1.28 Tbit/s throughput 8x8 optical switch based on arrays of Gain-Clamped Semiconductor Optical Amplifier gates

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Introduction

A key issue for future WDM optical networks is the availability of high-capacity and large-scale optical space switches. Among other technologies, Semiconductor Optical Amplifier (SOA) devices used as optical gates have already demonstrated their high potential in optical networks[1,2], specially in packet switching applications [1].

In such applications, WDM compatible SOA-based gates, which are also able to provide a high output power, are highly desirable. Gain-Clamped SOAs (GC-SOAs) have been specially developed to meet these last requirements. Such individual components are now commercially available [3], so now, the challenge is more to increase the size and the level of integration of such SOA-based space switches.

One way is the monolithic integration of SOAs with a passive optical circuit. Such InP-based switching matrices with high performance have been achieved, but the largest size already demonstrated is a 4x4 device, using a complex technological processing [4].

The SOA-array approach seems to be more attractive as it overcomes this switch size limitation, while remaining a cost effective solution. A 4x4 optical switching matrix based on such SOA gate arrays flip-chip mounted on a silica-based planar lightwave circuit was recently reported [5]. However, in the above approach, the dimension of the optical passive circuit compared to the silica wafer size and the low number of such matrices per wafer seem to limit the scalability and the cost effectiveness of such optical switching matrices.

In this paper, we present a modular and scalable approach which allows to overcome the former limitations on the optical switching matrix based on SOA gate arrays. We demonstrate here, for the first time to our knowledge, an 8x8 optical switch based on arrays of 8 GC-SOA gates. A WDM experiment in which a multiplex of 16 x 10 Gbit/s channels (200 GHz spaced) is launched into the 8x8 optical switch, is also reported.

Switch description

The 8x8 switch architecture considered is a strictly non-blocking broadcast and select architecture composed of N input 1:N splitters interconnected with N output Nx1 switches through a N^2-fibre perfect shuffle, with N=8 [6]. This space switch architecture based on 8x1 GC-SOA building block sub-elements is modular, flexible and thus can be easily extended and, of course, the same building blocks are re-usable in another switch architecture.

The 8x1 space switch module (shown in figure 1) consists of an 8 GC-SOA gate array flip chip mounted on an SiO_2/Si motherboard which integrates an 8:1 power combiner, electrical lines and electro plated AuSn pads for bumping [7]. An MT-8 connector was used for the fiber ribbon side of the device.

The typical characteristics of such a device are: insertion loss as low as 1 dB for the best path and 2.5 dB for the worst one for a 100mA injected current, polarisation sensitivity lower than 0.7 dB at 1550 nm and well below 1 dB across the 1525-1575 nm spectral range for all paths, gain ripple negligible thanks to the double refraction configuration used for the coupling between the InP and the silica waveguides [7].

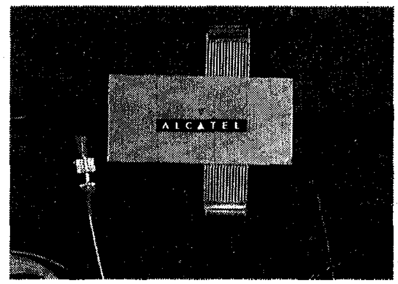

Fig. 1 : 8x1 GC-SOA based switch.

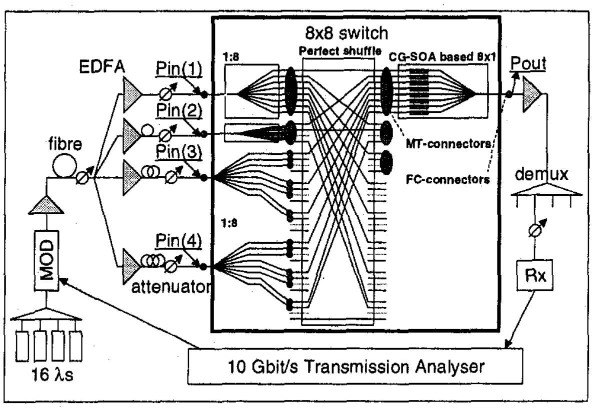

Fig. 2 : 8x8 experimental set-up.

The experimental 8x8 optical switch test set-up is depicted on figure 2. Four input 1:8 splitters are connected to one output 8x1 space switch module through a perfect shuffle fibre interconnect so that each input port of the 8x1 is fed with optical signal. MT-8 connectors are used to interconnect each part of the 8x8 switch.

The input optical signals were obtained by multiplexing 16 laser sources 200 GHz-spaced (1535 nm-1559 nm, in the ITU-T G.692 grid), simultaneously modulated at 10 Gbit/s (2^{23}-1 PRBS), decorrelated with SMF and split to the 4 input ports of the 8x8 optical switch test set-up.

Basic 8x8 switch performances (losses, PDL, isolation)

Figure 3 shows the 8x8 insertion losses versus wavelength for each selected port of the 8x1 switch. At 1550-1560 nm, the best path has 12 dB insertion losses and the worst path 14 dB (uniformity 2 dB). The central wavelength is about 1555 nm and the spectral bandwidth at –1 dB yields 35 nm. On the 16-λ WDM multiplex we used, the dependence of losses versus wavelength is about 2 dB.

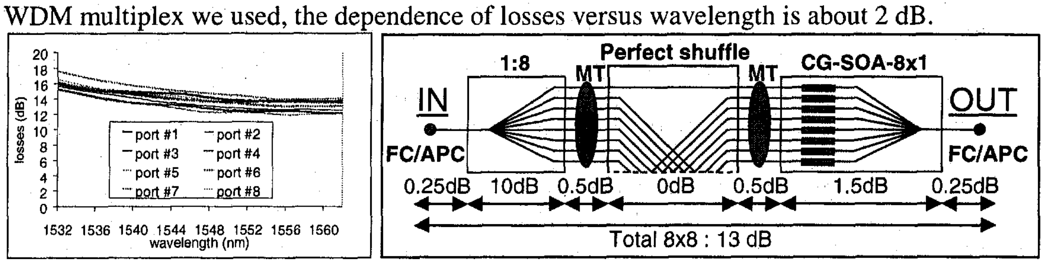

Fig. 3 : 8x8 insertion losses versus wavelength for the 8 ports, and insertion loss breakdown.

If we consider 0.25 dB for each FC/APC connector (x2), 0.5 dB for the MT connectors (x2), 0 dB for the perfect shuffle, 10 dB for the 1:8 splitters and about 1.5 dB loss for the 8x1 switch, the total 8x8 losses are about 13 dB (see figure 3), in agreement with the 12 to 14 dB observed.

The 8x8 Polarisation Dependent Losses (PDL) measured on each selected port varied between 0.5 and 0.9 dB. The 8x8 extinction ratio ranged between 32 dB (worst) and 38 dB, including the contributions of all the 8 input ports. Such a total optical crosstalk is compatible with low penalties on 10 Gbit/s signals [8].

WDM 16x10 Gbit/s validation

The current injected in the selected optical gate was 200 mA. The total 8x8 input power was +4 dBm, i.e. -8 dBm/λ, and the input Optical Signal-to-Noise Ratio (OSNR) was about 30 dB/0.1nm (see figure 4). The output power was between –22 and –24 dBm/λ, which corresponds to 8x8 optical losses from 14dB (@ 1555 nm) to 16 dB (@ 1535nm). The worst output OSNR was 24 dB/0.1nm.

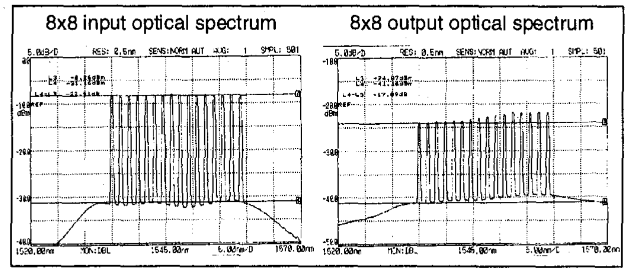

Fig. 4 : Input & output optical spectra (Pin=+4 dBm).

Figure 5 shows the power penalty of all the 16 wavelengths for the selected port number #1 of the 8x1 switch. For a total input power of +4 dBm, the penalty at BER=10^{-9} is between 0.8 and 1.3 dB (the worst channel is the lowest wavelength: 1535 nm). For lower power, the penalty is due to bad OSNR, and for higher power, the penalty is due to non-linear effects (de-clamping, FWM...). The 3-dB penalty dynamic range is 4 dB (from +1 dBm to +5 dBm total input power).

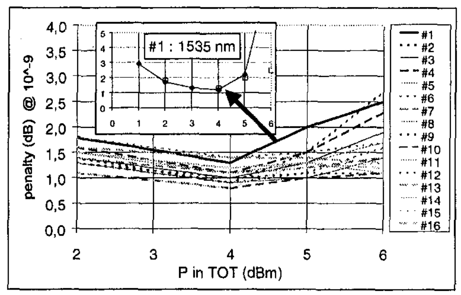

Fig. 5 : Penalty for all the 16 λs @ port #1.

Conclusion

We have demonstrated, for the first time to our knowledge, an 8x8 optical switch based on arrays of 8 GC-SOA gates. A preliminary WDM experiment using such an 8x8 optical switching architecture clearly highlighted that up to 1.28Tbit/s (8x16x10Gbit/s) throughput are achievable. The modular approach envisaged here will clearly ease the scalability of such an optical switching matrix.

Through the hybridisation technique and such a modular implementation of an optical space switching matrix, a cost-effective realisation of large-scale space switches based on SOA gate-arrays is becoming a reality. As SOA-based optical gates can be switched in the nanosecond range, the LOIS optical switching matrix we reported here on is very attractive for the future IP terabit optical routers.

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References

[1] D. Chiaroni *et al*, "Experimental validation of an all-optical network based on 160 Gbit/s throughput packet switching nodes", ECOC'98, paper WdD04, pp. 573-574, Vol. 1, September 20-24th, 1998.
[2] L. Berthelon *et al*, "A cross-border WDM networking field trial with all-optical wavelength-translating crossconnects", », OFC'98, postdeadline paper PD26, Feb 22-27, 1998.
[3] Alcatel 1921 SOA 1550nm WDM Semiconductor Optical Amplifier Module, Alcatel Optronics.
[4] W. Van Berlo *et al*, « Polarisation-insensitive, monolithic 4x4 InGaAsP-InP laser amplifier gate switch matrix », IEEE Photon. Lett., Vol. 7, N° 11, pp. 1291-1293, November 1995.
[5] T. Kato *et al*, «10Gb/s photonic cell switching with hybrid 4x4 optical matrix switch module on silica based planar waveguide platform», OFC'98, postdeadline paper PD3, February 22-27th, 1998.
[6] C. Artigue, « Large Integrated Optical Switches (LOIS) », invited talk, ACTS workshop on WDM networks and related technologies, Brüssels, Belgium, May 6th, 1998.
[7] F. Dorgeuille *et al*, "Loss-free 1x4 opto-hybrid space switch based on an array of 4 Gain-Clamped SOA gates", Eur. Conf. on Opt. Commun., Nice, France, pp. 176-177, Vol. 1, September 26-30th, 1999.
[8] T. Zami *et al*, "Crosstalk-induced degradation in an optical-noise-limited detection system", OFC'99, paper TuR4, Feb 21-26, 1999.