Improving the SOA Switching Speed of Wavelength-Striped Optical Packets Using Multipulse Current Injection

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Abstract: A reduced semiconductor optical amplifier switching speed is demonstrated for 8×10-Gb/s wavelength-striped optical packets using multipulse pre-emphasis current injection. The scheme yields a 20% improvement in switching speed; the power penalty performance is also characterized.

OCIS Codes: (060.4510) Optical communications; (130.4815) Optical switching devices; (250.5980) Semiconductor optical amplifiers

1. Introduction

The intense, accelerated growth in network access and capacity will necessitate next-generation high-performance computing systems and Internet packet routing systems to support extremely high-bandwidth traffic flows and applications. Future network infrastructures may incorporate emerging optical technology drivers such as optical packet switching (OPS) to address these high transmission bandwidths both in the access and carrier core domains. Indeed, the current transformative trend in deployed telecommunications networks is toward one of a purely packet-rooted architecture. OPS comprises a packet-based approach that can transmit extremely high-bandwidth optical messages with low latency end-to-end among the optical network's input and output ports. The semiconductor optical amplifier (SOA) is a key optical device for implementing OPS networks, due to its fast switching speeds, high extinction ratios, data transparency, broad gain spectrum, and ability to be integrated on a chip [1]. SOAs may be deployed as amplifiers, add-drop optical links, and wavelength converters in wavelength-division-multiplexed (WDM) networks. SOAs have also been utilized in optical network test-beds [2], [3], specifically acting as a fast switching gate within a 2×2 nonblocking wideband photonic switching node in order to achieve programmable high-speed switching on the optical physical layer [4]. It is thus evident that further reduction of the SOA's switching speed would be desirable to improve the overall performance of next-generation optical networks.

It has been previously proposed to realize predistortion and preshaping techniques to enhance the speed of laser diode switches [5]; similarly, pre-emphasis schemes have been used recently to increase the switching speed of silicon modulators [6]. A corresponding technique may be adopted to reduce the turn-on response time for SOAs, whereby an additional pre-emphasis impulse current can be injected in the device's active region to improve its rise time performance [7], [8]. Controlling the device's carrier population/depletion properties, and hence the carrier lifetimes, provides improved switching times. Previously, the effectiveness of this multipulse pre-emphasis current injection technique was shown in simulation and experiment to reduce SOA switching times [7]. Here, in this work, we show for the first time an improvement in the fast switching of high-bandwidth optical packets using a SOA device with multiple injection currents by transmitting wavelength-striped 8×10-Gb/s optical packets through the SOA. Furthermore, we characterize the bit-error rate (BER) performance of the SOA with and without the multipulse pre-emphasis drive currents and show a proven 0.05 dB improvement in the device's power penalty performance. This work showcases the feasibility of using a multipulse current injection technique for a SOA to reduce the switching time of high-data-rate optical packets, vastly improving the device's deployment as switching elements in future OPS networks.

2. Multipulse Current Injection for SOAs

The SOA switching time reduction technique demonstrated here is based on a pattern-modification of the injected current. The multiple pre-emphasis current injection pulses consist of a step signal and an impulse signal timed to have simultaneous rising edges; this is used to incur an increased optical gain at the onset (rising edge) of the step pulse (Fig. 1). The implemented shape of the current injection pulses are fast step signals, applied to the SOA in order to turn the device on or off. The on/off response is not instantaneous, as the device's active region must be populated by the injected carriers, or depleted by the suppressed carriers. An additional pulse is used to cause a rapid increase in the carrier population and thus reduce the overall carrier lifetime and by extension, the SOA's switching times. The SOA must remain in its linear regime of operation during the injection of all additional drive currents.

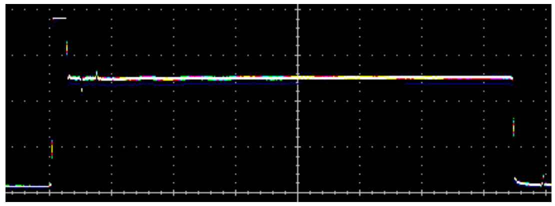

Fig. 1. The implemented multipulse current injection pulse for reducing the SOA turn-on response time.

3. Experimental Setup

A two-stage experiment is used to verify that pre-emphasis current injection yields a reduction in SOA switching time. In the first experiment, one continuous-wave (CW) laser transmits a single wavelength to the SOA; an improved response time is achieved. In the second experiment, high-bandwidth 8×10-Gb/s wavelength-striped optical packets are generated and propagate through the SOA, and the BER performance is assessed while the SOA performs a fast switching of broadband WDM optical packets. Since the first experimental setup is a subset of the second, we will only describe the latter setup below.

The second experimental setup (Fig. 2) for the subsequent BER measurements uses eight CW lasers (DFBs in Fig. 2) (ranging from 1537.4 nm to 1559.7 nm), which are combined with a multiplexer. The eight wavelength channels are simultaneously modulated with a 10-Gb/s nonreturn-to-zero (NRZ) signal that carries a 2^7-1 pseudorandom bit sequence (PRBS) using a single $LiNbO_3$ modulator (mod in Fig. 2). The modulator is driven by an electrical signal from a pulse pattern generator (PPG). The wavelength channels are decorrelated by 25 km of optical fiber and then propagate through the SOA. An Agilent ParBERT generates the two synchronized injection currents (step pulse signal and impulse signal), which are then delivered to the SOA as a single multipulse drive current pulse. At the output of the SOA, the multi-wavelength signal is monitored by an optical spectrum analyzer (OSA), while one wavelength channel propagates through a tunable grating filter (λ in Fig. 2), an erbium-doped fiber amplifier (EDFA), a second tunable filter, a variable optical attenuator (VOA), and is then received by a 10-Gb/s p-i-n photodiode with transimpedance and limited amplifier pair (RX). The packet analysis is performed with a bit-error-rate tester (BERT) that is synchronized with the PPG and gated for packet analysis by the ParBERT.

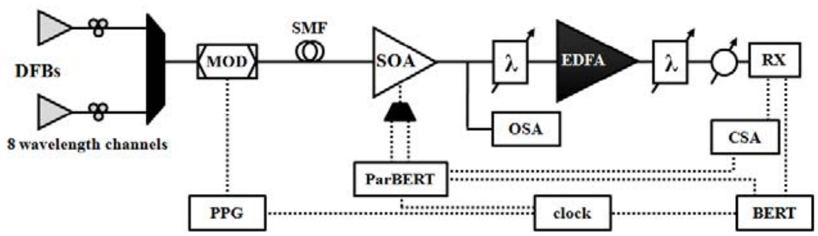

Fig. 2. Experimental setup used to determine BER performance. Solid lines indicate optical fiber, while dashed lines indicate electrical cable.

4. Experimental Results and Discussion

The SOA is a state-of-the-art Kamelian (Amphotonix Ltd.) device (OPB-10-15-N-C-FA) that is set to maintain operation in the linear regime. The impulse signal is set to 5 ns and it is found that varying the length of the impulse does not alter the SOA's switching speed, while varying its amplitude directly impacts performance. The step signal is set to 150 ns; for an eight-channel wavelength-striped packet at 10 Gb/s, the aggregate packet size is equivalent to the 1500 Byte maximum transmission unit (MTU) of an Ethernet packet.

In the first experiment using the single CW laser, a reduction in switching time of 0.5 ns is obtained (Fig. 3a), thereby validating the use of the multipulse current injection technique. In the subsequent experiment, broadband 8×10-Gb/s optical packets propagate through the SOA and its 20/80 rise time performance is examined (Fig. 3b). The switching on time without the pre-emphasis current injection is approximately 1.1 ns, while the corresponding switching on time with the pre-emphasis current injection is approximately 0.9 ns. Thus, a 20% decrease in SOA switching time is shown with this technique. The BER performance of SOA with and without the pre-emphasis current injection is also characterized for the 8×10-Gb/s optical packets. Using the ParBERT, the BERT is gated specifically on the starting bits of the packet to quantify the effect of the pre-emphasis drive current. Since the rise time of the SOA is improved, the BER is also improved at the rising edge of the packet. Error-free performance is confirmed at the output of the SOA, achieving BERs less than 10^{-12} on all eight wavelength channels of the wavelength-striped optical packet. Sensitivity curves for one supported wavelength for the device with and without the pre-emphasis signals are shown in Fig. 4. Compared to the SOA operating without the multiple injected currents (0.35 dB power penalty), the SOA operating with the multiple current injection achieves an improved power penalty of 0.3 dB. Thus, this multipulse current injection technique does in fact yield a better power penalty performance.

One should note that the Kamelian SOA has a rated rise time of 0.9 ns. Here, the SOA switching time is affected by the non-idealities of the experimental implementation. In practice, the SOA packaging and the trace layout extending between the current driver die (here, a commercial laser driver MAX3656) and the SOA cathode pin can pose limitations on the response time [9] due to the presence of small capacitances and inductances. Accounting for these practical values, the achieved rise times are reasonable. Further, only the rise time performance of the SOA with the pre-emphasis current injection is studied here; this work can easily be extended to improve fall (switching off) times. This work provides a relative study to the feasibility of a multipulse current injection for SOAs. In an ideal implementation, a differentiator and an integrated custom-designed pre-emphasis circuit can vastly improve both the SOA switching on and off times.

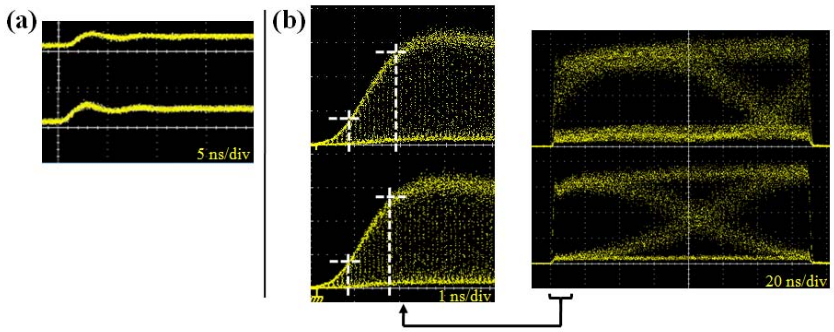

Fig. 3. [top: without pre-emphasis current injection, bottom: with pre-emphasis current injection] (a) Rise time of a single CW signal; (b) Waveforms of one 10 Gb/s channel of the 150-ns optical packet with magnified views of the rising edge: dashed lines show the 20/80 rise time.

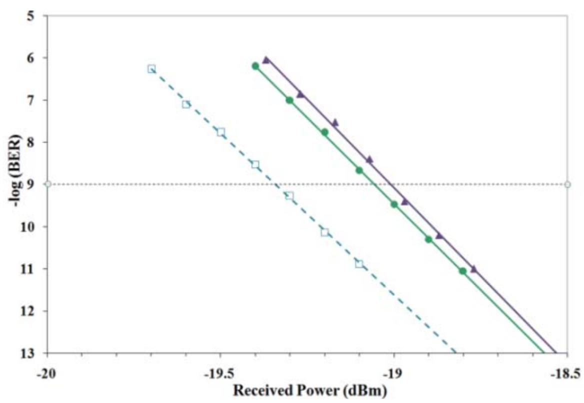

Fig. 4. BER sensitivity plots for one wavelength channel (λ=1559.7 nm) recorded without the multipulse pre-emphasis signal (purple, ▲), with the multipulse signal (green, ●), and the back-to-back signal (blue, □).

5. Conclusions

A multiple pulse pre-emphasis current injection technique is demonstrated for a SOA that shows a proven reduction in switching speed. We validate this implementation through the fast switching of 8×10-Gb/s wavelength-striped optical packets. The rise time is reduced by 20% and a 0.05 dB power penalty improvement is shown. The optimization in SOA switching may be valuable in the development of OPS in future large-scale optical networks.

6. References

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