64X64 fast optical switching module

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Abstract: We report a fully operating non-blocking and reconfigurable 64x64 fast switch module based on electro-optical spatial beam steering. A deflection time of 20nsec. was attained, with cross-talk figures better than –19.5dB. The module functions as switching core of a high-capacity packet switching backbone router.

OCIS codes: (060.1810) Couplers, switches, and multiplexers. (130.3120) Integrated optics devices

1. Introduction

The growing rates of present-day networks are demanding immediate solutions for bottlenecks created at network junction ports. High-count information channels are converging at each of these junctions. The switching and routing of this high-volume data is perhaps the main present challenge of optical systems and devices. The Optical Switching Module (OSM) reported here is based on a combination of waveguided and free-space optics, taking advantages of the benefits of both propagation regimes. The basic device is an electronic beam deflector operating on the principle of phased array antennas used in RADAR and other microwave systems. The idea of applying this concept to the optical regime has been proposed more than 25 years ago[1,2]. Many attempts of realization followed and are reported in the literature[3], all of them aiming to translate that idea from the RF to the optical portion of the electro-magnetic spectrum. In published work the number of resolvable points attained by those configurations, reached at most the number of a few tens. The deflector chips developed and reported here, are able to steer a beam light into more than 100 resolvable points, thus converting the deflector into a practical building-block of a NxN switching module. Such a module was realized and is reported here for N=64. As described in the following, we were able to overcome the main impediments encountered in order to increase the port count number. Furthermore, stringent cross-talk and loss issues arise once the device is aimed to serve as a data routing and switching module. We review here some of the critical issues involved.

2. The steering unit

The basic unit of the switch is a beam deflector consisting of 128 waveguides of the ridge type created by photolithography and subsequent reactive-ion plasma etching. Typically each waveguide was 9∝m wide and the separation between adjacent guides was 2∝m. The structures were formed on a multilayer AlGaAs structure grown on a N^+ doped GaAs wafer oriented in the [001] direction. Trenches of 3 microns depth were etched ensuring both optical and electrical insulation between separate waveguides. Further details on the fabrication process of the chip together with the electrical and optical characterization will be presented elsewhere. By proper waveguide design, the propagation loss of the waveguides was reduced to 1dB/cm. This loss value is, apparently the lowest reported in literature for active semiconductor waveguides. Each one of the waveguides is individually addressed by metal filled vias connecting external electrode to upper-waveguide conductor. Although each of the waveguides was able to support several optical propagating modes, the input optics ensured the excitation of essentially the basic mode only, and the effective numerical aperture in the transversal dimension was hence reduced. The maximum steering range required between extreme deflections was of about 7^0. Ideally a linear voltage and phase relationship is required in order to define a given deflecting angle. If θ is the angle in radians, its value is given by:

$$\sin(\theta) = \frac{\lambda}{\Lambda}\frac{\Delta\Phi}{2\pi} \qquad (1)$$

Where Λ is the period of the waveguide array, λ the radiation wavelength and ΔΦ the phase difference between adjacent waveguides. In a purely electro-optical modulation scheme, this phase difference is proportional to the applied voltage. Actually the semiconductor phase modulators have additional quadratic effects and are not completely exempt of amplitude modulation even in a simple single-waveguide scheme. To cope with these effects comprehensive procedures were applied in order to optimize the throughput signal at each switching state. Results of optimization were supplied into Look-Up Tables and stored in suitable memory units.

3. Input and Output Optics.

The coupling of light from an optical fiber into an array of many parallel waveguides is a challenging technological problem when high coupling efficiency is required. To our best knowledge it was not realized insofar for the large number reported here (128 waveguides) and for the rather tight confinement of the semiconductor waveguides utilized. The solution here was based on an assembly of three micro-lenses arrays of special fabrication and design. Linearly polarized light propagating freely out of a PM SMF was first conditioned by two cylindrical lenses with curvatures in the vertical and horizontal direction respectively. A third lens was then used to focus the beam down into the spot-size required at the entrance plane of the waveguides. The beam at that plane had mode diameters in the vertical and horizontal directions of 1.7∝m and 968 ∝m respectively. The input lens array furnished a high degree of collimation with wave-front distortions well bellow a quarter of wavelength. The total optical power loss due to field overlap was of -1.75dB. After entering the array light propagated along waveguides of 12.6mm length. The quality and uniformity of the array of waveguides was such that the wave-front was practically undistorted at the exit of the array. The outcoming beam was collimated in the vertical direction by a fourth cylindrical lens into a width of 6.5mm and then into a scan lens of 96mm focal-length, common to all 64 deflectors. The role of the lens was to translate angular deflection into lateral position at its focal plane, thus the voltage-controlled steering of each deflector unit converged into position-dependent switching capability. An array of 65 closely packaged multi-mode fibers was located at the back focal plane of the scan lens. The output fiber array was accurately positioned by means of a Silicon-based V-groove unit. The multi-mode fibers used, had a bandwidth-length product, sufficient for the requirements of switch interconnection, within the data router where the OSM is placed (12.5Gb/channel). The MMF ribbon was fed into line-card and terminated by custom-designed photo-diode detectors.

3. Switch Architecture

As pointed out, the device's aim is to serve as 64x64 optical switching unit. As such it was functionally divided into four input modules and one output module. Each input module consisted of 72 deflectors, each of them based on a 128 waveguide array. The number of deflectors was augmented from 64 to 72 in order to provide for protection and redundancy to increase production yield. 18 deflectors were processed together in a single AlGaAs slab, and mounted into a suitable ceramic substrate that provided structural support together with the necessary electronic interconnections and packaging. Four of such input modules were placed into an entire switching unit, in a T-like disposition as shown in Fig. 1. Four folding mirrors, one for each input module, directed the radiation into the common scanning lens. Each pair of input modules was placed in a story-type arrangement at the closest distance permitted by the mechanical support and electrical connections. One should note that such a story-type disposition of input modules implies scalability of the switching architecture up to much higher port-counts. The entire 64x64 Optical Switching Module was accommodated in a standard 19" rack mount.

Fig 1. Front view of mounted 64x64 OSM. Input fibers are seen in the lower part of photograph and output are in the upper part. Folding mirrors are seen at the center window

4. Switch characterization and performance.

Fully functional characterization of the optical switching module was performed. The testing of the device reported here has many aspects and includes the semiconductor waveguide optical and electrical behavior, input and output optics performance, mechanical tolerances and extensive tests of thermal and mechanical cycling. Here we show examples of two important parameters namely switching speed and crosstalk. Additional characterization data will be given at the Conference. In Figure 2, we display switching performance of CW light from one deflector into two different output ports. The graphs show the photocurrent of photodiodes placed at two different output ports. As seen, switching time is less than of 20 nanoseconds, limited mainly by the electronic logic gating time. These parameters are sufficient for the switch in order to allow IP format packet-switching. At the time of writing this report, the switch demonstrated the transport of 12.5 Gbit/sec data into a single channel with BER better than 10^{-12}.

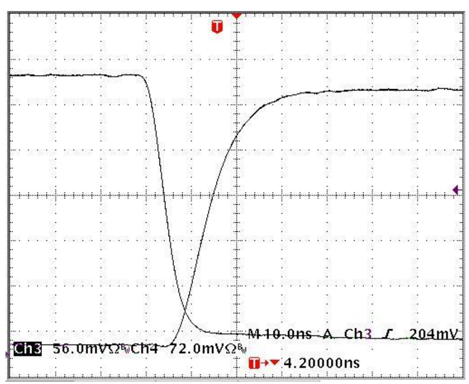

Fig. 2. Switchover behavior of the OSM. Light from a single input channel is switched between two different output channels and the photocurrents detected at the output ports are traced simultaneously.

Figure 3 demonstrates the switching capability of the device in terms of crosstalk. Each row of the matrix displays a different switching configuration of a single deflector aiming at different output ports. The aimed port is the main diagonal of the matrix and power levels at the off-diagonal ports represent cross-talk. As expected the worst-case crosstalk corresponds to nearest neighbor output ports and was better than 20dB. The worst-case crosstalk accumulated at all ports for a given switching state is 19.5dB. Total laser-to-detector loss of the entire system was better than –15dB for all switching configurations.

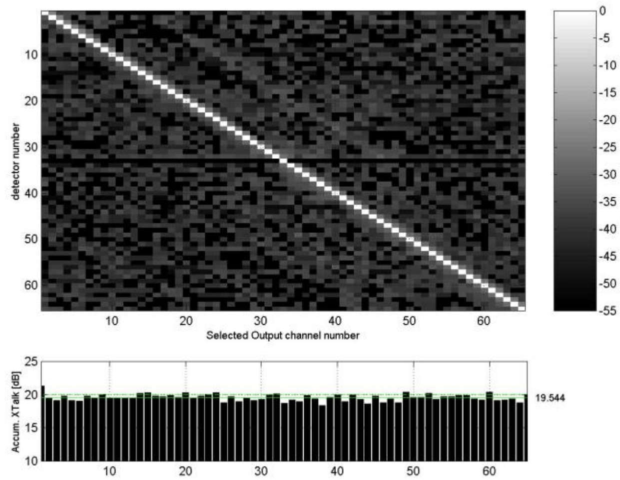

Fig. 3. Individual port and accumulated crosstalk for 64 different switching states

In conclusion, the reported unit satisfies all requirements in order to function as switching core of a high-capacity packet switching backbone router.

5. References

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