Detailed experimental and theoretical investigation and comparison of the cascadability of semiconductor optical amplifier gates and gain-clamped semiconductor optical amplifier gates

Danielsen, Søren Lykke; Hansen, Peter Bukhave; Wolfson, David; Mikkelsen, Benny; Stubkjær, Kristian; Emery, J.Y.; Pommereau, F; Renaud, M.

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Semiconductor optical amplifiers (SOAs) are attractive for space switching because they have up to 30 dB gain\(^1\) and high on-off ratios of 40–50 dB that are required to overcome crosstalk induced penalty.\(^7\) SOA gates do, however, have a limited input power dynamic range (IPDR) and thus limited cascadability caused by amplified spontaneous emission (ASE) and by gain saturation that leads to extinction ratio degradation.\(^8\) The influence of the latter can be reduced by using gain-clamped SOA gates (GC-SOA) for which the gain is clamped for operation above lasing threshold.\(^4\)

Here, a detailed investigation of the cascadability of GC-SOAs is presented and compared to that of conventional SOAs for different bit rates. The analysis is both theoretical and experimental and shows that at 2.5 Gbit/s more than 30 GC-SOAs can be cascaded while only seven conventional SOAs (at 1-dB penalty).

The superior performance of the GC-SOA is primarily the result of the saturation characteristics. These are illustrated in Fig. 1 for a 1000-\(\mu\)m-long GC-SOA (structure described in Ref. 5). Results for a 450-\(\mu\)m-long SOA (described in Ref. 3) are also shown. Note, the excellent agreement between measurements and theory. The gain of the GC-SOA is presented and compared to that of conventional SOAs for different bit rates. The analysis is both theoretical and experimental and shows that at 2.5 Gbit/s more than 30 GC-SOAs can be cascaded while only seven conventional SOAs (at 1-dB penalty).

The feasibility of SOAs is being investigated in various system trials. Encouraging results have been demonstrated by several groups both in the 1.3- and 1.5-\(\mu\)m windows. Semiconductor optical amplifiers are part of the answer towards the new functionality that advanced fiber-optic systems require.

remains constant until the amplified signal power level becomes comparable to the power of the lasing mode. Therefore, the extinction ratio degradation due to gain saturation is reduced.

This is also seen in Fig. 2(a), showing a very high measured IPDR of \(-19\) dB at 10 Gbit/s (taken at 2-dB penalty because a pre-amplified receiver is used). For a conventional SOA gate the usable IPDR is 10–15 dB at the same bit rate.\(^3\) At 15 Gbit/s the IPDR for the GC-SOA is reduced. At low input powers this is due to a higher required signal-to-ASE ratio. At high input powers, bit patternning due to the relaxation oscillations of the lasing GC-SOA causes limitations that get more pronounced at higher bit rates as clearly illustrated in Fig. 2(b) by the 15 Gbit/s pulse trace. Still, operation at 10 Gbit/s is sufficient for most network applications planned today.

In networks several gates must be cascaded. In the following we present a theoretical analysis of the cascadability of GC-SOA and conventional SOA gates. To make a fair comparison equal gains of 20 dB are used. Additionally, equal signal-to-ASE ratios are ensured with an input power to the GC-SOA of \(-15\) dBm (noise figure is \(-11\) dB) and \(-21\) dBm to the SOA (noise figure is \(-5\) dB). Figure 3 shows the penalty and extinction ratio versus the number of cascaded gates at 2.5 and 10 Gbit/s. At 2.5 Gbit/s more than 30 GC-SOAs can be cascaded with a penalty <1 dB. This is far superior compared to the conventional SOA for which the cascadability is limited to \(-7\) gates at 2.5 Gbit/s. Furthermore, it is noted, that even at 10 Gbit/s where the accumulation of ASE starts to become a factor and where the influence of relaxation oscillations sets in, the number of GC-SOAs that can be cascaded is higher than for the SOA at 2.5 Gbit/s.

In conclusion, the effective gain clamping and thereby limited extinction ratio degradation of GC-SOA gates make them attractive for network applications where high switching speeds and cascadability are required.

*Alcatel Corporate Research Center, c/o Alcatel Alsthom Recherche, Route de Nozay, F-91460 Marcoussis, France

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Fast optical amplifier gate array for WDM routing and switching applications

F. Dorgeuille, B. Lavigne, J.Y. Emery, M. Di Maggio, J. Le Bris, D. Chiaroni, M. Renaud, R. Baucknecht,* H.P. Schneibel,* C. Graf,* H. Melchior,* Alcatel Alsthom Corporate Research Centre, c/o Alcatel Alsthom Recherche, Route de Nozay, 91460 Marcoussis, France; E-mail: francois.dorgeuille@aar.alcatel-alsthom.fr

Clamped-gain semiconductor optical amplifiers (CG-SOAs) have already demonstrated their great potential for fast optical space switching of wavelength-division multiplexing (WDM) channels both in cross-