Wavelength Conversion with MZI-SOAs

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Abstract — Wavelength multicasting at 40Gb/s is demonstrated by all-optical multi-wavelength conversion based on a single MZI-SOA. Simultaneous ITU grid 200GHz spaced one-to-four conversion is achieved with negligible sensitivity difference among all the multicast channels. Furthermore, we propose some new all-optical applications enabled by this technology.

I. INTRODUCTION

All-optical multi-wavelength conversion (MWC) permits simultaneous wavelength multicast without the need for optic-electronic-optic conversions. It also reduces the switching hardware and operational costs, decreases the blocking probability and improves the optical network transparency and efficiency [1]-[4]. Although various MWC approaches have been reported, only solutions based on four wave mixing (FWM) [1], supercontinuum [2], cross absorption modulation [3], nonlinear polarization switching [4] and cross-phase modulation (XPM) [5] can support data rates of 40Gb/s or higher. Among these, XPM in Mach-Zehnder interferometer – semiconductor optical amplifier (MZI- SOA) offers the greatest combination of desirable characteristics [5]-[7]: integration potential, satisfactory and flat conversion efficiency, low power budget and wide conversion bandwidth covering SOA gain spectrum. MZI-SOA also allows differential schemes to operate beyond the speed limitations of SOAs.

In this paper, we present one-to-four MWC at 40Gb/s with ITU 200GHz channel spacing using a commercially integrated MZI-SOA in differential mode[8].

II. OPERATION PRINCIPLE OF XPM IN MZI-SOA

The optical amplifiers gain saturates for high power input signals, resulting in different optical gain for different input power levels. In SOA the gain dynamics are related to free carrier dynamics and are of the tens of picoseconds order; this value is comparable to the pulse duration in current WDM systems. Therefore, intra-channel patterning effects, inter-channel interference, and newly generated frequencies (due to non-linearities, i.e. Four wave mixing (FWM)) arise.

In addition to the optical gain, the active region refractive index also depends on free carrier density and distribution. The refractive index variations reflect on the optical signal phase. Furthermore, the gain and refractive index variations are linked by a parameter known as the linewidth enhan-cement factor (α). Therefore, the phase dynamics can be de-duced from the SOA gain dynamics by means of the α factor.

Consider a situation where a continuous wave (CW) signal, and an intensity modulated signal, at different wavelengths, are simultaneously amplified in a SOA. The electrical field at the SOA input is given by[10]:

$$E_{\mathrm{IN}}(t) = \sqrt{P_{\mathrm{IN1}}} \cdot e^{j\cdot\Phi_{\mathrm{IN1}}} \cdot e^{j\cdot w_1 \cdot t} + \sqrt{P_{\mathrm{IN2}}(t)} \cdot e^{j\cdot\Phi_{\mathrm{IN2}}(t)} \cdot e^{j w_2 \cdot t} . \quad (1)$$

Where P_{INi} and Φ_{INi} are the signals power and phase, and w_i are the frequencies of the signals.

In unsaturated condition the SOA has a constant gain, G_{UNSAT}. If the input signals saturate the amplifier, the resultant gain $G_{\mathrm{SIG}}(t)$ is dependent on the signals intensity. Assuming a simplistic situation (where α is a constant, the gain associated with intra-band effects is dominant, the SOA transversal dimension is small, and the cavity is lossless), the output signal at w_2 is described by:

$$E_{\mathrm{OUT}\,w2}(t) = \sqrt{P_{\mathrm{IN}}(t)\, e^{G_{\mathrm{SIG}}(t)}} \cdot e^{j\cdot\left[\Phi_{\mathrm{IN}}(t) - \alpha\cdot\Delta G_{\mathrm{N}}(t)\right]} \quad (2)$$

where $\Delta G_{\mathrm{N}}(t) = G_{\mathrm{SIG}}(t) - G_{\mathrm{UNSAT}}$.

Gain and phase modulations are clear in equation **Error! Reference source not found.** and have been found as a promising approach to achieve all-optical wavelength conversion. The cross-phase modulation non-linearity is used to obtain experimental AOWC in this work.

For intensity modulated (IM) signals, the intensity of the wavelength converted signal should preserve the input signal logical information. However, the XPM effect only affects the converted signal phase; therefore, XPM based WC of IM signals requires a phase-modulation to

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

Wavelength conversion is obtained through phase shift on the CWs, induced by XPM effect. The MZI then translates phase modulation into amplitude modulation. Since the phase change is only weakly dependent on the wavelength, input data can be transferred onto multiple

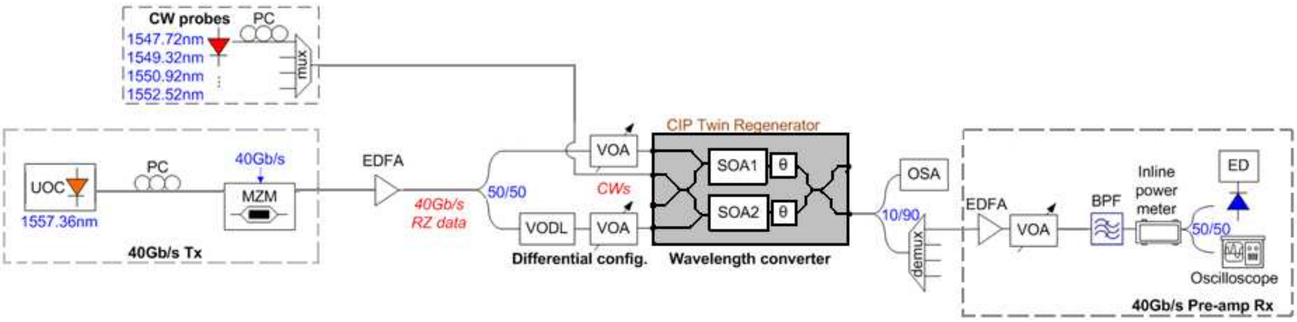

Figure 1: Experimental setup for 4 x 40Gb/s all-optical wavelength multicast. Tx/Rx: Transmitter/Receiver; PC: polarization controller; EDFA: erbium-doped fibre amplifier; BPF: band pass filter; VOA: variable optical attenuator; OSA: optical spectrum analyzer.

intensity-modulation (PM to IM) conversion stage. This conversion stage is usually performed in one of three ways: MZI or Michelson Interferometer, Terahertz Optical Asymmetric Demultiplexer, and the Delayed-Interference Signal Converter. The MZI interferometer has advantages in terms of integration and allows co- and counter-propagation and will be used in the tests of this work

III. EXPERIMENT AND RESULTS

Figure 1 illustrates the experimental setup. MWC was achieved by a hybrid integrated MZI-SOA regenerator from CIP. An ultra-fast optical clock (UOC) source generated 2-ps wide 40GHz optical pulses at 1558.17nm, which were modulated by a Mach-Zehnder modulator (MZM) with $2^{31}-1$ pseudo-random binary sequence to form the 40Gb/s return-to-zero (RZ) input signal. This signal was then tapped onto both MZI-SOA arms A and D, with the lower data path delayed for 7.6ps by a variable optical delay line (VODL). The optical power for arm A and D were 11.6 and 1.3dBm, respectively. Four continuous wave (CW) probes from 1547.72 to 1552.52nm within the power range of 3.4~5dBm were combined using an ITU 200GHz spaced multiplexer and fed into the MZI-SOA 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 -3dB bandwidth of all the optical filters including the (de)multiplexers was 130GHz. The photo detector (PD) had an electrical bandwidth of 37GHz. Both SOAs were pumped with 400mA current to

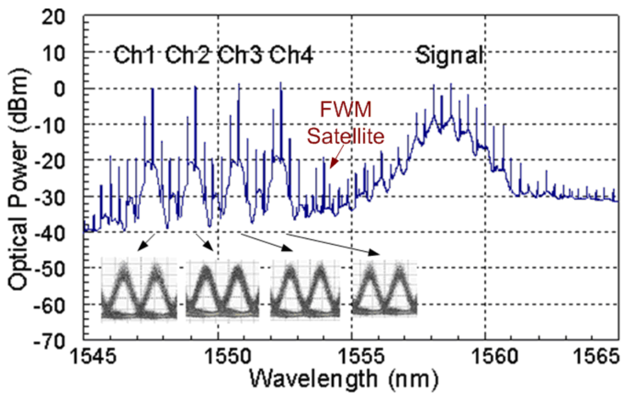

Figure 2: Output optical spectrum with all multicast channel eye diagrams as insets.

CW channels. Due to the slow SOA recovery time, the differential configuration requires a delayed and attenuated signal travelling in the lower arm to cancel the broadened converted pulse tails.

The output spectrum, with all the MWC eye diagrams as insets, is presented in Figure 2. Clear eye opening was obtained. It is also noticeable the FWM satellites due to the SOA nonlinear effect, however the out-of-band FWM by-products were more than 20dB lower than the MWC channels. The oscilloscope measured an average extinction ratio (ER) of 10.16dB for the multicast channels, with the worst being 9.68dB.

IV. CONCLUSION

Simultaneous one-to-four MWC at 40Gb/s employing a MZI-SOA regenerator with standard ITU 200GHz channel spacing were demonstrated. Clear, open eye diagrams and negligible performance difference among all the multicast channels were obtained. No error floor was observed.

New applications based on our scheme were proposed. MZI- SOAs are used for various functionalities and thus can be massively produced and integrated to reduce cost. For the MZI-SOA used, we estimate ten as the maximum MWC channel number 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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