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40 Gb/s All-Optical Multi-Wavelength Conversion via a Single SOA-MZI for WDM Wavelength Multicast

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***Abstract*— WDM wavelength multicast is demonstrated by all-optical multi-wavelength conversion. We report for the first time simultaneous 200 GHz spaced one-to-four conversion at 40 Gb/s using a commercial SOA-MZI with error free operation until 10^{-10}.**

I. Introduction

Multi-wavelength conversion (MWC) has attracted increasing interest in the last few years. It allows all-optical wavelength multicast by simultaneously converting data on one wavelength to several other wavelengths to be routed passively by optical waveguides, e.g. an optical arrayed waveguide grating. All the data information remains in the optical domain, which eliminates the necessity of employing multiple optic-electronic-optic (OEO) transponders, reduces the switching system and operational cost, lowers the blocking probability, and increases the optical network transparency, efficiency and effectiveness.

Many multi-wavelength converters (MWCR) have been reported. However, only a few of them can support high data rate up to 40 Gb/s: nonlinear fiber by four-wave mixing (FWM) or supercontinuum generation [1], electroabsorption modulator by cross absorption modulation [2], semiconductor optical amplifier (SOA) by nonlinear polarization switching [3] and SOA - Mach-Zehnder interferometer (MZI) by cross-phase modulation (XPM) [4]. Among these, XPM-based MWCRs using a SOA-MZI excel the others by offering a great combination of advantages [4, 5] such as satisfactory and leveled conversion efficiency, simultaneous conversion of a considerable number of channels, wavelength flexibility, wide conversion bandwidth, commercial product availability, integration potential, compactness, low power budget, ability of converting both return-to-zero (RZ) and non-return-to-zero (NRZ) data, possible signal regeneration and noise suppression, and the possibility of using differential scheme for high data rates. However, to our knowledge, so far at 40 Gb/s only one-to-three MWC with minimum 300 GHz channel spacing and a large 1200 GHz detuning has been reported without bit error rate (BER) measurements using a SOA-MZI [4].

In this paper, simultaneous one-to-four MWC at 40 Gb/s with ITU 200 GHz channel spacing and 600 GHz detuning is demonstrated based on a commercial hybrid integrated SOA-MZI regenerator using a push-pull configuration. The BER performance of such a system was evaluated in all the four MWC channels against back-to-back reference and single wavelength conversion cases. Error free operation until 10^{-10} was achieved.

II. Experimental Setup and Results

The experimental setup is shown in Fig. 1. The commercially available SOA-MZI wavelength converter was from a CIP twin regenerator for 10 Gb/s standard operation. ITU 200 GHz spaced wavelengths were deployed. The 40 Gb/s RZ data signal was generated by modulating a 40 GHz ultrafast optical clock (UOC) using 40 Gb/s pseudorandom bit sequence with pattern length of 2^{31}-1. The 2-ps pulse source was tuned to 1557.36 nm. An erbium-doped fiber amplifier (EDFA) was used to compensate the power loss in the modulation process. Push-pull configuration was employed to overcome the speed limit of the SOA carrier dynamics for the MZI to perform 40 Gb/s MWC. For this purpose the data signal was tapped onto both of the SOA-MZI arms *A* and *D* using a 50/50 coupler, with the lower data path delayed by a variable optical delay line (VODL) to achieve the differential mode. The optical power for the data channel and the delayed data channel were 7.3 dBm and -3 dBm respectively. The push-pull delay was around 6.5 ps. Four continuous waves (CWs) at wavelength 1547.72 nm, 1549.32 nm, 1550.92 nm and 1552.52 nm were combined by a multiplexer and injected in the co-propagating direction into SOA-MZI port *B*.

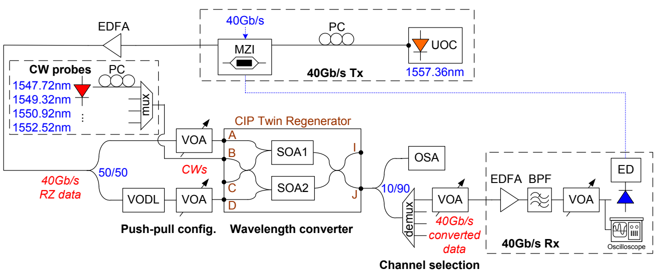

Fig. 1. Experimental setup for all-optical one-to-four MWC at 40 Gb/s using a commercial SOA-MZI regenerator

The SOA-MZI was kept at 28°C. Both SOAs were biased at 400 mA while in the upper arm a phase shifter after the SOA1 was controlled with a voltage of 7.8 V. Optical multicast signals could be obtained from both SOA-MZI outputs *I* and *J*, but only multi-wavelength converted channels at *J* were tested with BER measurements because it was the non-inverted output under such experimental conditions. The converted channels were selected utilizing an optical filter with a -3 dB bandwidth of 130 GHz for the detection at the pre-amplified receiver.

Fig. 2 presents the output spectrum with all the four simultaneously converted eye diagrams as insets. The eye diagrams of all the MWC channels were clear and open. However, the outer channels, Ch1 and Ch4, had visible noisy *one* level. This had been observed during all the measurements of one-to-four conversion. From the spectrum we also observed FWM satellite signals at both sides of the converted channels from the SOA nonlinear effect. The out-of-band FWM byproducts were about 17 dB weaker or more than the desired converted channels. The measurements taken from the oscilloscope indicated an average extinction ratio (ER) of 9.61 dB for the four simultaneously converted channels, while the largest ER difference among the different channels was no greater than 0.61 dB.

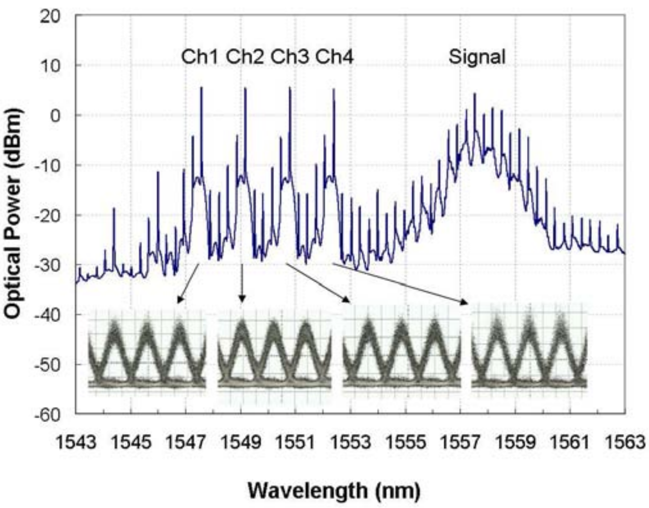

Fig. 2. Output spectrum of simultaneous one-to-four MWC with converted eye diagrams as insets

Fig. 3 shows the BER as a function of optical signal-to-noise ratio (OSNR) at the photo detector (PD) input for the four simultaneously converted channels, where the back-to-back reference and a single wavelength conversion curve were also plotted for comparison. The -3 dB bandwidth of the optical filter was 1 nm. From the BER results, we observed 4.5 dB OSNR penalty at BER of 10^{-9} for the single wavelength conversion to 1550.92 nm. This is mostly due to the pulse broadening caused by the wavelength conversion. The one-to-four simultaneously converted channels demonstrated a minimum 1 dB OSNR penalty with regard to the single wavelength converted case. From the BER curves it seems that Ch1 and Ch4 also had some error floor, which contributed to the OSNR sensitivity variation of around 2.7 dB at BER of 10^{-9} from the central channels Ch2 and Ch3. The worse performance of the outer channels agreed with the indication from the eye diagram insets presented in Fig. 2, where they exhibited evidently more noise at the logical *one* level. In Fig. 3, the eye diagrams of the 40 Gb/s RZ back-to-back signal, single wavelength conversion, one-to-four MWC outer channel Ch1 and inner channel Ch3 are also shown as insets. The eye opening of each case from the oscilloscope complied well with the BER measurements obtained.

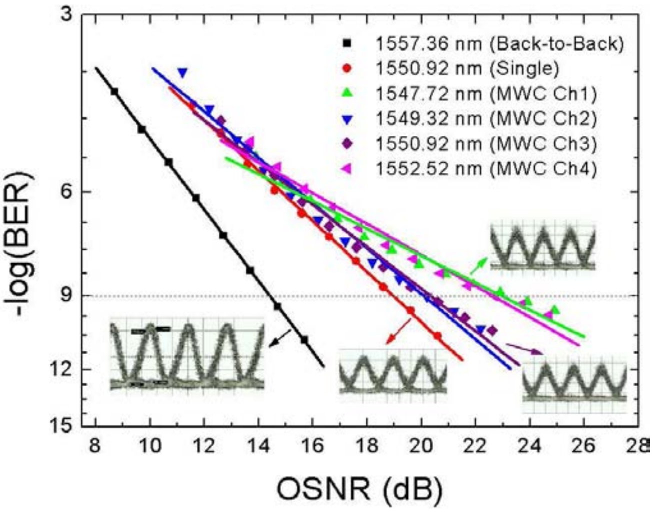

Fig. 3. BER of four simultaneously converted channels with respect to the back-to-back reference and single wavelength conversion

III. Conclusion

Single and simultaneous one-to-four MWC using a commercial SOA-MZI regenerator of 10 Gb/s standard operation speed was successfully demonstrated for 40 Gb/s conversion with differential configuration. For the first time to our knowledge, this was achieved at 40 Gb/s with error free operation until 10^{-10} at 200 GHz channel spacing and only 600 GHz detuning. Clear and open converted eye diagrams were obtained. The OSNR penalty at BER of 10^{-9} was 4.5 dB for the single wavelength conversion and around another 1 dB or more for the MWC. No assist light was employed [5]. We did not observe obvious performance limitations due to the number of MWC channels, therefore, we believe that more channels could be added if more laser sources were available, provided that they are placed inside the gain spectrum of the SOAs. Our results proved that a single SOA-MZI can be a promising candidate for all-optical wavelength multicast at 40 Gb/s.

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