionalities can be enabled by this technology. Optical layer wavelength multicast can be implemented in the wavelength division multiplexed (WDM)

networks for wavelength-routed scenarios or optical switches based on passive waveguides [8], or in WDM passive optical networks. All-optical multi-slot reflective packet buffering can be realised by MWC followed by a fibre Bragg grating. Gratings for different wavelengths can be written on a fibre at several intervals to retrieve packets in different time slots on multiple converted lambdas. In buffer-less or buffer-low networks with bursty traffic, by implementing MWC with passive waveguides, we can solve optical node contention to a certain degree by multiple deflection routing under an overall network control to prevent packet loss. More, but not exhaustive, MWC applications include $1 + 1$ link protection and grid networking that rely on high-speed data multicasting.

Conclusions: We have demonstrated non-inverted error-free all-optical SWC and simultaneous one-to-four MWC at 40 Gbit/s employing an SOA-MZI regenerator with standard ITU 200 GHz channel spacing. We obtained clear, open eye diagrams and negligible performance difference among all the multicast channels. No error floor was observed. We have further proposed several new applications of our scheme. SOA-MZIs are used for various functionalities and thus can be produced in large quantities and integrated to reduce cost. For the SOA-MZI we used, we estimate the maximum MWC channel number to be around ten within the SOA gain bandwidth for an acceptable performance, which is mainly restricted by the optical gain variation per channel that creates phase shift in the MZI arms.

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References

1 Yan, N., Teixeira, A., Silveira, T., Tosi Beleffi, G.M., Curti, F., Forin, D., Dalla Longa, F., Tafur Monroy, I., Monteiro, P., and Koonen, T.: 'Theoretical and experimental performance evaluation of all-optical multi-wavelength conversion by four-wave mixing in fiber at 10/20/40 Gb/s for optical layer multicast', *Microw. Opt. Technol. Lett.*, 2007, **49**, (5), pp. 1067–1071

2 Karasek, M., Kanka, J., Honzatko, P., Vojtech, J., and Radil, J.: '10 Gb/s and 40 Gb/s Multi-wavelength conversion based on nonlinear effects in HNLF'. Proc. ICTON, 2006, Tu.D1.7, pp. 155–161

3 Xu, L., Chi, N., Yvind, K., Christiansen, L.J., Oxenløwe, L.K., Mørk, J., and Jeppesen, P.: '7 × 40 Gb/s base-rate RZ all-optical broadcasting utilizing an electroabsorption modulator', *Opt. Express*, 2004, **12**, (3), pp. 416–420

4 Contestabile, G., Calabretta, N., Presi, M., and Ciaramella, E.: 'Single and multicast wavelength conversion at 40 Gb/s by means of fast nonlinear polarisation switching in an SOA', *Photonics Technol. Lett.*, 2005, **17**, (12), pp. 2652–2654

5 Reading-Picopoulos, D., Wang, F., Chai, Y.J., Penty, R.V., and White, I.H.: '10 Gb/s and 40 Gb/s WDM multi-casting using a hybrid integrated Mach-Zehnder interferometer'. Proc. Optical Fiber Communication Conf. (OFC 2006), Anaheim, CA, USA, 2006, Paper OFP2

6 Chung, H.S., Inohara, R., Nishimura, K., and Usami, M.: 'All-optical multi-wavelength conversion of 10 Gbit/s NRZ/RZ signals based on SOA-MZI for WDM multicasting', *Electron. Lett.*, 2005, **41**, (7), pp. 432–433

7 Yan, N., Jung, H.-D., Tafur Monroy, I., de Waardt, H., and Koonen, A.M.J.: 'All-optical multi-wavelength conversion with negative power penalty by a commercial SOA-MZI for WDM wavelength multicast'. Proc. Optical Fiber Communication Conf. (OFC 2007), Anaheim, CA, USA, 2007, Paper JWA36

8 Yan, N., Alcaide, A., Mendinueta, J.M.D., Tangdiongga, E., and Koonen, A.M.J.: 'Cost reduction and traffic performance improvement using direct forward optical layer multicast in optical label switching nodes'. Proc. 33rd European Conf. and Exhibition on Optical Communication (ECOC 2007), Berlin, Germany, September 2007, Vol. 2, 3.2.2, pp. 39–40