Polarization-interleaved WDM signals in a fiber optical parametric amplifier with orthogonal pumps

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Abstract: We have demonstrated a polarization-interleaved WDM system with a two-orthogonal-pump OPA (2OP-OPA). The sensitivity has been improved by about 2dB compared to its counterpart with all WDM channels co-polarized with the same signal gain.

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1. Introduction

Fiber optical parametric amplifiers (OPAs) have recently been demonstrated to be practical amplifiers with high gain [1], large bandwidth [2] and polarization-independence [3]. The quality of signals emerging from OPAs used as signal processors has been investigated by several groups recently, especially with regard to the pump-to-signal RIN transfer [4], cross-phase modulation (XPM) amongst WDM channels [5], etc. However, four-wave mixing (FWM) and cross-gain modulation (XGM) seem to be the fundamental limits for using OPA as WDM amplifier. Previous work has shown that this kind of degradation is already severe with only three WDM channels in one-pump OPA (1P-OPA) system [6]. It was also shown that unequal channel spacing slightly improves the degradation. However, the XGM effect still provides a basic detrimental effect when using OPA in WDM systems, mediated through the depletion of the pump(s). Comparing with 1P-OPA, two-pump OPA (2P-OPA) provides an extra degree of freedom, such that a flattened gain spectrum can be achieved by trading with the gain bandwidth [7]. We have already explored the possibility of using two-orthogonal-pump OPA (2OP-OPA) to suppress WDM crosstalks and showed promising preliminary results [9]. In this paper, we demonstrate that with the aid of polarization interleaving (POIN), the WDM signal degradation can be improved significantly.That is because FWM is strongly dependent on the states of polarization (SOPs) of neighboring channels and is essentially suppressed if two channels are orthogonal to each other [9].

2. Experiment

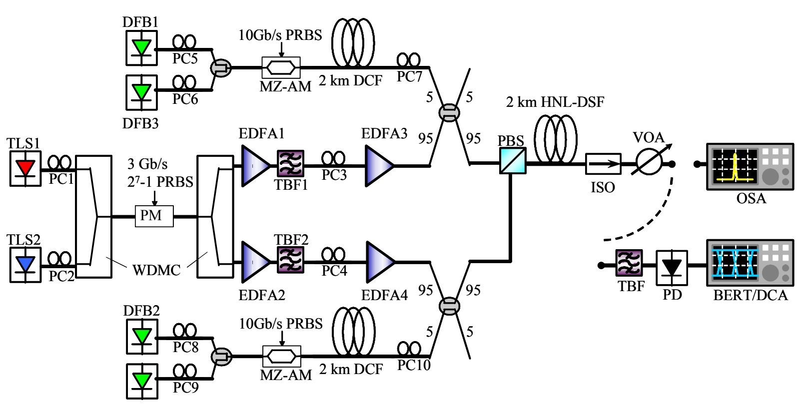

Fig. 1. 2OP-OPA with POIN configuration. Refer to the text for details.

We performed experiments to verify the predictions of the preceding section. The experimental configuration is shown in Fig. 1. The parametric gain medium consists of 2 km of HNL-DSF (OFS Ltd.) with a nominal zero-dispersion wavelength λ_0 of 1543.4 nm, and a dispersion slope of 0.019 ps/nm^{2}km. The fiber nonlinear coefficient γ is 10.4 W^{-1}km^{-1}. Two tunable laser sources, TLS1 and TLS2, set at 1529.45 nm and 1556.8 nm, respectively, serve as the pump sources. The pump wavelengths are selected to flatten the ASE gain spectrum, with the average wavelength approximately equal to λ_0. The CW pumps are phase-modulated (PM) by 3 Gb/s 2^7-1 pseudo-random bit sequence (PRBS) to suppress stimulated Brillouin scattering (SBS). The polarization controllers, PC1 and PC2, align the pump SOP's with PM, which helps to reduce the insertion loss. The two pumps are then separated by a WDM coupler (WDMC), amplified by two C-band EDFA's (EDFA1 & 2), and followed by tunable bandpass filters (TBF) with 0.84 nm (TBF1) and 1.96 nm (TBF2) bandwidth, respectively. Pumps #1 and #2 are then amplified by two separate EDFAs, with maximum output power of 21 dBm each, and they are combined with odd (#1, #3) and even (#2, #4) channels by 95/5 couplers, respectively. The two branches are then combined with a polarization beam-splitter (PBS). Furthermore, polarization controllers (PC3 and PC4) are used to ensure that the two pumps incident on the HNL-DSF are orthogonal. Similarly, PC7 and PC10 are used to maintain orthogonal SOPs between odd and even channels. We used 4 WDM channels (DFB1-4, with odd and even channels orthogonal to each other) with spacing of 100 GHz, as signals to determine the signal quality degradation. Each signal is intensity-modulated by a 10 Gb/s PRBS. The wavelength of each channel is shown in Fig. 3; they are de-correlated by 2 km of dispersion-compensating fiber (DCF). The input signal power of each channel is –6 dBm, and the signal gain of each WDM channel is about 13 dB, so that the signal output power of each channel is about 7 dBm. The output spectrum of HNL-DSF, followed by an isolator which prevents any reflection from the variable optical attenuator (VOA), is observed at the OSA. We define the FWM crosstalk term as the newly generated power right next to channel #1 (i.e. 1551.9 nm). After measuring the optical crosstalk, we also measure the eye diagrams and bit-error-rate (BER) using the digital communication analyzer (DCA) and BER tester. In order to quantify the improvement due to POIN, we also measure the eye diagrams and BER of the 2OP-OPA without POIN, with a setup similar to that used in Ref. [8]. Essentially the PBS is removed and all WDM channels are co-polarized.

3. Results and Discussion

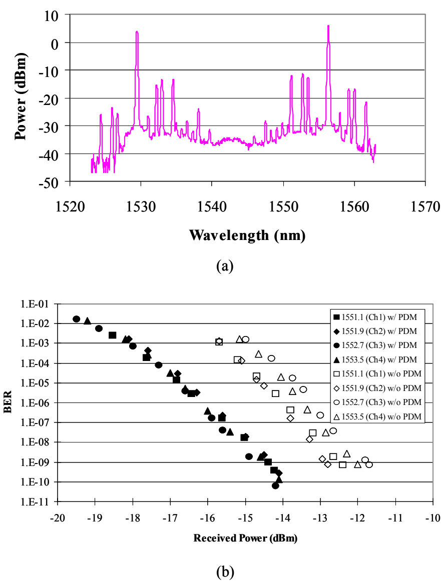

Fig. 2. (a) Spectrum of 2OP-OPA with three POIN signals; (b) BER curves for all four channels with and without POIN.

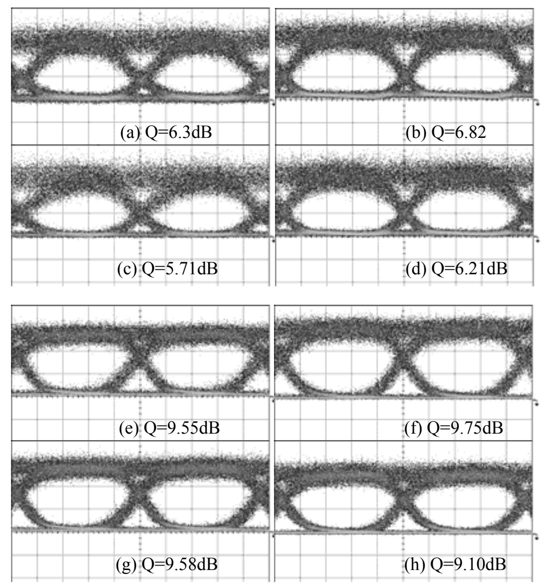

Fig. 3. Eye diagrams (with Q factors) for 2OP-OPA without POIN at different λ_s (nm): (a) 1551.1; (b) 1551.9; (c) 1552.7; (d) 1553.5. The corresponding eye diagrams with POIN (e) – (h).

Essentially there is no FWM crosstalk at channel #2 (1551.9nm) for 2OP-OPA with POIN signals as shown in Fig. 2(a), while it was about –19.4dB, measured with respect to channel #1 (1551.1nm) for the case without POIN as in Ref. [8]. This is consistent with reduced FWM if neighboring channels are in orthogonal SOPs. The eye diagrams for 2OP-OPA with POIN signals are also better than those without POIN signals, as shown in Fig. 3 (a) – (h); while the Q factor improves by at least 3dB. The improvement is also quantified in the BER measurements, which show about 2dB improvement in sensitivity compared with the case without POIN signals, as shown in Fig. 2 (b).

4. Conclusion

We have demonstrated, the first time to our knowledge, a polarization-interleaved WDM system with a two-orthogonal-pump OPA (2OP-OPA). The sensitivity has been improved by about 2dB compared to its counterpart with all co-polarized WDM channels with the same signal gain. These results should help design high-performance OPAs for use in WDM communication systems.

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