



Semiconductor optical amplifier assisted all-optical switches in parallel optical computation: A review

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Abstract

The necessity of different ultra-fast all-optical switches has received immense interest in recent years for optical parallel computation and information processing. Nonlinear Optical Loop Mirror (NOLM) provides a major support to optical switching based on all-optical logic and algebraic processing where the switching mechanism is based on Kerr nonlinearities of optical fibers. However more efficient and compact solutions can be realized by all optical switches using Semiconductor Optical Amplifiers (SOA) where the nonlinear coefficient is much higher. In this paper a concise review of semiconductor optical amplifier (SOA) based all-optical switches e.g., Terahertz Optical Asymmetric Demultiplexer (TOAD), Mach-Zehnder interferometer (MZI) switch and Ultra-fast non-linear interferometer (UNI) switches have been presented.

Keywords: all-optical switches, nonlinear optical loop mirror (NOLM), kerr nonlinearities, semiconductor optical amplifiers (SOA), terahertz optical asymmetric demultiplexer (TOAD), mach-zehnder interferometer (MZI) and ultra-fast non-linear interferometer (UNI) switches

1. Introduction

Information processing in broad sense includes data processing, arithmetic processing, algebraic processing, image processing as well as processing of control signals that is logical processing as a whole. From early age people were interested not only on sending information they were equally concerned on processing of information to enhance the scope of upgradation of new information. Peoples became massively involved to exploit all hidden and inherent properties of electrons to make the communication and data processing more and more comfortable. Computers have revolutionized research in science and technology. They offer many applications for mankind and development of civilization. The speed of electronic processors or that of conventional computers is achieved by miniaturizing electronic components to a very small micron- size scale so that those electrons need to travel only very short distances within a very short time. The goal of improving the speed of computer has resulted in the development of the Very Large Scale Integration (VLSI) technology with smaller device dimension and greater complexity. Very large scale integration (VLSI) technology has revolutionized the electronics industry and established the twenty-th century as the century of electronics. The need of high speed computing has created a pressing demand for realization of electronic circuits with miniaturization limit. When the tremendous growth and upgradation of electronic systems were continuing, scientists and technologists found some other problems. It was regarding the speed of operation of a most upgraded system. As electrons are charged

interacting particles so they will always suffer Coulomb interactions with other charged particles or even among themselves. Because of these character an electron when behaves as an information carrier, it faces Von-Neumann bottle neck problem, problems related to crosstalk, interaction with external electric, magnetic and electromagnetic fields and many others. Therefore an alternative technological solution to the problem of high speed computing is needed, and unless we look through a totally different pathway, we would be in limit for further improving in computer performance for the future.

2. Semiconductor Optical Amplifier assisted All-Optical Switches

2.1 Semiconductor Optical Amplifier (SOA)

Semiconductor optical amplifier is an optoelectronic device which under suitable condition can amplify an input light signal. SOA is basically a laser diode (LD). The incident light is amplified through stimulated emission. Mirrors are absent so no feedback is there from its input and output [13-29]. The input signal comes from either fibre, passes through the active region which is pumped by external current injection and then transmit through the another fibre. Only to get the amplification function the device must be protected from the self oscillations generating the laser effect. The schematic diagram of SOA is shown in Fig. 1. The material for the active region and the substrate are $\text{In}_{1-x}\text{Ga}_x\text{As}_y\text{P}_{1-y}$ and InP respectively.

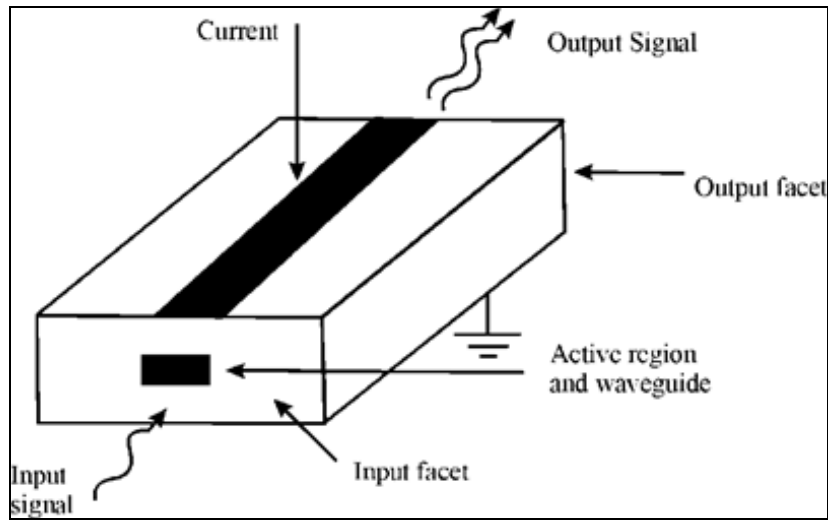


Fig 1: Schematic structure of SOA

2.2 Terahertz Optical Asymmetric Demultiplexer (TOAD)

A terahertz optical asymmetric demultiplexer (TOAD) is basically a Sagnac interferometer that uses an SOA offset from the midpoint of the loop [1-6]. It consists of a loop mirror with an additional intra-loop 2X2 (ideally 50:50) coupler. An incoming pulse (IP) enters the setup and is split into two counter-propagating components. There are clockwise (CW) and counter clockwise (CCW) that pass through the SOA at different times and recombine interferometrically at the coupler. Without a control pulse (CP), both components experience the same medium as they propagate around the loop and so the input signal is reflected back towards the point where it came from. But when a CP of significantly higher energy than the IP is injected into the loop, it alters the gain dynamics of the SOA. As a result, a differential phase shift is created between the two counter-propagating components and the input signal can be switched to the other side of the configuration. A polarization or

wavelength filter is used at the output to reject the control and allow only the input signal to exit. The control pulse has sufficient energy to significantly modify the optical properties of the SOA, but the input pulse has not. Also the incoming and control signals must be adjusted to have the proper synchronization, in such a way that the latter is launched into the SOA just before the former. The block diagram of a TOAD is shown in fig.

Now according to this behavior it is clear that in the absence of control signal the incoming signal is directed to the input port of TOAD and reaches output port-2 as shown in Fig. 2. In this case no light emerges at output port-1. With the presence of control signal the incoming signal exits through the output port of TOAD and reaches output port-1 as shown in Fig. 2.8. In this case no light is present at output port-2. Finally in the absence of incoming signal output port-1 and port-2 receive no light as the filter blocks the control signal.

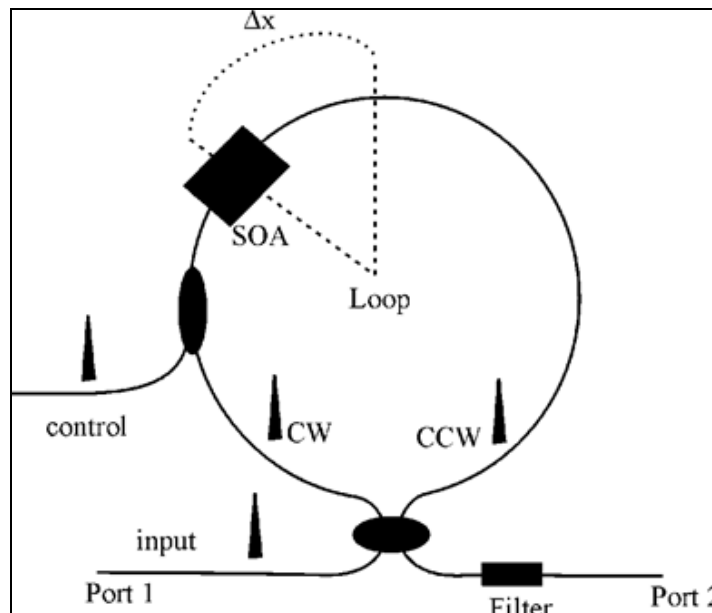


Fig 2: A TOAD based optical switch

Table 1: Truth table of the TOAD based optical switch.

Incoming Signal	Control signal	Output Port 1	Output Port 2
0	0	0	0
0	1	0	0
1	0	0	1
1	1	1	0

2.3 Mach-Zehnder Interferometer (MZI)

A Mach-Zehnder interferometer (MZI) switch is a very powerful technique to realize ultrafast switching. The block diagram of a Symmetric SOA-assisted MZI switch is shown in Fig. 4. In this switch two SOAs (SOA-1 and SOA-2) are inserted in each arm of a MZI [7-14]. It has two input ports (port-1 and port-2) and two output ports (port-3 and port-4).

The incoming signal pulse at the wavelength λ_2 enters port-1, is split equally by coupler C1 (50:50) and propagates simultaneously in the two arms of the interferometer. At the same time, pulsed signal at the wavelength λ_1 enters to the upper arm, through coupler C2 (90:10) such that most power passes through upper arm. It saturates the SOA-1 and changes its index of refraction, while the SOA-2 gets the unsaturated gain. As a result, a differential phase shift can be achieved between the data signal of two arms. Hence, light is present in the bar port (port-3), as shown in Fig. 4. In this case no light is present in the cross port (port-4), this is called the ‘switched state’. In ‘no-switched state’, when control signal is absent, both SOAs (SOA-1 and SOA-2) get the same unsaturated gain. In this case no light is present in

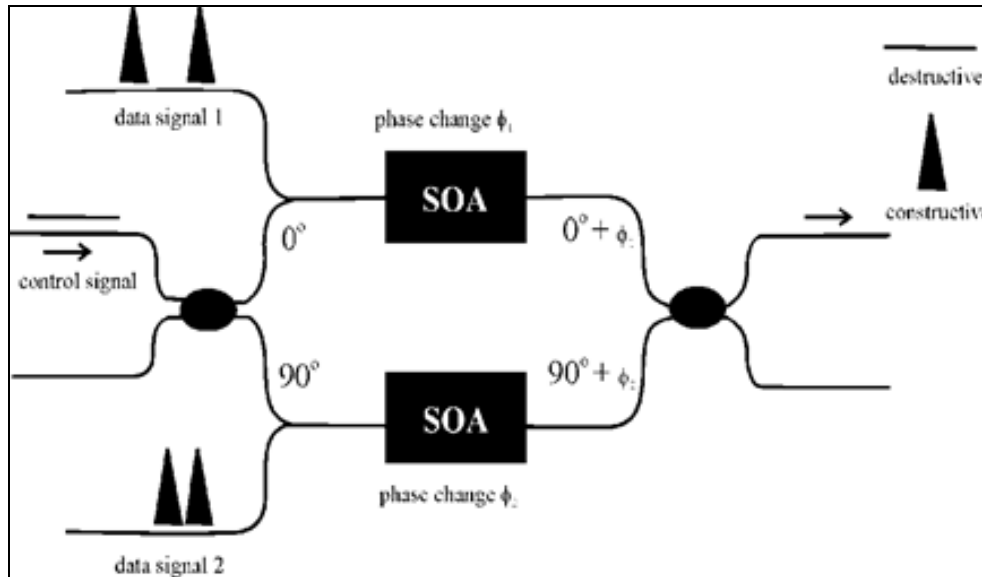


Fig 3: SOA based MZI optical switch

the bar port (port-3), then light is present in the cross port (port-4). Optical filters (F) are placed in front of the output ports for blocking the λ_1 signal (control signal). The MZI scheme is preferable over cross-gain saturation as it does not reverse the bit pattern and results in a higher ON-OFF contrast simply because nothing exits from bar port during 0 bits. Now, it is clear that in the absence of control signal, the signal exits through the cross port (port-4) of MZI as shown in

Fig. 4. In this case no light is present in the bar port (port-3). But in the presence of control signal, the incoming signal exits through the bar port of the MZI as shown in Fig. 4. In this case no light is present in the cross port. In the absence of incoming signal, the bar port and cross port receive no light as the filter blocks the control signal. Schematic block diagram of MZI is shown in Fig. 5.

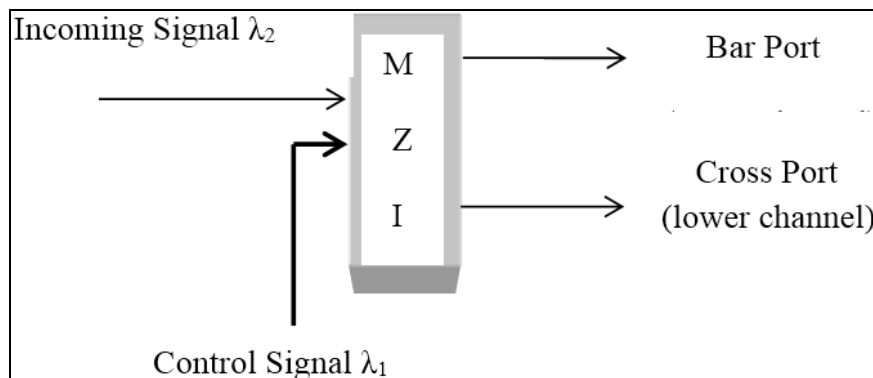


Fig 4: Schematic diagram of SOA based MZI optical switch

2.4 Ultra-fast Nonlinear Interferometer (UNI)

Ultra-fast Nonlinear Interferometer (UNI) is basically a polarization interferometer [15-18]. It is another ultra-fast optical

time division multiplexing (OTDM) switch. It uses an SOA as nonlinear element in a single-arm interferometer shown in Fig. 6.

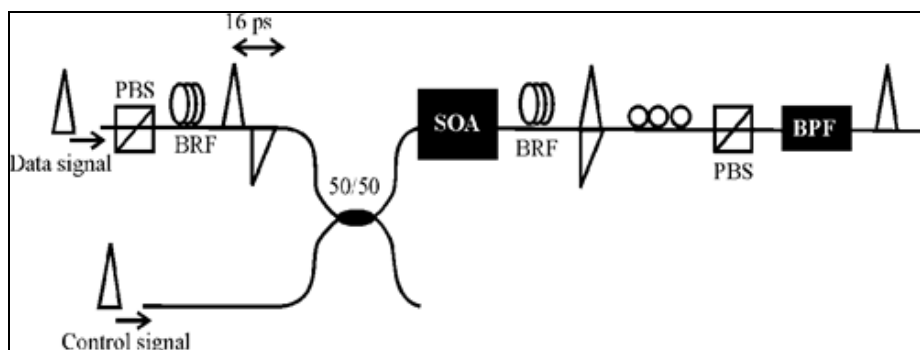


Fig 6: Schematic diagram of UNI, where PBS: Polarization Beam Splitter, BRF: Birefringent Fiber, BPS: Band Pass Filter

It is based on the carrier depletion of SOA by high energy control pulses. Input pulse enters through polarization sensitive optical isolator (PSI) and split into two orthogonally polarized modes (PM) by using a long length of birefringent fiber. The two data components will be delayed from each other by a temporal offset due to difference in refractive indices of the orthogonally polarized modes in the birefringent fiber.

Temporal offset (Δt) =

$$\frac{(n_x - n_y)L}{c}$$

Where, n_x and n_y are the mode of indices for the orthogonal fiber modes, L is the length of PM fiber and c is the speed of light in vacuum.

In this time a control pulse can be introduced precisely between the components of a data pulse. When these components pass through the SOA, only the data pulse whose components are separated by the control pulse will experience a differential phase change. As a result, when the pulses are realigned by another long length of PM fiber, the components will interfere with each other. Since the UNI is dependent upon birefringence to achieve switching, the system must use extensive polarization control throughout the network to maintain reliability. Only the pulse which experiences the differential phase change induced by the control pulse will be passed to the output through the polarization mode (PM) filter. Although the TOAD and the UNI share several characteristics, the integratability and practicality of the UNI are limited by the long lengths of PM fiber needed to induce the polarization walk-off. The switching window of the UNI is determined primarily by the birefringence of the PM fiber used to separate orthogonally polarized components of the data pulses in time. Enough walk-off is required to insert a control pulse between these two pulses. At the minimum, the walk-off should be longer than the control pulse width. Like any other SOA based switch, the UNI is limited by intra-band carrier dynamics and carrier heating. Switching windows of about 1ps can be expected. The switching repetition rate can be limited by the carrier recombination time in the SOA. However, 100 GHz repetition rates for bitwise logic functions have been reported [34].

3. Conclusions

Semiconductor Optical Amplifier based optical switches are expected to play an important role in optical parallel computation and information processing. An exhaustive study of SOA mechanism is yet to be established.

4. References

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