Gain-Clamped Semiconductor Optical Amplifiers for Reach Extension of Coexisted GPON and XG-PON

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Abstract: Optical amplification of coexisted GPON and XG-PON upstreams is demonstrated using a gain-clamped semiconductor optical amplifier (SOA). With gain clamping, performance degradation due to the cross-gain modulation between GPON and XG-PON signals is significantly reduced.
OCIS codes: (060.2330) Fiber optics communications; (060.2320) Fiber optics amplifiers and oscillators

1. Introduction

To support broadband multimedia services, optical fibers have penetrated into access network segment. Currently, GPON and EPON are being deployed by service providers all over the world [1][2]. As the user bandwidth demands are ever increasing, a new generation of passive optical networks (PONs) are being standardized by ITU-T and IEEE [3][4]. To ensure the smooth upgrade from GPON/EPON to 10G PONs, coexistence of both systems is mandatory and it can be done with wavelength division multiplexing.

In addition to bandwidth increase for next generation access networks, PONs with longer reach and larger splitting are also desired because longer reach can serve wider areas and large splitting can serve more users. Furthermore, service providers can achieve CO (central office) consolidation with less central offices, simplified network architecture, and reduced OPEX. GPON extension boxes using optical amplifiers and/or OEO repeaters have been standardized in ITU-T G.984.6 [1]. Among different reach extension technologies, SOA is attractive due to its high gain, low noise figure, low polarization dependence, and fast gain dynamics suitable for optical burst amplification [5]. In addition, SOA is bit rate and protocol transparent, and it can be designed to operate in 1310nm and 1490nm wavelength bands used by GPON, or 1270nm and 1577nm wavelength bands used by XG-PON. Hence, it is possible to use the same SOA extension box when upgrading from GPON to XG-PON. In fact, simultaneous amplification of GPON and XG-PON downstreams has been demonstrated recently [6]. However, crosstalk between GPON and XG-PON was found to be an issue in [6], and reach extension of coexisted GPON and XG-PON using a single SOA has not been studied for the upstream amplification.

This paper, for the first time, demonstrates simultaneous amplification of GPON and XG-PON upstreams using a gain-clamped SOA. The system performance of long-reach GPON and XG-PON are investigated using an SOA with and without gain clamping. Compared to normal SOA without gain clamping, gain-clamped SOA significantly improves the system performance because the cross-gain modulation between GPON and XG-PON upstreams is suppressed in gain clamped SOA. This paper is organized as follows: section 2 presents the SOA gain characteristics, section 3 demonstrates optical amplification of coexisted GPON and XG-PON upstreams using a single SOA, and section 4 summarizes the paper.

2. SOA Gain Characteristics

The SOA used in our experiments has a multiple quantum well active region, and it is designed to provide gain in the O-band with very low polarization sensitivity. Fig. 1 shows the ASE (amplified spontaneous emission spectrum from the SOA. The ASE has a peak around 1300nm, and for GPON and XG-PON nominal upstream wavelengths (1310nm and 1270nm), SOA gain is well above 10 dB. Fig. 2 shows the fiber-to-fiber gain provided by the SOA as a function of the input power at 1310nm and 1270nm wavelengths. The solid dots present the SOA gain for 1310nm wavelength, and the solid squares for 1270nm wavelength. SOA gain for the coexisted GPON and XG-PON case are also plotted in Fig. 2. The open circles show the SOA gain at 1310nm wavelength copropagating with a −5.3dBm cw signal at 1270nm wavelength, and the open square show the SOA gain at 1270nm wavelength copropagating with a −9.6dBm cw signal at 1310nm. Obviously, under a constant biasing current SOA gain is reduced for the coexistence case, because the cw signal at the other wavelength reduces the overall carrier density. If the input power of one cw signal is varied, the carrier density changes and the gain at the other wavelength will be changed. This effect of cross-gain modulation renders SOA not suitable for multiwavelength amplification. Therefore, using a single SOA to amplify both GPON and XG-PON upstream signals could be problematic as demonstrated in the following system experiments.

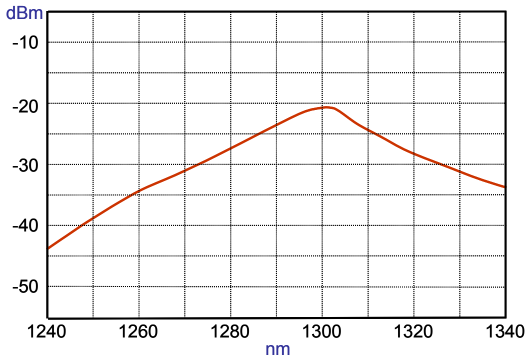

Fig. 1 ASE spectrum from SOA. The SOA is biased with 280mA current.

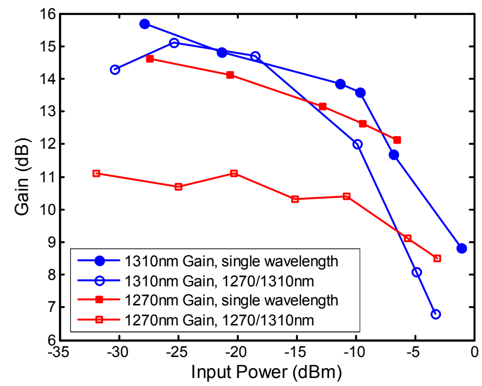

Fig. 2 Fiber-to-fiber gain provide by SOA as a function of the input power. The SOA bias current is 280mA.

3. Upstream amplification for coexisted GPON and XG-PON

Since the SOA can provide optical gain over the whole O-band, a single SOA is used to amplify both GPON and XG-PON upstreams in our experiments. The system experimental setup for reach extension of coexisted GPON and XG-PON is shown in Fig. 3. A GPON system with 1:32 split and 40km reach is setup in the experiments, and a single SOA is used to amplify the upstream signals. To study the performance of SOA under GPON and XG-PON coexistence, XG-PON signal is coupled with GPON signals with a 2:1 coupler, and both GPON and XG-PON upstreams copropagate through the SOA. At OLT (optical line terminal), a wavelength division multiplexer is used to separate GPON and XG-PON upstreams. A $2^{31}-1$ pseudorandom bit sequence is sent by the GPON upstream, and the bit-error-rate as a function of received power is measured in the experiments. After GPON performance is tested, the positions of GPON ONU and XG-PON ONUs are exchanged, and the XG-PON upstream performance is tested in a similar manner with a $2^{31}-1$ pseudorandom bit sequence.

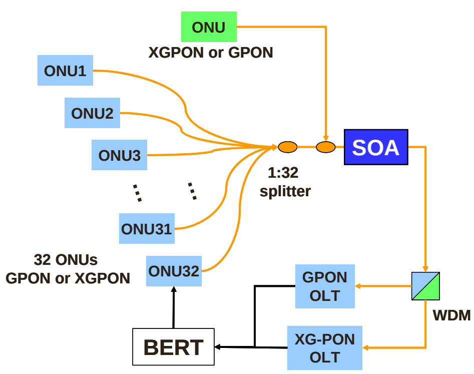

Fig. 3 Experimental setup for reach extension of coexisted GPON and XG-PON.

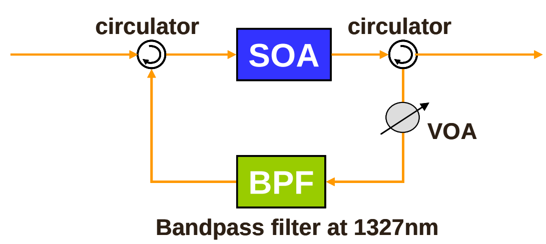

Fig. 4 Gain-clamped SOA with lasing wavelength at 1327 nm. The bandpass filter has a bandwidth about 1nm. The VOA (variable optical attenuator) is set at an appropriate value that creates strong enough lasing and gain clamping, but not so strong to ensure sufficient gain for other wavelengths.

In our experiments, the SOA bias current is kept constant at 280mA. The system performance is first measured with a regular SOA without gain clamping and then with a gain clamping SOA. The gain clamping of SOA is achieved with an optical feedback loop as shown in Fig. 4. The optical filter used in the feedback loop has a central wavelength at 1327nm and its bandwidth is about 1nm. The feedback loop creates a ring resonator and the system start to lase at 1327nm with proper setting of the optical attenuator. The attenuation is set with a value that creates strong enough lasing and gain clamping, but not so strong to ensure sufficient gain for other wavelengths. Since SOA is part of the ring laser, the strong lasing signal at 1327nm clamps the carrier density of the SOA to a constant value, and hence the gain-clamped SOA provide a constant gain at other wavelengths.

Fig. 5 shows the BER (bit-error-rate) curves for GPON and XG-PON upstreams; Fig. 5(a) shows the measured results for GPON and Fig. 5(b) for XG-PON. The results for back-to-back, single wavelength (1310nm for GPON and 1270nm for XG-PON), and coexisted GPON and XG-PON upstreams are all plotted in the figures. For the case of a regular SOA without gain clamping, the system performance is very good for single wavelength (GPON or XG-PON), but for coexistence case (two copropagating wavelengths), the performance is severely degraded due to

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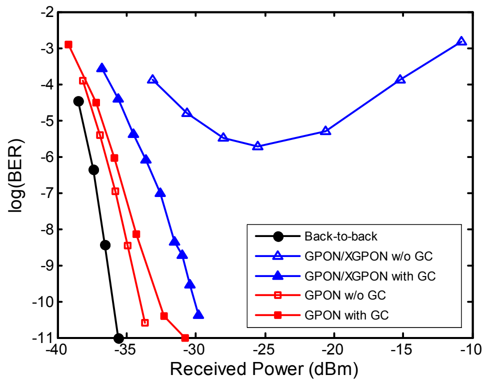
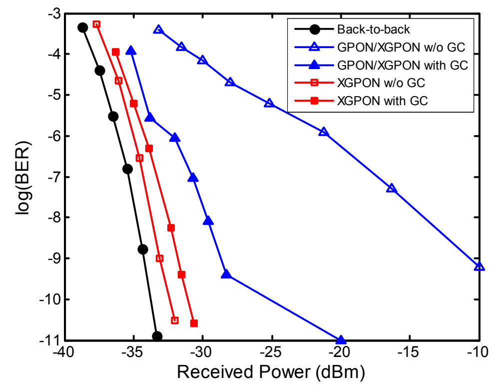


(a) GPON upstream performance.



(b) XG-PON upstream performance.

Fig. 5 BER measurement results for GPON and XG-PON upstreams. Solid dots are results for back-to-back without SOA. For single wavelength (only GPON or XG-PON upstream), open squares are results with a regular SOA (w/o GC), and solid squares represents results with a gain-clamped SOA (with GC). For coexisted GPON and XG-PON upstreams, open triangles are results with a regular SOA(w/o GC), and solid triangles represents results with a gain-clamped SOA (with GC).

cross-gain modulation. In Fig. 5(a), the GPON upstream can not achieve error free performance when the XG-PON upstream has an input power of –9.6dBm to SOA. When a gain-clamped SOA is used, GPON upstream performance has a power penalty about 3.5dB for the coexistence case compared to single GPON upstream. Similarly, when a GPON signal with a power of –5.3dBm is copropagating with the XG-PON signal, the XG-PON performance is degraded by more than 20dB (compared to single wavelength case) if a regular SOA is used, while the power penalty is only about 4 dB if a gain-clamped SOA is used. For GPON and XG-PON coexistence, Fig. 6 shows the waveforms for XG-PON signal with regular SOA and gain-clamped SOA. With a regular SOA, the cross-talk between GPON and XG-PON signals is clearly seen in waveforms at SOA output. When gain-clamped SOA is used, the crosstalk is suppressed due to carrier density clamping in the SOA. The waveform of GPON signal shows similar effect of cross-gain modulation using a regular SOA, while gain-clamped SOA suppresses this effect. These experimental results demonstrate gain-clamped SOA is a good candidate for reach extension of coexisted GPON and XG-PON systems. Even though this work investigates gain-clamped SOA for coexisted GPON and XG-PON upstreams, the same principle applies for coexisted GPON and XG-PON downstreams.

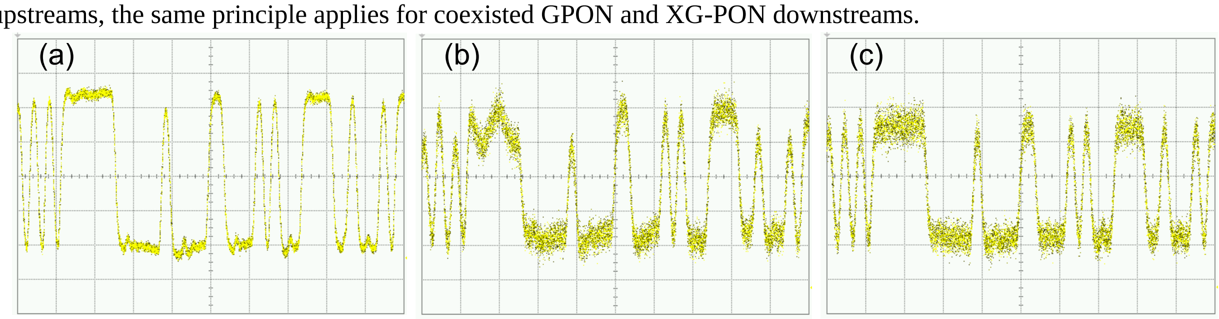


Fig. 6 Waveform of XG-PON upstream signal. (a) XG-PON waveform from ONU transmitter. (b) XG-PON upstream waveform from the output of a regular SOA. (c) XG-PON upstream waveform from the output of a gain-clamped SOA. The input power of GPON signal at SOA input is -14 dBm.

4. Conclusions

For reach extension of coexisted GPON and XG-PON, this paper investigates simultaneous amplification of GPON and XG-PON upstreams using a single SOA. When a regular SOA is used, cross-talk due to cross-gain modulation between GPON and XG-PON upstreams severely degrades the system performance. With gain-clamped SOA, the cross gain modulation in SOA is suppressed and good performance is demonstrated for coexisted GPON and XG-PON systems.

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