7×10-Gbit/s All-optical Wavelength Multicast based on Cross-gain Modulation and Cascaded Four-wave Mixing Effects in an SOA Using Single Pump Laser Source

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Abstract: By combining XGM, and cascaded FWM effects in an SOA, seven multicast channels with 100-GHz spacing are demonstrated using single pump laser source. The power penalty of these multicast channels is less than 3.3 dB.

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1. Introduction

All-optical wavelength multicasting, where an input channel can be simultaneously replicated onto multiple output wavelengths, is one of the key enabling techniques for implementing a multicast-capable optical network to handle the explosive growth traffic. By using this technique, the efficiency and throughput of dense wavelength-division-multiplexing (DWDM) optical networks can be improved significantly in the presence of multicast traffic [1]. Moreover, all-optical multicasting eliminates the expensive optical-electronic-optical (O/E/O) conversions at the routers, which solves the electronic bottleneck issue and reduces the power consumption due to the O/E/O conversions [2-10].

Substantial effort has been made to realize all-optical wavelength multicast [2-10]. These techniques can be categorized into self-phase modulation (SPM), cross-gain modulation (XGM), cross-phase modulation (XPM), cross-absorption modulation (XAM), four-wave mixing (FWM), and fiber-optics parametric amplifier (FOPA) in the fibers with high nonlinearity, semiconductor optical amplifier (SOA), or electro-absorption modulator (EAM). However, these techniques, other than the technique based on SPM [3], require the use of multiple laser diodes (LD) as either high power pumps or low power probes in order to obtain a large number of multicast channels. Subsequently, temperature controllers (TEC) are necessary to stabilize the emission wavelengths of these LDs. The implementation cost will be increased accordingly.

Thus, it is highly desirable to design an all-optical wavelength multicasting scheme with none or only single LD to obtain as many multicast channels as possible. In [3], the authors propose a multicast scheme based on SPM without any external laser source. By spectrum slicing the SPM-broadened signal, six multicast channels are obtained. Unfortunately this scheme requires the signal to be amplified to a high power level in order to generate the SPM effect.

In this paper, by combining XGM, and cascaded FWM effects [9-11] in an SOA, seven 10-Gbit/s on-off keying (OOK) multicast channels with 100-GHz wavelength spacing are experimentally demonstrated by using only a single pump laser source. The number of multicast channels demonstrated is the highest reported for a single laser configuration. The channel spacing can be further reduced to 50-GHz or even 25-GHz by assigning the wavelengths to be between the pump and probe signal. Due to the relatively high conversion efficiency (CE) and high gain in the SOA, the required powers of the pump and probe signal are considerably smaller than those of most reported multicast schemes [2-8]. In addition, there are other advantages of using an SOA for nonlinear optics application. These include ease of photonic integration, physical compactness, wide gain bandwidth, and the absence of stimulated Brillouin scattering (SBS) effect. From the experimental results, it is found out that the maximum power penalty of these multicast channels is less than 3.3 dB at bit error rate (BER) = 10^{-9}.

2. Experimental setup and results

Fig. 1 shows the experimental setup. The light source, LD1, (at 1558.17 nm) is intensity modulated (IM) by a 10-Gbit/s data stream (2^{31}-1 pseudo-random bit sequence (PRBS)) and amplified by erbium doped fiber amplifier (EDFA) 1. Variable optical attenuator (VOA) 1 is used to adjust the probe signal power coupled into the SOA. LD2 (at 1557.36 nm) is used as the pump laser source. EDFA2 is used to amplify the power of the pump. The pump and probe signal are then multiplexed by a wavelength division multiplexer (WDMUX) before injected into the SOA.

The powers of the pump and probe signal launched into the SOA are set to 11.8-dBm and 5.8-dBm, respectively. Polarization controllers (PC) 1 and 2 are used to adjust the polarization states of the pump and signal to obtain the best CE for all the multicast channels. The SOA (CIP-XN-OEC-1550) used here has a small signal gain of about 34 dB, and a 16.5-dBm saturation output power, when the bias current is set at 550-mA. At the receiver side, another WDMUX with 100-GHz wavelength spacing is used to de-multiplex all the multicast channels at the output of the SOA. EDFA3 is used to amplify this channel and a tunable filter (TF) (0.5 nm 3-dB bandwidth) is used to further reject the amplified spontaneous emission (ASE) noise. VOA2 is used to adjust the optical power before the eye diagram and BER of the multicast channels are measured. For safe operation of the SOA, the maximum total input power is less than 13-dBm, and the bias current below 600-mA.

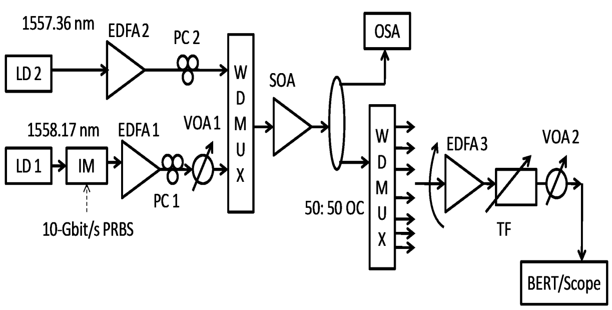

Fig. 1. Experimental setup. LD: laser diode. IM: intensity modulator. SOA: semiconductor optical amplifier. OC: optical coupler. WDMUX: wavelength division multiplexer. PC: polarization controller. EDFA: erbium doped fiber amplifier. TF: tunable filter. OSA: optical spectrum analyzer. PRBS: pseudo-random bit sequence. BERT: bit error rate test. VOA: variable optical attenuator.

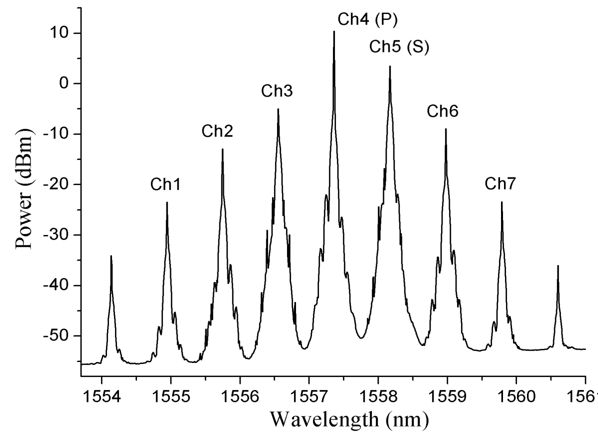

Fig. 2. Optical spectra measured by the OSA at the output of the SOA.

Fig. 2 shows the optical spectra measured by the optical spectrum analyzer (OSA) with a resolution of 0.01 nm at the output of SOA. The bias current of the SOA is 550-mA. It can be seen that seven multicast channels, including the pump and probe signal, are generated with 100-GHz wavelength spacing. These multicast channels are individually located at 1554.94 nm (Ch1), 1555.75 nm (Ch2), 1556.55 nm (Ch3), 1557.36 nm (Ch4), 1558.17 nm (Ch5), 1558.98 nm (Ch6), and 1559.79 nm (Ch7), which comply with the ITU-T grid. Ch4 (P) is generated by the XGM effect in the SOA. Ch3 and Ch6 are generated by the degenerate FWM effect. Ch1, Ch2, and Ch7 are generated as a result of the cascaded FWM effect. The CE, defined as the power of multicast channels to the power of signal, is larger than -27 dB. The optical signal-to-noise ratio (OSNR) of these multicast channels is over 30 dB.

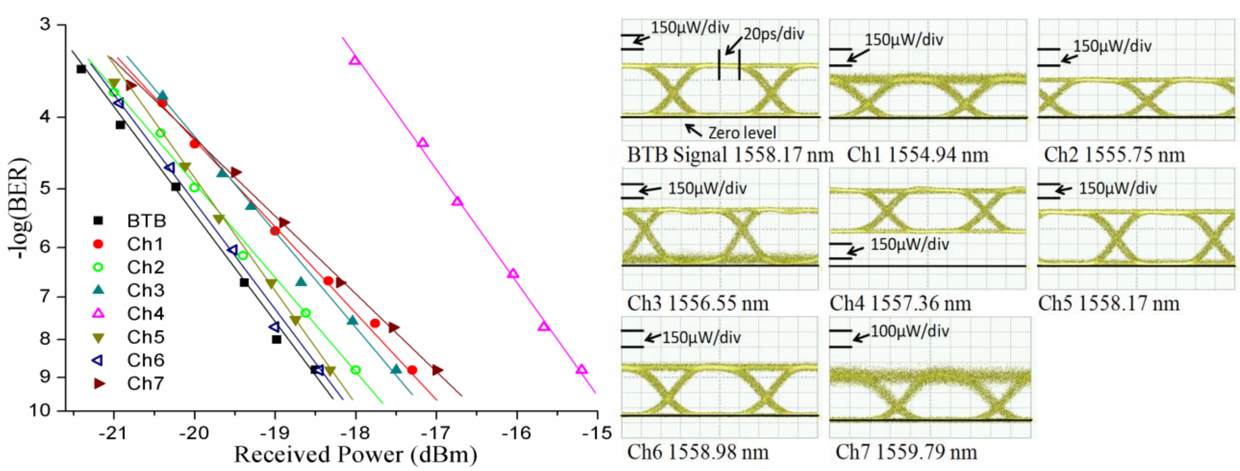

Fig. 3. BER curves and corresponding eye diagrams of the BTB signal and the multicasting channels.

The BER performance and the corresponding eye diagrams (zero level indicated) are shown in Fig. 3. It can be seen that Ch4 has the largest power penalty, about 3.3 dB at BER = 10^{-9}. This is owing to the high DC power coming from the pump (see the eye diagram of Ch4). Nevertheless, we believe by slightly detuning the central wavelength of TF to filter one side-band, which is similar to the vestigial sideband (VSB) modulation signal [12], DC component in Ch4 can be further suppressed, and the BER performance of Ch4 can be improved. In addition, the data format of Ch4 is inverted to the original signal due to the XGM operation principle [9]. Nevertheless, the data format of Ch4 can be easily converted back by using a NOT gate at the receiver side. While for the other multicast channels, Ch7 has the maximum power penalty, which is about 1.5 dB. This is due to the lower OSNR, and more ASE noise is introduced by EDFA3. And this relative larger power penalty can be further reduced by using an EDFA with lower noise figure (NF). Ch3 suffers a high noise level at bit “0”, which is due to the relative small pump-to-signal ratio that increases the effect of inter-symbol interference (ISI) in the SOA [13].

It is worth noting that the powers of the seven multicast channels are not equal, however, we may use the power equalization technique to make them having the same power level [14]. In addition, the channel spacing can be further adjusted to 50-GHz or even 25-GHz, the CE of the multicast channels can be further increased, and more channels can be obtained (e.g., the cascaded FWM idlers next to Ch1 and Ch7 can be used due to the improved OSNR), but this will require the WDMUX to have very good suppression performance to separate these multicast channels without crosstalk. Lastly, the bit rate of the multicast channels can be easily increased to 40-Gbit/s or even higher because the carrier recovery time of this SOA is typically 10-ps.

3. Conclusion

In summary, we have experimentally demonstrated a simple all-optical wavelength multicasting technique that has the highest number of multicast channels in an SOA for a single pump laser source. Combing the XGM and FWM (including cascaded FWM) effects in an SOA, seven 10-Gbit/s multicast channels with 100-GHz wavelength spacing are successfully demonstrated. The experimental results show that the CE of these multicast channels is larger than -27 dB and the maximum power penalty is less than 3.3 dB at BER = 10^{-9}. The channel spacing can be reduced to 50-GHz or even 25-GHz and the data rate can be increased to 40-Gbit/s and beyond. In addition, it should be possible to use an ultra-long bulk SOA that has a very high FWM efficiency [11] to further increase the number of multicast channels.

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5. Reference

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