

Semiconductor Optical Amplifier Gate Arrays: Devices and Applications

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Abstract

This paper gives an overview of the results of SOA and clamped gain SOA gate arrays operating at 1.55 μm as well as their performances in routing and switching applications and their potential for large-scale space switches.

Introduction

Semiconductor Optical Amplifier (SOA) gates have already demonstrated their potential for space switching in WDM routing applications [1] as well as for contention resolution and fast packet selection in optical packet switching applications [2]. Compared to other solutions for space switching, or more generally for optical path selection, SOA-based space switches are the only ones which simultaneously provide high on/off ratio (~ 50 dB), low insertion loss or even gain, fast switching (1 ns range) as well as high integration potential. In addition, though as active devices they generate some noise, good performances have been demonstrated up to 10 Gb/s with 16 channels [1] thanks to clamped-gain SOA (CG-SOA) versions and even at 20 Gb/s [3].

Most of the foreseen architectures for WDM routing [4] and packet switching [5] will however require a huge number of SOA gates that call for low cost integrated components. Two routes have been followed to increase the level of integration: full monolithic integration of SOAs with a passive optical circuit and monolithic integration of SOA gate arrays with hybrid interconnection to passive optical devices either directly via fibres or via SiO_2 PLC platforms. Though the largest size demonstrated to date for monolithic [6] and hybrid [7] versions of SOA-based InP space switches is 4x4 in both cases, the SOA gate array version allows more design freedom, better scalability and cost effectiveness.

This paper gives an overview of recent results on SOA- and CG-SOA-gate arrays and their applications. Potential and critical issues are also highlighted in view of large-scale space switches.

SOA gate arrays

Several 4-SOA arrays operating at 1.3 μm [8] and 1.55 μm [9-12] have been reported, aiming either at low operating current (25 mA) [8] for parallel optical loss compensators or at high gain (≥ 16 dB) [13] for fast path selection. Most arrays incorporate mode expanders to ease the coupling directly to fibres or to SiO_2 waveguides. Thanks to hybrid integration of such arrays on PLC platforms, a full 4x4 space switch [7] with 4 arrays and an 8-channel wavelength selector with 2 arrays [14] have been recently realised. Several of these arrays were successfully used for packet switching with guardbands between packets of a few ns thanks to the high gating speed of SOAs [2,7]. However, these arrays, which present excellent characteristics for single channel operation, are not compatible for WDM applications as inter-modulation can occur because of the gain saturation..

Clamped gain SOA gate arrays

The limitation of SOAs with WDM channels is overcome in CG-SOAs where the signal induced gain fluctuations are suppressed by clamping the gain by a lasing oscillation. Such CG-SOAs compatible with multi-wavelength operation [15] have also been integrated in arrays of 4 [16]. Thanks to integrated mode expanders and a multi-fibre pigtailed technique with lensed fibre ribbons, high performance CG-SOA arrays have been achieved [17] and validated inside an optical cross-connect node in field trial operation within the European ACTS OPEN project [18]. In particular, four modules with a mean fibre to fibre gain of 11 dB, a maximum gain variation among the 16 gates of only 2.5dB, a worst polarisation sensitivity $< 0.9\text{dB}$ and a mean noise figure ($2n_{sp}/C_1$) of 11.5dB were realised and implemented in the field. Similar such clamped gain SOA arrays have also been validated for optical packet switching within a sub-equipped 16x16 with 16 wavelengths broadcast-and-select packet switch [19]. Recently 8 CG-SOA arrays have been achieved [20], further increasing the level of integration and keeping uniform performances with a gain variation < 1.8 dB on the whole array.

The characteristics of recent SOA and CG-SOA gate arrays are summarized in table 1.

Potential and critical issues for large scale SOA-based space switches

As seen from recent publications, high performance of SOAs have been maintained in arrays of 4 and 8 gates for single channel and WDM operations. In addition, combination of SOA arrays with PLC platforms allows to benefit from low loss passive SiO₂ waveguide circuits and collective low cost assembly with self-aligned flip chip technique. As soon as the scale of the switching matrix increases, optical path balance becomes important which means that not only the characteristics of the array but also the coupling have to be homogeneous. The coupling has also a direct impact on the noise figure. Further improvement of mode expanders would therefore be beneficial especially in view of increasing the size of the arrays. However, there will be undoubtedly a trade-off between the size of the array, the size of the PLC and the fabrication yield. A possible modular and scalable approach to build large space switches will be shown at the conference.

Conclusion

High performance SOA arrays and CG-SOA arrays have been demonstrated. For the first time, such components have been used in field trials and are now operating for about one year without any failure showing the reliability of these technologies. The great potential of integration brought by the PLC platforms and the collective self-aligned techniques opens the way towards large-scale SOA space switches for WDM routing and switching applications.

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	SOA arrays						CG-SOA arrays	
	4	4	4	4	4	4	4	8
number of SOAs	4	4	4	4	4	4	4	8
reference	NEC [8]	NTT [9]	NTT [10]	Lucent [11]	AAR/ETHZ [12]	AAR/ETHZ unpublished	AAR [16]	AAR [20]
operating window (µm)	1.3	1.55	1.55	1.55	1.55	1.55	1.55	1.55
SOA vertical structure	bulk	bulk	bulk	MQW	bulk	bulk	bulk	bulk
Mode expanders	no	yes	yes	yes	yes	yes	yes	yes
Optical coupling to	lensed fibres*	flat end DSF*	SiO ₂ guide PLC	cleaved fibres	cleaved fibres	cleaved fibres	lensed fibres	lensed fibres*
Fibre to fibre gain (dB)	7	10	9	11.4	8	16	12.5	19
max gain difference in the array (dB)	1	very low	1.5	<4	2	2	2	<1.8
polar. gain depend. (dB)	<1	<0.2	<0.8	<1	2	2	<0.3	<2
operating current per active gate (mA)	25	50	40	200	80	100	50-200	80-200

* measured on optical bench

Table 1: Summary of characteristics of SOA and CG-SOA arrays.