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Cascadability improvement of a cross-gain modulation wavelength converter using a grating based optical add/drop multiplexer

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Introduction:

All-optical wavelength converters (AOWC) will be key components in future broadband wavelength division multiplexed (WDM) optical networks. Among several AOWCs already demonstrated, the AOWC based on cross-gain modulation (XGM) in semiconductor optical amplifier (SOA) is the simplest to realise and conversion to the same wavelength is possible using counter-propagating configuration which is also needed in the all-optical networks [1]. An important issue for the AOWC to be used in the WDM networks is cascadability [2], however, up to now, only a few theoretical results of the cascading XGM-AOWC have been reported [3] [4]. This is mainly due to the insufficient high frequency response of the AOWC caused by the finite gain recovery time of the SOA. Recently, it has been reported that the response frequency of the AOWC can be improved by filtering the chirped converted signal using a fiber grating after the SOA [5].

In this paper, for the first time, the cascadability of the XGM-AOWC converting optical signal to the same wavelength is studied experimentally in a re-circulating loop at 10 Gbit/s. By adding Mach-Zhender optical add/drop multiplexer (OADM) based on fiber gratings after the SOA, the maximum cascading rounds in the loop is improved from two to six. This is because the chirped signal from the SOA is reshaped by the steep edge of the transfer function of the OADM, consequently the frequency response of the AOWC is improved.

Experimental setup:

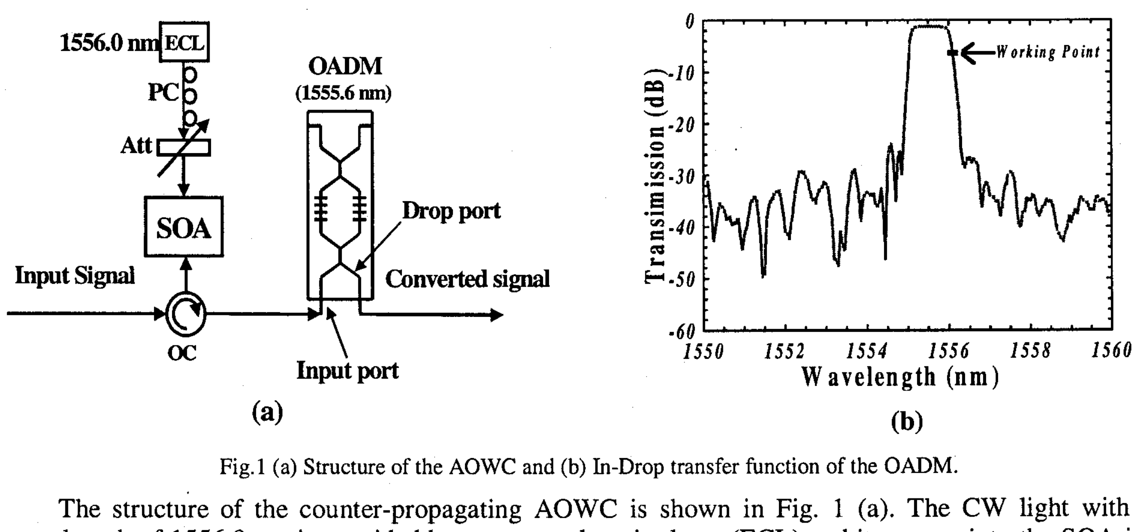

Fig.1 (a) Structure of the AOWC and (b) In-Drop transfer function of the OADM.

The structure of the counter-propagating AOWC is shown in Fig. 1 (a). The CW light with the wavelength of 1556.0 nm is provided by an external cavity laser (ECL) and its power into the SOA is -1 dBm after a polarization controller and an attenuator. The input signal is launched into the SOA through an optical circulator (OC). The OADM with certer wavelength of 1555.6 nm and the 3-dB bandwidth of 1 nm is used to reshape the converted signal when the wavelength of the converted signal is at the red side of its In-Drop transfer function [6]. The converted signal from the SOA comes into the OADM from the Input port and comes out from the Drop port. The In-Drop transfer function of the OADM and the working point in the experiment is shown in Fig. 1 (b). The SOA used in the experiment has a chip length of 800 μm, and the fiber-to-fiber gain is 20 dB at a bias current of 180 mA, which is used in our experiment.

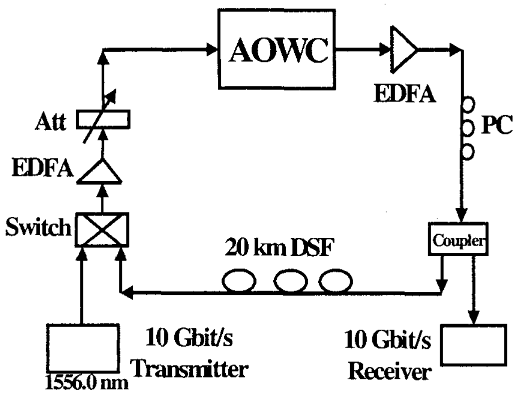

Fig.2 Experimental setup.

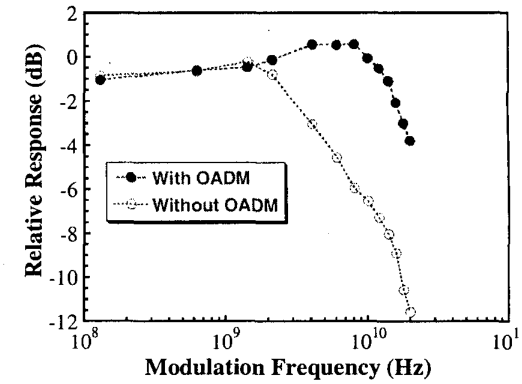

Fig.3 Small signal bandwidths for the same wavelength conversion in the AOWC without and with the OADM.

The loop set-up used in the experiment is shown in Fig.2. An externally modulated 10 Gbit/s (PRBS 2^{31}-1) transmitter emitting at the same wavelength as the CW light provides the input signal to the AOWC in the loop, as shown in Fig. 2. The input power into AOWC is +8 dBm, and kept constant for every round trip. Only 20 km DSF fiber is used in the loop, so the dispersion is neglected. The signal is coupled out via a 10 dB coupler and launched into a 10 Gb/s receiver.

Results and discussions:

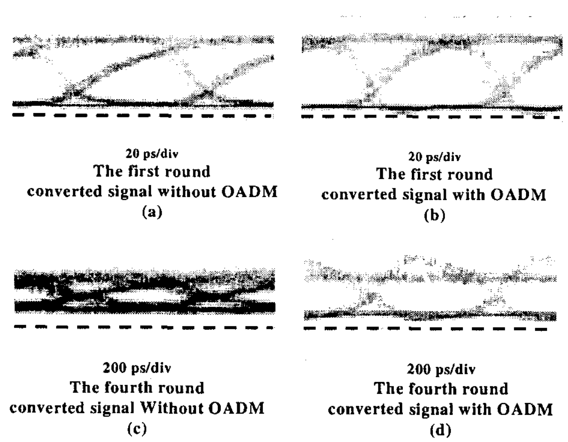

Fig.4 The eye diagrams of the converted signal without (a), (c) and with (b), (d) the OADM after the first and fourth round in the loop experiment respectively.

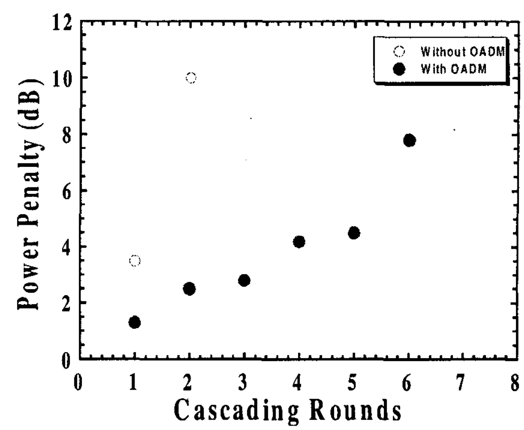

Fig. 5 Power penalty of the converted signal versus the cascading rounds in the loop.

Fig.3 shows relative response of the AOWC versus the modulation frequency at the wavelength of 1556.0 nm with and without the OADM. As we know, the converted signal after the SOA has blue chirp on the rising edge and red chirp on the falling edge which are caused by the carrier density changing in the SOA [1]. After the OADM, the falling edge of the converted signal with red chirp is suppressed by the steep edge of the transfer function of the OADM, and consequently the response of the AOWC at high frequency is improved [5]. It can be seen from Fig. 3 that the high frequency response is increased significantly and 3-dB bandwidth is improved from 4 GHz to 18 GHz by adding the OADM. Fig.4 (a) and (b) show the optical eye diagrams of the converted signal without and with the OADM respectively after the first conversion. It can be seen from Fig. 4 (a) and (b) that the rising and falling edges are improved by using the OADM due to the improved response bandwidth. It can also be seen from Fig. 3, the OADM has no influence on the degraded low frequency response of the AOWC which is determined by the gain changing curve of the SOA [1]. Fig. 4 (c) and (d) show the eye diagrams of the converted signal without and with the OADM respectively after the fourth cascading round in the loop. From Fig. 4 (c), we can see that the insufficient response of the high frequency in the AOWC is the most important factor limiting the AOWC without the OADM to be cascaded. From Fig.4 (d), it can be seen that the low frequency response degradation in the converted signal becomes the most important limiting factor in the cascading experiment because the OADM can compensate the high frequency degradation but it has little influence on the low frequency components. So, the cascadability of the AOWC can be improved by adding the OADM but not infinite, it is determined by the low frequency response of the SOA.

The AOWC without the OADM can only to be cascaded two rounds in the loop experiment, but the cascadability can be improved to six rounds without error floor at BER of 10^{-9} by adding the OADM. Fig. 5 shows the power penalty of the converted signal with and without the OADM after different rounds in the loop transmission respectively.

If the SOA has sufficient responding time, theory shows that the maximum cascaded stages are seven [2] for the XGM-AOWC converting to the same wavelength due to the degraded ER and accumulated ASE noise which can not be improved by the OADM. So, our experimental result is close to this limit. However, in our experiment, the minimum power penalty of the converted signal without the OADM is 3.5 dB after the first conversion. It should also be stressed that using a loop configuration to test cascadability of the XGM-AOWC prevents any individual adjustments of the operation conditions for the cascaded AOWCs. Furthermore, it is expected that the cascadability of the XGM-AOWC converting to both longer wavelength and shorter wavelength can be improved by adding the OADM with corresponding center wavelength.

Conclusion:

The cascadability of the XGM-AOWC converting to the same wavelength is studied experimentally at 10Gb/s in a loop setup. The maximum cascaded round of the XGM-AOWC is improved from two to six in the loop experiment by adding the OADM due to the improved high frequency response. The low frequency response degradation in the converted signal becomes the most important limiting factor in the cascading experiment. The result is close to the theoretical limit, which is determined by the degradation of ER and accumulation of ASE noise.

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