Wavelength-Division-Multiplexed (WDM) Data-Block Switching for Parallel Computing and Interconnects

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ABSTRACT

We report a new generation switch, the data-block switch, which can greatly increase the capacity and reduce the complexity of the interconnect network of a parallel computing system. By using WDM techniques, parallel data can be multiplexed and transmitted through a single fiber. By using photonic switching techniques, we can switch a block of parallel data in one switch operation to any site desired. In this work, we demonstrate such an operation with our fabricated 1 x 2 semiconductor optical amplifier (SOA) switch. This integrated device is an active/passive Y-junction waveguide device with a passive waveguide region in the middle and 3 active waveguide regions at each end. The amplified spontaneous emission spectrum of the SOA shows that this broadband switch can easily cover a wavelength range of more than 64 ITU wavelength grids (100 GHz). The switch operation of multiple wavelengths and the switching speed of the device were studied. A switching time of around 400 ps was achieved.

Keywords: packet switching, integrated optical devices, semiconductor optical amplifier, WDM, interconnect, parallel computing.

1. INTRODUCTION

Modern parallel processors rely on high-bandwidth, low-latency networks to connect their processors and memories together[1]. Today, most interconnection networks, like most other computer components, are built using electronic technology. However, it is becoming increasingly difficult to build such high-performance interconnection networks, as evidenced by the high cost of connecting commodity microprocessors into a single parallel computer. As the clock rate of 64-bit microprocessors projected toward 1 GHz around the year 2000, the propagation delays and capacitate coupling in long parallel wires will obviously become problems for high performance parallel processing. Optical interconnect has been proposed to eliminate these problems[2]. However, with single wavelength operation, there is basically no improvement in the wiring complexity. Fig. 1 shows the basic structure of a shared-memory parallel processor. One can notice that there are N^2 crossbar switches and their control circuits at each cross point in the figure, where N is the total number of bits for the data and control buses. The idea of the proposed WDM packet switching is to use one photonic switch to replace all the N^2 high-speed electronic switches and to use one fiber to replace the N wires. Each bit is then represented by one wavelength. Such a system will greatly simplify the complexities of wiring and switching fabrics of a parallel processor and make the switching control much easier.

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2. WDM AND PHOTONIC SWITCHING TECHNOLOGIES

Compared with electronic technology, the photonic approach has an extra degree of freedom, the light wavelength, for signal multiplexing and demultiplexing. Recent development of the WDM technology in optical communication system has demonstrated terabit per second transmission capacity. Without spending any efforts on laying new fibers, transmission system capacity can be multiplied by simply adding new wavelength channels into an existing fiber network. The WDM technology can be further developed to synchronize all the wavelength channels in the time domain. Different wavelengths in a WDM system can be utilized to represent different bits in a data or control bus. Like the growth of the microprocessors from 4 bits, 8 bits to 32 and even 64 bits, the number of bits sent in parallel along optical fiber can also grow with the development of the WDM device technology to the nearly unlimited bandwidth of optical devices. However, due to the dispersion characteristics of an optical fiber, signals with different wavelengths will propagate with different speeds. In a fixed period of time, the larger the wavelength difference between each bit, the wider the delay spreads will be. It is necessary to reduce the wavelength span if there is a considerable amount of distance between processors. For example, the dispersion in a conventional single mode fiber at 1.55 μm is about 20 ps/km/nm. For a 64-wavelength system with each wavelength separated by 100 GHz (ITU standard, ~ 0.8 nm at 1.55 μm), the delay spread between the two extreme bits will be around 100 ps for an 100 m long interconnect fiber and it is one quarter of a bit for a 2.5 Gb/s transmission system. In the future, a densely spaced WDM (DWDM) system with smaller channel spacing can help to reduce the delay spread and keep each wavelength channel synchronized.

Electronic switching has been a very matured technology and capable of switching at a reasonably high speed. Compared with the electronic technology, photonic switches have the advantages of having a very broad passband that is close to hundreds of terahertz (THz). Such a bandwidth is more than thousand times of that of an electronic switch. When combining with the WDM technology, a photonic switch can direct all the wavelength channels from one node to another in one single switching operation. The switching speed or, more exactly, the switch reconfiguration speed is in the subnanosecond scale. Such a combination can produce an ultrahigh interconnect capacity with very low latency.

3. DEVICE FABRICATION AND MEASUREMENT

To demonstrate the operation of the data-block switching we have made an integrated 1 x 2, SOA, Y-junction, photonic switch[3] as shown in Fig. 2. The total size of device is 2 x 0.5 mm. It is fabricated on an InP substrate by wet etching and regrowth processing. The Y-junction passive waveguide, with a stripe width of 3.75 μm, has a buried rib structure with two outputs separated by 250 μm. The total length of the passive waveguide is 1,200 μm. The SOA active regions are sitting at both the input and output sides of the device to overcome the loss and help the fiber coupling. Each one of the SOAs has a length of 400 μm and a width of around 1 μm. They are made of InGaAs/InGaAsP multiple quantum well gain material at 1550 nm and with a semi-insulating blocked buried heterostructure (BH). The SOAs have very broad gain profile covering more than 50 nm as Fig. 5 (a). After the anti-reflection coating, the ripple in the spontaneous emission spectrum is smaller than 0.2 dB at the working bias current.

Fig. 3 shows the switching characteristics of the SOAs. An optical “DC” signal is switched on and off by the SOA gates controlled by external electrical signals. Both the rising and falling time are around 600 ps that was partially contributed from the driving electronics.

The experiment setup for the data-block switching is shown in Fig. 4. The multi-wavelength light signals, with 7 of them near 1550 nm (separated by 100 GHz spacing) and one at 1533 nm, are coupled into an 8 x 1 optical coupler and launched into the switch. Fig. 5 (b) shows the multiwavelength spectrum. A tunable filter at the switch output is used to select signals to observe the switching results at each particular wavelength. Fig. 5 (c) and (d) shows the switched “1010” signal streams at 1553 nm and 1533 nm, respectively. The "1" and "0" can be clearly identified when the switch is turned "ON" and the background of the "OFF" state is clear. Very good contrast ratios are obtained and there are very little differences between the received signals at the two extreme wavelengths.

4. CONCLUSION

In conclusion, we have demonstrated a new type of switching operation, the data-block switching, which can direct a full block of parallel data to a desired location with one single photonic switch in one switching operation. Such a switching scheme will become more and more important as the speed of 64-bit CPUs is increasing above several hundreds of MHz. An optical crossbar built using such a scheme can far outperform conventional electronic crossbars and allow parallel processors to scale to hundreds of processors while allowing the use of true shared memories. High performance parallel computing and future low cost multi-processor supercomputers will be made possible through this technology.

5. ACKNOWLEDGMENT

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6. REFERENCES

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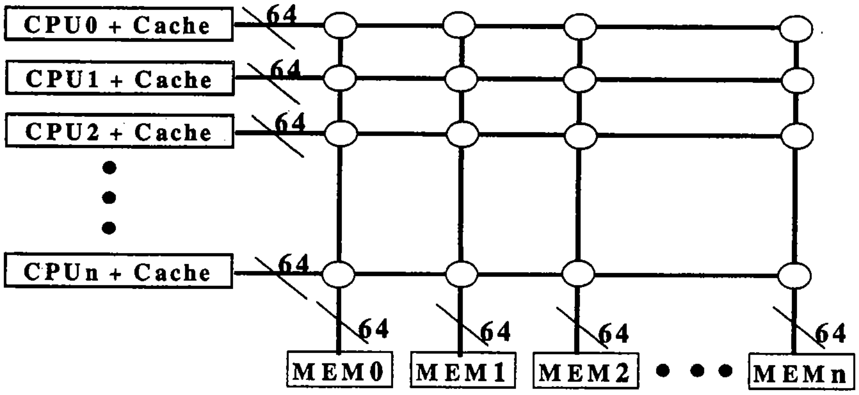


Fig. 1. A parallel processor interconnection architecture.

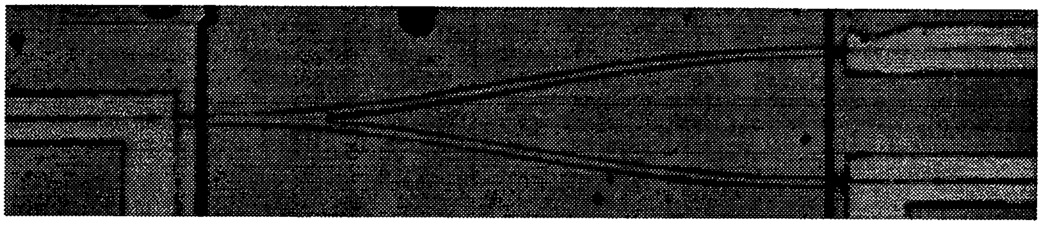


Fig. 2. A fabricated 1x2 SOA gates switch.

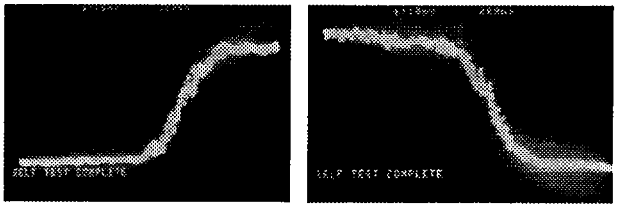


Fig. 3. Switching characteristics of an SOA switch.

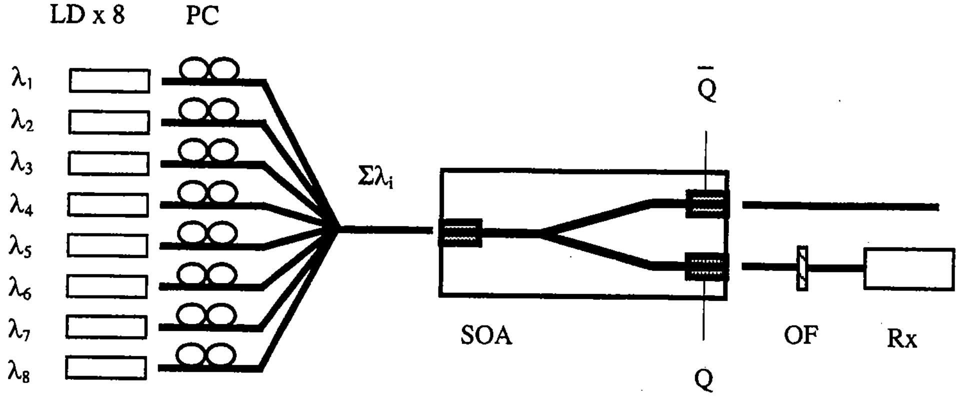
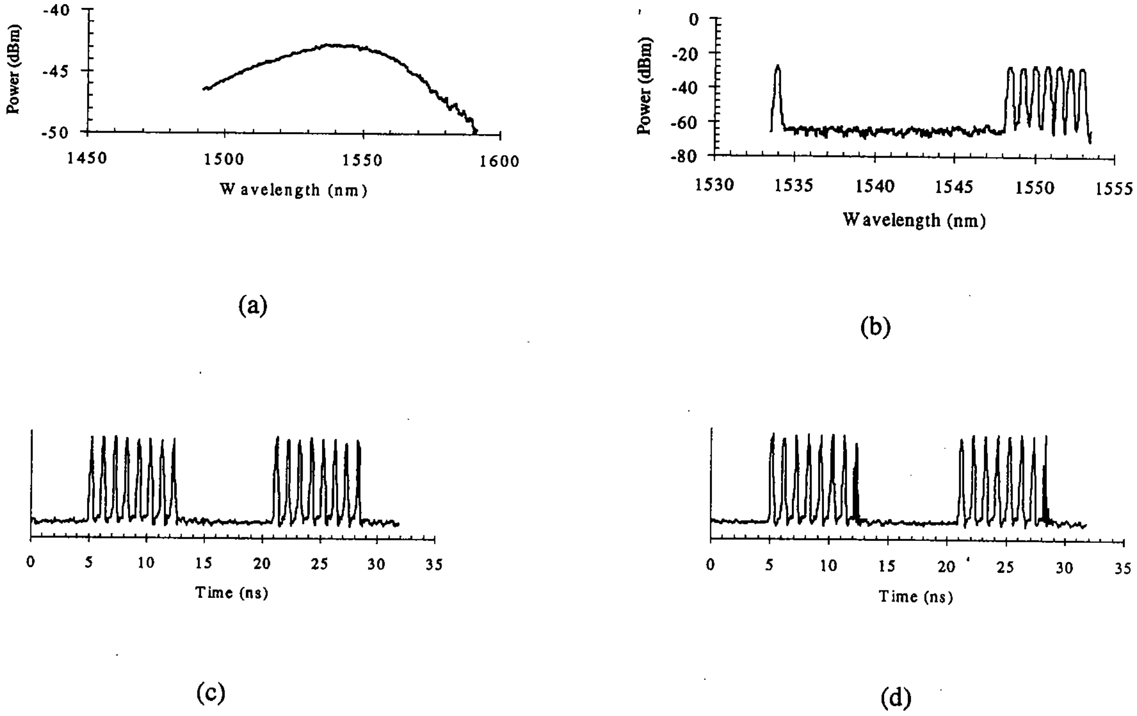


Fig. 4. Experimental setup. PC: polarization controller. OF: optical filter. LD: DFB laser.



(a)

(b)

(c)

(d)

Fig. 5. (a) The SOA gain profile. (b) Multiwavelength signals. (c) Switched "1010" data streams at 1553 nm. (d) Switched "1010" data streams at 1533 nm.